Colorado Water Institute Annual Technical Report FY 2011

Introduction

Water research is more pertinent than ever in Colorado. Whether the project explores the effects of decentralized wastewater treatment systems on water quality, optimal irrigation scheduling, household conservation patterns, the effects of wastewater reuse on turfgrass, the economics of water transfers, or historical and optimal streamflows, water is a critical issue. In a headwaters state where downstream states have a claim on every drop of water not consumed in the state, the quality and quantity of water becomes essential to every discussion of any human activity.

The Colorado Water Institute (CWI), an affiliate of Colorado State University (CSU), exists for the express purpose of focusing the water expertise of higher education on the evolving water concerns and problems being faced by Colorado citizens. We are housed on the campus of CSU but work closely with all institutions of higher education in Colorado. CWI coordinates research efforts with local, state, and national agencies and organizations. State funding allows CWI to fund research projects at CSU, the University of Colorado, and Colorado School of Mines.

Our charges this year included requests from the legislature and state and federal agencies. Water allocations and agreements and the potential treatment and reuse of industrial water are two examples. The Colorado Department of Natural Resources requested our assistance in engaging researchers and Extension in the public discussions of water quantity issues around the state. Water Roundtables in designated water basins elicited input from stakeholders with the goal in mind of creating an environment for water sharing arrangements in the state.

CWI serves to connect the water expertise in Colorado's institutions of higher education to the information needs of water managers and users by fostering water research, training students, publishing reports and newsletters, and providing outreach to all water organizations and interested citizens in Colorado.

Research Program Introduction

The Colorado Water Institute funded 3 faculty research projects, 3 student research projects, and 2 internships this fiscal year. The Advisory Committee on Water Research Policy selected these projects based on the relevancy of their proposed research to current issues in Colorado.

Under Section 104(b) of the Water Resources Research Act, CWI is to plan, conduct, or otherwise arrange for competent research that fosters the entry of new scientists into water resources fields, expands understanding of water and water-related phenomena (or the preliminary exploration of new ideas that address water problems), and disseminates research results to water managers and the public. The research program is open to faculty in any institution of higher education in Colorado that has demonstrated capabilities for research, information dissemination, and graduate training to resolve State and regional water and related land problems. The general criteria used for proposal evaluation included: (1) scientific merit, (2) responsiveness to RFP, (3) qualifications of investigators, (4) originality of approach, (5) budget, and (6) extent to which Colorado water managers and users are collaborating.

Active NIWR projects and investigators are listed below:

Faculty Research

1. *Paleohydrology of the Lower Colorado River Basin*, Rajagopalan Balaji, University of Colorado, $29,964 (104b)
2. *Water Quality Impacts of the Mountain Pine Beetle Infestation in the Rocky Mountain West: Heavy Metals and Disinfection Byproducts*, John McCray, Colorado State University, $140,162 (104g)
3. *Adjoint Modeling to Quantify Stream Flow Changes Due to Aquifer Pumping*, Roseanna Neupauer, University of Colorado, $117,847 (104g)

Student Research

1. *Aquifer Storage and Recovery Optimization*, Anne Mauer (Sale), Colorado State University, $5,000 (104b)
2. *Environmental Impacts of Ag-to-Urban Water Rights Transfers in the South Platte River*, Meagan Smith (Arabi), Colorado State University, $5,000 (104b)
3. *Variables Controlling Reservoir Sedimentation in the Colorado Front Range*, Umit Duru (Wohl), Colorado State University, $5,000 (104b)

Internships

1. GEOLEM Internship, Steve Regan, USGS, $30,000
2. MOWS- Modeling of Watershed Systems, Steve Regan, USGS, $20,000

For more information on any of these projects, contact the PI or Reagan Waskom at CWI. Special appreciation is extended to the many individuals who provided peer reviews of the project proposals.

Adjoint Modeling to Quantify Stream Flow Changes Due to Aquifer Pumping

Basic Information

Title:	Adjoint Modeling to Quantify Stream Flow Changes Due to Aquifer Pumping
Project Number:	2009CO195G
Start Date:	9/1/2009
End Date:	8/31/2012
Funding Source:	104G
Congressional District:	Colorado - 2
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Surface Water, None
Descriptors:	Stream Depletion, Adjoint Model, Modeling
Principal Investigators:	Roseanna M Neupauer

Publications

1. Neupauer, Roseanna M, 2011, "Adjoint Modeling to Quantify Stream Flow Changes Due to Pumping," pg. 16-17 of Colorado Water, Volume 28 issue 2.
2. Neupauer, Roseanna M, 2011, "Adjoint Modeling to Quantify Stream Flow Changes Due to Pumping," pg. 16-17 of Colorado Water, Volume 28 issue 2.

Annual Report
Project Number 2009CO195G
Adjoint Modeling to Quantify Streamflow Changes Due to Aquifer Pumping
Roseanna M. Neupauer
University of Colorado

The purpose of this project is to develop an adjoint modeling methodology to quantify stream depletion due to aquifer pumping. The methodology can be used to directly quantify stream depletion for a well at any location in the aquifer. The benefit of the adjoint approach is that with one simulation of the adjoint model, stream depletion can be calculated for a well at any location in the aquifer. If, for example, multiple locations are being considered for a new well, stream depletion can be calculated using standard modeling approaches; however, one simulation is required for each possible well location. In the adjoint approach, the same information can be obtained with a single simulation. Thus the adjoint approach less computationally intensive. This documents reports on the accomplishments on this project between June 2011 and May 2012.

Prior work on this project involved the development and testing of the adjoint theory for confined and unconfined aquifers with weak coupling between the river and aquifer. Specifically, we assumed that stream depletion (i.e., reduction in stream flow rate due to aquifer pumping) did not affect the stream stage. This assumption allowed us to develop and test the adjoint methodology for a moderately complex system. A recognized challenge of this method is that the groundwater flow equation for an unconfined aquifer is non-linear; while the corresponding adjoint equation is linear and depends on the aquifer head. This is a challenge because the adjoint equation has a different form as the forward equation and therefore cannot necessarily be solved directly using standard groundwater flow modeling software (e.g., MODFLOW). Also, the benefits of using the adjoint method are negated if it is necessary to calculate aquifer head. We found that that if we linearize the forward governing equation, we avoid these problems and introduce only negligible error. In the past year, we published one journal article on this work (Neupauer and Griebling, 2011).

The main work for the past year focused on developing and testing the adjoint methodology for a strongly-coupled river and aquifer system. Specifically, we modeled the relationship between stream stage and stream flow rate using Manning's equation; thus, when stream flow rate is reduced due to stream depletion, the stream stage is also reduced. The governing equation for flow in the stream is a non-linear equation; thus the corresponding adjoint equation is linear (and therefore has a different form than the forward equation) and depends on the stream stage. We performed a rigorous theoretical development of the adjoint equation. In addition, we tested the adjoint models using MODFLOW with the Stream (STR) package. In order to solve the adjoint model with MODFLOW, we needed to modify the source code of the STR package to handle the different form of the adjoint equation, as compared to the form of the forward equation. In addition, we introduced assumptions about the stream stage to avoid having to calculate stream stage from a forward simulation. We tested these assumptions and modifications on a hypothetical aquifer system, and demonstrated that the adjoint method is considerably faster (almost two orders of magnitude faster) and is very accurate. This work was presented at the 2011 National Academies Keck Futures Initiative, the 2011 American Geophysical Union (AGU) Fall Meeting, and the Hydrologic Sciences Student Symposium at the University of Colorado (awarded the best student presentation award). Also, it was presented at and published in proceedings of the World Environmental and Water Resources Congress (Griebling and Neupauer, 2012a) in May 2012. In addition, it is documented in an M.S. thesis (Griebling 2012), which was completed in May 2012. One journal article is in preparation on this work (Griebling and Neupauer, 2012b), which is expected to be submitted to *Water Resources Research* in June 2012. In addition, a conference proceedings paper is in press (Griebling and Neupauer, 2012c).

Students:
Scott A. Griebling – M.S. student, graduated in May 2012
Gregory D. Lackey – M.S. student, started May 2012, expected completion is August 2013.

Presentations:
Griebling, S.A. and R.M. Neupauer, Quantifying Stream Depletion Due To Groundwater Pumping Using Adjoint Methodology, 7th Annual Hydrologic Sciences Student Symposium, University of Colorado, Boulder, Colorado, April 2012.
Griebling, S.A. and R.M. Neupauer, Applying Adjoint Methodology to Quantify Stream Depletion Due to Aquifer Pumping, American Geophysical Union, Fall Meeting 2011.
Neupauer, R.M., Adjoint Simulation of Water Fluxes between Streams and Aquifers, The National Academies Keck Futures Initiative, Ecosystem Services: Charting a Path to Sustainability, November 2011.

Publications:
Neupauer, R.M. and S.A. Griebling, Adjoint simulation of stream depletion due to aquifer pumping, *Ground Water*, doi:10.1111/j/1745-6584.2001.00901.x, 2011.
Griebling, S.A. and R.M. Neupauer, Quantification of Stream Depletion Due to Aquifer Pumping Using Adjoint Methodology: A Case Study, 2012 World Environmental and Water Resources Congress, American Society of Civil Engineers, 2012a.
Griebling, S.A. and R.M. Neupauer, Coupled surface water and groundwater adjoint model to quantify stream depletion, in preparation for submission to *Water Resources Research*, expected submittal date: June 2012b.
Griebling, S.A. and R.M. Neupauer, Adjoint Methodology to Simulate Stream Depletion due to Pumping in a Non-linear Coupled Groundwater and Surface Water System, Proceedings of the Conference on Computational Methods in Water Resources, 2012c, in press.

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Paleohydrology of the Lower Colorado River

Basic Information

Title:	Paleohydrology of the Lower Colorado River
Project Number:	2010CO226B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	4th
Research Category:	Climate and Hydrologic Processes
Focus Category:	Surface Water, Hydrology, Climatological Processes
Descriptors:	None
Principal Investigators:	Rajagopalan Balaji

Publications

1. Lukas, Jeffrey, 2011, "Paleohydrology of the Lower Colorado River Basin," pg. 9-11 of Colorado Water, Volume 28 issue 2.
2. Rajagopalan, Balaji, 2011, Paleohydrology of the Lower Colorado River Basin, Colorado Water Institute Proposal, 6 pages.

Paleohydrology of the Lower Colorado River Basin
Project Progress Report to the Colorado Water Institute
May 21, 2012

Project Personnel
PI: Balaji Rajagopalan, University of Colorado
Co-PIs: Jeff Lukas, Western Water Assessment
Other Investigators: Lisa Wade, University of Colorado (Rajagopalan MS student); Connie Woodhouse and David Meko, University of Arizona
Collaborators: Dave Kanzer, Eric Kuhn, and John Currier, Colorado River District

Note: The funding for this project from non-CWI sources is not aligned with the CWI funding year, so *Year 1* refers to the period August 2010-July 2011, and *Year 2*, August 2011-July 2012. Since the last status report to CWI was in January 2011, this status report covers progress and results from the second part of Year 1 of the project and most of Year 2.

Background and goals of the project
The Colorado River Basin (CRB) is the most important source of water in the southwestern United States, and the State of Colorado draws a substantial portion of its water supply from the CRB (Figure 1). Since the Upper Colorado River Basin provides between 80–90% of the total CRB's annual flow on average, previous investigation of water supply reliability for the CRB has focused on the Upper Basin. Given the smaller contribution of Lower Colorado River Basin (LCRB) flows, they have been typically left out of the CRB water supply modeling, or represented with constant terms. Also, the Gila River (Figure 1), which contributes about half of the LCRB flows, is not explicitly incorporated in the legal and management structure governing the rest of the CRB. However, as the demand on the CRB system approaches the supply, the 10–20% contribution from the Lower Colorado River Basin (LCRB) becomes more critical. In order for these flows to be incorporated into planning frameworks, it is important to understand their long-term variability and develop robust simulation methods that can capture the variability. Observed flow data that are limited in time (~100 years) cannot provide the full range of variability, even with stochastic models built on them. Paleohydrologic reconstructions of annual flow using tree rings, however, provide much longer (500–1000+ years) records of past natural variability, and thus a much richer sampling of potential flow sequences, including severe and sustained droughts of greatest concern to water resource managers. Thus, the overall goals of this project are to develop new paleo-reconstructions of Lower Basin hydrologic variability and incorporate them into a more robust assessment of the risk for the entire Colorado River Basin.

This project was primarily motivated by the interests of the Colorado River District (CRD), which is responsible for the conservation, use, protection, and development of Colorado's apportionment of the Colorado River. Beginning in the fall of 2010, the project has been carried out with funding from CWI/NIWR, the CRD, the University of Colorado (CU) Western Water Assessment, and graduate student support from the CU Department of Civil and Environmental Engineering.

Methods and Results
The methods and results for the main project components for the second half of Year 1, and Year 2, of the project are as follows:

Conducted analyses of gaged flows in the Lower Basin, and developed naturalized annual flow records for the Lower Basin for the historic period (~1906 to present) to use as targets for the paleohydrologic reconstructions, for these two locations:

- *The flow for the Gila River near its confluence with the Colorado*
- *The intervening flow on the Colorado River between Lees Ferry and Imperial Dam*

The hydrology of the Gila River is almost entirely modified by reservoir operations and depletions before it joins the Colorado River, and these modifications began in the first decade of the 1900s (Figure 2). Several headwater gages on the mainstem Gila and its major tributaries (Salt River, Verde River, Tonto Creek) are above the dams and most diversions and remain mainly natural (Figure 2). In 1946, USBR developed estimates of natural flow at gages downstream of the dams and diversions, including Dome, AZ (the closest gage to the mouth), for the period 1897–1943. After extensive analysis of the gaged records for the Gila River Bain, we developed a local polynomial regression model between the USBR-estimated naturalized flow at Dome for the 1897–1943 period and the near-natural gaged flows at the headwater gages. The modeled estimated natural flows for the Gila near Dome cover the period 1915–2010 (Figure 3). We also retained the gaged flows at Dome (Figure 2) as a calibration series since they represent the inputs to the Colorado from the Gila under current, managed conditions and are more relevant for the system risk model as we implemented it.

The US Bureau of Reclamation maintains a "natural flow" dataset for the Colorado River and major tributaries (see Figure 1) for the 29 input nodes for their CRSS system model, but for the 9 nodes in the Lower Basin, these flows have not been explicitly naturalized. Also, the necessity of reconciling the *total* flows entering the top of the Lower Basin with those gaged at the bottom (Imperial Dam) means that some of the calculated *intervening* flows (which are much smaller in magnitude) may contain artifacts of the water-balance modeling. In fact, we discovered that of the 9 nodes within the Lower Basin, flows at 5 nodes from 1906-2008 were well-correlated with observed precipitation and streamflow in adjacent basins, while the flows at the other 4 nodes were essentially uncorrelated with observed hydroclimate. We found also that the total flows at the 5 "good" nodes were well-correlated with flows simulated by the VIC hydrology model. Thus, we retained the flows at the 5 good nodes to represent the Lees Ferry to Imperial reach, for calibration with the tree-ring data.

Compiled and screened the available tree-ring chronologies within and adjacent to the Lower Basin.

Long-lived, moisture-sensitive conifers are widespread in the Lower Basin and adjacent areas of Arizona, New Mexico, Utah, and Colorado. Over 60 tree-ring chronologies that were recently collected for three other projects were recompiled for this project: The Salt River Project (SRP)-LTRR Project (U. of Arizona and SRP), the North American Monsoon project (U. of Arizona), and the Non-Parametric Project (U. of Colorado, USBR, and Hydrosphere). After we screened these chronologies for location and length, we retained 35 chronologies for reconstruction modeling. All of the sites are located in or near the Lower Colorado River Basin and extend from at least 1612 to 2005.

Generated and evaluated tree-ring reconstructions for Gila flows and the mainstem intervening flows using multiple methods.

Paleohydrologic reconstructions have been generated using many different statistical approaches, all of which have particular strengths and weaknesses. The most commonly used approach has been multiple linear regression (MLR); thus, to establish a baseline for comparison with new approaches, we used two variants of forward-stepwise MLR (with and without PCA, see below) to reconstruct streamflows for both sub-basins chronologies directly as predictors. We also used Lowess regression, which uses a robust lowess-smoothed relationship instead of a linear relationship, to reconstruct flows for the Gila River. We also implemented two new statistical methods for tree-ring reconstruction of streamflow. For the first method, K-NN-Local polynomial (KNN-LP), we employed a cluster analysis on our regional network of tree-ring chronologies to identify spatially coherent subregions that have a common climate signal, then performed Principal Component Analysis (PCA) on the clusters to obtain the leading modes of variability. The leading modes are used as predictors in a local polynomial model to fit to the *k*-nearest-neighbors (K-NN) of observed natural streamflows. This approach modifies the K-NN resampling method of Gangopadhyay et al. (2009) and adds the ability to produce flows beyond the range of the observed data and also capture nonlinearities. The second method introduces the extreme value analysis (EVA) framework, peaks-over-threshold (POT) method, to reconstructing threshold exceedances of streamflow. The EVA/POT models the probability of threshold exceedance, and the magnitude of exceedances, and is especially suited for reconstructing intermittent streamflow, such the gaged flows at the mouth of the Gila River. These methods are able to capture additional aspects of streamflow that are difficult or not possible to reconstruct with traditional linear regressions. This method was also applied to the natural flows of the Gila River but those results are not shown in the figures.

The four tree-ring reconstructions of Gila River natural flows explain between 41 and 60% of the variance in the observed flows (Figure 4). They all capture the low flows better than the high flows, and show very similar patterns of variability both during the observed period (Figure 4) and the longer paleo-period (Figure 5), testifying that the underlying tree-ring information is robust to the specific statistical method. The KNN-LP and Lowess methods are able to express larger magnitudes in high-flow years than the MLR reconstructions. The KNN-LP method also often shows the smallest flow magnitude in low-flow years. The mean and median reconstructed flow is generally lower before 1900 than after 1900, and the 20th century appears anomalous, with two major wet periods, compared to preceding three centuries. The KNN-LP reconstruction of mainstem Colorado River intervening flow (Figures 6 and 7) is very similar to the Gila reconstructions, and explains about half of the variance in the observed flows. As with the Gila, the low flows are reconstructed more accurately than the high flows. The EVA reconstruction of the Gila River *gaged* flows (Figure 8; compare with Figure 2) demonstrates for the first time that highly intermittent annual flow series, with positive flows in less than half of all years, can be effectively reconstructed using tree rings.

These new reconstructions for the Lower Basin also demonstrate that long-term hydrologic variability in the Lower Basin is different enough from the variability in the Upper Basin to justify including the former in system risk assessment as a complement to the latter. Figure 9 shows a “bar chart” of tree-ring reconstructed wet (above the long-term average; black) and dry (below-average; white) flow periods for the Colorado River at Lees Ferry, Gila River at Dome, and Colorado River intervening flows below Lees Ferry, since 1600. The Lees Ferry (Upper Basin) reconstruction and the two Lower Basin reconstructions agree on system state just over 2/3 of all years; while in 1-in-11 years, Lees Ferry is “dry” while the Lower Basin is “wet”.

Performed system response analysis using the new Lower Basin reconstructions as input to Rajagopalan et al. (2009) water-balance model of the Colorado River Basin.

The water-balance model is simple yet representative of the water resources system in the basin, and has been previously used (Rajagopalan et al., 2009) to investigate the risk of active system storage being depleted under different scenarios. For this project, the model setup now included variability in Lower Basin flow and the ability of periodic Gila River discharges to reduce the releases needed from Lake Mead. As in the previous study, the water-balance model was driven by natural variability alone and with climate change scenarios (progressive flow reductions), under two different reservoir operation rules and demand management alternatives. We found that the periodic Gila River discharges do provide some mitigation of water supply risk. They reduce the Colorado River system risk of depletion slightly in all scenarios; for example, the cumulative risk by 2057 is reduced from 37% to 33% percent under the particular scenario shown and described in Figure 10. Furthermore, including the Gila reduces the average shortage volume per year, increases the storage volume in the system and reduces the average number of shortages.

Summary

The project has been successful in its objectives of (1) robustly representing the long-term hydrologic variability of the Lower Colorado River Basin using multiple statistical methods, including two novel approaches, and (2) incorporating that variability into Colorado River Basin system risk modeling. We have found that the variability of Lower Basin flows does matter, and that in particular the Gila River may have a measurable impact on future system risk due to its periodic significant discharges into the mainstem.

Project deliverables

- MS thesis (Wade) in Civil Engineering to be defended in May 2012
- Two manuscripts in preparation to be submitted to peer-reviewed journals (e.g. Water Resources Research) in summer 2012
- Final project report to be submitted to CWI and CRD in summer 2012
- Presented a poster (Wade, et al.) at the University Council on Water Research (UCOWR) annual meeting in July 2011
- Presented a poster (Wade, et al.) at the American Geophysical Union (AGU) Fall Meeting in December 2011
- Presented a poster (Wade, et al.) at the CSU Hydrology Days in April 2012

References

Gangopadhyay, S., Harding, B., Rajagopalan, B., Lukas, J., and Fulp, T. (2009). A Non-Parametric Approach for Paleohydrologic Reconstruction of Annual Streamflow Ensembles. *Water Resources Research* **45**, W06417.

Rajagopalan, B., Nowak, K., Prairie, J., Hoerling, M., Harding, B., Barsugli, J., Ray, A., and Udall, B. (2009). Water Supply Risk on the Colorado River: Can Management Mitigate? *Water Resources Research* **45**, W08201, doi:10.1029/2008WR00765.

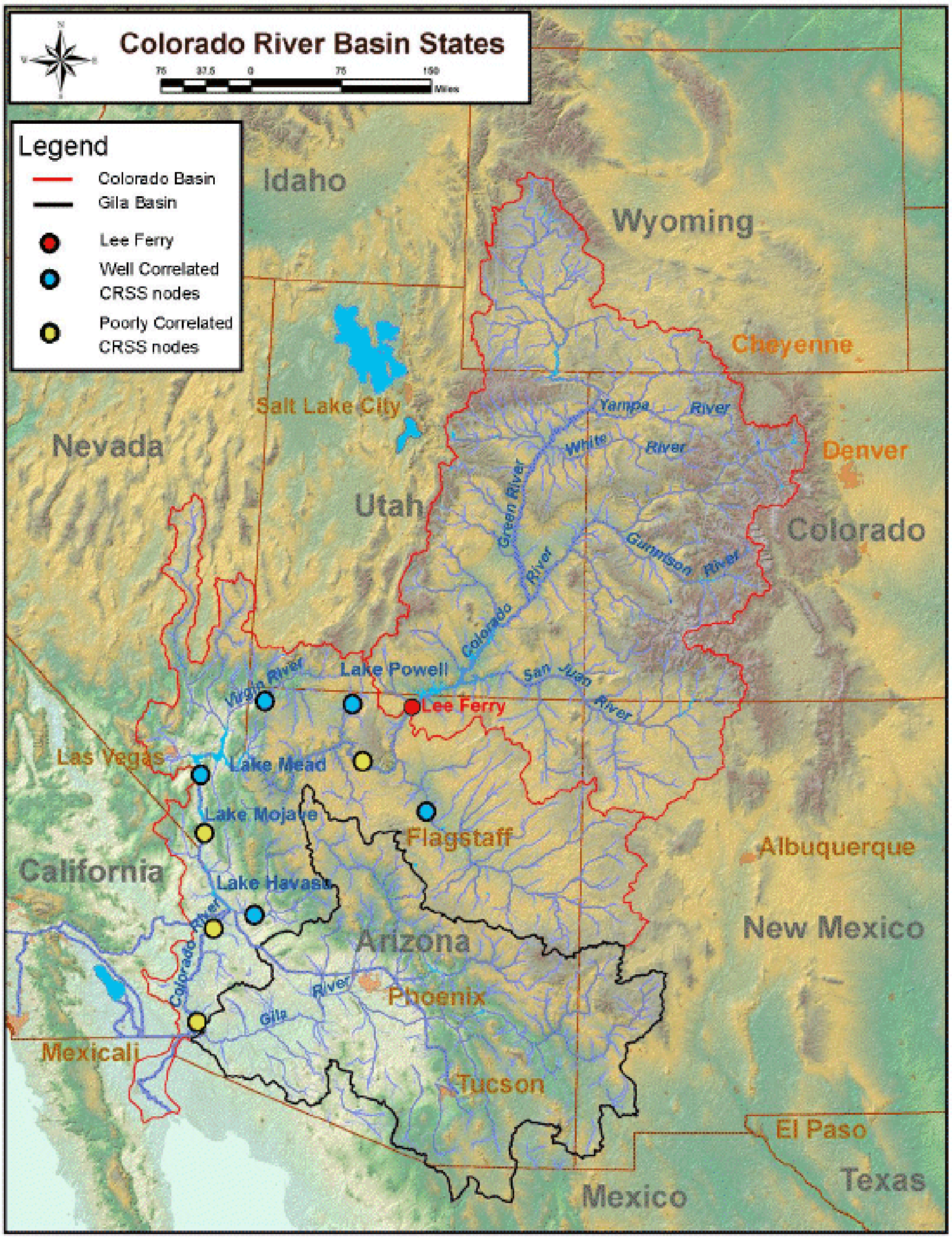


Figure 1. Colorado River Basin (CRB). The basin is divided at Lee Ferry (red dot) for legal and management purposes into an Upper Basin and Lower Basin (red boundaries). The watershed of the Gila River is outlined in black. USBR's 9 CRSS model nodes in the Lower Basin are shown as blue and yellow dots. The intervening flows at the 5 blue nodes are well-correlated with precipitation while the 4 yellow nodes are not. We used only the 5 blue nodes in our Lower Colorado mainstem flow reconstruction.

