Colorado Water

Colorado State University

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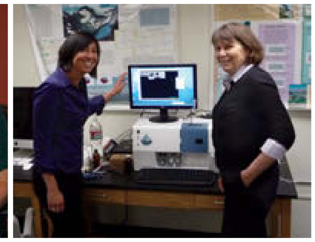
Theme: Student Research





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Highlights

In Every Issue

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Front Cover: Top photos: The 2012 student researchers with their advisors. Photos courtesy of Victor Sam, Umit Duru, Anne Maurer, Meagan Smith, and Alia Khan. Bottom photo: Student researcher Evan Rambikur works to align an LAS receiver at the dry grassland site. Photo by José Chávez

This Page: Dillon Reservoir, Dillon, Colorado. Photo by Michael Kaufmann

Editorial

by Reagan Waskom, Director, Colorado Water Institute

The water community in Colorado is marking several significant anniversaries in 2012: the 75th anniversary of the formation of the Colorado Water Conservation Board (CWCB), the Colorado-Big Thompson Project, and the Colorado River Water Conservancy District, as well as the 50th anniversary of the Frying Pan-Arkansas Project. Information about these and other Water 2012 celebrations can be found at www.water2012.org.

The Land Grant University system is also celebrating this year—July 2, 2012 marks the 150th anniversary of President Abraham Lincoln's signing of the Morrill Act, creating the land grant universities. Looking back from the vantage point of our current political climate, this was a remarkable accomplishment, coming in the midst of the bloodiest year of the Civil War and just as Union Commanding General George McClellan was in full retreat toward Washington. It was not a given that the Union would survive the war between the States on that day in July of 1862, yet Lincoln had the vision and foresight to sign a bill that created a public university in each state committed to assuring that common people with the talent and motivation to earn a university degree could have that opportunity. Up until that moment, higher education had been the privilege of the wealthy class. The Morrill Act created an educational system and philosophy that changed the world.

A primary focus of the Land Grant universities envisioned in 1862 was the development of the science of agriculture, to feed the growing nation. Subsequent legislation created the Agricultural Experiment Stations and the Cooperative Extension Service, leading to the development of the four-part mission of the modern Land Grant University—teaching, research, outreach and service. From the moment that Colorado Agricultural College (now CSU) welcomed its first five students in 1879, the issues of Colorado agriculture and water were paramount. Mathematics professor Elwood Mead initiated the irrigation engineering curriculum shortly after he arrived in 1883, one of the first in the nation. In 1888, the State Board of Agriculture established irrigation engineering as one of only four distinct courses of study that could be pursued by undergraduates during their junior and senior years. That same year, the Colorado Agricultural Experiment Station (AES) was established by the Colorado Legislature, and the inaugural issue of the Bulletin series of Colorado AES publications was titled, "Report on Experiments in Irrigation and Meteorology." Physics

Professor Charles Lory began his career as a ditchrider on irrigation systems in Weld County and eventually became President of Colorado Agricultural College in 1909. President Lory initiated Cooperative Extension in 1914, and the first County Agents were in Logan and El Paso County dispensing knowledge on irrigation management.

While water related research and outreach has been critically important as Colorado's land and water resources were developed, the central role of Colorado State University remains training students to become educated and productive members of society. The exact number is unknown, but CSU has trained thousands of water managers, irrigators, and water scientists over the past century.

The Colorado Water Institute (CWI) was established at CSU in 1965 to support university faculty in their preparation and training of students. CWI's legislative mandate includes working with water faculty from all public institutions of higher education in Colorado on applied research projects focused on Colorado-specific problems. This issue of the *Colorado Water* newsletter spotlights student research projects supported in part by CWI. Students receive training from their faculty advisors while working on practical problems, often in close connection with professional water managers. A broad spectrum of student interest in water, from water quality and treatment to agriculture and water supply, is contained in short newsletter articles. The time and mentoring provided by faculty advisors are ultimately what make these projects successful and help launch students in their careers as the next generation of water professionals.

Quantifying Relationship Between Irrigation Activities and Wetlands in a Northern Colorado Watershed and Assessing Added Value of Irrigation Waters

Meagan Smith, MS Candidate, Civil Engineering, Colorado State University
Faculty Advisor: Mazdak Arabi, Co-Author: 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.

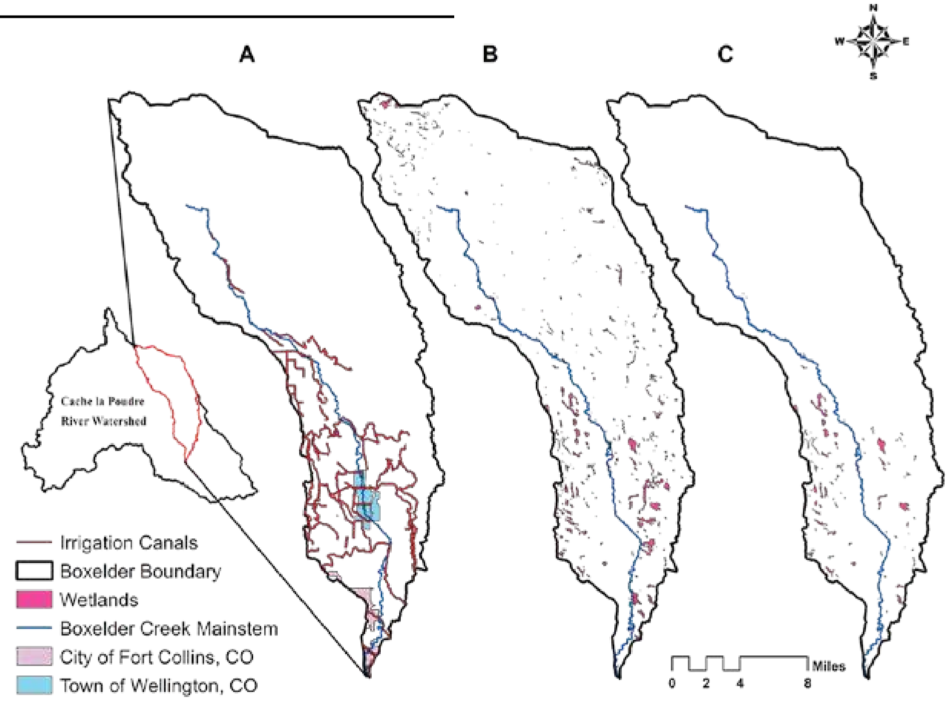


Figure 2. *Boxelder Creek watershed showing A) creek main stem, irrigation canals, Wellington and Fort Collins, B) creek main stem and all identified wetlands, excluding managed reservoirs, C) creek main stem and subset of irrigation dependent wetlands.*

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,

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

[a]Additional controls included Ksat and CN
*, **, *** indicates $p < 0.1$, $p < 0.05$, $p < 0.001$, respectively
ns - Not significant, $p > 0.1$

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 ($70 \leq CN \leq 83$).*

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 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 direct and indirect financial impacts associated with the resulting change in agricultural production. Realizing that removing water from agriculture could have considerable effects on

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.

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.
Courtesy of Meagan Smith

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, Geosciences, Colorado State University
Faculty Advisor: Ellen Wohl

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.

Sediment accumulation also occurs throughout 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 2002 Hayman Fire and, to a lesser extent, the 1996 Buffalo Creek 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. 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:

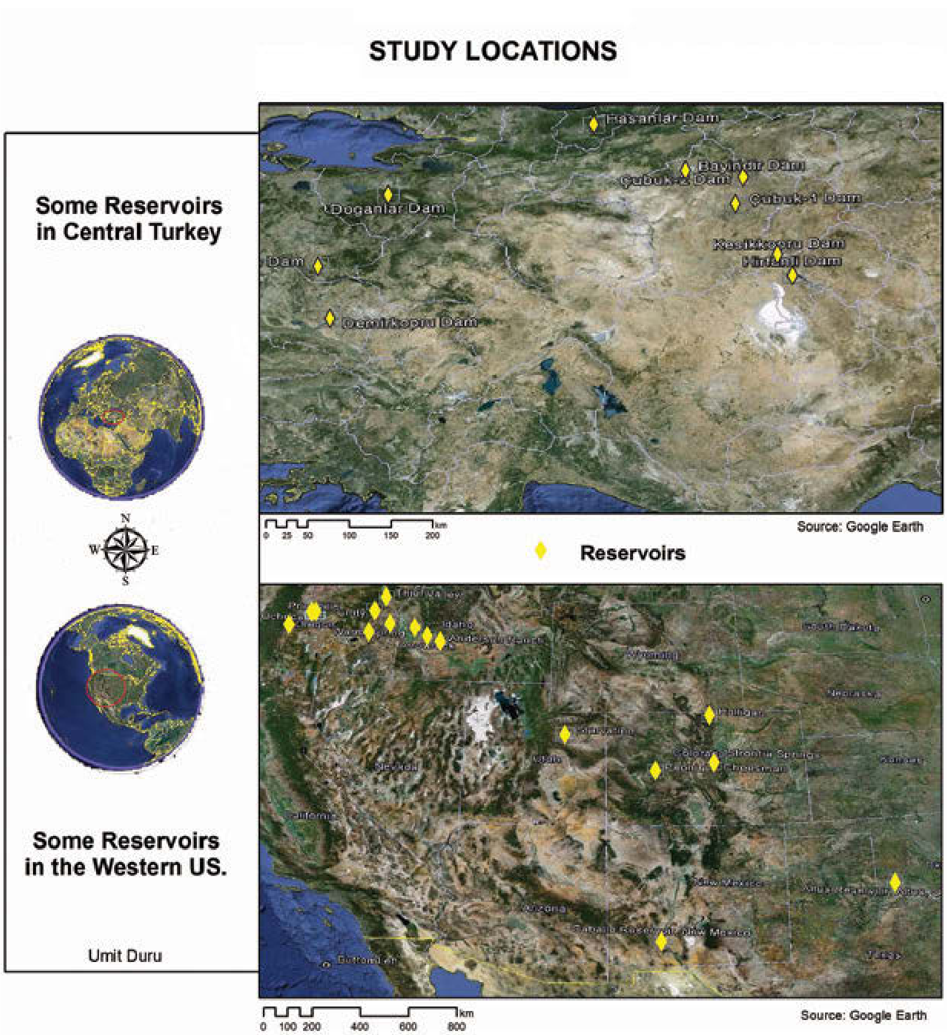
1. Sediment yield correlates most strongly with disturbance history, and to a lesser extent with lithology, topography, land cover, drainage density, and land use.

2. 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.

3. 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.

4. 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 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.

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

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.

The Efficacy of Use of *Moringa Oleifera* Seeds and Powdered Activated Carbon to Remove Cyanobacterial Metabolites from Drinking Water

Victor Sam, MS Candidate, Civil & Environmental Engineering, Colorado State University
Faculty Advisor: Pinar Omur-Ozbek

Our Ancient Little Blue-Green Friend

Cyanobacteria, also known as blue-green algae, are photosynthetic bacteria found across the world from the lush bayous of Louisiana to the barren areas of Antarctica. They may appear as scum layers or cause a pea soup appearance in lakes, ponds and other slow moving water bodies. Cyanobacteria are among the most important bacteria known, as they created the Earth's oxygen rich environment over 2.5 billion years ago. Cyanobacteria are also an essential part of the aquatic food chain as a food source for phytoplankton, and can fix nitrogen from air into a form that can be used by plants.

When periods of mass cyanobacterial growth occur, they are often referred to as blooms. The occurrence of cyanobacteria blooms in surface waters has become more frequent throughout the world due to warmer climates and an abundance of nutrients such as nitrogen and phosphorous. While cyanobacteria may be very beneficial to the environment, they can also be harmful. Blooms can abruptly interfere with an ecosystem's balance by reducing light penetration, out-competing other native organisms, and causing dissolved oxygen depletions when they die off. In addition, throughout their life cycle, cyanobacteria can produce and release various metabolites, which can deteriorate water quality.

Some metabolites only impact aesthetic quality of drinking water. Earthy odors may be caused by geosmin, which has an odor detection concentration of 2-10 ng/L by the human nose. The presence of geosmin in drinking water may reduce consumer confidence in the water utility efficiency even though it is not harmful. Other cyanobacterial metabolites have been determined to have adverse health effects. Cyanotoxin poisonings, due to accidental ingestion of contaminated water by humans or animals, have been reported in 50 countries around the world and in 35 U.S. States during 2011. The most common cyanotoxin is microcystin-LR, which can cause anything from mild skin irritations to death from liver failure. Although human deaths have been extremely rare, there are emerging concerns regarding the cyanotoxins as they are detected more often today due to more frequent algal blooms. Due to the adverse health effects of toxin exposure, the World Health Organization has set a drinking water guideline limit of one ug/L for microcystin-LR.

Recent studies showed that cyanotoxins and odorants co-exist together. In many cases, these detrimental metabolites reach their highest concentration in water when the cyanobacteria die off and decompose. Conventional water treatment processes cannot remove these potentially harmful metabolites from drinking water. Costly and energy intensive processes such as membrane filtration or advanced oxidation may be employed; however, it should be noted that these treatment technologies might not be readily available or financially possible for many communities around the world, as they require extensive upgrades to existing treatment facilities. It is essential to investigate other cost effective and available methods.

Research Goals

Cyanobacterial metabolites can pose problems that can affect water use and human health across the world. With climate change and poor nutrient discharge management, bloom events have become more widespread across the world. This study investigated the removal of the two cyanobacterial metabolites, odorous geosmin and toxic microcystin-LR, from source waters to below detection/regulation limits while considering practicality, sustainability and cost effectiveness. The effectiveness of the Moringa oleifera tree seed extract (MOTSE) and powdered activated carbon (PAC) were investigated as a treatment to remove the detrimental cyanobacterial metabolites in this study. Environmental samples were also collected across Northern Colorado to better understand the occurrence of geosmin and cyanotoxins.

Experimental Procedure

Jar testing was used to determine the removal of cyanobacterial metabolites from source waters using MOTSE and PAC. The active component from the Moringa Oleifera seed was extracted following a recently developed standard method. This extract induces coagulation to purify polluted water. Coagulation occurs when pollutants such as dirt particles are attracted to the coagulant (e.g. MOTSE) to form larger and denser flocs (masses formed in a fluid

Extraction procedure of active component of the moringa oleferia tree seed. Steps involved deshelling, pulverization, salting and purification. Extraction and experimental procedures performed at the Department of Civil & Environmental Engineering Water Quality Lab at Colorado State University.

Courtesy of Victor Sam

through precipitation or aggregation of suspended particles). The pollutants then settle or can be filtered out. Coagulation using chemicals or polymers is common practice in conventional water treatment plants.

Many utilities already use PAC to remove taste-and-odor compounds from source waters, but specific dosages of PAC for effective treatment depend on the water quality and concentration of the cyanobacterial metabolites. The lignite powdered activated carbon, Hydrodarco® B from Norit Americas Inc. is a specialized product that is designed for the removal of organics that cause taste-and-odor problems. This product is expected to be able to remove microcystin-LR as well. So far, there are not any studies conducted on concurrent removal odorants and toxins.