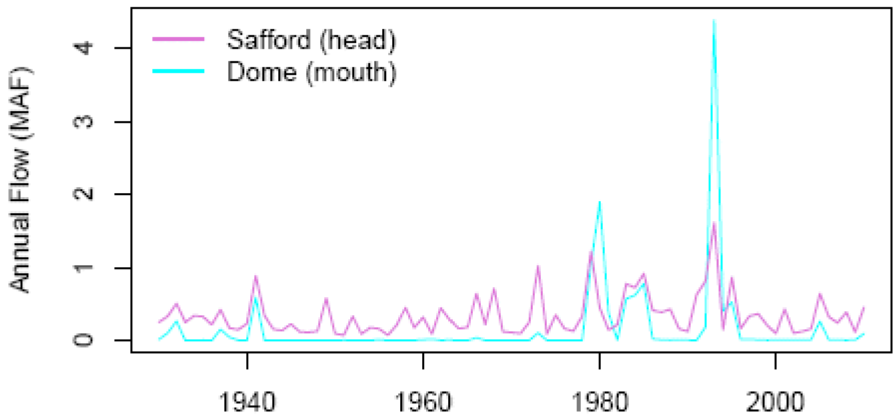


Figure 2. Gaged annual streamflows (1929–2011; USGS) for the Gila River at two gages: Safford Valley, near Solomon, AZ, in the headwaters of the basin; and near Dome, AZ, at the confluence of the Gila and the Colorado River. The flows at Safford represent near-natural conditions; intensive use of the river downstream of Safford results in flows at the mouth that are zero in most years, spiked with periodic large flows, such as in 1980 and 1993.

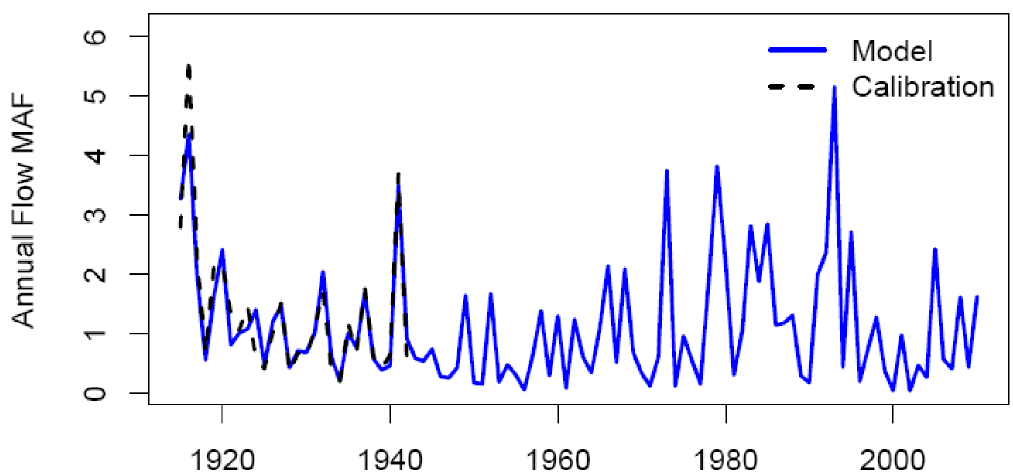


Figure 3. Our model (blue) of estimated natural annual streamflows (1915–2010) for the Gila River near Dome, AZ, at the confluence of the Gila and the Colorado River. The model predictors are gaged headwaters flows, including the Safford gage shown in Figure 2, calibrated on natural flows for 1897–1943 estimated by USBR in 1946 (black line).

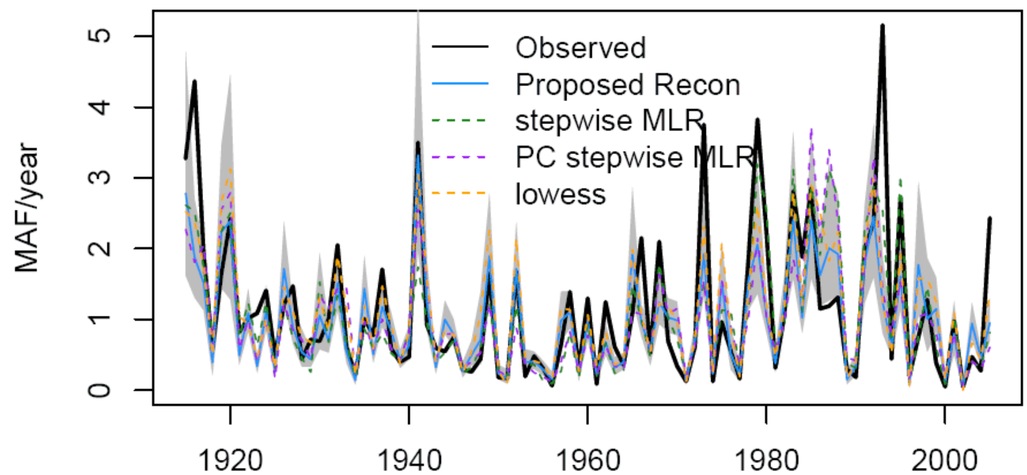


Figure 4. Four different methods for tree-ring reconstruction of natural annual streamflows (1915–2005; colored lines) for the Gila River near Dome, AZ, compared with the modeled natural streamflows ("Observed") shown in Figure 3. The "Proposed Recon" (blue line) is the KNN Local polynomial model, with the gray shading showing the 5 and 95 percent confidence intervals around that reconstruction.

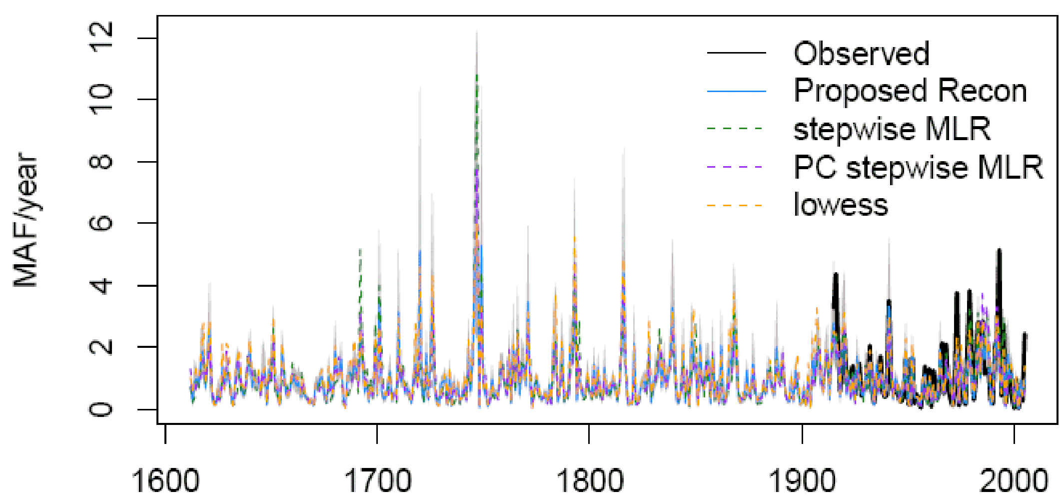


Figure 5. Same as Figure 4, but showing the full temporal extent (1612–2005) of the four tree-ring reconstructions for the Gila River near Dome, AZ. Note that the reconstructions show annual flows higher than any since 1900, and multi-year low flow periods more persistent and severe than those since 1900.

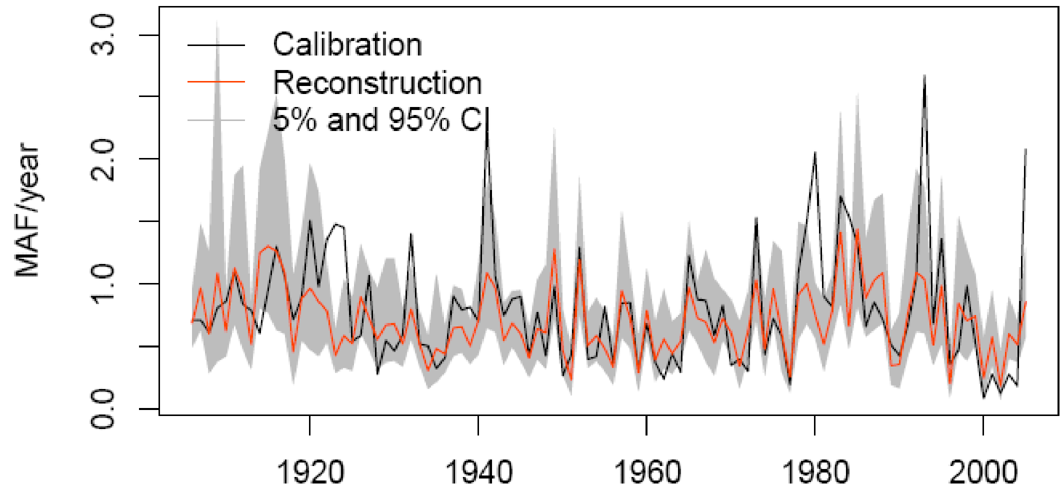


Figure 6. Tree-ring reconstruction (red line) of annual intervening streamflows, 1906–2005, for 5 CRSS nodes which represent most of the inflows to the Colorado River between Lees Ferry and Imperial Dam (observed, black line). The reconstruction was generated using the KNN Local polynomial model, with the gray shading showing the 5 and 95 percent confidence intervals around that reconstruction.

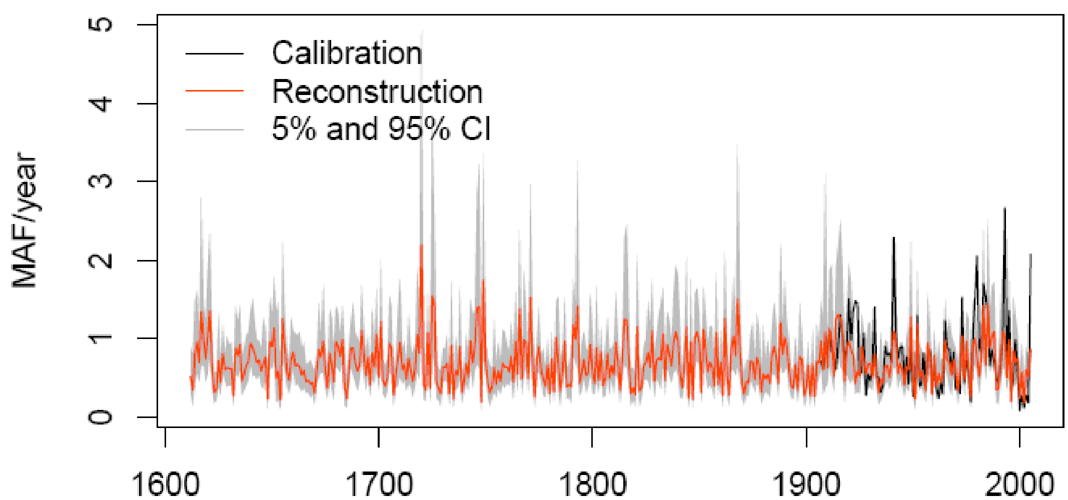


Figure 7. Same as Figure 6, but showing the full temporal extent (1612–2005) of the KNN-LP tree-ring reconstruction for the mainstem Colorado River inflows.

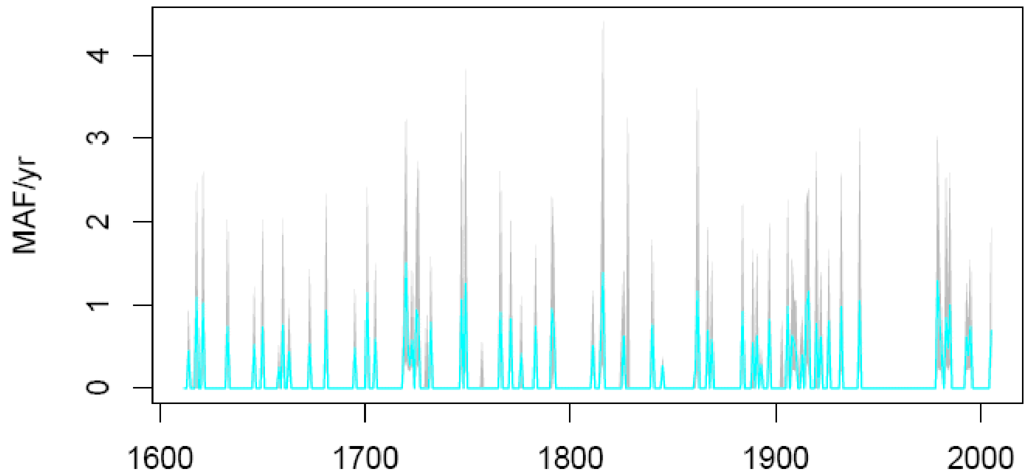


Figure 8. Tree-ring reconstruction of "as-managed" gaged flows (shown in Figure 2) for the Gila River near Dome, AZ (1612–2005) at the confluence of the Gila and the Colorado River, using the Extreme Value Analysis (EVA) method. As with the gaged record, most of the reconstructed flows are zero, representing the intensive use of the Gila River, with occasional high discharges into the Colorado River which provide some capacity to substitute for releases from Lake Mead.

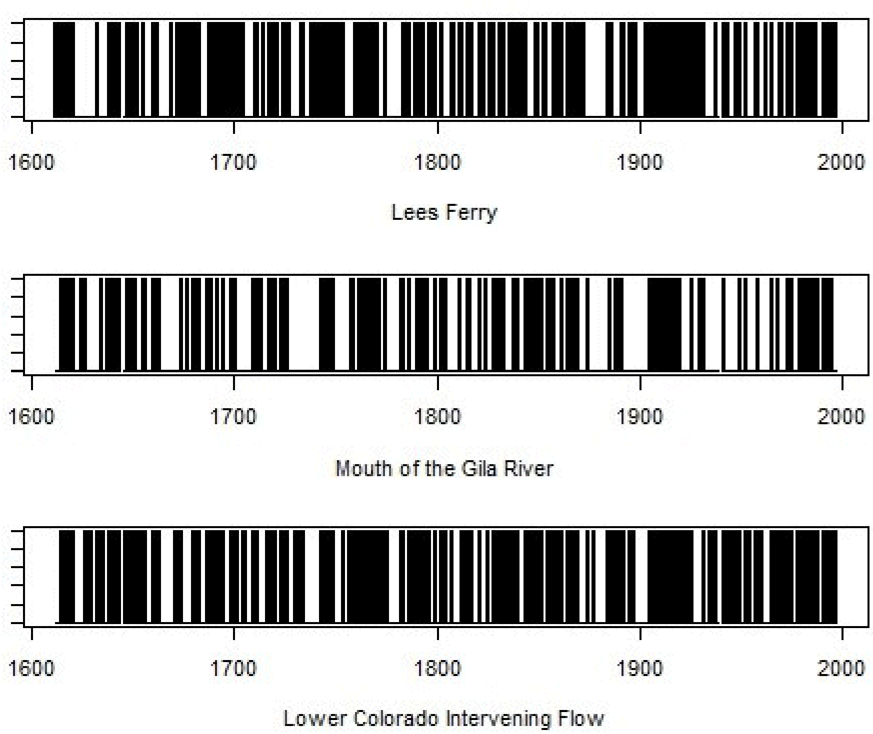


Figure 9. "Bar-codes" of tree-ring reconstructed *wet* (above the long-term average; black) and *dry* (below-average; white) flow periods for the Colorado River at Lees Ferry (Upper

Basin), Gila River at Dome (Lower Basin), and Colorado River intervening flows below Lees Ferry (Lower Basin), since 1600.

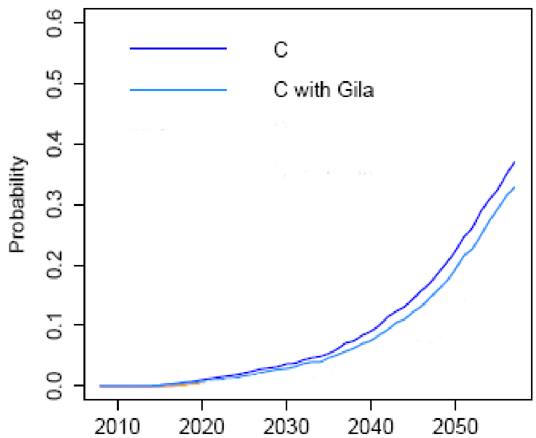


Figure 10. Probability of depletion of Colorado River Basin system storage, as modeled under these conditions: progressive reduction in flows of 20% due to climate change, current policy for implementing shortages, and basin demands held at actual 2008 demand. Trace "C" (dark blue) does not account for inflows from the Gila. Trace "C with Gila" (light blue) allows the periodic Gila inflows, as seen in the gaged record and reconstructed using tree rings (Figure 8), to influence upstream releases of water, slightly reducing (33% vs. 37%) the risk of depletion by 2057.

Environmental Impacts of Ag-to-Urban Water Rights Transfers in the South Platte River Basin

Basic Information

Title:	Environmental Impacts of Ag-to-Urban Water Rights Transfers in the South Platte River Basin
Project Number:	2011CO234B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	4th
Research Category:	Climate and Hydrologic Processes
Focus Category:	Water Supply, None, None
Descriptors:	None
Principal Investigators:	Mazdak Arabi

Publications

1. Arabi, Mazdak, 2011, Environmental Impacts of Ag-to-Urban Water Rights Transfers in the South Platte River Basin, Colorado Water Institute Proposal, 2 pages.
2. Smith, Meagan, 2012 "Quantifying a relationship between irrigation activities and wetlands in a Northern Colorado watershed and assessing this added value of irrigation waters," pg. 2-6 of Colorado Water, Volume 29 issue 3.

Quantifying a relationship between irrigation activities and wetlands in a Northern Colorado watershed and assessing this added value of irrigation waters

Meagan Smith, MS Candidate, Civil Engineering, Colorado State University
Faculty Advisor: Mazdak Arabi and Chris Goemans

Introduction

Continued rapid population growth throughout much of the arid West is increasing the competition between agriculture and municipal and industrial (M&I) uses for the limited available water resources. Colorado is one example where population is projected to nearly double by 2050, resulting in an estimated increase in water demand of between 600,000 and one million acre-feet/year.[1] Colorado anticipates addressing the gap between municipal supplies and demand through new water supply development, conservation, reuse, and the reallocation of water from agriculture to urban uses.[1]

When assessing water management options, water planners must strike a balance between socioeconomic and environmental considerations. With the extremely high cost of developing new water supplies and the uncertainty of the approval process, planners are likely to rely heavily on other in-basin management options. While conservation and reuse are valuable tools, the amount of “new” water that can be generated is limited based on current technology, social acceptability and strict guidelines within the Doctrine of Prior Appropriation. Combining this with the fact that more than 85 percent of Colorado’s freshwater supplies are currently used in agriculture1 sheds light as to why many planners are likely to turn to agricultural water transfers to fill a large portion of their anticipated supply gap. These probable transfers are expected to result in irrigated acreage losses in nearly every river basin in Colorado. The South Platte River Basin alone is projected to lose as many as 108,000 irrigated hectares (267,000 acres) by 2050, more than 32 percent of the lands under irrigation in 2005.[1]

1. CWCB, 2010. Colorado Water Conservation Board Statewide Water Supply Initiative 2010. http://cwcb.state.co.us/water-management/water-supply-planning/Pages/SWSI2010.aspx

Left: Figure 1. *Private bird watching blind along near wetland along Larimer County Ditch.*
Photo by Meagan Smith.

In recent years, agricultural transfers have received considerable attention due to the economic and social impacts associated with the permanent dry-up of irrigable lands. While the direct and indirect production impacts associated with permanent transfers have been well documented, awareness of the public benefits of agriculture beyond its economic output from production is growing.[2] These benefits include, but are not limited to, the values associated with access to locally produced foods, open space, and wildlife habitat. In order to make informed decisions, and to fully understand their repercussions, planners must have an indication of all of the effects of permanent water transfers.

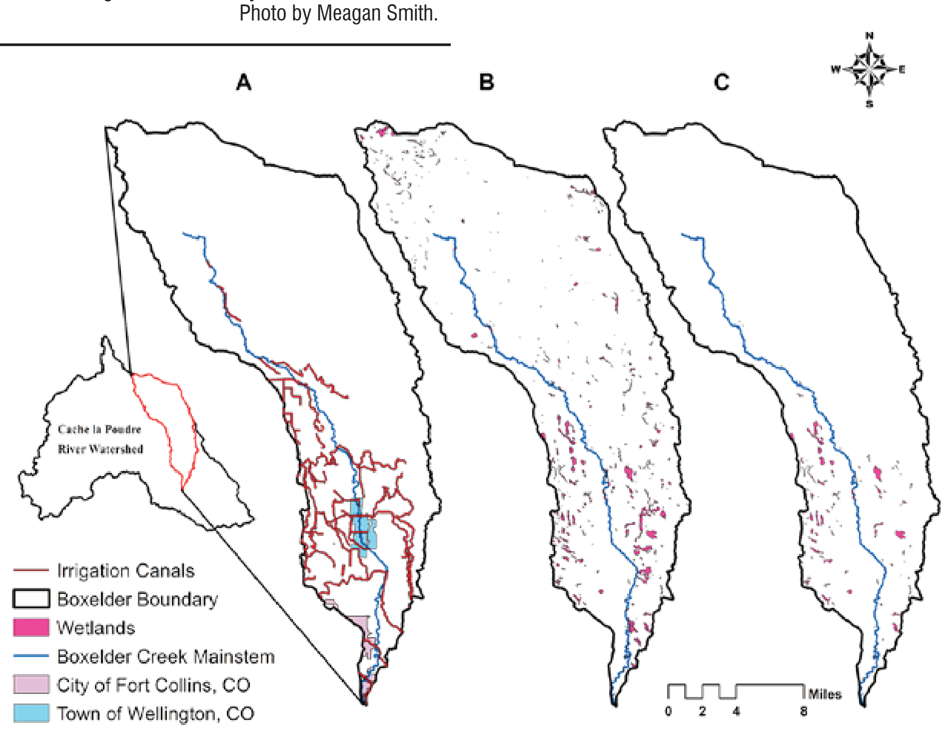


Figure 2. *Boxelder Creek watershed showing A) creek main stem, irrigation canals, Wellington and Fort Collins, B) creek main stem and all identified wetlands, excluding managed reservoirs, C) creek main stem and subset of irrigation dependent wetlands.*

Background

Colorado's agricultural lands are often not adjacent to points of river diversions. Therefore, irrigation water must be conveyed through a series of canal systems en route to field application. Construction over the last 130 years of canals throughout the state has allowed for the spread of irrigated agriculture further and further away from the water source. This has created a unique environmental interdependence on irrigation and its associated return flows with the surrounding ecosystem health and function, specifically the creation and maintenance of wetlands that would otherwise not exist.[3]

These incidental wetlands have come to function comparably to naturally occurring ones, providing ecosystem benefits, including recreational opportunities, wildlife habitat, water filtration, flow control, and even carbon sequestration. These benefits have received little attention, in part because they are typically not reflected in estimates of the value of water in agriculture, nor are they reflected in market transactions. Furthermore, unlike the planning stages for new water supply projects, Colorado water law does not consider potential environmental impacts when evaluating the transfer of water out of agriculture. This information is needed to appropriately evaluate the trade-offs associated with the reallocation of agricultural water.