Raw Horsetooth Reservoir water obtained from Fort Collins Water Treatment Facility was used for the experiments. One-liter glass beakers were filled with the source water and were spiked with geosmin and microcystin-LR to achieve levels that correspond to common bloom events. Geosmin concentrations ranged from 10 to 50 ng/L and microcystin-LR concentrations ranged from 2 to 10 ug/L. The MOTSE or PAC were added to the jars at 5-30 mg/L that represent dosages used by water treatment plants. The jars ran under a gang stirrer for 30 minutes to uniformly mix and keep the solutions suspended at a rate of 50 rpm and 30 additional minutes was allowed for settling. The experimental water was then filtered through a 0.45 µm glass filter to remove the coagulant or PAC. All jar tests were done in triplicates for every selected metabolite/treatment concentration with extra jars used as controls which did not receive MOTSE or PAC. Raw Horsetooth Reservoir water was also tested for concentrations of geosmin and microcystin-LR. Geosmin remaining in the samples was determined by solid-phase microextraction (SPME) followed by gas chromatography coupled with mass spectrometry (GC/MS). Microcystin-LR was measured through multiple reaction ion monitoring through a liquid chromatography coupled with mass spectrometry (LC/MS/MS) equipped with an electrospray ionization source.

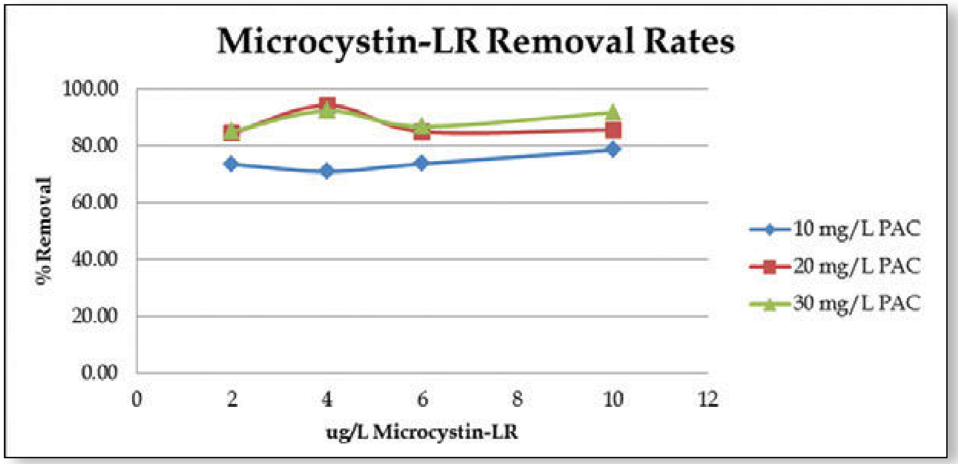
Grab water samples were collected between May and October of 2011 from the surface waters in Northern Colorado as shown on the map. The sampling period was chosen for the best detection of peak cyanobacteria growth and activity. A microcystin-LR screen was run for the samples using an enzyme linked immunosorbent assay (ELISA) specialized to detect microcystins. The presence of microcystin-LR in the positive samples were confirmed by LC/MS/MS. Environmental samples were screened for geosmin as well.

Results

The removal of cyanobacteria metabolites, microcystin-LR and geosmin, using the MOTSE was proven to be inefficient at all doses used (5-30 mg/L). Only up to nine percent of microcystin-LR removal and geosmin removal was observed. When put in tandem with PAC, the MOTSE

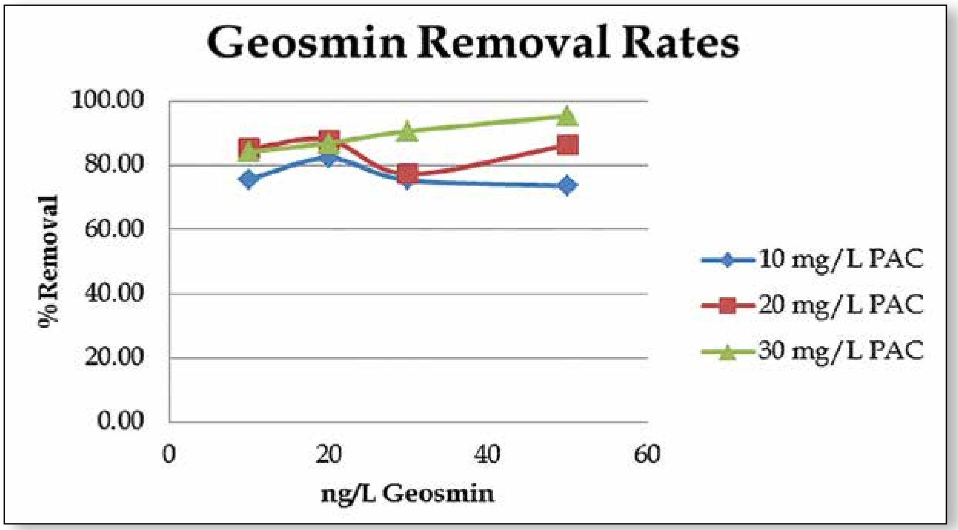
Victor Sam sets up the HPLC (High Performance Liquid Chromatography) for microcystin-LR analysis. GC & LC/MS/MS analysis was done at the Center for Environmental Medicine Analytical Lab at Colorado State University.

Courtesy of Victor Sam



Microcystin-LR removal rates when treated with PAC.

Courtesy of Victor Sam



Geosmin removal rates when treated with PAC.

Courtesy of Victor Sam

		PAC Dosage		
		10 mg/ L	20 mg/ L	30 mg/ L
Microcystin LR (below 1 ug/L)	2 ug / L	✔	✔	✔
	4 ug / L	⊘	✔	✔
	6 ug / L	⊘	⊘	✔
	10 ug / L	⊘	⊘	⊘
Geosmin (below 7 ng/L)	10 ug / L	✔	✔	✔
	20 ug / L	✔	✔	✔
	30 ug / L	⊘	✔	✔
	50 ug / L	⊘	✔	✔
Key	⊘	Not below threshold		
	✔	Below threshold		

Recommended dosages of PAC to treat for microcystin-LR and geosmin.

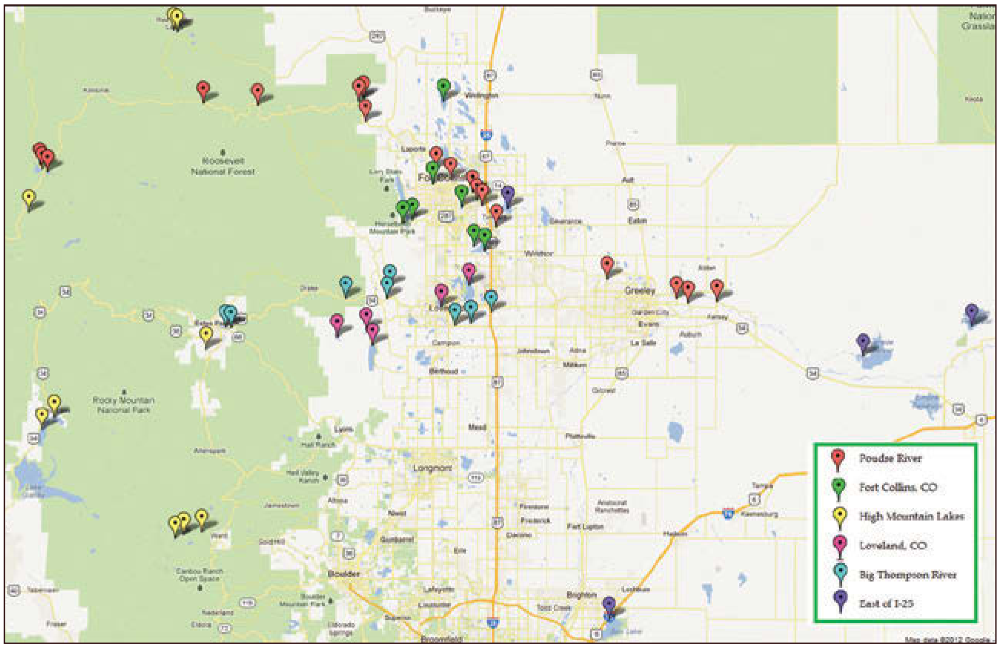
Courtesy of Victor Sam

hindered the removal efficiency of both geosmin and microcystin-LR by 38 percent and seven percent, respectively. On the other hand, the Hydrodarco® B PAC from Norit, removed both microcystin-LR and geosmin effectively when used alone. Up to 94 percent of microcystin-LR was removed with 20 mg/L of PAC, and 95 percent of geosmin was removed with 30 mg/L of PAC. Even the lowest dosage of PAC at 10 mg/L resulted in removal rates around 75-80 percent for both metabolites. It was also observed that removal rates of lower concentrations of the metabolites were negatively affected by lower concentrations of the co-present metabolite. For example, lower levels of microcystin-LR reduced the removal efficiency of low levels of geosmin. It is suspected that competition among the various macro and meso pores of PAC played a factor in this.

The grab samples collected from 52 sites that include Poudre and Big Thompson Rivers, the city of Fort Collins and Loveland reservoirs, high mountain lakes, and areas east of interstate 25 were screened for geosmin and microcystin-LR. Only one site, Barr Lake, was confirmed to have detectable levels of microcystin-LR that ranged from 0.83 to 1.43 ug/L throughout the sampling period. A total of 23 sites had detectable levels of geosmin that ranged from 0.7 ng/L to 20 ng/L. Areas with the highest concentrations of geosmin were found among the slow moving areas in the Poudre River and Fossil Creek. Almost all peak levels of both geosmin and microcystin-LR occurred in the month of June.

Conclusions

The environmental sampling showed that some Colorado waters can have detectable levels of both geosmin and microcystin-LR. It is likely



The 52 sampling sites in Northern Colorado screened for geosmin and microcystin-LR.

Courtesy of Victor Sam

a water treatment plant that uses surface water as a source will have to deal with the treatment of the cyanobacterial metabolites at some point during their operational period.

Through this study, it was found that the removal of both metabolites below the human detection/regulation limit of about seven ng/L for geosmin and one ug/L of microcystin-LR, was possible by using the Hydrodarco® B PAC. A dosage of 30 mg/L of PAC can remove up to 6 ug/L of microcystin-LR below the WHO guideline. A PAC dosage of 20 mg/L can remove up to 50 ng/L of geosmin below the human detection limit given the one hour mixing and settling time observed in the experiments.

Acknowledgements

Funding for this research was provided by the Colorado Water Institute and the Department of Civil and Environmental Engineering of Colorado State University. Technical support was provided by Greg Dooley from the Center for Environmental Analytical Laboratory at Colorado State University.

Large Aperture Scintillometers for Evapotranspiration Evaluation

Evan Rambikur, MS Candidate, Civil and Environmental Engineering, Colorado State University
Faculty Advisor: José L. Chávez

Introduction

How do we effectively manage application of irrigation water for crop production in arid and semi-arid environments? One of the primary inputs necessary for knowing appropriate timing and amounts of irrigation is actual evapotranspiration (ET). For practical applications, ET can be estimated using a reference ET value (e.g., alfalfa, ET_r) and a crop coefficient (K_c).The value of ET_r is computed using weather data from a local standard weather station, and K_c values for different crop types are published in the literature. On a research basis, different methods for estimation/measurement of actual ET have emerged including scintillometry, which uses electromagnetic radiation transmission to capture information on the turbulence in the atmospheric boundary (near-surface) layer. For the specific case of the large aperture scintillometer (LAS), estimates for the surface sensible heat flux can be obtained for representative path lengths up to 4.5 km (2.8 mi.). Sensible heat flux (energy) occurs as a result of air temperature gradients between the land surface and some height within the boundary layer (e.g., two m). Since ET is also a process that uses available energy at the land/crop canopy surface, researchers can take advantage of a land surface energy balance in conjunction with LAS measurements to indirectly estimate (vegetative) ET rates. Thus, ET estimates using an LAS are obtained from LAS sensible heat flux (H) and ancillary measurement of net radiation (R_n) and soil heat flux (G).

In this study, LAS technology was tested at two different locations in the Arkansas Valley, Colorado. Three LAS systems (LAS model, Kipp and Zonen B.V., Delft, The Netherlands) were deployed during the 2011 study period. An LAS system operates by emitting a near-infrared light beam from a transmitter to a receiver, which is set up at least 250 m (820 ft) away. The transmitter and receiver have the same aperture diameter and must be aligned with each other. For the optimum (performance evaluation) case study, the LAS should be set up over a horizontally uniform terrain at least 1.5 m (five ft) from the ground or crop canopy surface. It is worth noting that the Kipp and Zonen LAS has been criticized in the literature for having issues with inter-sensor variability and inherent (design) biases. This study tested the performance of the Kipp and Zonen LAS for predominantly dry and irrigated surfaces in order to more comprehensively evaluate the LAS method of ET estimation. The evaluation of the LAS results was performed using concurrent heat flux measurements made with an Eddy Covariance system at both the dry and irrigated sites. The Eddy Covariance (EC) instrumentation consisted of a 3D sonic anemometer (CSAT3, CSI, Logan, UT) and a krypton hygrometer (KH20, CSI, Logan, UT). The 3D sonic anemometer provides information on wind speed in three orthogonal directions (i.e., x, y, and z), as well as sonic (air) temperature, and vapor pressure is measured by the hygrometer. The EC system yields direct estimates of sensible heat and ET fluxes.

Field Campaign

During the 2011 summer, a short-term experiment was conducted with three LAS units operating over a uniform, dry grassland area in order to assess the LAS inter-sensor consistency. Following this experiment, two of the LAS units were removed with one of them (LAS 2) being re-located to the Colorado State University (CSU) Arkansas Valley Research Center (AVRC), while one unit (LAS 1) remained at the grassland site (LAS 3 was moved to another location near Iliff, CO). The EC instrumentation was also set up at the grassland site for some time, overlapping the period of the LAS inter-comparison study. Eventually, the EC instrumentation was moved to the AVRC, providing a reference for LAS 2. At both sites, sensors were installed to measure air temperature, relative humidity, and horizontal wind speed. These sensors were necessary for processing the LAS data. At the dry grassland site, soil water content sensors were installed at two locations in the near surface soil along with soil temperature sensors and soil heat flux plates, in order to capture the heat flux into the soil (G).

Image 3. *LAS 1 receiver at the dry grassland site, along with net radiometer (left) and ancillary sensors and data collection equipment.*
Photo by Evan Rambikur

(Left to right) Abhinaya Subedi, Stuart Joy, and Mcebisi Mkhwanazi measure the height of a LAS transmitter tripod at the dry grassland site.

Photo by Evan Rambikur

Net radiation (R_n) sensors were also installed at the same two locations on site. At the AVRC, LAS 2 was installed with a path length spanning two irrigated alfalfa fields. There were four available stations for measurements of R_n and G at the AVRC. In addition, eight soil water content sensors (ACC, TDT, Acclima, Inc., Meridian, ID) were installed at four depths and two locations during the study period. These were installed to estimate ET from two neighboring corn fields south of the LAS path. Unfortunately, the data from these sensors were unreliable, and therefore no further analysis with these data was made. The alfalfa in both fields was harvested about three weeks following the LAS installation, and reached a height of approximately 40 cm (16 in) near the end of the study period. Due to the nature of the surface (furrow) irrigation timing for both alfalfa fields, the alfalfa growth conditions were generally not homogeneous.