The goal of this ongoing research is to provide a greater understanding of the overall ecosystem impacts of irrigation, as well as a more complete valuation of all aspects of transferring water out of agriculture, not just those associated with changes in production. This is being done in two parts: (1) by developing a geographic information system (GIS) methodology to quantify the relationship between the size of incidental wetlands and water use in agriculture, controlling for geo-spatial characteristics of the contributing areas, both natural and anthropogenic, and (2) by quantifying the dollar value of these wetlands utilizing an ecosystem benefits transfer model created by Loomis and Richardson.[4] Subsequent sections provide an overview of the study, project methodology and preliminary results.

2. Howe, C., and C. Goemans, 2003. Water Transfers and Their Impacts: Lessons From three Colorado Water Markets. Journal of the American Water Resources Association (JAWRA). 39(5): 1055-1065.
3. Peck, D., D. McLeod, J. Hewlett, and J. Lovvorn, 2005. Irrigation-Dependent Wetlands Versus Instream Flow Enhancement: Economics of Water Transfers from Agriculture to Wildlife Uses. Environmental Management. 35(6): 842-855.
4. Loomis, J. and L. Richardson. 2008. Benefit Transfer and Visitor Use Estimating Models of Wildlife Recreation, Species and Habitats. National Council for Science and the Environment 2006 Wildlife Habitat Policy Research Program – Project Topic 1H: Development of an Operational Benefits Estimation Tool for the U.S. http://dare.colostate.edu/tools/benefittransfer.aspx

Methods and Results

Right: Figure 3. *Wetland along Lake Canal near southernmost tip of watershed.*

Photo by Meagan Smith

Study Area

The Boxelder Creek Watershed was chosen for this study due, in part, to the complex network of irrigation infrastructure that both traverses the watershed, taking irrigation water to fields in Weld County, as well as serves the watershed, irrigating nearly 11,320 hectares (28,000 acres) within the basin. Boxelder Creek, a tributary of the Poudre River, drains 739 km2 (285 mi2) along the Front Range of northern Colorado and a small portion of southeastern Wyoming. The creek originates in Wyoming and flows southeast through the towns of Wellington and Fort Collins, drained and recharged by irrigation canals several times, before reaching its confluence with the Poudre River just downstream of the Boxelder Sanitation District. Figure 2A depicts the basin with the main stem of Boxelder Creek and the many irrigation canals that intersect the area (examples of the watershed in figures 1 and 3).

Geographic Analysis

A comprehensive digital map of wetlands in the Boxelder Watershed was created utilizing digital riparian mapping from the Colorado Department of Wildlife,[5] in conjunction with National Wetlands Inventory maps, digitized for this project by the Colorado Natural Heritage Program, and heads-up digitizing using current aerial photography. This exhaustive wetland map depicts more than 1,525 hectares (3,770 acres) of wetlands in the Boxelder Creek watershed, not including managed reservoirs. As previously stated, the interest here is in investigating incidental wetlands. Although most reservoirs in the basin are for irrigation management, they were created intentionally, not as a byproduct of conveyance or application. The contributing area for each wetland was then delineated using ArcHydro and the Hydrology Toolbox functions in ArcGIS 9.3.1.

Further inspection of the aerial photography led to classifying each wetland based on its apparent dominant water source. This was done to account for the many wetlands in Boxelder Basin located in areas far removed from irrigation activities. By comparing Figure 2A and 2B, a pattern can be discerned regarding the presence of wetlands in relation to the location of irrigation canals. The result of the classification is a subset of 100 wetlands (Figure 2C), totaling more than 560 hectares (1,480 acres), having a dominant water source of irrigation.

In order to assess the impact of distance on the relationship between the geo-spatial characteristics of the contributing areas and the size of wetlands, four distance buffers were created for each wetland (50m, 100m, 250m, and 500m) and intersected with the delineated contributing areas, creating four areas of influence to assess for this study. The data was then compiled for each area of influence. Table 1 lists the geo-spatial characteristics considered for the analyses, the source of the data, and any modifications made. It is important to note that topographic conditions do not vary significantly across the sample area.

Data Analysis

In order to assess which of the five geo-spatial characteristics under consideration have a dominant

Variable	Geo-spatial Characteristic	Data Source	Modifications
Flood Irrigation	Number of hectares under flood irrigation	CDSS GIS Data - Division 1 Irrigated Lands 2005	Data layer intersected with each defined area of influence
Sprinkler Irrigation	Number of hectares under sprinkler irrigation	CDSS GIS Data - Division 1 Irrigated Lands 2005	Data layer intersected with each defined area of influence
Length of Canal	Meters of irrigation canals	CDSS GIS Data - Division 1 Structures	Data layer intersected with each defined area of influence
K_{sat}	Shallow groundwater flow potential, approximated by Saturated Hydraulic Conductivity	USDA NRCS Soil Survey Geographic Database (SSURGO)	K_{sat} values were depth weighted for each soil polygon, then area weighted within defined areas of influence
CN	Runoff potential, approximated by NRCS curve number	USDA NRCS National Cartography & Geospatial Center Land Use Data	Land use layer intersected with SSURGO layer (soils data) and CN assigned for each intersection (Novotny, 2011). CN area weighted within defined areas of influence

Table 1. *Geo-spatial characteristics considered for analyses, including source and modifications.*

5. CDOW, 2008. Colorado Division of Wildlife – Strategic Plan for the Wetland Wildlife Conservation Program: Version 1.0. http://wildlife.state.co.us/LandWater/WetlandsProgram/

	Full Sample[a]	Observations with highest 1/3 of CN	Full Sample[a]	Observations with highest 1/3 of CN	Full Sample[a]	Observations with highest 1/3 of CN	Full Sample[a]	Observations with highest 1/3 of CN
	50 m		100 m		250 m		500 m	
Flood Irrigation	0.142***	0.209*	0.103***	0.174**	0.056***	0.049**	0.027***	0.024**
Sprinkler Irrigation	ns	0.245**	ns	0.162**	ns	0.052**	ns	0.027*
Length of Canal	0.0009***	0.003***	0.0009***	0.0023***	0.0008***	ns	0.0007***	ns
Constant	1.842	-0.707	2.192	-0.907	2.446	-0.636	1.903	-0.516
R2adj	0.381	0.355	0.441	0.414	0.476	0.355	0.39	0.284
Sample Size	100	33	100	33	100	33	100	33

Table 2. *Multiple regression coefficients and adjusted coefficients of determination (R2adj) of models relating flood irrigation, sprinkler irrigation and length of canal to ln(wetland size) for the full data sample and a subset of sample with the highest 1/3 of curve number values (70 ≤ CN ≤ 83).*

impact on the size of wetlands, tree regression, in conjunction with bootstrap aggregation, was utilized.[6,7] Tree regression is a method of non-parametric regression, which does not require the extensive list of assumptions needed for other regression models. In order to assure the stability of the tree regression model, bootstrap aggregation was used to grow multiple regression trees based on 1000 independently drawn bootstrap replicas of the input data. The importance of each characteristic was then averaged over the 1000 replicas.

In addition, multiple-linear regression analysis was performed, including all five geo-spatial characteristics for each area of influence. This allowed further confirmation of the dominant variables, as well as determination of how well these variables explain the variation in wetland size in Boxelder Creek Watershed.

Results from both analyses support the same conclusion. The three dominant characteristics, which remain constant across all four areas of influence, are; (1) length of canal, (2) area under flood irrigation, and (3) runoff potential.

Furthermore, as part of the initial analysis, we investigated the individual effect of runoff potential (CN) and shallow groundwater flow potential (Ksat) on the relationship between irrigated lands and/or length of canals on wetlands size. This was done by further regression analysis across multiple ranges of CN values and Ksat values. As seen in Table 2, initial results show that as CN increases, reflecting an increase in runoff potential, the effect of sprinkler irrigated lands becomes significant. To this point, the results for Ksat have proven inconclusive for our data set, but we will continue to explore.

Economic Analysis

As previously stated, economic impact studies on agriculture-to-urban water transfers have historically only considered the

6. Breiman, L., J. Friedman, R. Olshen, and C. Stone. 1984. Classification and Regression Trees. Boca Raton, FL: CRC Press LLC
7. Breiman, L. 1996. Bagging Predictors. Machine Learning. 42(2): 123-140. DOI: 10.1007/BF0058655.

direct and indirect financial impacts associated with the resulting change in agricultural production. Realizing that removing water from agriculture could have considerable effects on incidental wetlands and the ecosystem services they provide, a benefits transfer model, created by Loomis and Richardson, was utilized to estimate the economic value of these services. The model evaluates nine possible ecosystem services, while controlling for measures that account for geographic location, overall scarcity of wetlands in the region, type of wetlands being evaluated and household income.

For this study, the ecosystem services included for valuation are (1) reduced costs of water purification, (2) recreational observation of wildlife, (3) value provided by proximity to the environment, and (4) non-use appreciation of species habitat. The 560 hectares of wetlands identified as irrigation dependent results in $3.38 million of added value to agricultural water in the Boxelder Creek watershed. Further analysis will include investigating the extent to which a reduction in wetland size, due to increased on-farm and conveyance efficiencies or transfers of water out of agriculture, will affect the ecosystem service value provided by the wetlands.

Discussion and Implications

The tree regression and multiple-linear regression analyses generated many of the same conclusions; (1) the three most significant predictors for explaining the variability in wetland size in the Boxelder Creek watershed, regardless of buffer width, are meters of canal, followed by number of hectares of flood irrigation, followed by curve number; (2) sprinkler irrigation has a lesser effect on wetland size than flood irrigation, however, as CN increases, the effect of sprinkler irrigation is more pronounced; and (3) saturated hydraulic conductivity (Ksat), used as a proxy for shallow groundwater interactions, appears to be insignificant for this data set.

Due to the amount of flood irrigation in this region, it was anticipated that it would prove to be a significant source of water for wetlands. The regression analyses substantiated this assumption; however, initial results point to length of irrigation canals within the contributing area to be the most significant predictor in both analyses. This suggests that canal seepage is a significant source of water for wetlands in this study. These findings shed light on potential impacts of conveyance efficiency measures, such as lining irrigation canals.

It was also anticipated that sprinkler irrigated lands would have a lesser impact on the size of wetlands than flood irrigated lands; however, it was not anticipated that sprinkler irrigation would only prove to be significant at the highest CN values. This could have bearing on the impact to wetland size of increasing on-farm efficiency, such as moving from flood to sprinkler irrigation.

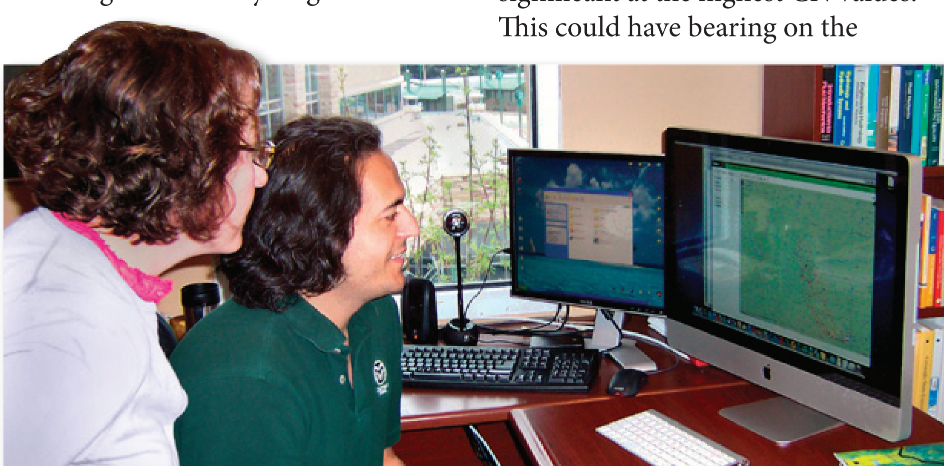
One of the main drivers of this research is to assess the extent to which irrigation is a significant source of water for wetlands in the study area. Initial findings suggest this is the case. However, additional studies should be performed to further investigate the role of groundwater with the creation and maintenance of wetlands in the study area.

In Conclusion

Although the framework within the doctrine of prior appropriation, combined with Colorado's no injury requirement, does an excellent job of protecting water rights holders from altered or diminished water supplies, it does so by limiting the water transfer amount to the historical consumptive use. This inherently results in water that would have returned to the stream through return flows either never actually leaving the stream, or at minimum, returning via a different conduit.

Preliminary results of this study suggest that altered flow patterns, including those resulting from decreased conveyance flows, irrigation canal lining, or increased application efficiencies, have the potential of diminishing, or even eliminating, irrigation-dependent wetlands. This presents another value loss that should be accounted for when planning water transfers out of agriculture, and weighed when investing in conveyance or on-farm efficiency improvements.

I would like to thank the Colorado Water Institute for helping to fund this research. For more information regarding this research and findings, please contact Meagan Smith at meagan.smith@yahoo.com.



Meagan Smith with her faculty advisor, Mazdak Arabi, Civil Engineering, CSU.

Aquifer Storage and Recovery Optimization

Basic Information

Title:	Aquifer Storage and Recovery Optimization
Project Number:	2011CO235B
Start Date:	3/1/2011
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Descriptors:	None
Principal Investigators:	Reagan M. Waskom

Publications

1. Sale, Tom, 2012, Aquifer Storage and Recovery Optimization, Colorado Water Institute Proposal, 2 pages.
2. Mauer, Anne, "Combined Source Infrastructure Assessment Model," pg. 19-21 of Colorado Water, Volume 29 issue 3.

Combined Source Infrastructure Assessment Model

Anne Maurer, MS Candidate, Civil and Environmental Engineering, Colorado State
Faculty Advisor: Tom Sale

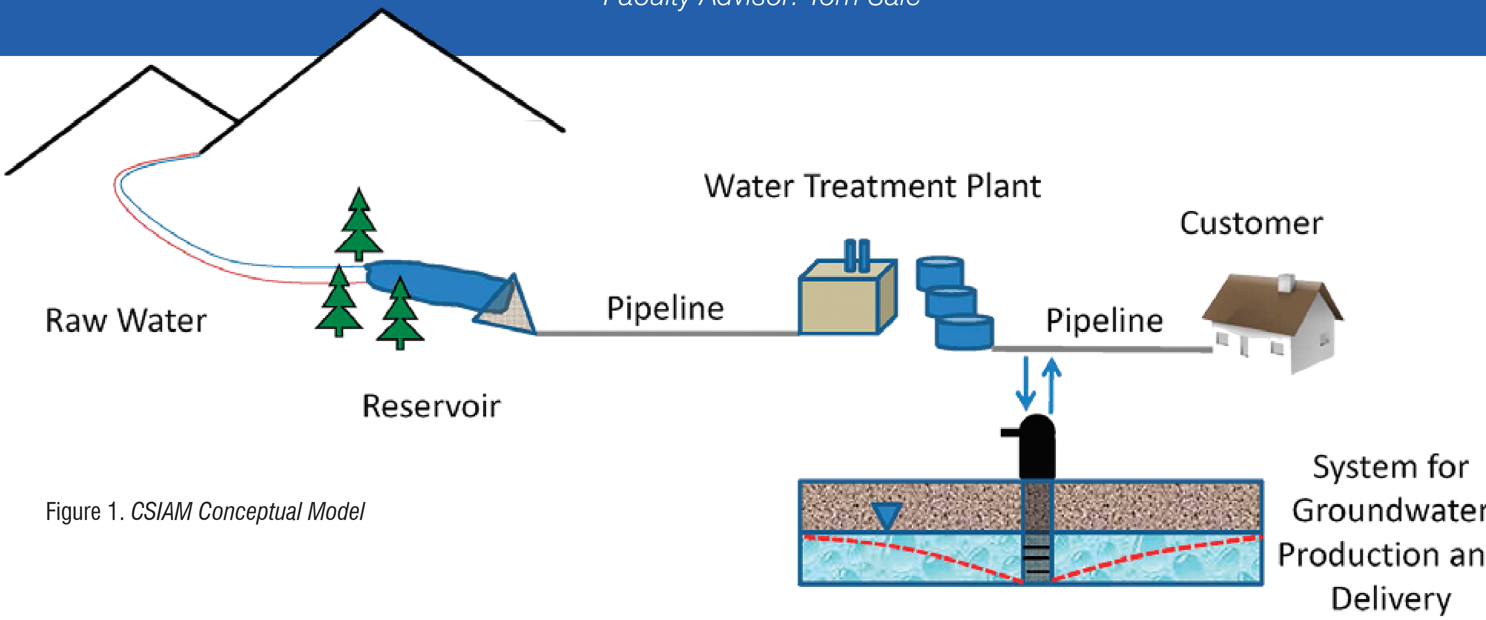

Figure 1. *CSIAM Conceptual Model*

Purpose of Study

The world is facing the critical problems of increasing population, climate change, and intensifying competition for water resources. With all of this, integrated utilization of surface and groundwater is becoming an ever more important strategy for sustaining water production needed to address irrigation, domestic supply, and industrial demands. The term "conjunctive use" is used to describe the coordinated management and development of surface and groundwater. Conjunctive use includes the ability to store and/or utilize surplus water from one source to meet the deficit of another source. Unfortunately, design and analysis of costs associated with conjunctive use projects can be difficult. Challenges include 1) appropriate sizing of water storage, water treatment, and well fields under conditions of evolving demands; 2) resolving timing of surface water use, groundwater use, and groundwater storage; and 3) efficiently developing estimates of costs associated with a range of options.

Anne Maurer with her faculty advisor, Tom Sale, Civil and Environmental Engineering, CSU.

The purpose of the study was to develop a Combined Source Infrastructure Assessment Model (CSIAM) that can be used to 1) resolve appropriate infrastructure and operations for combined source water systems and 2) develop feasibility level cost estimates.

General approaches to conjunctive use include combined use of surface and groundwater with and without groundwater recharge. The primary advantages to systems with groundwater recharge include an ability to "bank" water in aquifers during periods when surplus surface water is available, and to reduce the necessary capacities of surface water structures (e.g., water treatment plants) to meet peak demands.[1] A central tenant of the model is to recharge groundwater when surplus surface water is available. This is based on minimizing the size of surface water reservoirs and, correspondingly, minimizing water losses to seepage and evaporation. Funding for the project was provided by the Colorado Water Institute and the Town of Castle Rock, Colorado.

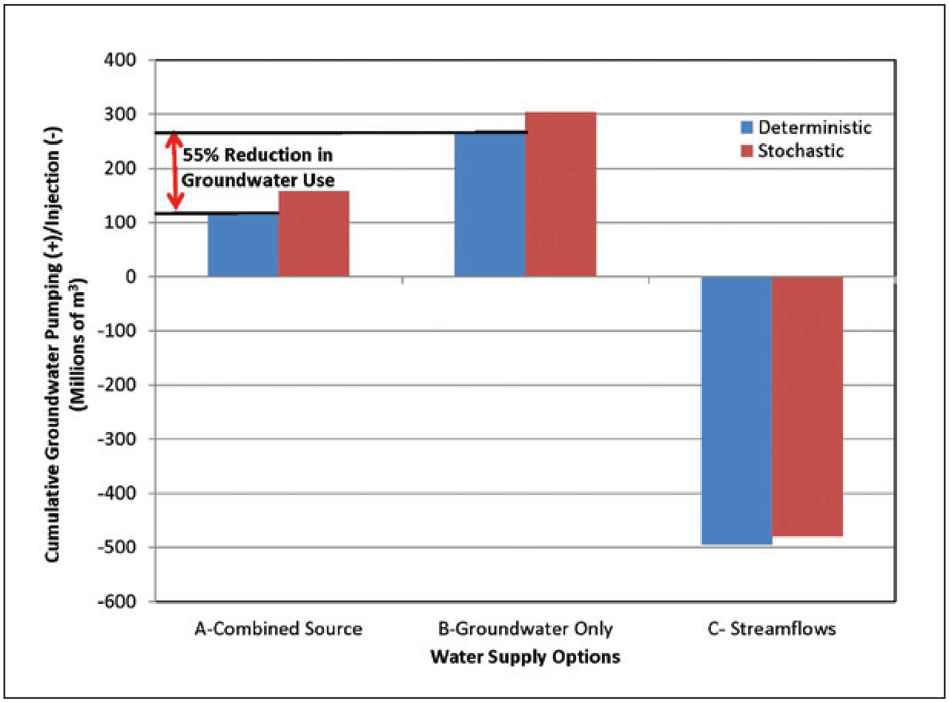

Figure 2. *Comparison of Cumulative Pumping (+)/Injection (-) Volumes for Each Scenario*

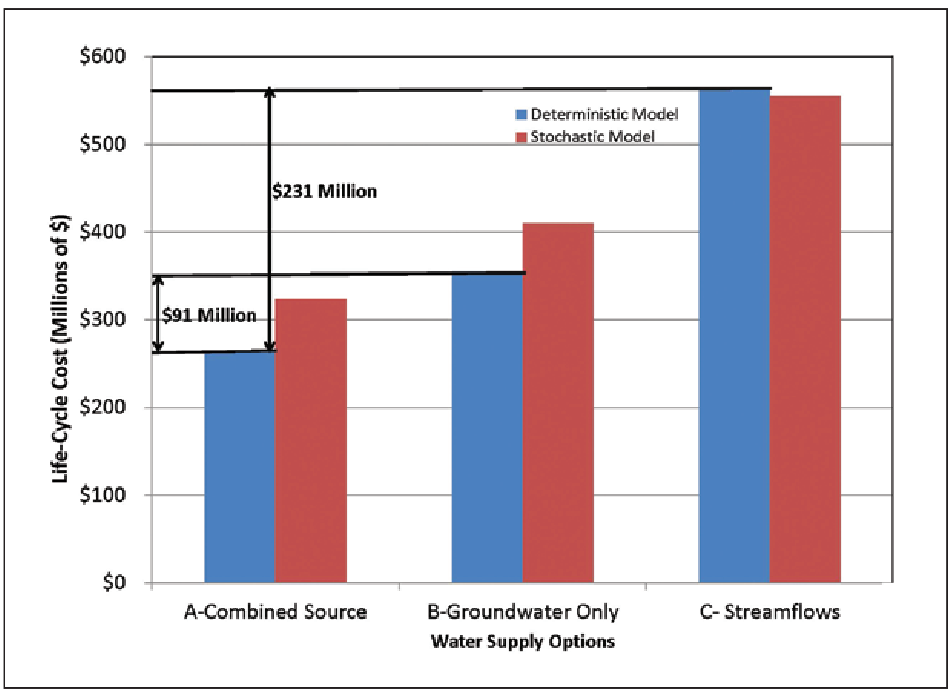

Figure 3. *Comparison of Life-Cycle Costs for Each Scenario*

Research Objectives

The objective of this research is to develop a model that can assist with design and analysis of costs associated with conjunctive use strategies. The vision of the model is that of a general tool that can be used for a wide variety of water supply options. Figure 1 represents a conceptual view of the combined source system that the model is based on.