Results

Data were collected periodically from both sites and processed using standard algorithms in order to obtain time series flux estimates. The data were processed to produce 30 minute averages of sensible heat (H) and evaporative heat (ET) flux. For the LAS inter-comparison, the H fluxes were compared and for the LAS to EC comparison, both H and ET fluxes were compared.

LAS Inter-comparison

In regard to LAS consistency, based on the results observed at the grassland site, it is considered that the deviation in H between LAS units is dependent on inherent bias and conditional bias. For part of the study when the LAS units were well aligned, the mean bias deviation, normalized by the mean absolute value of the LAS H reference (MBE/|Ō|), ranged between six and 11 percent. This relative deviation corresponds to the assumed inherent bias. After a slip in alignment, the scatter and deviation in H increased between the LAS units. The estimated misalignment-induced error increased the mean bias to a maximum observed value of 24 percent (MBE/|Ō|). Note that LAS 2 almost completely lost alignment for approximately half of the study. This misalignment is assumed to have occurred due to strong, stormy winds, which caused a physical shift in the alignment of the transmitter and/or receiver.

LAS to EC Comparison

At the dry grassland site, the sensible heat flux (H) obtained with the LAS correlated fairly well with the corresponding H obtained with the EC system. It was observed that the H from each LAS was approximately equal to or larger than the H from the EC. The coefficient of determination (r^2; for the linear regression of LAS to EC H) was better than 0.9 for all LAS units. Further, the ET derived from the LAS was consistently larger than the ET from the EC for the study period at the dry grassland site. At the AVRC site, H from the LAS was generally larger than H from the EC. However, the correlation between LAS and EC H values was not as consistent as was observed for the dry grassland site. Furthermore, at the AVRC, the magnitude of the ET derived from the LAS was generally similar to that of the EC system, albeit with some observed scatter. For the AVRC site, the heterogeneous surface conditions (crop type, growth, surface wetness) must be considered for appropriate understanding of the heat flux results. It was observed that H from the LAS and H from the EC correlated better when the wind direction was from the east/southeast direction (during the daytime). This result suggests that the heat flux source areas contributing to the LAS and EC fluxes were similar for this wind direction. During these periods of better H correlation, the ET derived from the LAS was generally greater than or equal to the ET from the EC.

Discussion

Comments on the LAS performance are based on the assumption of validity of the EC-measured H and ET. Based on the results observed in this study, it can be concluded that, in general, the LAS-predicted sensible heat fluxes correlated well with EC-predicted H. However, the correlation was impacted by apparent LAS receiver and transmitter inherent bias and misalignment issues. The assumed inherent bias issues may have actually been a result of setup issues which were manifested in a different power requirement for each LAS, and would thus be a correctable (and not inherent) bias. Further, the conclusion of good LAS H performance relies on the assumption (above) that the disagreement between LAS- and EC-derived H at the AVRC site can be explained by differences in the heat flux source areas. Despite the fair agreement of H fluxes between the LAS and EC, the poor correlation between LAS- and EC-derived ET is discouraging, which was especially apparent for the dry grassland site results. Nonetheless, this result reflects on the accuracy/spatial representativeness of the R_n and G measurements and the validity of the land surface energy balance model rather than on the ability of the LAS to predict H. Therefore, it is tentatively concluded that the LAS can predict H with reasonable accuracy in both dry and irrigated environments, but that caution must be taken in further predicting ET as a residual of the energy balance. This subsequently limits the validity of the LAS energy balance method for estimation of crop ET for irrigation management or validation of other ET estimation methods.

Advisor José Chávez and Investigator Evan Rambikur.
Photo by Abhinaya Subedi

Acknowledgements

The investigator and advisor would like to acknowledge and thank the Colorado Water Institute (CWI) for sponsoring this study. We are grateful to the CWI for supporting graduate research. We also are thankful to the Colorado State University Colorado Agricultural Experiment Station for their support. In addition, we want to extend our appreciation to the following individuals, who in one way or another participated in the study: Allan Andales, Michael Bartolo, Lane Simmons, Gale Allen, Darell Fontane, and Stuart Joy.

LAS 2 receiver at the AVRC site with data logger enclosure and laptop in the foreground. Alfalfa field was being cut (harvested).
Photo by Evan Rambikur

Novel Technique for Evaluation of Relationships Between Phytoplankton and Dissolved Organic Material

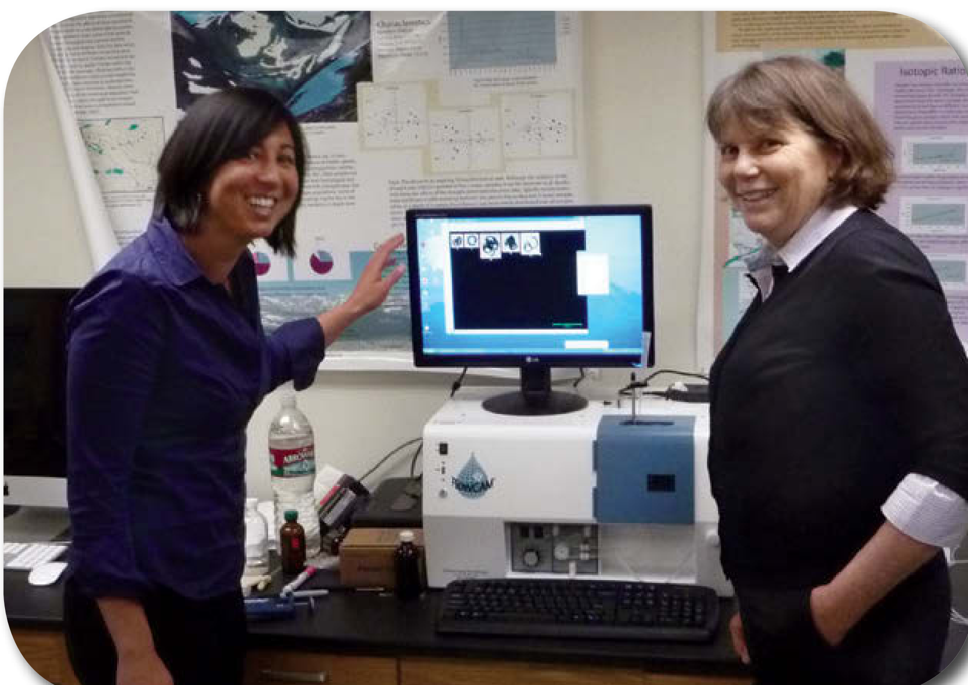
Alia Khan, MS Candidate, Civil and Environmental Engineering, University of Colorado-Boulder
Faculty Advisor: Diane McKnight

Maintaining adequate supplies of clean drinking water is vital to human health. Technological advancements in water treatment allow the removal and treatment of some pollutants and pathogenic bacteria. However, disinfectants such as chlorine can react with natural organic matter (NOM), which is measured as dissolved organic carbon (DOC) concentration, in source waters to create disinfection byproducts (DBPs), some of which are known carcinogens. In recent years, documented rises in DOC concentrations have occurred across the northeastern United States as a response to the amelioration of acid rain. In Colorado, changes in DOC concentrations in the future may be driven by increasing growth of algae, a large source of DOC, due to a longer period of ice-free conditions on lakes and reservoirs under a changing climate and increasing nutrient inputs from atmospheric deposition and other anthropogenic sources.

These changes may present challenges to ensure safe drinking water as a result of increased DOC in Colorado. Removal of the DBPs post treatment is possible, but is often difficult and costly for drinking water utilities. Furthermore, because the formation of chlorinated disinfection by-products have been directly correlated with DOC levels, prevention of elevated DOC levels pre-treatment could be more efficient for drinking water utilities.

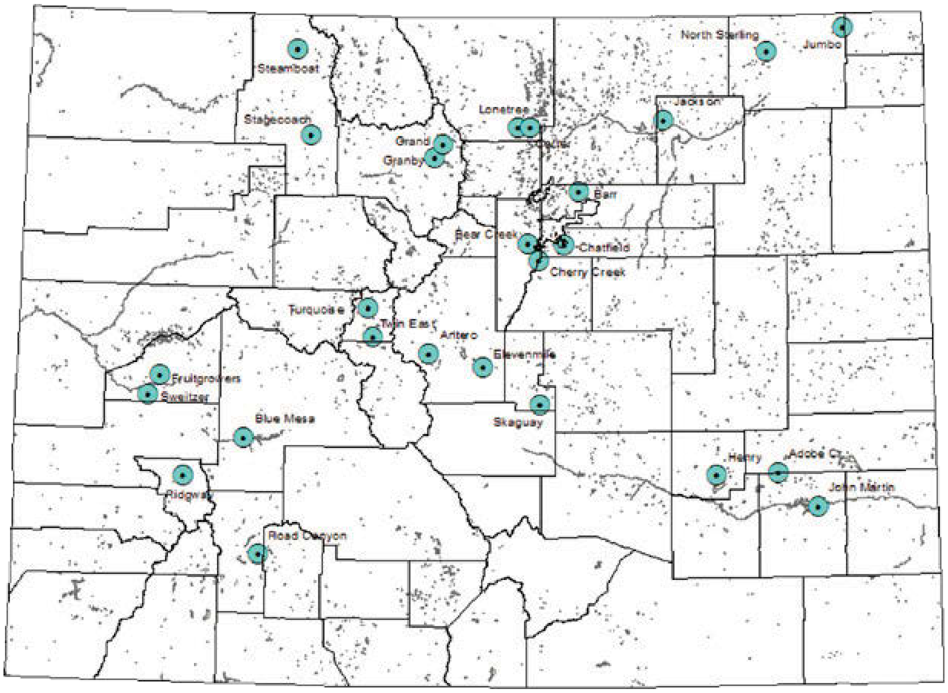
In the summer of 2010, the Colorado Department of Public Health and Environment (CDPHE) conducted a High Quality Water Supply study to assess the impact of algal growth in Colorado lakes and reservoirs on DOC concentrations and the potential to form DBPs. Twenty-eight lakes were sampled during July and August, at the peak of summer stratification, and 10 other drinking water reservoirs were sampled biweekly from May through September 2010. Chlorophyll-a, an indicator of algal biomass, was used to assess the relationship between algal concentrations and DOC concentrations. During the field sampling, additional surface samples were taken and preserved with Lugol's, an iodine based solution, for phytoplankton identification and enumeration with a Fluid Imaging Technologies FlowCAM®. Funding from the Colorado Water Research Institute supported the development of a protocol to analyze the phytoplankton samples.

Identification of phytoplankton species and relative abundances can help understand the drivers of the phytoplankton dynamics and chlorophyll levels aiding in further comprehension for protecting source water quality in lakes and reservoirs. Unlike traditional microscopy, the FlowCAM® enables rapid monitoring of particles in fluid by combining flow cytometry with microscopy. Flow cytometry is the process of quantifying and phenotypically identifying cells suspended in a fluid by passing them through a laser beam and capturing the amount of



Adviser Diane McKnight and student Alia Khan, discuss how different phytoplankton species found in the samples may impact the DOM quality of the respective lake sample. The species in this picture is annabeana, a filamentous cyanobacteria found in high abundance in some of the samples.

Courtesy of Alia Khan



Geographic distribution of Colorado lakes and reservoirs sampled for the study.

light scattered by every particle. The FlowCAM® automatically counts and images each particle, while also evaluating characteristics of the digital image, such as shape and intensity. Such imaging microscopes are becoming used more frequently by water treatment plants in order to monitor algal activity in source water lakes and reservoirs, such as in the case of invasive species.

A newly developed protocol was needed to take advantage of the capability of this instrument's potential for new and novel applications to ongoing research on the ecology of alpine and sub-alpine lakes and reservoirs. A method has been identified to routinely analyze the samples from the High Quality Water Study, which may be representative of the range of phytoplankton communities occurring in Colorado. First, 150mL of the 500mL grab sample was transferred to a settling tube for 24 hours. Next, 130 mL of the sample was aspirated from the top of the sample in order to not disturb the settled particles. The sample was then transferred to a 50ml centrifuge tube. If the sample looked visibly cloudy, it was filtered with a 100um mesh net to avoid clogging in the flow cell. The 10X objective was used with a 100um flowcell. Acetone was run for five minutes to clean the flowcell and tubing. The FlowCAM® was then focused using a small volume of spare sample. A 2mL of sub-sample was then run through the FlowCAM®. After the sample finished running, image library files were made through the interactive data platform, and sorted based on image characteristics associated with each of the dominant algal species. Total particles counts were also noted.

Results show that Cyanobacteria, diatoms, and green algae are the most abundant algal groups present. In the samples with the highest chlorophyll a concentrations the phytoplankton community was dominated by filamentous cyanobacteria.

The results from the analysis of the phytoplankton using the FlowCAM® are being analyzed to understand the statistical relationships between the phytoplankton species, chlorophyll-a, nutrient levels, physical characteristics of the lake, and DOC concentrations. These results will be the basis of a MS Thesis in the Environmental Studies Department at University of Colorado – Boulder.

Acknowledgements

Thanks to the Colorado Water Institute for funding to support the development of a protocol for the Fluid Images FlowCAM for phytoplankton analysis of Colorado lakes and reservoirs. We also appreciate access to phytoplankton samples collected for the High Quality Water Study from the Colorado Department Public Health and Environment to assess algal impacts on disinfection byproduct formation. Lastly thanks to collaborators Prof. Fernando Rosario, Prof. Scott Summers, and Amanda Hohner at the Department of Civil, Environmental and Architectural Engineering at the University of Colorado.

Cyanobacteria (left) and diatoms were two of the most common types of algae found in the study.