The research objectives for this study included:

1. Development of both a deterministic and stochastic hydraulic model that determines long-term water demands, surface reservoir volumes, volume of water delivered to a surface water treatment plant, number of wells, injection/recovery volumes from wells, and resolution of required infrastructure needed for combined source system operation

2. Development of a cost model based on the hydraulic model that estimates the capital costs, operation and maintenance costs, life-cycle costs, and present value costs of the combined source system being evaluated

3. Application of the model to determine the least-cost option that maximizes reliability of the combined source system by testing different surface water treatment plant sizes.

The town of Castle Rock was used as a test case for the CSIAM.[2] The town is located in the high plains of central Colorado at the base of the Front Range. Historically, the Castle Rock has relied primarily on groundwater from the Denver Basin aquifers. Three future water use scenarios are considered, including:

1. Pyne, R. D. G. (2005). Aquifer Storage Recovery: A Guide to Groundwater Recharge through Wells, ASR Press.
2. CH2M Hill, Inc. (2006). Town of Castle Rock Water Facilities Master Plan. Castle Rock.

• Scenario A: Use of groundwater, treated wastewater, and return flows (treated surface water collected downstream of the town's wastewater treatment plant)

• Scenario B: Use of groundwater only

• Scenario C: Use of a hypothetical new stream surface water source

While the town of Castle Rock provides a basis for applying the model, the results should not be viewed as having direct bearing on future actions in the town of Castle Rock. Many of the key issues that will ultimately drive the town's water supply plans are not included in this analysis.

Results

Each scenario was evaluated using the deterministic and stochastic version of CSIAM. Figure 2 presents a comparison of the cumulative groundwater use for a 30-year period. Figure 3 presents life cycle costs for a 30-year period. Figures 4 and 5, respectively, present the number of pumping and injections well needed. Results indicate that combined use (Scenario A) results in a 55 percent reduction in cumulative groundwater pumping relative to a groundwater-only system (Scenarios B). Furthermore, Scenario A is $91 million less expensive than Scenario B. Another key result is that Scenario A is $231 million less expensive than the surface water-only option (Scenario C).

Conclusion

The CSIAM provides a basis for resolving infrastructure components and costs associated with combined source water systems. Per the test case, potential benefits of combined source systems include reduced use of groundwater and lower costs relative to solely relying on groundwater. Furthermore, the test case indicates that the combined source system has a lower cost than solely relying on surface water. A comprehensive presentation of the CSIAM, methods, assumption and results is presented in Maurer (2012).[3]

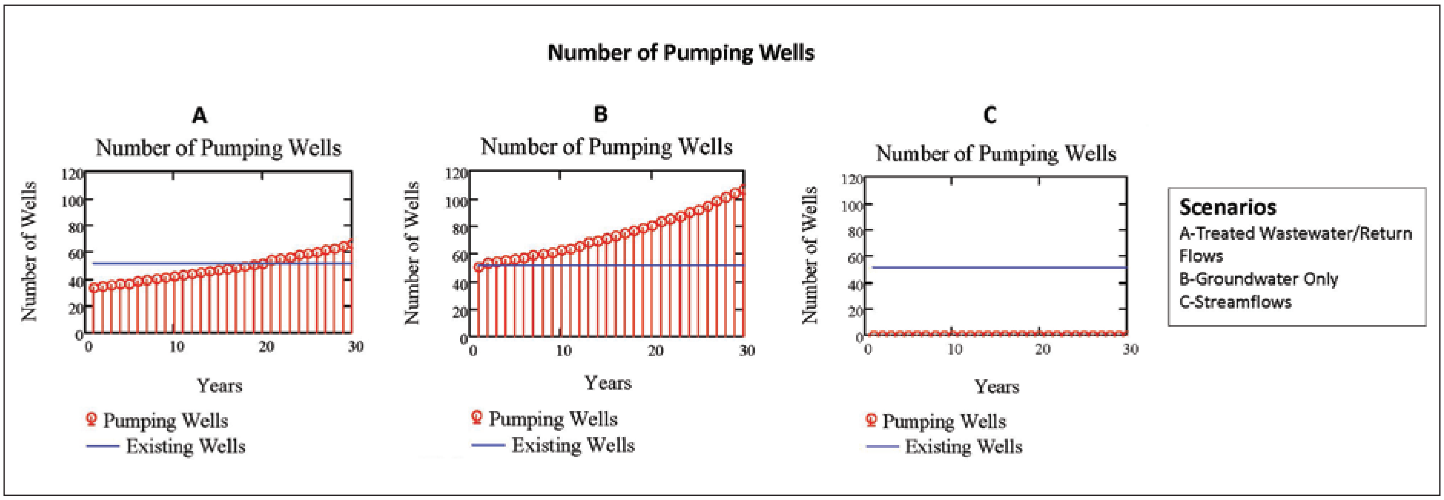

Figure 4. *Number of Pumping Wells for Each Scenario*

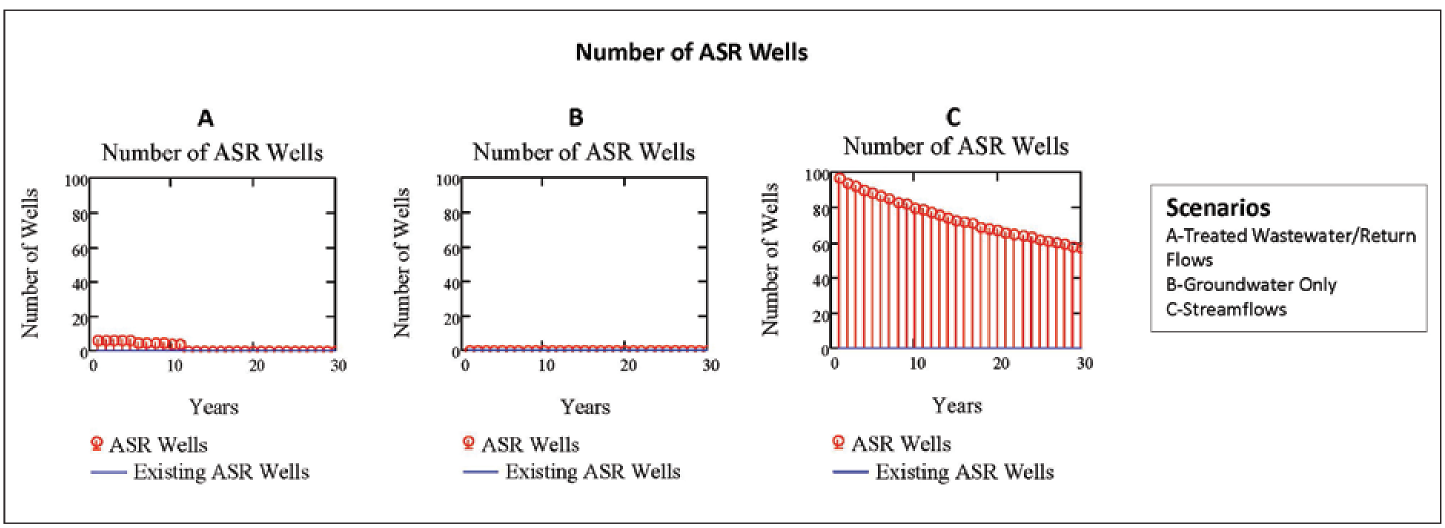

Figure 5. *Number of ASR Wells for Each Scenario*

3. Maurer, A. (2012). Combined Source Infrastructure Assessment Model. (Master's Thesis) Colorado State University.

Variables Controlling Reservoir Sedimentation in the Colorado Front Range

Basic Information

Title:	Variables Controlling Reservoir Sedimentation in the Colorado Front Range
Project Number:	2011CO236B
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Principal Investigators:	Ellen Wohl

Publications

1. Wohl, Ellen, Variables Controlling Reservoir Sedimentation in the Colorado Front Range, Colorado Water Institute Proposals, 3 pages.
2. Duru, Umit, "Variables Controlling Basin Scale Sediment Yields to Reservoirs in Dry Lands of the Western U.S. and Central Turkey," pg. 7-9 of Colorado Water, Volume 29 issue 3.


Twin Lakes Reservoir.
Photo by Bill Cotton.

Variables Controlling Basin Scale Sediment Yields to Reservoirs in Dry Lands of the Western U.S. and Central Turkey

Umit Duru, Ph.D. Candidate, Colorado State University
Faculty Advisor: Ellen Wohl

Abstract

Sediment deposition in a reservoir alters not only the aesthetic quality, but also the useful life of the reservoir as a result of lost storage capacity and operating flexibility. The objective of the first component of this research will be to evaluate the relative importance of various parameters influencing sediment yield and rate within a reservoir and between 30 reservoirs in the western United States and Central Turkey. The null hypothesis is that reservoir sedimentation rate correlates most strongly with the magnitude (spatial extent, frequency) of disturbance that alters land cover (e.g., forest fire), since disturbance can mobilize large volumes of sediment from hillslope and valley-bottom storage sites. The alternate hypothesis is that reservoir sedimentation rate correlates most strongly with one of the following topographic factors: drainage area, relief, or elevation. The overall methodology of this research is to develop a geographic information system (GIS)-based statistical model to determine the factors that are most important for sedimentation and sediment yields in reservoirs of the western United States and Central Turkey.

Introduction

Reservoirs around the world experience problems with sediment filling, which results in loss of storage capacity and operating potential. Sediment accumulation in reservoirs has environmental and economic consequences, especially in semiarid regions where reservoirs were mostly built for irrigation and water supply, as well as generating electricity or flood control. In some cases, the sediment delivery is large compared with the reservoir capacity, and reservoir capacity and useful life are depleted faster than planned. Also, in many regions, reservoirs have already been constructed in the most desirable areas. If these existing reservoirs completely fill with sediment, new reservoirs would be constructed in less desirable and more expensive areas.

Sediment input to reservoirs likely reflects several potential controls (e.g., drainage area, relief, lithology, land use, disturbances such as fire or deforestation) on basin-scale sediment yields in arid and semiarid regions. The smallest sediment particles may not be kept within the reservoir for a long time, but may instead be discharged downstream without settling in the reservoir. Larger particles may be retained in a reservoir, depending on how completely suspended sediment settles out in the reservoir. Furthermore, during peak flow seasons, inflowing water with huge volumes of sediment can enter a large reservoir and not be subsequently disturbed. To overcome the effect of sediment deposition, a portion of the volume is reserved for sediment storage in large reservoirs, which requires extra volume for the reservoir and increases the construction expenses.

This sediment accumulation also occurs all through the reservoir. As the useful storage capacity starts to be depleted, the reservoir becomes insufficient to maintain the intended purposes. For example, ~600,000 cubic meters of sediment have filled Strontia Springs Reservoir in Colorado, in large part due to the 1996 Buffalo Creek Fire (to a lesser extent) and the 2002 Hayman Fire. The fires scorched the vegetation on the land upstream from the reservoir.

Previous work in the western U.S. and central Turkey thus suggests that topography, land cover, and disturbances such as wild fire influence sediment yield, but it remains unclear how the relative importance of these factors varies at temporal and spatial scales that are particularly relevant to reservoirs in the region, namely ~50-100 years and 1,000-7,000 km2, respectively. I have begun to systematically examine this issue. The primary objective of my work is to assess the relative importance of several potential control variables in terms of influence on sediment yield in the specific study areas. Potential control variables include lithology, topography, land cover, land use, and disturbance history. A second objective is to develop a sediment yield model based on statistical analyses of correlations among the potential control variables and sediment yield. The final objective is to evaluate regional differences in correlations between potential control variables and sediment yield among Colorado, other portions of the western U.S., and central Turkey. These objectives will be evaluated by testing the following hypotheses:

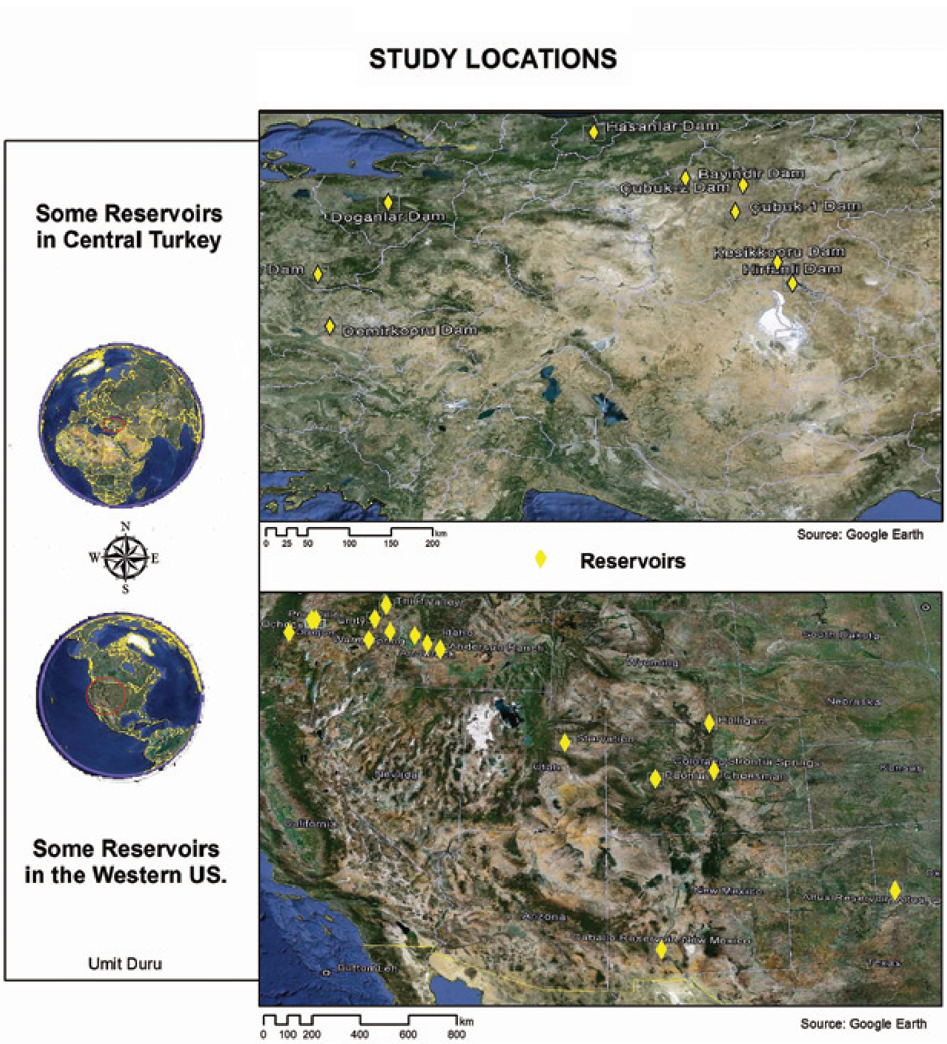
H1. Sediment yield correlates most strongly with disturbance history, and to a lesser extent with lithology, topography, land cover, drainage density, and land use.

H2. The relative importance of potential control variables will be consistent among diverse arid/semiarid regions of moderate to high relief (the Colorado Front Range, other portions of the western U.S., and the Central Anatolian Plateau of Turkey).

Hypotheses 1 and 2 will be tested by statistically evaluating correlations among (i) sediment input and temporally variable control variables (land cover, disturbance), either at annual intervals or averaged over time intervals dictated by the availability of information on land cover and disturbance for each reservoir and for the entire set of reservoirs, and (ii) average sediment input and all control variables for the entire set of reservoirs.

H3. Sediment yield will not be evenly spread across the contributing basin upstream from a reservoir. This hypothesis is based on the fact that it might be possible to identify which tributary potentially brings more sediment input to the reservoirs based on variable characteristics such as land cover, natural disasters, and topography in the basin.

H4. A correlation exists between reservoir size or shape and volume of sediment accumulated per year (i.e., total sediment volume normalized by time interval of accumulation).



Locations of selected reservoirs in the U.S. and Turkey.

Study Location

The research focuses on the Colorado Front Range, other sites in the arid/semiarid portions of the western U.S. for which suitable reservoir data are available, and the Central Anatolian Plateau of Turkey (Figure 1).

First, three reservoirs (Halligan, Cheesman, and Strontia) that have the most available data were selected for study in the Front Range. Second, I used the Reservoir Sedimentation Information System (RESIS) II database of the Army Corps of

Blue Mesa Reservoir.
Photo by Bill Cotton.

Reservoirs across the United States

Halligan Reservoir, CO	Cascade, ID	Prineville, OR
Cheesman Lake, CO	Caballo, NM	Thief Valley, OR
Strontia Reservoir, CO	El Vado, NM	Unity, OR
Paonia, CO	Altus, OK	Warm Springs, OR
Anderson Ranch, ID	Agency Valley, OR	Starvation, UT
Arrowrock, ID	Bully Creek, OR	
Black Canyon, ID	Ochoco, OR	

Reservoirs across Central Turkey

Hirfanli, Kirsehir	Cayoren, Balikesir	Cubuk 1, Ankara
Kesikkopru, Ankara	Doganci, Bursa	Cubuk 2, Ankara
Bayindir, Ankara	Hasanlar, Duzce	Demirkopru, Manisa

Engineers, Bureau of Reclamation, and U.S. Geological Survey to choose additional reservoirs that met three criteria: arid or semiarid climate, mountainous or hilly terrain, in the western United States. From this database, I identified 16 additional reservoirs that met these criteria. Third, I have selected reservoirs in Turkey for which suitable sedimentation data are available and which are comparable to those in the western U.S. based on climate, topography, and drainage area.

Some of the reservoirs listed above have limited data on reservoir operations and sedimentation over time. Numerous conversations with water resource managers and requests for information have indicated that data on sediment yield or patterns of sediment accumulation within reservoirs since the time of reservoir construction are very limited. These conversations also indicate that we are not likely to receive permission to conduct bathymetric surveys of reservoirs for which original bottom topography data (i.e., bottom topography at time of reservoir construction) are available. To date, I have been able to obtain data for nine reservoirs and 1:250.000 scale digital maps for these reservoirs in central Turkey, three reservoirs in Colorado, and 10 reservoirs in the western U.S. Climate and hydrologic conditions are similar within the regions in which these reservoirs are located. I am continuing to contact water resources managers in an effort to identify additional reservoirs for which either (i) sedimentation data over time are available or (ii) original bottom topography data are available and bathymetric surveys will be permitted.

Method

For each reservoir chosen for inclusion in this study, I will complete the following analyses:

1. I will characterize variables potentially influencing sediment yield, including catchment geology, drainage area, topography, annual precipitation, land cover and disturbance history, history of reservoir construction and operation, and initial bottom topography and subsequent sediment accumulation.

2. I will use GIS software to characterize the variables and to statistically evaluate correlations between potential control variables and sediment yield via stepwise linear regression and other statistical approaches.

3. I will undertake these analyses for each reservoir individually, and then for progressively larger subsets of all of the reservoirs (i.e., Colorado Front Range, other sites in western U.S., Turkey, and all sites combined). Most of the empirical erosion rate approaches are based on the universal soil loss equation (USLE), MUSLE (modified USLE), sediment yield as a function of drainage area, and sediment yield as a function of drainage characteristics.

Water Quality Impacts of the Mountain Pine Beetle Infestation in the Rocky Mountain West: Heavy Metals and Disinfection Byproducts

Basic Information

Title:	Water Quality Impacts of the Mountain Pine Beetle Infestation in the Rocky Mountain West: Heavy Metals and Disinfection Byproducts
Project Number:	2011CO245G
Start Date:	9/1/2011
End Date:	8/31/2014
Funding Source:	104G
Congressional District:	D-CO7
Research Category:	Water Quality
Focus Category:	Water Quality, Hydrogeochemistry, Treatment
Descriptors:	None
Principal Investigators:	John E. McCray, Reed Maxwell

Publication

1. McCray, John, 2011, Water Quality Impacts of the Mountain Pine Beetle Infestation in the Rocky Mountain West: Heavy Metals and Disinfection Byproducts, Colorado Water Institute Proposal, 38 pages.

Annual Report

Water Quality Impacts of the Mountain Pine Beetle Infestation in the Rocky Mountain West: Heavy Metals and Disinfection Byproducts

The following report summarizes the work performed under Subaward Number G-2914-1; PI: Dr. John E. McCray for the reporting period ending 28 February 2012. The project was contracted on 14 November, 2011, and thus this report covers approximately 3.5 months during the specified reporting period.

1. *Research: Project Synopsis*

   The goal of the research funded under this subaward, is to understand the potential for disinfection byproduct formation and metal mobilization resulting from perturbations to the water and nutrient cycles in forested watersheds currently experiencing a severe mountain pine beetle epidemic (Figure 1). The subaward provides the means to add these analyses to the existing USGS research project being conducted in Rocky Mountain National Park, under the supervision of Dr. Dave Clow.

   During this reporting period, the following tasks were completed: (a) PhD student was identified for the project: Ms. Lindsay Bearup (BS Agricultural and Biological Engineering, Penn State; MS Hydrology Colorado School of Mines); (b) a project kick-off and planning meeting was conducted with Dr. Clow (USGS), PI McCray, and PhD student Lindsay Bearup; (c) analysis of surface water samples (archived by Dr. Clow) has begun at Colorado School of Mines, and is currently underway for trace metals and stable isotopes, (d) Planning and coordination for additional sample collection (soils, groundwater, surface water) during the 2012 field season was also completed. The goal of the current analyses is to understand whether metal concentrations are higher than naturally expected, and to obtain information about hydrologic flow paths in RMNP using isotope analysis. Preliminary isotope sampling has also begun (Figure 2). The goal for sample collection in the next field campaign is to better address the questions on whether the potential for disinfection byproduct formation and metal mobilization result from perturbations to the water and nutrient cycles in forested watersheds currently experiencing a severe mountain pine beetle epidemic

2. *Publications*

   The literature review co-authored by Lindsay A. Bearup during this reporting period and funded by this subaward, directly contributed to the following review article, currently in preparation for submission to *Environmental Resource Letters*:

   Mikkelson KM, Bearup LA, Maxwell RM, Stednick JD, McCray JE and Sharp JO. Bark-beetle epidemic effects on water quality and quantity: a review. *In preparation for Enironmental Research Letters.*

3. *Information Transfer Program*

   Nothing accomplished this period.

4. *Student Support*
   This subaward provided funding for one PhD student during this reporting period.

5. *Student Internship Program* – N/A

6. *Notable Achievements and Awards* –

   a. PhD student was identified for the project. Ms. Lindsay Bearup (BS Engineering, Penn State; MS Hydrology Colorado School of Mines)
   b. Project kick-off and planning meeting with Dr. Clow (USGS), PI McCray, and PhD student Lindsay Bearup was completed.
   c. Literature review completed and will be submitted for publication in May 2012.
   d. Water samples archived by USGS were analyzed for aqueous phase metals and isotopes.
   e. Draft sampling plan completed for soils, groundwater, and surface waters, with analytes metals, DBPs, and isotopes.

Figure 1: MPB impacted forest along the East Inlet to Grand Lake in Rocky Mountain National Park.

Figure 2: PhD Student, Lindsay Bearup taking a snow sample for stable isotopes in Rocky Mountain National Park.

Information Transfer Program Introduction

Requests from the Colorado legislature to facilitate and inform basin-level discussions of water resources and help develop an interbasin compact for water management purposes emphasized the role Colorado Water Institute plays in providing a nexus of information. Some major technology transfer efforts this year include:

- Providing training for Extension staff in various water basins to help facilitate discussions of water resources
- Encouraging interaction and discussion of issues between water managers, policy makers, legislators, and researchers at conferences and workshops
- Publishing the bi-monthly newsletter, which emphasizes water research and current water issues
- Posting and distributing all previously published CWI reports to the web for easier access
- Working with land grant universities and water institutes in the intermountain West to connect university research with information needs of Western Water Council, Family Farm Alliance, and other stakeholder groups
- Working closely with the Colorado Water Congress, Colorado Foundation for Water Education, USDA-CSREES funded National Water Program to provide educational programs to address identified needs

Technology Transfer and Information Dissemination

Basic Information

Title:	Technology Transfer and Information Dissemination
Project Number:	2011CO233B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	4th
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	Reagan M. Waskom

Publications

1. Colorado Water Newsletter, Volume 28 - Issue 2 (April/May 2011), Colorado Water Institute, Colorado State University, Fort Collins Colorado, 37 pages.
2. Colorado Water Newsletter, Volume 28 - Issue 3 (June/July 2011), Colorado Water Institute, Colorado State University, Fort Collins Colorado, 41 pages.
3. Colorado Water Newsletter, Volume 28 - Issue 4 (August/September 2011), Colorado Water Institute, Colorado State University, Fort Collins Colorado, 41 pages.
4. Colorado Water Newsletter, Volume 28 - Issue 5 (November/December 2011), Colorado Water Institute, Colorado State University, Fort Collins Colorado, 41 pages.
5. Colorado Water Newsletter, Volume 29 - Issue 1 (January/February 2011), Colorado Water Institute, Colorado State University, Fort Collins Colorado, 33 pages.
6. Bauder, James W and Smith, MaryLou. 2011. Nutrients and Water Quality A Region 8 Collaborative Workshop -- Workshop Summary and Recommendations. Colorado Water Institute, Colorado State University, Fort Collins, CO. 57 pages. http://cwi.colostate.edu/publications/IS/111.pdf

Colorado Water Institute Activities

2011 Arkansas River Basin Forum

April 27- 28, 2011 — "Retaining. Rethinking. Restoring."

The 2011 Arkansas River Basin Water Forum, hosted by the Fountain Creek Watershed, Flood Control, and Greenway District, will be held April 27-28 in south Colorado Springs at the Norris-Penrose Event Center (http://www.norrispenrose.com).

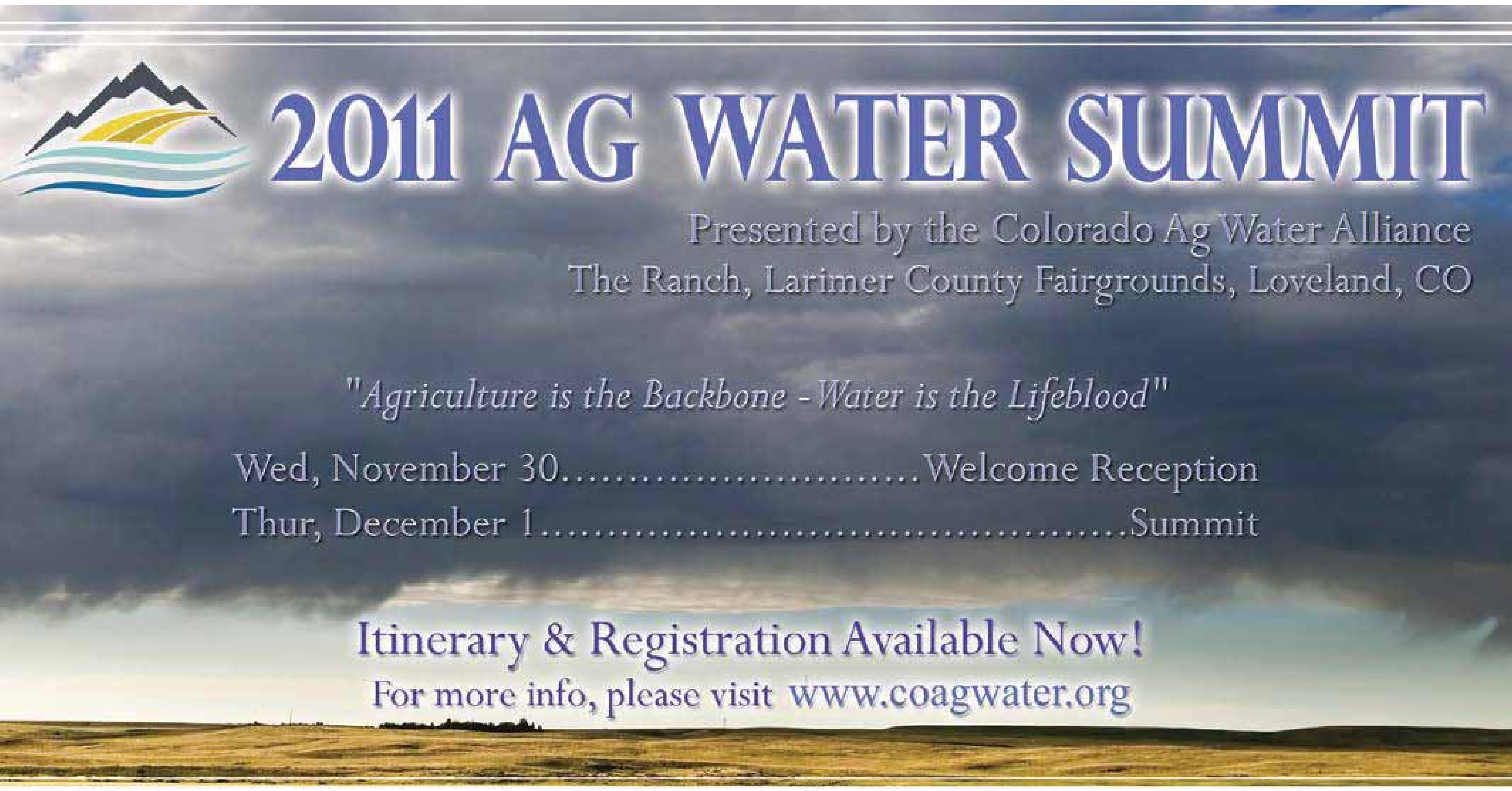
The Forum has been a focal point for highlighting current water issues in the Arkansas River Basin and in Colorado since its inception in 1995. Planners, presenters, and attendees represent a wide variety of organizations, agencies, and public citizenry working on water resources issues in the basin. As the basin contends with an array of restoration and resource management issues, the Forum theme this year is "Retaining. Rethinking. Restoring."

Scholarships: The Forum sponsors are pleased to offer $2000 in scholarships to outstanding graduate students. More information is available at our web site (http://www.arbwf.org/).

Keynote Speaker:
Mr. John Stulp, Special Policy Advisor to the Governor on Water

Topics:
- Ecological restoration approaches and tools
- Nutrient discharge management
- Land use planning and flood control
- Emerging contaminants

Registration prior to April 22 is $45 for both days, $25 for one day, and no charge for students. Please visit the Forum website at http://www.arbwf.org/ or contact Dr. Perry Cabot at (719) 549-2045 for more information.


2011 AG WATER SUMMIT
Presented by the Colorado Ag Water Alliance
The Ranch, Larimer County Fairgrounds, Loveland, CO
"Agriculture is the Backbone - Water is the Lifeblood"
Wed, November 30……………………Welcome Reception
Thur, December 1………………………………Summit
Itinerary & Registration Available Now!
For more info, please visit www.coagwater.org

Water Tables 2012 Will Celebrate Western Water Organizations

Patricia J. Rettig, Head Archivist, Water Resources Archive, Colorado State University Libraries

> *"One man cannot build or administer a water system; one farm cannot pay the expenses of its maintenance. There is, then, at the threshold of life in an arid region a fundamental necessity for co-operation; for organization; for the association of men."*

Stated in 1898 by leading irrigation advocate William E. Smythe, this concept of the need in the arid west for cooperation, organization, and association has come to fruition time and again over the past century. The Water Resources Archive will celebrate this history of western water organizations during its next Water Tables event on Saturday, February 18, 2012.

Water Tables 2012, the seventh annual fundraiser for the Water Resources Archive, will be held on the Colorado State University main campus in Fort Collins. Reservations will be accepted beginning in January. The sit-down dinner will feature at least twenty water professionals and historians as table hosts, with each table focusing on a different organization that has played a role in western water development.

Perhaps it is fitting that one of the oldest organizations to be represented at Water Tables has its origins in irrigation research. As settlers moved west, they dug irrigation ditches to make the vast lands into productive farms. Soon a need for reliable information about the water supply and successful irrigation practices became apparent. The U.S. Department of Agriculture began its irrigation investigations in 1898, and the branch in Fort Collins, now known as the Water Management Research Unit, was established in 1911. Long-time unit employees Gordon Kruse and Harold Duke will serve as table co-hosts.

Several organizations with lengthy and fascinating histories will be celebrating their 75th anniversaries in 2012. Among them is Northern Water, formed following passage in 1937 of landmark state legislation authorizing creation of conservancy districts. Historian Daniel Tyler will host a table discussing Northern Water's history. Tables are also planned to celebrate the histories of complementary organizations formed in 1937: the Colorado River Water Conservation District and the Colorado Water Conservation Board.

Water Tables 2011 table host Tom Cech and wife Grace examine some historic documents. Photo by CSU Photography, courtesy of the CSU Water Resources Archive.

Water Tables 2011 table host Jeris Danielson chats with guests.
Photo by CSU Photography, courtesy of the CSU Water Resources Archive.

These organizations, and the event's overall theme, were chosen to coincide with the statewide Water 2012 celebration, as well as the tenth anniversary of the Water Resources Archive. Water 2012 arose with the recognition of the forthcoming 75th anniversaries as mentioned, but is going beyond to celebrate Colorado's water, its uses, its value, and its history.

Join the Water Resources Archive February 18 to learn about long-standing historic water organizations, as well as emerging ones. Some of the newer organizations to be represented include the Colorado Foundation for Water Education, table hosted by executive director Nicole Seltzer, and the Colorado Water Trust, table hosted by executive director Amy Beatie.

The need in the arid west for cooperation, organization, and association will always continue. Learning the lessons of the past will help future endeavors succeed. The Water Tables reception gives everyone a chance to mingle and network with all the hosts and guests while the dinner provides time for focused discussion and learning opportunities. It will be a night not to miss.

Proceeds from Water Tables support the Water Resources Archive, which works to preserve, promote, and make available records of Colorado's water history. The complete list of table hosts and organizations will be posted on the Water Tables website in January. For more information about the Water Resources Archive, see http://lib.colostate.edu/archives/water/ or call (970) 491-1844.

Nutrient Workshop Results in Recommendations for EPA and State Water Quality Agencies

James Bauder, Land Resources and Environmental Science, Montana State University
MaryLou Smith, Policy and Collaboration Specialist, Colorado Water Institute

Nutrients. The word sounds so healthy, but those who work with water quality know that "nutrients" can mean trouble. Nutrients can degrade important water resources and create health and environmental risks.

As part of its responsibility under the Clean Water Act, the U.S. Environmental Protection Agency (EPA) has directed states to develop numeric standards for how much phosphorus and nitrogen can be present in water after it has been treated, as well as in streams and lakes.

Jennifer Meints moderates the largest breakout group session, Ag-NPS (animal/confined animal feeding operations), as they identify barriers to nutrient controls and make recommendations for the EPA.

Water quality numeric standards from EPA are not new. Standards are already in place for water contaminants such as NH_4 (ammonium), pathogens, ammonia, and selenium. But the coming imposition of nutrient standards has stirred considerable controversy. For one thing, much of the nutrients problem stems from introduction of nutrients into water from diffuse, or nonpoint sources (NPS), such as stormwater and agriculture, which are exempted by the Clean Water Act. But point sources, easily identifiable and traceable, are impacted by NPS, over which they have little, if any, control. Also, nutrients can naturally occur at higher levels than the proposed standards for streams and lakes.

The April/May issue of *Colorado Water* reported that 200 stakeholders and agency representatives gathered in Salt Lake City in February 2011 to delve into the issue in EPA Region 8: Colorado, Utah, Montana, Wyoming, and North and South Dakota. The report from the workshop was recently released and can be downloaded at http://www.cwi.colostate.edu/nutrients

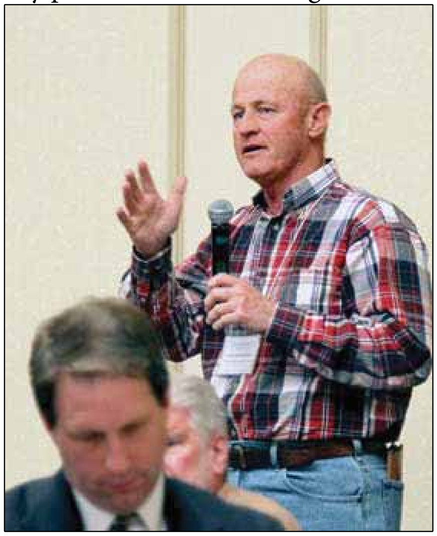
Workshop organizers, including Colorado Water Institute, worked with EPA Region 8 to convene the regulators and regulated and see if together, the two groups might create solutions.

Because the science is complex, we need policy and management that can adapt and evolve as we know more. With emphasis on what's practical, workshop participants were challenged to consider a full range of societal values and weigh benefits against costs while seeking to apply limited resources where they could gain the most improvement. The workshop was divided into three sections to address three distinct questions.

Question 1: What is the Problem?

University professors and researchers from the USDA and EPA shared perspectives. They discussed that data are not always consistent, and impairment we see today may reflect activities long past. The interplay of nitrogen and phosphorus together in lakes may create more harm than phosphorus alone. Findings of a major USGS study of nutrients in streams and groundwater between 1992 and 2004 showed that though there are natural sources of nitrogen and phosphorus in water, the highest concentrations are found in areas of highest input. Nutrients create complexities that span many different fields.

Responders shared experiences and observations from stakeholder and agency points of view. Hearing how Wisconsin gained support to develop numeric standards by engaging stakeholders garnered significant interest. A watershed group activist from Montana relayed her group's problems convincing water quality degradation contributors such as golf courses and



Alan Johnstone participates in a dialogue/response session during the What is the Problem? portion of the workshop.

horse operations to take action because they fell back on arguments that interfering or masking biological factors in the stream confounded the data.

Questions 2: What is Being Done About the Problem?

Participants heard from each of the six Region 8 state departments of water quality.

Colorado

According to Steve Gunderson from Colorado Department of Public Health and Environment (CDPHE), Colorado has had nutrient controls on several major reservoirs since the 1980s and has been developing state-wide numeric nutrient criteria for lakes, reservoirs, and flowing waters for more than ten years. Recently, the state's water quality control division proposed to EPA an alternative nutrients standard approach they believe will achieve water quality improvements better and faster while reducing transaction costs. A group of dischargers who formed a coalition to promote its interests supports the proposal, according to a coalition representative at the workshop.

Montana

Mike Suplee from Montana said his state already has nutrient standards in the Clark Fork, an EPA-designated superfund site, but they apply only to the Clark Fork during summer flow conditions. Now the state DEQ believes it can implement nutrient standards for many of Montana's wadeable streams and the Lower Yellowstone River. Montana wants to develop nutrient criteria and standards that are science based while giving full consideration to the need for flexibility, ecological diversity, and an evolving approach.

Utah

Walt Baker from the Utah Division of Water Quality says his state's attention has been centered around the total maximum daily loads (TMDL) process, with the most useful metric for urban control appearing to be measures of total phosphorus. The state is proud of its model effort in working with animal/concentrated animal feeding operations (AFO/CAFO) to manage nutrients sourced from livestock. The state commits $1 million annually to bolster 319 funding directed toward dealing with nonpoint source (NPS) issues. Cost effectiveness compared to ecological benefits appears to be a prime topic of discussion in Utah.

North Dakota, South Dakota, and Wyoming

In contrast to Colorado, Montana, and Utah, the other three Region 8 states appear to be taking a slower, wait and see approach to nutrients. These states are predominantly agricultural with low populations, so they are dealing primarily with agricultural NPS issues and some impacts related to the rapidly growing oil, gas, coal, and mineral extraction industries in North Dakota and Wyoming. The Wyoming DEQ, according to John Wagner, participates in an extensive on-going water quality monitoring and data collection effort, however, providing a solid base for future standards development. Patrick Snyder from the South Dakota Department of Environment and Natural Resources said they rely primarily on narrative standards for nutrients, though they have developed a water quality assessment tool called Trophic State Index to rate lakes, ponds, and reservoirs based on the amount of biological productivity in the water. North Dakota's Mike Ell reported that his state seeks active engagement of stakeholders before standards are seriously investigated, though they are incorporating nutrient criteria into their ongoing monitoring and database development as they address other water resource issues.

Innovative Tools and Case Studies

Both the regulators and the regulated introduced a smorgasbord of innovative tools being used to deal with nutrients in water, as well as some uplifting success stories. The use of precision agriculture to match fertilizer applied to fertilized needed and urban "Don't P on Your Lawn" campaigns to eliminate phosphorus as a lawn fertilizer were strategies suggested to minimize the amount of nutrients imported into watersheds. A consulting engineer recommended striking a balance between nutrient removal and other sustainability goals—he described a study about the relative benefit vs. cost of aggressive nutrient treatment, which in some cases may require high energy input and introduce fuel based chemicals and polymers that can cause other undesired consequences. A public works director discussed hydrologic mirroring of predevelopment conditions in post development site construction as a strategy for keeping sediment out of stormwater in the first place. Nutrient credit trading was introduced as a strategy for meeting aggressive nutrient reduction goals when certain conditions apply, like an availability of nutrient reduction alternatives.

A North Dakota State speaker plainly stated that finding solutions for nonpoint source pollution is a lot more about people than it is about the hard sciences. "By involving producers, we can identify which water quality improvement practices give us the most bang for the buck," he said. But working with farmers means meeting with them out on their farms in the mud and the rain listening to what they have to say.

Success Stories

In Colorado's Bear Creek Watershed, between trading, a coordinated erosion stormwater control program, and treatment plant upgrades, phosphorus discharge load was reduced from 5,255 pounds per year to 1,334. They advised that producing convincing data is not always easy, but without data, progress and conviction come slowly.

In eastern South Dakota, establishing regional groundwater protection areas with groundwater protection ordinances led to significantly reduced nitrate concentrations—from 10 milligrams per liter in 1994 to one to two milligrams per liter by 2010.

Troy Bauder participates in the NPS breakout group session, which ultimately narrowed down a list of recommendations to give to the EPA about regulating nutrients in that sector.

In Park City, Utah, an $18 million advanced tertiary treatment facility solved the problem of nutrient-rich wastewater being discharged into a small trout stream often dewatered downstream by pre-existing irrigation water rights. The frustrating downside of that success story, which could have been avoided by a watershed-scale planning approach, is that now the community has an acute ammonia toxicity issue downstream because of reduced in-stream flows.

A favorite success story was about a partnership of agencies and stakeholders in Utah who worked together to reduce livestock degradation of water quality through voluntary, locally-driven actions. Agencies gained the trust of stakeholders to cooperate in inventorying AFO operations, developing and implementing nutrient management and mitigation plans, providing cost assistance for corrective actions, and tracking progress. As of July 2010, 98% of the operations needing to correct unacceptable conditions have developed and implemented nutrient management plans.

Question 3: How can Stakeholders and Agencies Work Together Better to Resolve the Problem?

Representatives from key stakeholder groups relayed their experiences trying to collaborate with agencies. A Colorado Nutrient Coalition representative suggested that stakeholders and agencies cooperate to articulate a reasonable vision for dealing with nutrients, and that vision may need a legal structure. Two agricultural producers stressed that we need to factor in the value of our food supply when we make decisions about nutrient standards, because nutrients are necessary for growing food.

Summary of Workshop Recommendations

While there was a consensus among workshop participants that there is a nutrient problem in the region, there were expressions of concern and strong suggestions about how nutrient controls and standards should be developed and implemented to increase likelihood that they will truly lead to cost-effective water quality improvements.

Flexibility in Approach to Improve Water Quality

"One size will not fit all" was commonly voiced. Workshop participants believe real solutions will come from site-specific, sector-specific approaches, championed by those directly aware of local circumstances, allowing flexibility as more is learned. Specifically:

- We need to think and work smarter, to focus resources on issues and circumstances which will achieve the most benefit per unit of resources and effort expended, to learn lessons from others wherever possible.
- Adaptive management should be considered integral to any TMDL, nutrient controls and standards. We need to be allowed variances in dealing with nutrient sources and loads where appropriate.
- Regulatory agencies need to recognize and accept that 100% achievement many not either be possible or necessary with respect to controls and standards. For example, controls applied to a smaller percentage of sources may result in higher overall water quality results.

Building Relationships to Improve Water Quality

Much of the dialogue among workshop participants revolved around the need for building trust between stakeholders and regulators. Specifically:

- Communication, relationships and trust should be established as foundational, involving all stakeholders. This would bring a new, improved image to the EPA and state agencies, and the cooperation it fosters at the local level would lead to water quality improvements.
- Regulators and regulated should work together to do away with the current us-versus-them attitude. Regulated groups should be connected to the process.
- Individuals from agencies interacting with stakeholders relative to nutrients should become more knowledgeable about day-to-day operations of stakeholders. Regulatory agencies and policymakers need to gain a better understanding and appreciation for stakeholders' situations, perspectives, and financial means.
- Continuity in agency staff is needed to foster productive relationships to solve water quality problems.
- Education, information exchanges and continued dialog on nutrients are needed to provide continuity in the engagement of the public, stakeholders, and regulated entities.

Financing Improvements in Water Quality

Since current fiscal realities are not expected to turn around overnight, creative approaches will be needed. Specifically:

- We should investigate nutrient trading across sectors in order to achieve water quality goals.
- Means of financing the costs of nutrient controls and minimizing the economic burden to stakeholders need to be built into any nutrient control program. Our society creates and externalizes our nutrient problems and will benefit from nutrient controls, thus society needs to bear the costs of control.
- The relationship between benefits and costs needs to be understood and communicated to stakeholders, ratepayers, and dischargers, along with discussion of who is going to bear the cost of controls.

Nutrient Controls and Standards to Improve Water Quality

Workshop participants from across all sectors were consistent in their assertion that nutrient controls and standards will benefit from enhanced local engagement.

- Nutrient controls and standards should be based on local level input and management constraints, with participation and involvement of local stakeholders through the entire process.
- On the other hand, uniform sampling and data collection protocols should be established for each sector involved in the nutrient control/nutrient management issue. Data sharing should be improved among all entities.
- Nutrient controls and standards should be based on sound science that elucidates relationships between nutrient loading, water quality impairments, and effectiveness of best management practices.
- Water quality improvement or protection through nutrient controls and standards should be marketed where appropriate, rather than mandated or regulated. To this end, education needs to be used as a complementary tool for achieving nutrient controls and standards. Education is needed for the general public, policymakers, stakeholders, and managers.

Finally, workshop participants unanimously recommended the need for the Region, States, and stakeholders to continue and sustain dialog leading to creative and collaborative solutions to nutrient problems.

Workshop Sponsors

United States Environmental Protection Agency

Utah Water Research Laboratory UWRL

Applying knowledge to improve water quality
Northern Plains & Mountains Regional Water Program
A Partnership of USDA NIFA & Land Grant Colleges and Universities

Colorado Water Institute

2011 Annual Universities Council on Water Resources Conference Held in Boulder, Colorado, July 12-14

Lindsey A. Knebel, Editor, Colorado Water Institute

Members from the Universities Council on Water Resources (UCOWR) and the National Institutes for Water Resources (NIWR) met in July for the annual UCOWR conference in Boulder, Colorado.