Combined Source Infrastructure Assessment Model

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

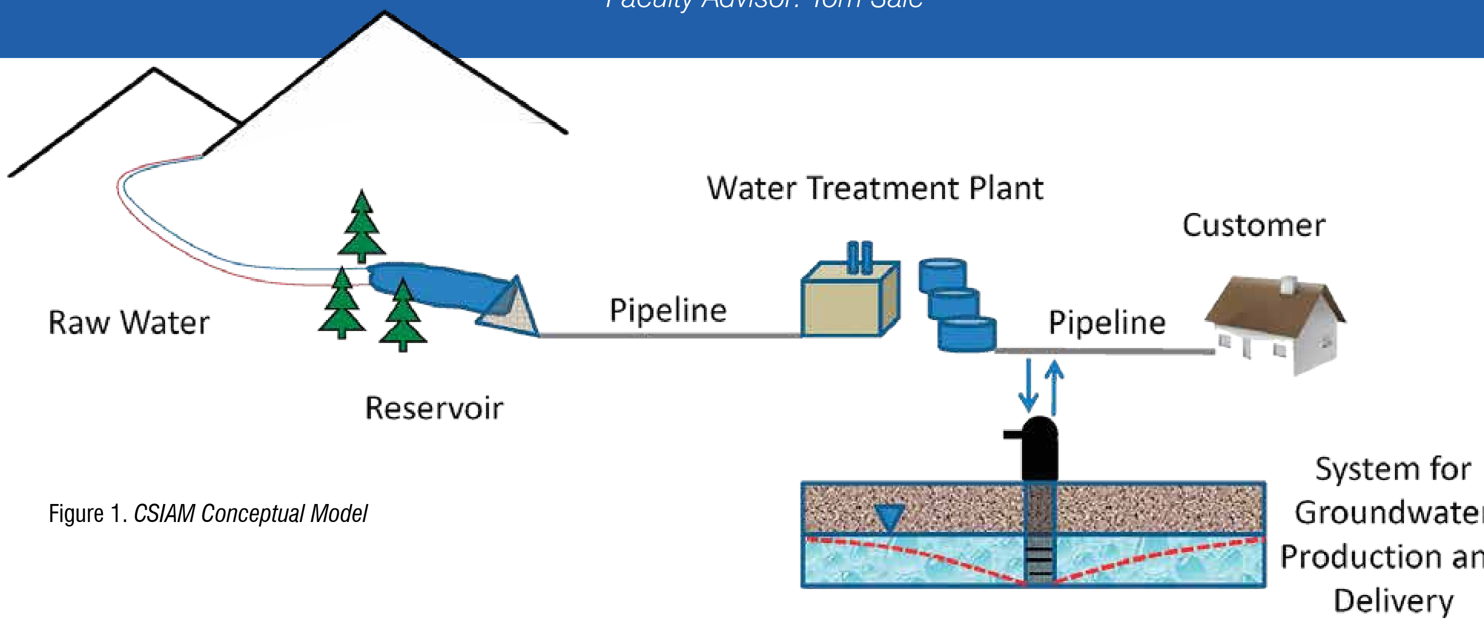


Figure 1. *CSIAM Conceptual Model*

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.
Courtesy of Anne Maurer

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.

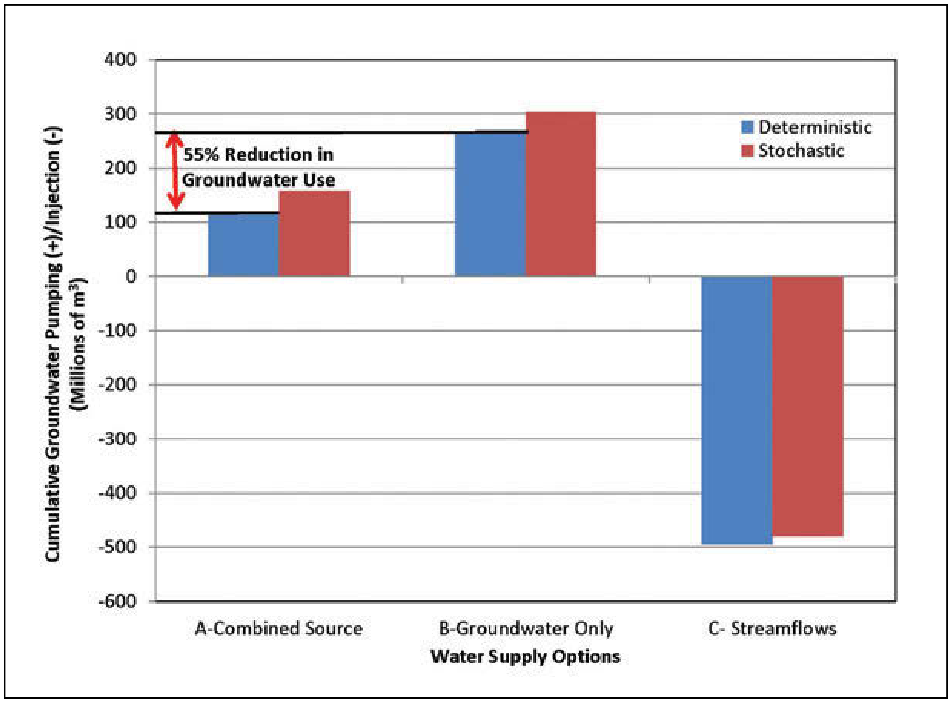


Figure 2. *Comparison of Cumulative Pumping (+)/Injection (-) Volumes for Each Scenario*

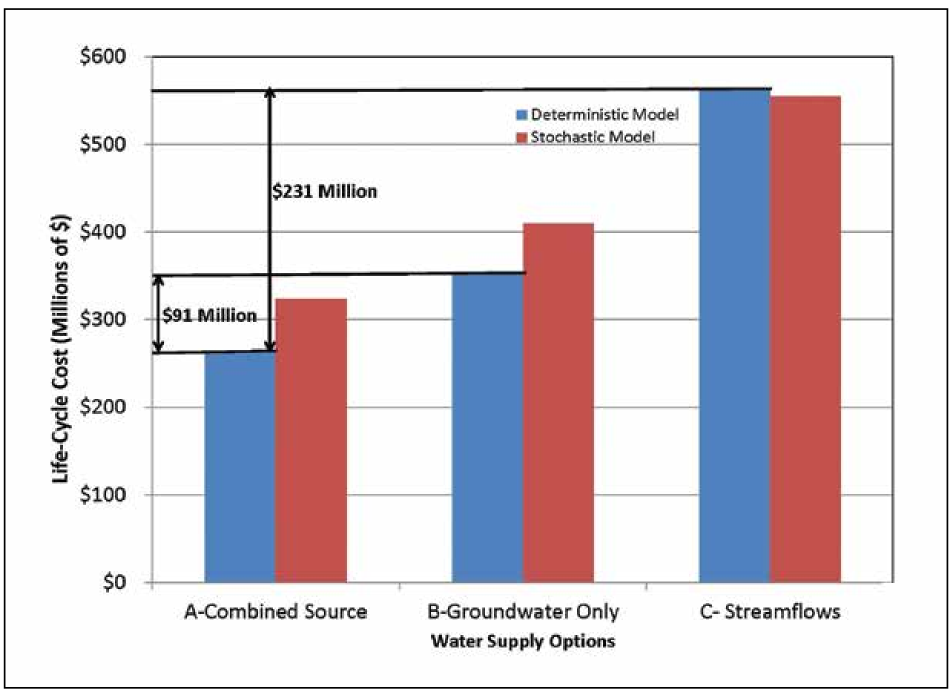


Figure 3. *Comparison of Life-Cycle Costs for Each Scenario*

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.

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.

Three future water use scenarios are considered, including:

- 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 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]