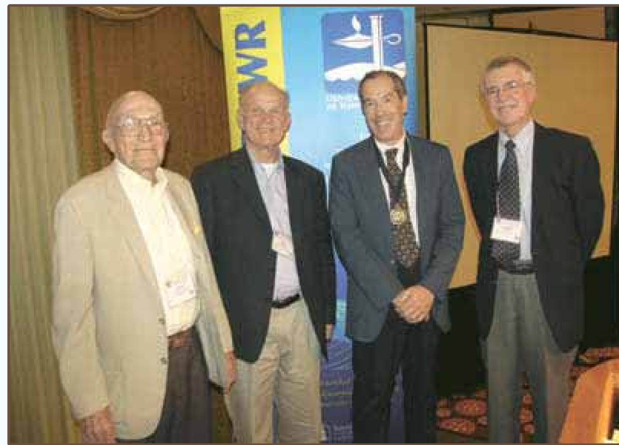
The 2011 conference committee included members from the Colorado Water Institute (CWI), New Mexico State University, Utah State University, Texas AgriLife Research, University of Arizona, and UCOWR. The conference focused on "Planning for Tomorrow's Water: Snowpack, Aquifers, and Reservoirs."

Keynote sessions at the conference were Water in the West, Water and Society, and International Water. Some of the other technical sessions included Snowpack and Snowmelt, Crop Water Use and Management, Climate and Water, Water Governance, and Remote Sensing, among others.

Several keynote speakers gave presentations on timely water issues. During the Water in the West Session, Tom Iseman of Western Governors' Association, and Roger S. Pulwarty, director of the National Integrated Drought Information System at the National Oceanic and Atmospheric Administration (NOAA) in Boulder, Colorado, presented on what's being done in the West.

Keynote speakers for the Water and Society session were Colorado Supreme Court Justice Greg Hobbs and Steve Solomon, book author and writer for the New York Times and other publications.

For the final keynote session, International Water, speakers were Robert Pietrowsky, Director of the U.S. Army Institute for Water Resources (IWR), and Mike O'Neill, National Program Leader for Water Resources with the USDA National Institute of Food and Agriculture. Pietrowsky discussed the necessity of developing international water infrastructure, education, and institutional capacity, and O'Neill talked about international water issues and solutions to global problems.



Warren Hall medalists Chuck Howe, Neil Grigg, 2011 medalist Jery Stedinger, and medalist Robert Ward at the UCOWR banquet.

Photo by Jessica L. May

Highlights of the conference included a tour of the Boulder Creek Watershed (pre-conference), a poster session, and an awards banquet.

The 2011 Warren A. Hall Medal went to Jery Stedinger of Cornell University for his outstanding career contributions in hydrologic science. "He really brings energy, enthusiasm, engagement, dedication, and commitment to whatever task he undertakes," said the award presenter. Other awards included Friends of UCOWR recognitions, Education and Public Service awards, and notable dissertation awards.

UCOWR is an organization of over 90 member universities and organizations from both the U.S. and abroad that focuses on water resources education, research, and public service. The annual conference explores timely water topics. UCOWR also publishes the *Journal of Contemporary Water Research & Education*, which can be accessed on their website at www.ucowr.org.

During the conference, Boulder Creek was experiencing unusually high flow rates.

Photo by Jessica L. May

Colorado Water Congress Holds Annual Convention

Reagan Waskom, Director, Colorado Water Institute

The Colorado Water Congress held its 54th Annual Convention at Denver Tech Center on Jan. 25-27, 2012. The conference theme was, "The Year of Water Celebration - Our Stories, Our Work, Our Vision." Workshops on the Colorado River, water quality, water conservation and water projects were among the concurrent sessions held on Wednesday, capped with a reception with the newly formed POND committee (Professionals Outreach, Networking and Development), which is designed to promote networking opportunities among water professionals.

The Thursday morning general session, moderated by Floyd Ciruli, opened with a video welcome by Gov. Hickenlooper declaring 2012 the Year of Water for Colorado. This year celebrates the 75th anniversary of the Colorado Water Conservation Board (CWCB), the Northern Colorado Water Conservancy District, and the Colorado River Water Conservation District. Parker Water and the Frypan-Arkansas project celebrate their 50th anniversary of water delivery. Gov. Hickenlooper's Special Advisor for Water, John Stulp, read a proclamation declaring the 2012 Year of Water a year of action and celebration of water in Colorado. Floyd Ciruli offered that we might be at one of those moments in history where Colorado is posed to make significant progress in water management. The issues of the mid-1930s that spawned the CWCB and Conservancy Districts are still with us today: transbasin projects pitting East slope against West, Ag vs. cities, groundwater vs. surface water, interstate disputes, basin of origin mitigation, Colorado River entitlement, conservation vs. new infrastructure, and a focus on jobs. Patty Limerick, CU History professor, provided an opening talk on historic context of 1937, the New Deal, and the history of the Denver Water Board. She noted that a tremendous potential exists in 2012 for Colorado to do things in a different way that still respects tradition.

Supreme Court Justice Greg Hobbs led a session featuring water authors and the 2012 book list. Craig Childs, author of House of Rain, discussed the indigenous search for water in the arid southwest and how it shaped the indigenous civilization. Anasazi, Hohokam, and others all lived around water and small wet places, until prolonged drought came to the southwest, forcing them to leave for more hospitable places. John Waterman, author of Colorado River: Flowing Through Conflict, discussed his raft trip down the river from source to the sea and what he observed. And finally, Steve Maxwell, author of Future of Water, offered a business and finance perspective on water. Maxwell noted several key trends to watch: water shortages already prevalent in many areas of the world and climate and population growth portend more of the same; failing infrastructure and the unfortunate propensity to require infrastructure catastrophe before systems are upgraded; privatization—using private capital to solve public problems; and the surge of investor interest in water sector. Maxwell stated that technology will not solve the problems without major change in price, behavior, and policy. Public understanding is weak, and many problems could be more easily addressed with a more knowledgeable public.

(Left to right): Frank Jaeger, Parker Water & Sanitation District; Eric Wilkinson, Northern Colorado Water Conservancy District; Eric Kuhn, Colorado River Water Conservation District; Joe Frank, Lower South Platte Water Conservancy District; Jim Broderick, Southeastern Colorado Water Conservancy District; Travis Smith, Rio Grande River; and Jennifer Gimbel, Colorado Water Conservation Board.

Photo by Carla Quezada

Mike Gibson, manager of the San Luis Valley Water Conservancy District, took over the duties of president of the Colorado Water Congress. Gibson noted that the issue that he plans to promote is getting more young people to take an interest in water as a career path. At the closing luncheon, the CWC also paid tribute to the late state Sen. Fred Anderson, who died at the age of 83 while shoveling snow on Dec. 23.

The highlight of the annual convention was the Wayne N. Aspinall water leader of the year award. David Robbins, president and co-founder of the Denver law firm of Hill & Robbins and Chair of the Colorado Water Institute Advisory Board, was recognized as the newest Aspinall leader. Robbins is widely know for his work defending the Rio Grande Water Conservation District against attempts to remove water from the San Luis Valley via pipelines in the 1980s and 1990s. He subsequently worked with Congress to write legislation for the Great Sand Dunes National Park, further protecting the San Luis Valley's water against future transfers. In his acceptance speech Robbins noted, "We should not give away a drop of water that this state needs, we owe it to future generations."

John Stulp, Water Advisor to Governor Hickenlooper, reads the Governor's proclamation of the 2012 Year of Water.

Photo by Carla Quezada

Colorado Water 2012

Caitlin Coleman, OSM/VISTA Communications Coordinator, Colorado Foundation for Water Education

Fishing, skiing, rafting, irrigating, drinking, and simply living—the ways in which we use water are countless. Coloradans and visitors alike regularly enjoy recreational opportunities, tree-lined streets, rolling lawns, and local produce, seldom remembering that we've worked hard to adapt to Colorado's arid climate and create this illusion of bounty over the past 150 years.

Now, partners across the state are engaging Coloradans in a year-long celebration of water through an initiative called Colorado Water 2012.

"We want 2012 to be fun—a series of activities, events, and contests in every part of the state that makes people think about the value of water," said Wendy Newman, Colorado Water 2012 project consultant.

In addition to raising awareness about water as a valuable and limited resource, Water 2012 aims to increase support for managing and protecting Colorado's water and waterways. Ideally, Water 2012 partners will see this increased support as more people attend their events, as they receive more donations and inquiries, and as they attract more volunteers.

Colorado Water 2012 also hopes to showcase models of cooperation and collaboration among Colorado water users. This will strengthen the bond between water organizations and their constituents, connect Coloradans to existing and new opportunities to learn about water, and motivate Coloradans to become proactive participants in Colorado's water future. The hope is that new people will seek information about water throughout 2012 and will take steps to continue learning and using that knowledge, Newman said.

Colorado Water 2012 volunteers accept a $10,000 grant from the Xcel Energy Foundation to assist with the production of library and museum exhibits. June 1, 2011.

"Water is a vital aspect of our local and state economies, ecosystems, and our quality of life," Newman said. "Let's celebrate that and get people involved in learning and planning for the future of water in Colorado."

Erika Arment, a student volunteer from the Art Institute, works on designing a suite of marketing materials for Colorado Water 2012

Months before the January kick-off of Water 2012, partners are busy planning activities and working together to coordinate their efforts. Newman leads a group of more than 200 partners in a meeting on the first Wednesday of each month to review their progress in planning the celebration. From Denver in June to the Rio Grande Basin in July, with other basins soon to come, monthly meeting locations rotate throughout the state, ensuring that all reaches of Colorado hear about 2012 and have the opportunity to get involved in the celebration.

These partners represent state and local governments, basin roundtables, water providers, non-profit leaders, artists, students, educators, and other citizens. The basin roundtables and the Interbasin Compact Committee are using Colorado Water 2012 as a platform within their local river basins to communicate what they're doing to plan for Colorado's water future.

Partners are grouped into committees and are designing displays, building a website, creating a calendar of events, seeking and applying for funding, and planning the local festivals, contests,

and activities that will become the core of Colorado Water 2012. Events will educate Colorado's residents about our water history, create awareness about current and emerging water issues, highlight careers in water, connect people to volunteer opportunities, and grow Colorado's culture of stewardship.

"There's a lot going on now to prepare for 2012—it's incredible to see so many people involved in and doing a great job developing this initiative," said Nicole Seltzer, executive director of the Colorado Foundation for Water Education and chair of Colorado Water 2012.

To date, a group of student volunteers from the Art Institute in Denver has created an entire suite of branded marketing materials, including a website template, letterhead, museum exhibit design, and more. It will be possible to produce their exhibits thanks to Colorado Water 2012 partners Liz Gardener and Christel Webb, who wrote and received a $10,000 grant from the Xcel Energy Foundation. In addition to this grant, Colorado Water 2012 has been funded by a $30,515 contribution from the Colorado Water Conservation Board (CWCB) from the Water Supply Reserve Account, while local partners have contributed a tremendous $27,000.

"It's truly a grassroots effort but partners are working together and really making this happen," Seltzer said.

Initially, 2012 was a simple milestone for Colorado water—the 100 year anniversary of the Rio Grande Reservoir and the 75^{th} anniversary of the General Assembly's 1937 legislation that created the Colorado River Water Conservation District, the Northern Colorado Water Conservancy District and the CWCB. It's also the 50^{th} anniversary of the Southeastern Water Conservancy District and the 10 year anniversary of the Colorado Foundation for Water Education.

The Colorado Foundation for Water Education saw these anniversaries as an opportunity to reach people throughout the state and began thinking of fun ways to celebrate the organizations that have shaped the management of Colorado's water resources—this idea led the foundation to spearhead Colorado Water 2012.

"We started out small but have been gaining a lot of momentum. As each new person joins Colorado Water 2012, they bring new ideas and additional capacity to reach more Coloradans," Seltzer said. "Although we have more than 200 partners now, there's still a lot that people can do to help—we want to reach as many people as possible in every part of the state."

All are invited to partner with Colorado Water 2012. For more information, to be added to the email list, to make a financial contribution, or to schedule a meeting in your area, contact Wendy Newman, Colorado Water 2012 project consultant at wnewman@cfwe.org or 720-289-6015 and visit www.water2012.org.

Photo by Kyle Thompson

Spring 2011
Interdisciplinary Water Resources Seminar

Sponsored by: CSU Water Center, USDA-ARS, Civil and Environmental Engineering, and Forest, Rangeland, and Watershed Stewardship

Thursdays from 12:00 to 1:00 PM

January 27 **LSC Room 208**	**Mazdak Arabi & Jorge Ramirez** **Joint Lecture: Building a Better Water Future in Education, Research, and Economic Development**
February 2 **LSC Room 224-226**	**Steve Silliman** **Darcy Lecture- Characterization of a Complex, Sole-Source Aquifer System in Benin, West Africa**
February 10 **LSC Room 208**	**Robert Ward & Mark Fiege** **Joint Lecture: History of the Poudre River**
February 17 **LSC Room 208**	**Steven Fassnacht & Mike Gillespie** **Operational Measurements of Snowpack Properties across the Cache la Poudre Watershed: Monitoring and Research to Increase Our Understanding of the Basin**
February 24 **LSC Room 228**	**Dennis Ojima & Brad Udall** **Climate, Water, and Ecosystems: The Changing Socio-Ecological Systems of the West**
March 3 **LSC Room 208**	**Deborah Entwistle, Carl Chambers & John Stednick** **Watershed Analysis on National Forest Lands**
March 10 **LSC Room 208**	**Stephanie Kampf & Jeffrey Niemann** **Basin and Catchment-Scale Hydrologic Regimes in the Cache la Poudre**
March 17	**No Seminar** **Spring Break**
March 24	**No Seminar** **Hydrology Days Mar. 21-23; www.hydrologydays.colostate.edu**
March 31 **LSC Room 208**	**John Bartholow & Brian Bledsoe** **Crafting a Flow Recommendation for the Cache la Poudre River through Fort Collins**
April 7 **LSC Room 208**	**George Varra** **Water Management on the Poudre River**
April 14 **LSC Room 208**	**Ken Carlson & Keith Elmund** **The Built Environment of the Cache la Poudre River**
April 21 **LSC Room 208**	**Ellen Wohl** **Geomorphology of the Poudre River**
April 28 **LSC Room 220-222**	**Boris Kondratieff & Ashley Ficke** **Biomonitoring of the Poudre River**
May 5 **LSC Room 228**	**Panel: Reagan Waskom, Mazdak Arabi, Jorge Ramirez, & Colorado Water Innovation Cluster** **Discussion of Poudre Watershed Monitoring Plan**

* Room may be changed if needed. Check weekly announcements.

All interested faculty, students, and off-campus water professionals are encouraged to attend.

For more information, contact Reagan Waskom at reagan.waskom@colostate.edu or visit the CWI web site.

GRAD592
Interdisciplinary Water Resources Seminar

Fall 2011 Theme: **Exploring Jobs, Careers and Leadership in Water Resources**
Mondays at 4:00 PM, NATRS 109

Course Description

The purpose of the 2011 Interdisciplinary Water Resources Seminar (GRAD592) is to expose students to the broad gamut of opportunities and trends within the field of water resources through guest lectures by prominent Colorado water practitioners.

More specifically, the seminar will:

- Examine jobs and careers in the international, government, private and NGO sectors
- Discuss how students can best prepare for water jobs and careers
- Examine the trends and future of various sectors of the industry
- Discuss leadership in the water resources professions

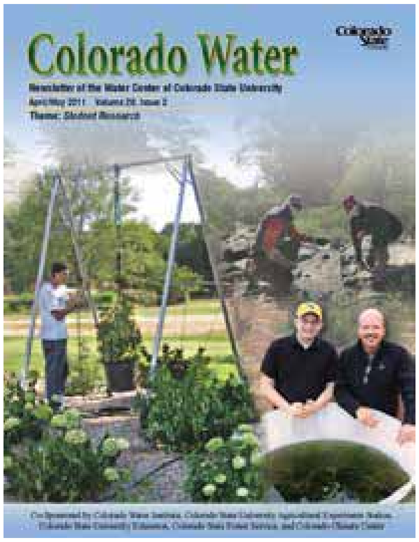
Students interested in taking the one-credit seminar should sign up for GRAD592, Water Resources Seminar, CRN 67067. Grading will be on a pass/fail basis with student participation and written assignments comprising the grade requirement. The seminar will be held at 4:00 PM Monday afternoons in NATRS 109. (Students who have enrolled in GRAD592 in the past, can also enroll for this offering.)

Grading Policy / Attendance

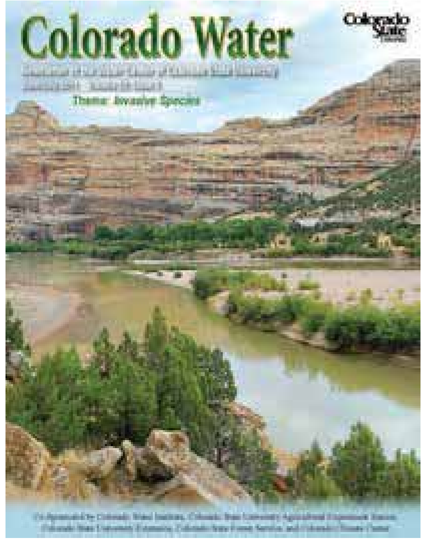
For students taking the 2011 Interdisciplinary Water Resources Seminar (GRAD592), the course will be graded as pass/fail. To receive a passing grade, students will be asked to prepare responses to 8 of the lectures.

Aug 22	Purpose, overview, and expectations
Aug 29	Barbara Richardson, CSU Career Center
Sept 5	**Labor Day - No Class**
Sept 12	Russell Young, Hach Co.
Sept 19	Jonathan Bartsch, CDR Associates
Sept 26	Jerry Pena, MWH Global
Oct 3	Jim Finley, Telesto Solutions
Oct 10	Dale Gabel, International Water Association and CH2M Hill
Oct 17	Jim Kircher, U.S. Geological Survey
Oct 24	Chuck Hennig, U.S. Bureau of Reclamation
Oct 31	Wayne Vanderschuere, Colorado Springs Utilities
Nov 7	Marc Waage, Denver Water
Nov 14	Sue Morea, CDM
Nov 21	**Thanksgiving Break - No Class**
Nov 28	Jennifer Gimbel, Colorado Water Conservation Board
Dec 5	Student discussion and participation

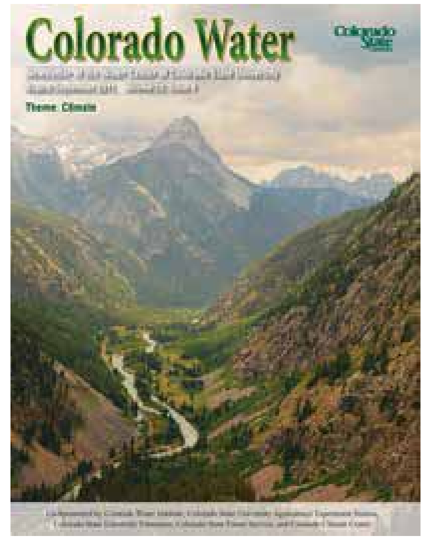
All interested faculty, students, and off-campus water professionals are encouraged to attend.
For more information, contact Reagan Waskom at reagan.waskom@colostate.edu or visit the CWI web site at http://www.cwi.colostate.edu



Colorado Water
Vol. 28, Issue 2
Student Research

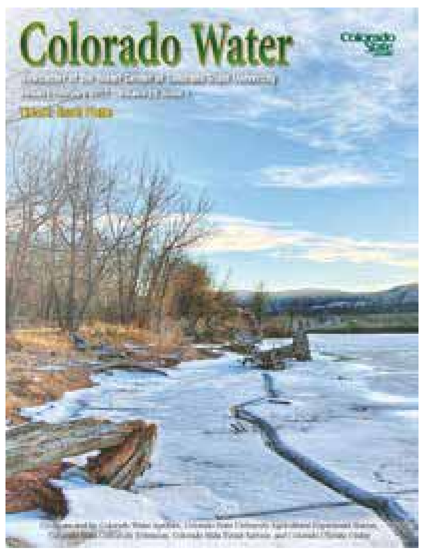


Colorado Water
Vol. 28, Issue 3
Invasive Species



Colorado Water
Vol. 28, Issue 4
Climate

Colorado Water
Vol. 28, Issue 5
Water Quality & Health



Colorado Water
Vol. 29, Issue 1
South Platte

Other Colorado Water Institute Reports/Activities

Tamarisk Management in the Arkansas River Watershed

Cameron Douglass, PhD Candidate, and Scott Nissen, Professor, Bioagricultural Sciences and Pest Management Deptartment, Colorado State University

The research described in the following article was partially funded by a grant from the Colorado Water Conservation Board (CWCB) with the goal of understanding the potential outcomes of tamarisk management efforts in the Arkansas River watershed.

The Problem

The Upper Arkansas River watershed (Cañon City to Holly) contains many diverse ecosystems. Particularly important are the riparian areas, located between aquatic ecosystems and drier, upland habitats. In the western U.S., riparian areas like those in the Arkansas River watershed account for about 1% of the total land area, but 80% or more of the total biodiversity. Intact riparian areas perform many other critical functions, such as mitigating the negative impacts of floods and filtering pollutants from the water. Over the previous century, the health of riparian areas in Colorado and throughout the western U.S. have been substantially degraded by altered river flows (dams) and invasion by non-native plant species, among other factors. For example, the intentional introduction of non-native woody species such as tamarisk (saltcedar, *Tamarix* spp.) and Russian olive (*Elaeagnus angustifolia*) in the early 1900s has negatively impacted riparian forests along the Arkansas River and its tributaries. Riparian forests that were historically dominated by native willow (*Salix* spp.) and cottonwood (*Populus* spp.) species are now mainly tamarisk, and to a lesser and more localized extent, Russian olive. This shift from native plants to invasive ones has caused numerous problems for both aquatic and riparian systems, including reducing the ability of affected riparian areas to absorb and minimize flood effects.

Tamarisk Management

The collective recognition that tamarisk has negatively impacted the Arkansas River watershed has led to aggressive, collaborative efforts aimed at removing tamarisk and Russian olive trees. There are a number of methods that can be used to control both species, including chemical, mechanical, and biological techniques. Successful tamarisk management is an intensive and lengthy process that requires integrated approaches, usually a combination of chemical treatments that kill living plants and mechanical methods of removing the standing dead trees. It is important to consider what the ultimate management objective is for the site that is to be treated; for example, whether the final goal is restoring the site to a native plant community or simply removing trees and restoring recreational access.

Environmental constraints (such as the arid climate), the large area invaded, and costs of tamarisk removal and habitat restoration mean that active site restoration activities (such as re-seeding desired species or planting native riparian trees) are not always feasible. While there are examples where desirable re-vegetation can occur naturally, there have also been cases where tamarisk removal created conditions that favored re-invasion by other noxious weeds. The goal of our project was to evaluate and compare the impact that commonly used tamarisk control strategies have on the plant communities, with a focus on impacts that effect natural re-vegetation.

Project Description

In 2009-2010 we established four experiment sites in the watershed: two locations along tributaries of the river above Pueblo (Four Mile Creek and Hardscrabble Creek), one adjacent to Lake Meredith near Ordway, and the fourth in the floodplain of the main Arkansas River channel at La Junta. At each experiment site, the following treatments were carried out in 1-2 acre adjacent plots (a portion of the site was also left untreated as a reference):

- Aerial helicopter application of Habitat® (active ingredient: imazapyr)
- Removal of entire, living trees using a track hoe equipped with a thumbed bucket (Figure 1)
- Shredding of aboveground biomass (tree trunk, stems and leaves) using a Hydro-Ax (Figure 2)

Figure 1. *Track hoe equipped with thumbed bucket being used to excavate entire, living tamarisk trees*

18-24 months after application, soil concentrations will no longer be toxic to desirable plant species.

Plots in which tamarisk was mechanically removed had plant communities that were similar to untreated areas, indicating that these removal methods did not negatively impact natural re-vegetation the first year following treatments. A majority (67%) of all plant species found during 2010 surveys was native to Colorado; however, six of the ten most abundant species found would be considered weedy (Table 1). One of the common introduced species (Downy brome, *Bromus tectorum*) is classified by the Colorado Department of Agriculture as being "noxious." This result suggests that, despite the disturbance caused by heavy equipment and tree excavation, mechanical tamarisk removal does not necessarily lead to the establishment of other invasive plants. In a few cases, we did find isolated patches of other noxious plants (perennial pepperweed (*Lepidium latifolium*) and Russian knapweed (*Acroptilon repens*)), but these tended to be at sites where the species had already been part of the plant community, and

Figure 2. *Prentice Hydro-Ax equipped with a Fecon mulching head being used to shred the aboveground portion of tamarisk trees.*

Since completing these initial treatments we have sampled soils for herbicide residues and carried out surveys of the plants that are naturally re-establishing in treated plots, in addition to other monitoring. The two mechanical removal methods, and especially the Hydro-Ax shredding, resulted in tamarisk re-growth (Figure 3), and so the one-year-old regrowth was treated in one of the following ways in 2010-2011:

- Releases of tamarisk leaf beetles (*Diorhabda carinulata*)
- Individual tree (growing season) foliar applications of Habitat®
- Individual tree (winter dormant season) basal bark applications of Garlon 4 Ultra® (active ingredient: triclopyr)

Results

We found that the average tamarisk tree canopy retains 74% of helicopter-applied imazapyr herbicide (Habitat®), which means that only a relatively small amount of the herbicide ends up in soils underneath the trees. However, imazapyr is a non-selective herbicide (kills all plants) and we found that many desirable understory plant species were sensitive to even low concentrations of Habitat® that were found in soils underneath tree canopies after aerial herbicide applications. Overall, plant species abundance and diversity in aerially sprayed plots was 67% lower than in untreated plots (Figure 3). The only plant that was commonly found in plots after aerial Habitat® application was kochia (*Bassia scoparia*), which we suspect is resistant to imazapyr. Imazapyr breaks down relatively quickly, especially in wetter soils, and we expect that

Figure 3. *One year after initial plot treatments at site adjacent to Lake Meredith, treatments included: Untreated (A); Aerial helicopter application of Habitat® herbicide (B); Aboveground portion of tamarisk trees shredded using a Hydro-Ax (C); and Entire tamarisk trees excavated using a track hoe (D).*

Regional Water Program Creates Comprehensive Drinking Water Resource Webpage

Erik Wardle and Troy Bauder, Water Quality Program, Department of Soil and Crop Sciences, CSU
Julie Kallenberger, Assistant Regional Water Coordinator, Colorado Water Institute
Adam Sigler, Water Quality Associate Specialist, Montana State University

Sustainable supplies of quality drinking water are essential to the well-being of rural residents, small towns, and other users throughout the West. Protection and safe use of this valuable resource requires an understanding of potential contaminants and their sources. Drinking water quality standards for human consumption are enforced in public water supplies under the Safe Drinking Water Act; however, private wells are not regulated under this legislation. Consequently, private well water users are responsible for monitoring and understanding the suitability of water supplies for domestic, livestock, and irrigation use. Much of the water used by rural residents in the West is supplied by private wells pumped from groundwater aquifers. These aquifers can be susceptible to impacts from agriculture, mining, oil and gas development, and other surface land uses.

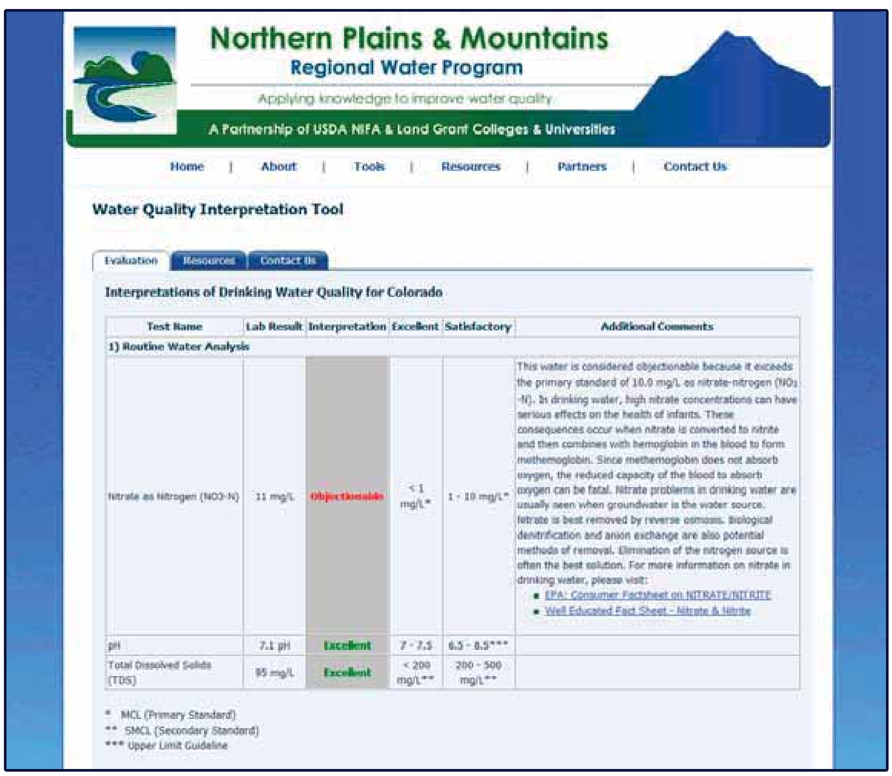
Potential groundwater quality impairments in Colorado and nearby states include salinity, nitrate, bacteria, sulfate, arsenic, hardness, excessive softness, metals, and an array of less common issues such as barium, radon, selenium, and organic compounds. The need for water testing, treatment, and protection is often not apparent to rural property owners until they discover a problem. Once this occurs, rapid access to high quality information from a source that can be trusted to be accurate and non-biased is critical. Correspondingly, easily accessible water quality information and educational curriculum for Extension professionals, technical service providers, landowners, and private well users is needed to address water quality questions and mitigate water problems in these environments.

State regulatory agencies and county environmental health offices in EPA Region 8 (Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming) have noted the need for private well and septic owner education to protect public health and water resources. In response, the Northern Plains and Mountains (NPM) Regional Water Program has developed a comprehensive website (region8water.colostate.edu/drinking_water) for well and septic educational information that includes newly developed resources and offers previously unavailable materials. Resources include an online Water Quality Interpretation Tool to help rural water users understand water quality analytical test results, a series of factsheets on drinking water quality and treatment, an educational DVD to provide homeowners information about their well and septic systems, well and septic record-keeping folders to encourage maintenance, and a guide on how to start a local well testing program. Let's look at these resources in a bit more detail.

Water Quality Interpretation Tool

This online assessment tool allows users to enter the results of their water quality analytical test and receive immediate feedback about suitability of the water for drinking, livestock consumption, or irrigation use. Increased understanding of test results is key to helping well owners

A sample interpretation from the tool shows high nitrate (as nitrogen) water.



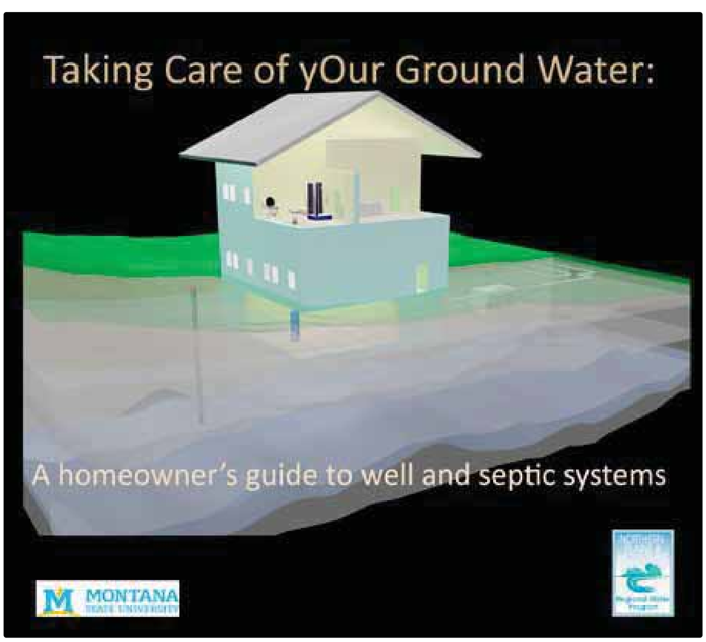
take possible actions to protect and/or treat their water for its intended uses. The tool delivers state-specific interpretations and directs users to additional resources related to the quality of their water supply. These resources include information on proper testing procedures, private and public resources available for testing water, treatment options, contaminant specific details, and well and septic system management. The tool is free, easy to use, and it requires no registration or personal information.

Well Educated Fact Sheets

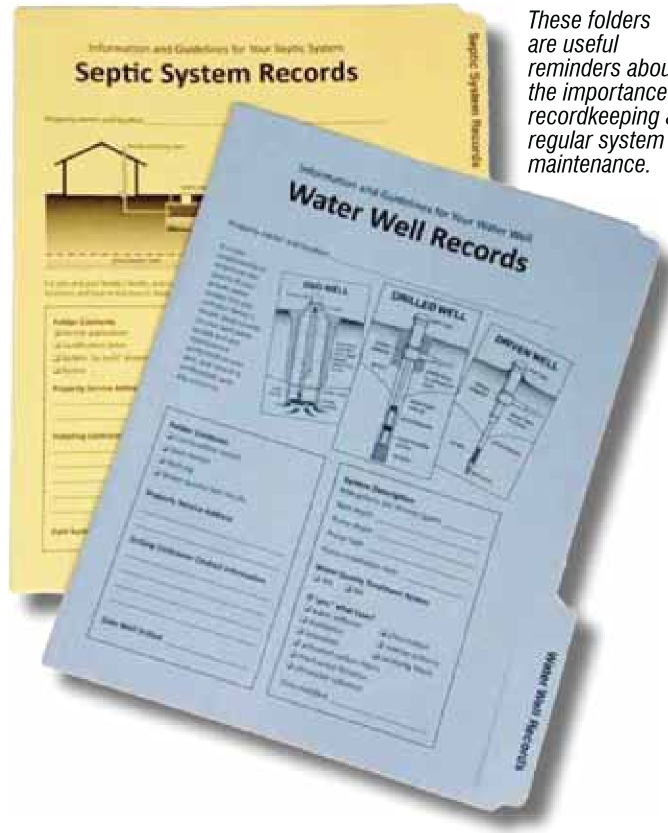
This series of fact sheets addresses issues related to drinking water quality. They provide detailed information on common water contaminants, drinking water standards, and further assistance with interpreting test results.

Well & Septic Educational Videos

Also included is an educational DVD called "Taking Care of yOur Ground Water." This DVD was designed to educate homeowners about caring for their well and septic systems to protect their drinking water resources. The title film provides basic information on well and septic systems and offers guidance on what users can do to ensure their systems function properly. There are additional chapters covering specific topics in more detail. These videos include, "Sampling for Well Water Quality," "Water Treatment Options," and "Protecting the Wellhead," among others. All videos include detailed three-dimensional graphics to aid the viewer in understanding the inter-workings of well and septic systems. Postcard surveys included in the DVD jacket have shown that most viewers are finding the material useful for understanding their well and septic systems, and some have identified and corrected potential problems that could impact their families' health.



In addition to hard copies of the DVD, these videos are available for online viewing.



These folders are useful reminders about the importance of recordkeeping and regular system maintenance.

Well & Septic File Folders

Maintaining accurate and complete records is essential to helping households protect the health of their family and the environment. The well and septic file folders are a tool to encourage users to save their water quality test results, keep detailed installation and maintenance records, and provide critical information to users. The folders contain a description of typical systems, suggestions for maintenance, tables for critical dates, and other essential information to help private well and septic owners keep their systems operating efficiently. As was done with the DVDs, postcard surveys were distributed with the folders, and they have shown that people have found folders useful to keep well and septic records.

Guide to Offering a Well Testing Program

In order to support those that have interest in offering a well water testing program in their communities, the NPM team has created a comprehensive document titled "Private Well Testing Program Guidance." The document is intended to provide complete information for an organization or individual that wishes to start a well testing and educational program in their area. A well testing program is a public education program that guides private well owners through the process of testing their water, helps them to interpret their water quality results, and reminds them about the importance of testing. Testing is the most accurate way for well owners to learn about the quality of their well water. Sampling is not complicated or expensive, but many homeowners do not know where to begin. Providing a well testing program offers well owners guidance on how to collect samples and which parameters to select for analysis. This process may help homeowners find issues with their well and learn how to remediate the problem. Using this document is a great way to organize an effective program that can have lasting benefits for private well water users who may otherwise not know the quality of their water.

Until recently, these resources were only available through scattered web sources and local providers. The comprehensive website that the NPM team put together allows access to all of these resources in one convenient location. These materials have already reached thousands of homeowners through Land Grant University faculty, state Extension networks, county environmental health offices, and water quality districts in the six cooperating states. By organizing these resources in one location, the NPM team expects to increase access to and use of these tools, thereby increasing knowledge and understanding of well and septic systems, groundwater protection, and water quality testing. Although most of these resources are available free of charge, some materials may have a small fee in order to recuperate costs of production. However, at the state level, resources may be available to help reduce these costs. Whether a private well user, Extension specialist, health department agent, citizens group, small community, or other interested group, the NPM team encourages you to visit the drinking water resources webpage and put these tools to work for you.

For More Information Please Visit:

Region 8 drinking water resources page:
www.region8water.colostate.edu/drinking_water

Colorado State University Extension Water Quality Programs:
www.csuwater.info

Or Contact

Erik Wardle - CSU Water Quality Program
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Julie Kallenberger – Colorado Water Institute
julie.kallenberger@colostate.edu

Didymo, a Threat to Mountain Streams in Colorado

James Cullis, PhD Candidate, and Diane McKnight, Professor, Institute for Arctic and Alpine Research, University of Colorado at Boulder

Didymosphenia geminata or didymo is a benthic diatom that has become a nuisance species in streams throughout the United States, Europe, and Asia. In North America, concerns about didymo blooms were first documented on Vancouver Island in the mid 1990s, and since then, there has been an apparent increase in the tendency for nuisance blooms to develop in many other watersheds in the United States and Canada. The preferred natural habitat for didymo is in the mountain streams of the Rocky Mountain region but is spreading to the north-eastern U.S. and has even been observed in Oklahoma. There are many streams in Colorado impacted by didymo, which poses a threat to the sustainability of these streams and the enjoyment potential of recreational users.

Didymo prefers stable substrate as shown by the massive extent of active (brown) and dried (white) mats at the Little Qualicum River on Vancouver Island

Photo by James Cullis

In 2004, didymo invaded a stream in New Zealand, and it spread quickly to most watersheds on the South Island. Due to favorable conditions for growth, the impact was startling, with mats up to 20 cm thick developing and covering 100% of the streambed. This significantly raised awareness of the potential impact of this nuisance species on the sustainability of stream ecosystems, prompting the classification of didymo as a threat to biodiversity in New Zealand. In January this year, didymo was observed in streams in Chile, and the impact was described in *Science*. Worldwide, didymo is now acknowledged as the most harmful invasive species in lotic systems.

Another name for didymo is "rock-snot," which refers to the thick mats that can blanket the streambed. Didymo mats have been compared to toilet paper or dead sheepskins. Such extensive mats greatly impact the aesthetic appearance of the stream and the enjoyment by recreational users such as fishermen, boaters, and swimmers. Didymo mats also significantly alter the habitat structure, thus potentially affecting the functioning of the stream ecosystem. With abundant didymo mats, there is a shift in macro-invertebrate species from large stoneflies and mayflies to smaller worms and other species that find refuge in the mats. These have a lower calorific value and hence, larger fish species, such as trout, have to invest more energy in foraging for reduced returns. The result is smaller fish. There are also concerns that thick mats can clog the intakes to water treatment plants or irrigation canals, resulting in reduced hydraulic efficiency and increased cleaning and maintenance costs.

Nuisance and harmful algal blooms are typically triggered by natural and/or manmade increases in nutrient concentrations in large rivers, lakes and oceans. In contrast, didymo prefers cold, clear, low-nutrient streams. Didymo therefore presents a paradox: how can such thick mats develop under these low nutrient conditions? The mechanism is still unknown, but is being actively investigated. There is some evidence that the stalk material may trap and concentrate the necessary nutrients during growth and in the chemical processes that convert particulate forms of phosphorus to more soluble reactive forms to be used by the cells. Alternatively, studies in New Zealand have concluded that the thicker mats did not help in securing vital nutrients for the cells, but were rather a consequence of the low nutrient conditions.

It is still not clear what has caused the apparent increase in didymo blooms. Some suggest that it is related to increasing ultraviolet light, increasing

A rock sampled from Boulder Creek showing a circular area where the approximately 5mm thick didymo mat has been removed for analysis.

Photo by James Cullis

nitrogen deposition, changes in the flow regime, or even the emergence of a new genetic variation. One clear thing is that humans have played a role in how it is spread to new areas.

Like other aquatic species, didymo is transported by numerous vectors. Individual cells can survive for extended periods of time outside the stream environment, allowing the diatom to re-establish colonies after droughts or when transported to new streams. The first documented nuisance didymo blooms in North America occurred at popular fishing sites along rivers on Vancouver Island. These blooms followed a significant increase in recreational fishing and the rise in popularity of felt soled wading boots. It is very likely that didymo was introduced to New Zealand and possibly Chile on the boots of a recreational fisherman from either Europe or North America.

Felt boots are an ideal means for transporting didymo, as they provide a continuous damp environment in which the cells can remain viable for weeks and even months. They are also difficult to clean and disinfect completely. Felt boots are also significant vectors for the transport of other nuisance species, such as whirling disease and New Zealand mudsnails. Felt boots have now been banned in New Zealand, and strict rules on cleaning and disinfecting wading boots were introduced at popular fishing sites. In September 2008, Trout Unlimited called for the elimination of felt boots in the US by 2011. As yet there have been no federal laws to this effect, but individual states such as Alaska, Vermont and Maryland have introduced legislation to this effect.

There are few if any invertebrates or fish that consume didymo mats. In addition, traditional mitigation measures for algal blooms that include reducing nutrient inputs from the catchment have no impact, as didymo prefers low nutrient conditions. There is therefore little that can be done to remove didymo once it is established. Currently the only defence against didymo, as with zebra mussels, is to try to stop it getting into the watershed in the first place. This is hard to achieve, and once it's established, there is only the potential that didymo may be managed and the extent of nuisance blooms controlled.

Didymo is a classic case study for studying stream ecology as it represents some of the key stream ecology concepts and highlights the role of humans in altering stream ecosystems. Here students from the University of Colorado partake in a class project to investigate the relative ability of felt and Vibram soled wading boots to transfer didymo cells from an impacted stream under the guidance of Prof. Diane McKnight.

Photo by James Cullis

As with most organisms adapted to living in mountain streams, the flow regime remains one of the most significant controls on growth. Studies in the U.S., New Zealand and Canada show higher didymo presence and persistence in stable bed rock channels and regulated flows downstream of lakes and reservoirs. The current hypothesis is that because didymo is adapted to living in high shear environments of mountain streams, flood events sufficiently high to mobilize the bed sediments are the only mechanism for getting rid of didymo by physically scouring it from the stream bed. This raises the potential to consider managed flood releases from dams as a possible mitigation measure. Flushing flows are already becoming part of the management of dams in the U.S., including for habitat maintenance along the Colorado River downstream of Glen Canyon Dam, and they are being used in New Zealand specifically to restore didymo-impacted streams.

Research has shown dams to be hot spots for didymo growth as they produce cold, clear, low-nutrient water ideal for didymo growth and reduce major flood events. There are, however, many aspects that need to be considered before flushing flows can be considered as a sustainable management option, particularly in Colorado and the West. Firstly is a need to quantify the magnitude, duration, and timing of floods necessary to remove didymo. Secondly, it is important to determine the real impact of didymo and hence the benefits for managing its growth. Only then will it be possible to assess the likely tradeoff between making water available for flushing flows to get rid of "rock snot" and the many other competing demands for water.

Until that happens, the best approach in Colorado would be to raise awareness and attempt to limit its spread. Recognizing the potential threat from didymo is important, as the conditions that favor didymo growth mean that streams most at risk are also amongst the most picturesque and favored trout streams in a state where fishing and tourism is such a vital part of the local economy.

Irrigation Water Management Update

Denis Reich, Water Resource Specialist, Colorado Water Institute

So far, 2011 has been an eventful year for water, including record snowpack, West Slope flooding, eastern plains drought, and a new agreement between east and West Slope water managers. When water grabs the headlines, it feels like vindication for the many hours of less glamorous but by no means less important water work put in by hydrologists, engineers, and educators throughout the state. Newspapers don't usually get a lot of copy from aquatic weed studies, groundwater well monitoring, or irrigation scheduling, yet the many unrecognized hours of hard graft on these oft overlooked topics provide the foundation for milestone improvements in statewide water resource management.

In terms of scale, work across the state with irrigation, particularly within agriculture, still has the potential to provide the largest bang for the buck. Today, agriculture still owns the rights to use the bulk of Colorado's water on the lion's share of private land. Whether or not we fully appreciate agriculture, it still remains a large piece of the state's water personality in 2011.

Integral to agriculture's continued relevance is optimal irrigation water management, or IWM. IWM is defined by the Natural Resources Conservation Service (NRCS) as "the process of determining and controlling the volume, frequency, and application rate of irrigation water in a planned, efficient manner." Such a broad definition leaves plenty of room for how the "process" of "planned" efficiency should occur. Thanks to many years of IWM application and experimentation, it is clear that the process has two key determinants: the system being employed to irrigate, and how water is scheduled and applied.

Improving the system or the efficiency of a system being used for irrigation increases the precision with which water can be applied to a crop. This has a number of advantages, including the ability to maintain optimum soil moisture more consistently, which enhances yields, and significant reductions in runoff and groundwater percolation, which have historically contributed to water quality problems such as salinity and selenium. Improvements can also be expensive, which is why pivot, side-roll, drip, and micro-spray systems tend to be more prevalent in areas of the state where water is also expensive and/or crops are of higher value, such as the South Platte and Rio Grande basins. The NRCS also offers financial assistance through programs like the Environmental Quality Incentive Program (EQIP) to help agricultural producers cover the costs of installing new, more efficient programs. Cost share can be as high as 75 percent for beginning farmers and ranchers or producers in salt affected watersheds.

From left to right: Randy Kramer (ex Conservation District Irrigation Specialist); Randy Meaker (Montrose area producer); and Denis Reich, of CWI, talk irrigation scheduling with Uncompahgre Valley producers.

Courtesy of Denis Reich

Where producers have justified the expense and invested in an upgrade to a high efficiency system—and there are many that have—they invariably come to appreciate the reduced labor and improved control of water delivery. But when moving to a system that manages irrigations more precisely, the need for equally precise scheduling information becomes essential to avoid overwatering early in a season and under-watering as temperatures climb. The NRCS is also beginning to require producers to track water use and record their irrigation scheduling as a component of contracted system improvements.

The Benefits of Scheduling

Irrigation scheduling is the more affordable piece of the IWM puzzle. Scheduling can also have more influence on crop performance than the system itself, but it is usually the first to be overlooked since it is largely invisible. It's only over time that the symptoms of a mismanaged system become clearly apparent producers scramble to cover the costs of a poor harvest. Applying the correct amount of water at the appropriate rate with a suitable frequency is critical to fulfilling the potential of any irrigation system. Each of these factors is determined by the depth and thirstiness of a crop's root system in combination with the soil type, irrigation system, and daily weather. Optimum soil moisture is the key to a well irrigated operation, and estimating soil moisture and the optimum point at which to irrigate is what all good irrigators are concerned with.

Producers employ various techniques for tracking soil moisture and triggering irrigations, with soil moisture sensor equipment, ball probes, moisture by feel, and weather stations being some of the more common techniques. A balanced approach using both weather stations and some form of soil moisture assessment is a proven formula to account for microclimates and soil variability. An astute irrigator treats his soil like a checking account for moisture, carefully filling it to capacity where possible without drowning the root system, and refilling before soil gets "overdrawn," which can lead to crop stress and hurt yields.

CoAgMet Expansion

The Colorado Climate Center at Colorado State University (CSU) led by State Climatologist Dr. Nolan Doesken is the current custodian of the CoAgMet (Colorado Agricultural Meteorological) network. CoAgMet is the statewide network of 64 active weather stations specifically designed for monitoring localized weather conditions in agricultural regions of the state. CoAgMet had its humble beginnings in the early 1990s as a partnership between CSU Extension's Plant Pathologists and the USDA's Agricultural Research Services Water Management Unit. The first group of eight stations monitored crop water use and disease pressure via landlines and modems. As water efficiency became a larger player in producer's bottom lines the demand for reliable weather station data grew. Individual producers, ditch companies, and conservancy districts began sponsoring stations to bring more local weather information to their area.

Wendy Ryan and Noah Newman of the Colorado Climate Center install a CoAgMet Weather Station.

Courtesy of Denis Reich

In recent years, CoAgMet has gone online with a website at www.CoAgMet.com that is updated daily to provide crop, turf, and reference evapo-transpiration amounts. New algorithms allow for green-up after hay cuttings, and the 1996 Kimberley-Penman Equation (which includes a more accurate wind coefficient) is available along with the standardized ASCE standard Penman-Monteith reference equation. By the end of the 2011 growing season, the hourly ASCE Penman-Monteith equation will also become available, which accounts for hourly fluctuations on top of the standard diurnal maximum and minimum.

Deep Nitrogen Removal with Sunflowers

Extension Joel P. Schneekloth, Regional Water Resource Specialist, Colorado State University Extension and Colorado Water Institute

With irrigated production, many times nitrogen will leach below the root zone of irrigated crops such as corn. Subsequent years of the crop may increase the amount of nitrogen present in soil. This nitrogen buildup can make regions with shallow groundwater susceptible to groundwater contamination, a threat to water quality in the connected water supply.

What crop can effectively remove that nitrogen from deeper in the soil profile? Sunflowers have a deep rooting system and have extracted water from depths greater than six feet. Previous work with dryland sunflowers has also shown nitrogen extraction to depths of six feet. Additionally, irrigated sunflowers have shown promise for irrigated crop production when irrigation water is limited because of sunflowers' ability to root deeply and utilize water sources.

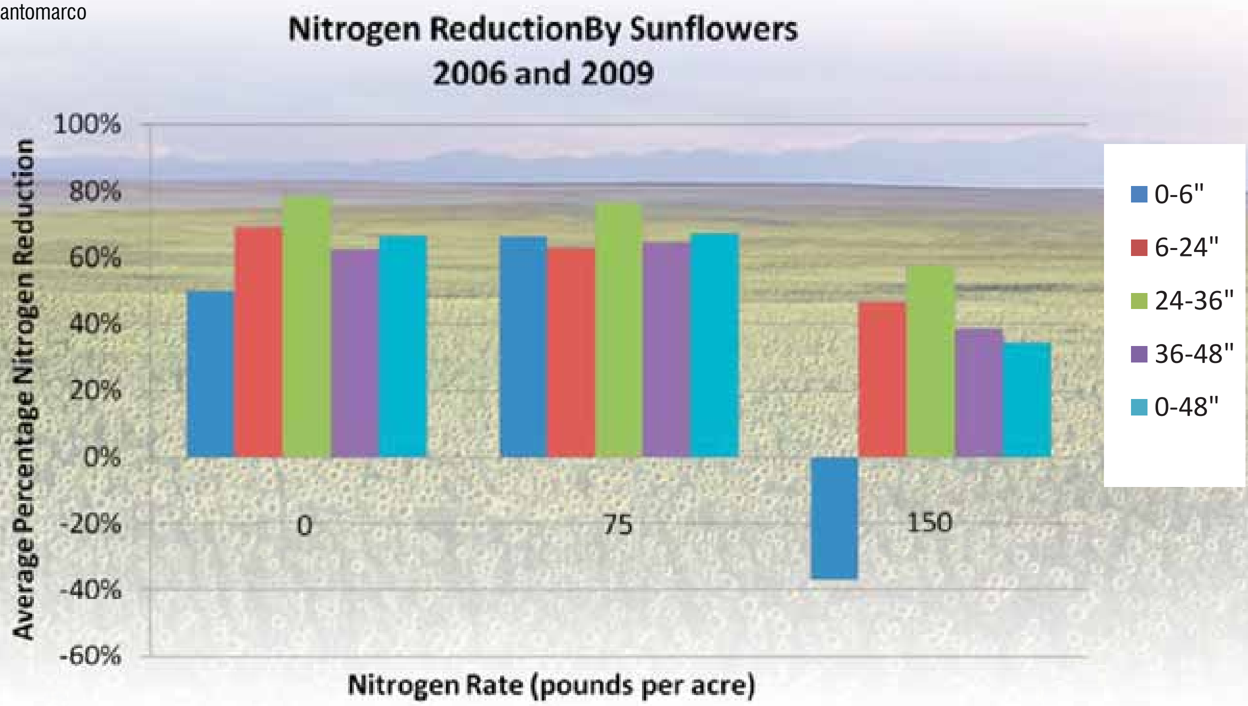
In 2006, 2009, and 2010, a nitrogen rate study was conducted looking at the optimal nitrogen management as well as the deep nitrogen removal of fully irrigated sunflowers. Nitrogen rates of 0, 75, and 150 pounds per acre were applied to sunflowers pre-planting to simulate typical producer management for nitrogen applications. Nitrogen rates above 150 pounds per acre decreased yields, so they will not be discussed. Soil samples prior to planting and after harvest were taken to a depth of three feet in 2006 and to four feet in 2009 and 2010 to look at removal of nitrogen by irrigated sunflowers.

Residual soil nitrogen at the beginning of the growing season was similar in 2006 and 2009. In 2010, residual soil nitrogen was greater, with average residual nitrogen levels greater than 250 lbs per acre. Removal of residual nitrogen was similar in 2006 and 2009. The removal of nitrogen varied by the amount of nitrogen applied prior to planting. However, both the 0 and 75 lbs N removed similar amounts with approximately 67 percent of the beginning nitrogen removed by the crop during the growing season. The average reduction in residual nitrogen ranged from 60 to 80 percent from six to 48 inches. When 150 lbs per acre nitrogen was applied, the nitrogen removal was reduced. The average reduction in residual nitrogen was 34 percent compared to 67 percent for 0 or 75 lbs N. Grain yields did increase from 0 to 75 lbs nitrogen applied. However, the yield increase was less from 75 to 150 lbs nitrogen.

In 2010, beginning residual nitrogen was greater than 250 lbs per acre to a depth of 48 inches. This was three times greater than 2006 or 2009. When no nitrogen was applied,

Figure 1. *Average reduction of residual nitrogen by depth and sample zone for 0, 75, and 150 lbs nitrogen applied for 2006 and 2009. A negative number indicates an increase in residual nitrogen.*

Photo by Matt Santomarco



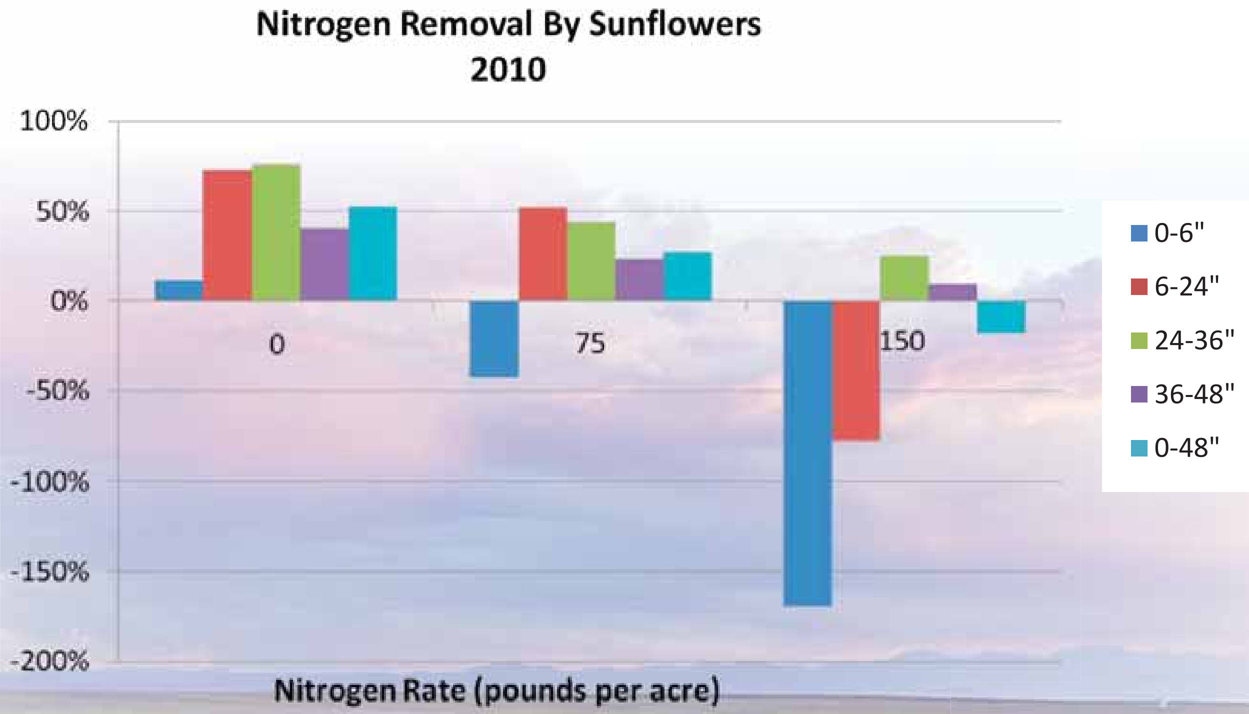


Figure 2. *Average reduction of residual nitrogen by depth and sample zone for 0, 75, and 150 lbs nitrogen applied for 2010. A negative number indicates an increase in residual nitrogen.*

Photo by Matt Santomarco

sunflowers removed approximately 50 percent of the residual nitrogen. Sunflowers removed approximately 70 percent of the residual to a depth of 36 inches and nearly 40 percent of the residual nitrogen from 36 to 48 inches. When nitrogen was applied, the removal was reduced with less than 50 percent removal at all depths for 75 and 150 lbs nitrogen applied. With applications of nitrogen, the surface and six to 24 inch residual nitrogen did increase. Grain yields decreased with additional nitrogen applied with high residual nitrogen as compared to the increase in yield in 2006 and 2009.

Irrigated sunflowers have shown that they can effectively remove residual nitrogen from depths greater than 24 inches. In some instances, this was a substantial amount of nitrogen. Soil sampling to a depth of four feet can reduce applications of nitrogen for producers and reduce the potential for leaching of nitrogen into the aquifer. When residual nitrogen is high, applications of nitrogen can reduce grain yields while increasing soil residual levels.

Current work on fertility management of irrigated sunflowers is looking at nitrogen amounts as well as timing of applications. These timings would mimic fertigation management and looking at the possible reduction in amounts of nitrogen as compared to a complete pre-plant program. Funding for this work was provided by the National Sunflower Association and Colorado Sunflower Association.

Demonstrating Conservation Tillage Techniques for Surface Irrigated Fields in Northern Colorado

Extension *Erik Wardle* and *Troy Bauder*, *Water Quality Program, Department of Soil and Crop Sciences, Colorado State University*

Introduction

Professionals that work in academia and other public sector institutions are tasked with meeting the needs of the citizens we serve. Professors, researchers, and Extension personal at Colorado State University are continually looking for ways to increase the positive impacts of our work. While some research certainly necessitates an in-house approach, collaboration and cooperation with organizations outside of the university system is equally important. These partnerships enhance the impact of research and outreach activities, integrating scarce resources to accomplish more with less. An excellent example of this type of collaborative project is currently taking place along the Northern Front range of Colorado (Figure 1).

During the summer of 2010, a group of agencies and individuals interested in conservation tillage[1] decided to pursue funding to solidify an ongoing demonstration project intended to promote these practices in the area. The strength of this project comes from the locally driven interest in conservation tillage under furrow[2] irrigation and the strong collaboration among participating entities.

The project planning and advisory committee consists of Colorado State University faculty and staff from Soil and Crop and Bio-agricultural Sciences and Pest Management Departments, the director and staff of the Agricultural Research Development and Education Center (ARDEC), and an Extension water specialist. Government entities represented in the project include NRCS field office staff and a senior Agricultural Research Service scientist. Other public sector participants include the Fort Collins and Big Thompson Conservation districts. Key to the success of this project are the multiple producer participants who were the driving force behind the continuation work being conducted. In addition, representatives from the tillage implement industry and seed companies have been important to this process. After funding was secured for the work, the scope and focus of the project was set by the group at a meeting in fall of 2010. The focus of the project is the evaluation and demonstration of conservation tillage practices under furrow irrigation. Outreach and promotion of these practices is being done with online data sharing, photo and video production, conference presentations and field days.

Figure 1. *Project planning and advisory committee meeting fall 2010.*

Photo by Erik Wardle

1. Conservation tillage is defined by the Natural Resources Conservation Service as any practice that leaves at least 30 percent crop residue cover on the soil surface.
2. Furrow irrigation refers to surface flood irrigation where each crop row is irrigated by running water down a small ditch created to move water through the field.

Background photo by Bill Cotton

The Problem

Although viewed as an outdated irrigation practice by some, furrow irrigation continues very important to Colorado agriculture. Conversion to more efficient irrigation systems is restricted by cost, land suitability, and efficiency rules in the Arkansas Basin. According to the 2008 Farm and Ranch Irrigation Survey, over 1.5 million acres of cropland are irrigated with surface methods in Colorado. While center pivot sprinkler irrigation is expanding, there is still significant acreage under surface irrigation that could use improved tillage methods. Conservation tillage is fairly common in the eastern part of the state but is much less prevalent along the Front Range, especially under furrow irrigation. Traditional practices in furrow irrigation involve multiple energy-consuming tillage operations intended to loosen soil, bury residue, smooth and level soil surfaces, and create a suitable seedbed. However, these systems leave the bare soil surface vulnerable to wind and water erosion during seasonal periods where weather conditions are often most conducive to soil loss before the crop canopy is developed. Tradition and legitimate concerns regarding furrow irrigation performance help continue these outdated practices. Residue can cause furrow 'dams' during irrigation, slowing water movement down the rows and affecting irrigation uniformity. Cool spring soil temperatures in undisturbed ground can limit early season plant growth and slow stand establishment. Disease and insect pest concerns in some crops have also limited widespread adoption of conservation tillage practices.

Recent developments in planting and tillage system technologies are offering more options for alleviating cool spring soil temperatures and successfully dealing with crop residue during planting and irrigation. These tillage systems, coupled with more accurate and economical Global Positioning Systems (GPS) are gaining widespread acceptance in certain parts of the Western Great Plains and Colorado, but are much less common in the Northern Front Range.

Conservation tillage in furrow irrigation is not only possible, but offers many agronomic, economic and environmental benefits. First, the benefits of soil moisture preservation with increased crop residue in many environments and cropping systems are well known and have been documented for many years. One benefit of this soil moisture preservation is that early season irrigations can often be avoided, conserving water and reducing energy demands of pumping wells. Soil erosion prevention from both wind and water with increased residue is also a proven benefit. Erosion reduction from conservation tillage in a furrow irrigation system occurs not only prior to the irrigation season, but also during furrow irrigation by decreasing irrigation-induced sediment and increasing water infiltration into the soil.

Sediment from irrigation water runoff can contribute to water quality degradation by transporting nutrients (nitrogen and phosphorus), adsorbed pesticides, and potentially selenium to surface water bodies. As such, the Colorado Phosphorus Risk Assessment lists residue and tillage management as a Best Management Practice appropriate to decrease the relative potential for off-site P movement for sites with high P runoff potential. In Colorado, as in other areas of the United States, an excessive amount of nutrients in surface water can cause excessive algae blooms which reduce sunlight penetration and available oxygen, resulting in fish kills. Irrigation induced erosion reduction with conservation tillage, and its associated decreases in nutrient transport to surface water bodies, may be one tool to help alleviate nutrient problems in the South Platte River and meet the coming nutrient standards.

Project Field Work and Outreach

The goal of this project is to evaluate and promote conservation tillage on furrow irrigated fields as a practice that is environmentally and economically sustainable. In order to accomplish these goals, our team has a number of on-going field and outreach activities. At ARDEC, we have a replicated field scale demonstration and research site that shows conventional tillage, and two conservation practices, minimum-tillage and strip-tillage[3] (Figures 2 and 3). This site is being intensively monitored for crop health, soil moisture, irrigation efficiencies, and runoff water quality parameters. In addition, all activities at ARDEC are being recorded to help develop a detailed farm budget for these systems. This information will be used to assess the capacity of these systems to produce high yields, improve soil health, save fuel and labor and improve a producer's bottom line. Our cooperating producers in the area are innovative farmers that are practicing conservation tillage on a production scale. In addition to the ARDEC site, documenting on-farm practices that local growers are finding to be successful is enriching the outcomes of this project.

This is the first year of the project, and initial results continue to be processed and made available through the project webpage, conservationtillage.colostate.edu. A field day held in July of this year was well attended and provided

3. Conventional tillage refers to the utilization of multiple common local tillage operations leaving no residue on the soil surface; minimum-tillage means only tillage operations deemed absolutely necessary are done with most of the soil surface left undisturbed; strip-tillage is a practice where a narrow band of soil is disturbed in order to create a prepared seedbed.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	9	0	1	6	16
Masters	3	1	0	13	17
Ph.D.	1	1	1	3	6
Post-Doc.	0	0	0	0	0
Total	13	2	2	22	39

Notable Awards and Achievements

- Nolan Doesken receives CFWE 2011 President's Award
- Evan Vlachos receives Honorary Doctorate
- Joesph D. Vassios receives Outstanding Graduate Student Award

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Awards and Achievements

<img src="http://cwi.colostate.edu/HostedPics/NIWR_Events/nolan.jpg">
Nolan Doesken receives CFWE 2011 President's Awards

Nolan Doesken, State Climatologist at Colorado State University (CSU), was recently awarded with the Colorado Foundation for Water Education's (CFWE) President's Award, which goes to "those who demonstrate steadfast commitment to water resources education," according to CFWE, which is a non-profit, non-advocacy organization that promotes the better understanding of Colorado's water resources via education and access to accurate information. "As an outstanding water educator, Nolan travels throughout Colorado, showing how its climate shapes our great land, wildlife and people," says the CFWE website. Doesken recalls the list of previous winners of the President's Award, saying he felt honored to be included alongside such well-known individuals. Doesken has worked with the Colorado Climate Center since 1977, serving as Assistant State Climatologist until 2006, when he received his current title as State Climatologist. His three primary goals there, he says, are as follows:

1. Monitor climate by recording measurements and tracking trends and variations.
2. Conduct applied research of benefit to the citizens of Colorado, especially drought research, and mostly water-related.
3. Share research with citizens of Colorado via service and outreach.

His work in education, as a CFWE award indicates, has been significant -- one primary example is a project called CoCoRAHS, the Community Collaborative Rain, Hail, and Snow Network. The goal is to engage the public in helping scientists better understand where water comes from in Colorado. By the end of 2012, Doesken plans to have every K-12 school in the state reporting precipitation information with the program. "If you see how much precipitation falls from the sky and how it is distributed across the state," says Doesken, "you become more impressed with how we thrive and how we manage our water in Colorado." CoAgMet (Colorado Agricultural Meteorological Network) is another example of Doesken's projects that extend his research to the state -- its importance, he says, is the ability to track evapotranspiration (how water is used by crops, and how this varies over time). One aspect of Doesken's job that he enjoys is overseeing the Fort Collins Historic Weather Station. Since some of the earliest days of climate recording, CSU has maintained daily recordings of temperature, humidity, wind, soil temperature, evaporation, barometric pressure, and other data. Some of the processes have been automated but much of the process is checked by hand as it was in the late 1800s. Doesken has given presentations, overseen field trips, and trained student employees at the station since the 1980s.

<img src="http://cwi.colostate.edu/HostedPics/NIWR_Events/evan.jpg">
Evan Vlachos Receives Honorary Doctorate

In March, Evan Vlachos, who has been a lawyer, professor, researcher; consultant in urban planning, water resource planning and management, forecasting and futurism, technology assessment and demography; and other areas for over 40 years, was presented with an honorary doctorate in civil engineering from the Aristotle University of Thessaloniki (AUTH) in Greece. Following the award, Vlachos and CSU President Tony Frank attended and signed an international memorandum of understanding (IMOU) that called for a partnership between the universities on certain water-related projects. Vlachos emphasized that the event signifies an emphasis on integrated, interdisciplinary, and transnational research and communication between the universities. Vlachos was born in Greece, and he earned a law degree there before coming to the U.S. and earning a Master's and Ph.D. in sociology as well as a Certificate of Russian Studies. In his career, Vlachos's work included directing the Environmental Resources Center, acting as Associate Director of the International School for Water Resources, and serving as member and chairman of the Environmental Advisory Board, the U.S. Army Corps of Engineers, and the Advisory Panel on Environmental and Earth S&T in NATO, Brussels, to name a few, and he has authord many books and articles. Vlachos's interests when he first came to the U.S. were sociology and the environment, which quickly grew into studying and learning about water and other related issues. He explains that receiving an honorary doctorate in civil engineering is a tremendous honor for someone who studied as a lawyer and sociologist. The IMOU signing took place during a Water Day meeting, during which President Frank made a speech, and the two universities discussed water issues. The IMOU included the following as tentative joint projects between CSU and AUTH:

- Transboundary hydrodiplomacy (with focus on the Balkans and Circum-Mediterranean areas) and special attention to transboundary aquifers;
- Water Resources Planning and Management, with emphasis on new techniques, as well as, methodological advances and models;
- The increasing number of extreme hydrological events and their consequences for water-scarce and waterstressed hydrological regimes;
- The use of scenarios for outlining options in comprehensive planning and management;
- Exchanges of students and faculty for improving ties with the Unesco ICIWaRM program at CSU and AUTH; and
- Comparative drought and desertification studies affecting the agricultural economies of Colorado and Greece.

Vlachos explains that CSU has experience in agriculture and a reputation in the water field, and AUTH has a central location in Europe with many similar agreements with around 200 European universities. The agreement would also bring more international students to each university, strengthening international ties and increasing knowledge. Vlachos discusses growing up in Greece, saying that fresh water was scarce. "Water is a sacred thing," he says, and it's important for historians and anthropologists, who understand older, traditional ways of dealing with water scarcity, to be involved. Such an integrated approach is necessary for water resources. ICIWaRM, the International Center for Integrated Water Resources Management, is an example of an integrated and international approach to water. ICIWaRM was established in 2007 by organizations "sharing an interest in the advancement of the science and practice of integrated water resources management around the globe," according to its website. Vlachos expresses his hope that this international approach to water issues will continue with CSU, which has been known for its involvement in water. "We're engineering the planet," he says.

<img src="http://cwi.colostate.edu/HostedPics/NIWR_Events/Vassios.jpg">
Joesph D. Vassios Receives Outstanding Graduate Student Award

Colorado State University Ph.D. candidate Joe Vassios was recently honored with the annual Outstanding Graduate Student Award from Aquatic Plant Management Society. Vassios says the graduate work he was recognized for has focused on "examining the absorption and translocation of the aquatic herbicides triclopyr, fluridone, and penoxsulam in two aquatic plant species, hydrilla and Eurasian watermilfoil." In addition to this research, Vassios has been active in CSU Professor Scott Nissen's aquatic plant management research program. He's also been "evaluating current and new methods for control of sago pondweed in irrigation canals and new control methods for Eurasian watermilfoil in lakes, ponds, and irrigation canals." Vassios plans to graduate in fall 2011, and says he hopes to pursue an industry career in the aquatic plant management field. He holds a Bachelor of Science in Soil and Crop Sciences and a Master of Science in Bioagricultural Sciences and Pest Management, both from CSU.