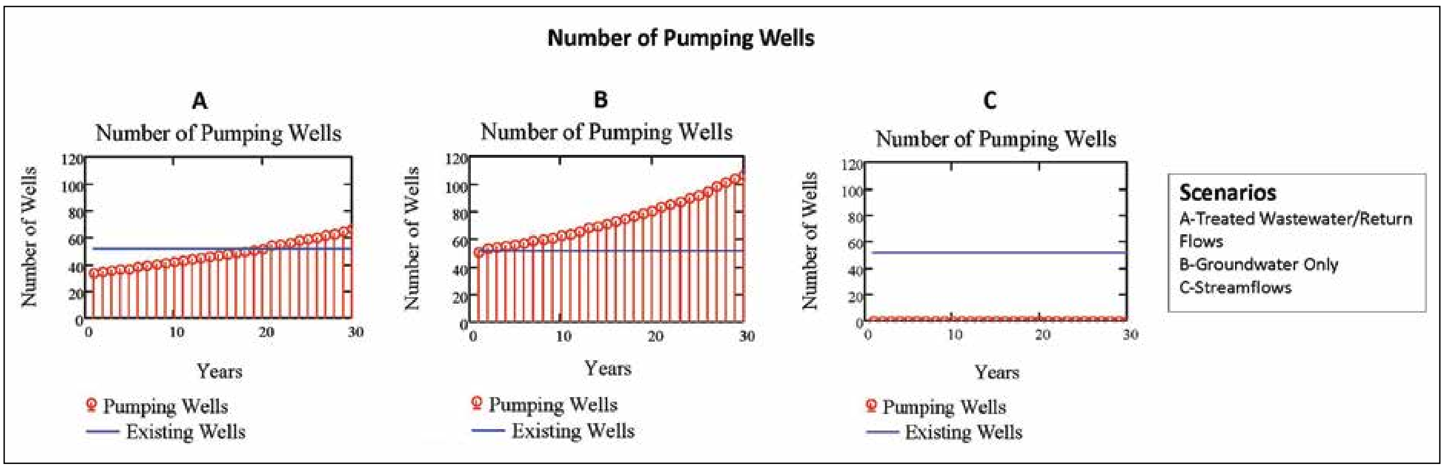


Figure 4. *Number of Pumping Wells for Each Scenario*

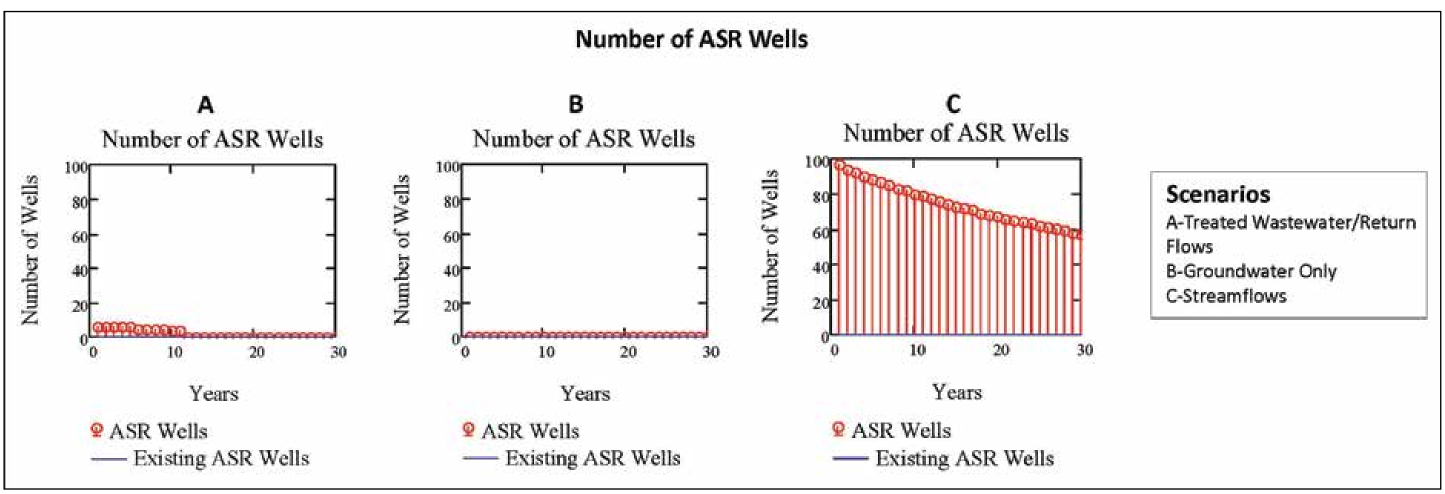


Figure 5. *Number of ASR Wells for Each Scenario*

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

Student Research Opportunities Abound in the Water Resources Archive

Patricia J. Rettig and Clarissa J. Trapp, Water Resources Archive, Colorado State University Libraries

A common challenge for graduate students in any discipline is the selection of their thesis or dissertation topic. The topic cannot be too broad or too narrow, needs to hold their interest for a few years, and must have adequate information resources available. And, ideally, it should be something that no one has done before.

A good solution for graduate students is to mine the unique materials found in archives. The vast majority of archival material, especially on the topic of water, has never been used for thesis or dissertation research, thus providing students excellent opportunities to use historical materials in diverse ways.

The Water Resources Archive at Colorado State University offers numerous opportunities for unique student research. The majority of the documents can be found nowhere else, making the Archive an excellent resource for original research.

Robert Glover, undated. Glover spent his career with the Bureau of Reclamation researching and developing improvements to dam design, and his extensive work on Hoover Dam led to the development of a refrigeration system to accelerate concrete cooling. His papers are a rich resource for original research.
From the Glover Papers, Water Resources Archive, CSU Libraries

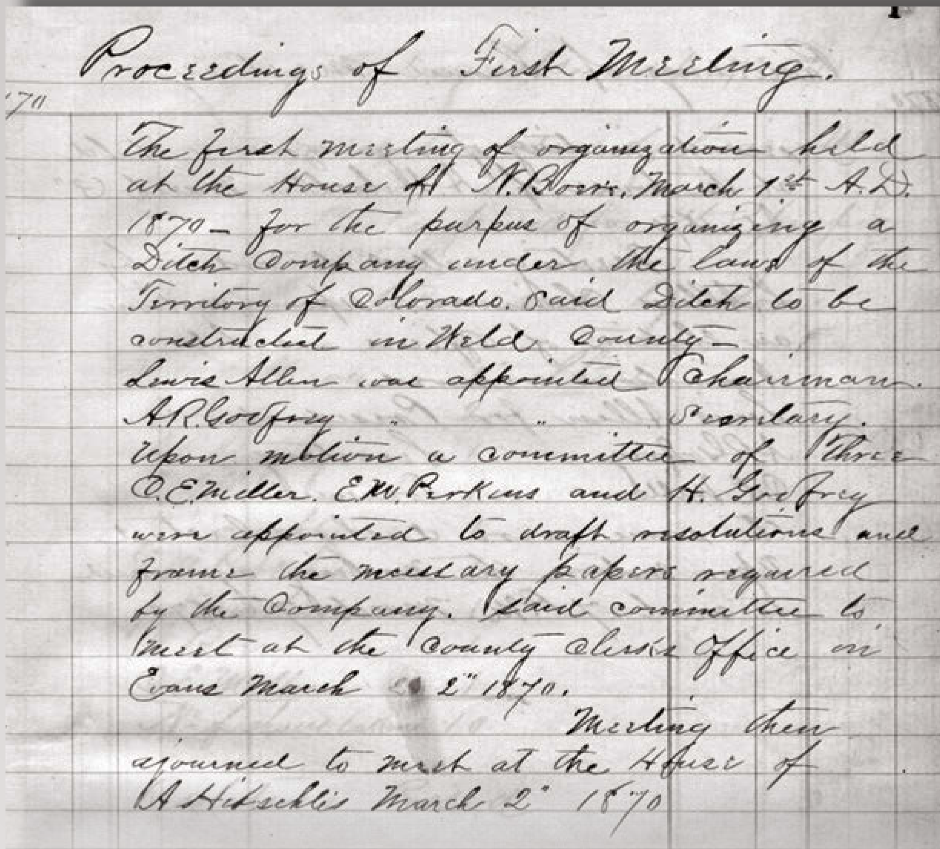
The potential topic areas for student research are wide and varied, applying to just about any water-related discipline, from engineering to political science, from sociology to landscape design. Many topics also prove to be multidisciplinary, such as the sociology behind water policy, the application of engineering knowledge to legal decisions, or the history of irrigated agriculture. Archival research can also give context for the history and development of current events and issues, which can provide a researcher with a more compelling case for their arguments. Below are just a few of the many topics that can be researched for theses and dissertations.

Irrigation organizations: Ditch companies and other irrigation-related organizations have been and continue to be an integral part of Colorado's development. Using several collections in the Archive, researchers could conduct a comparative study of ditch companies to bring forth details of how such companies were formed, differences based on location and personalities, and issues dealt with over the years. Minute books, annual reports, legal documents, and maps are some of the documents that would make this possible. Those interested in ag-urban water transfer might also mine more recent records and oral histories in the Archive's collections for information about how irrigation organizations negotiate such transfers.

Water conservation and state policy: The xeriscape movement—focused on creating water-efficient landscapes—had its origins in Denver, and those origins are well documented in the Records of Xeriscape Colorado. Researchers can examine the extent to which collaboration between scientists, politicians, and concerned citizens began to materially change urban landscapes and water consumption. Researchers might also study state-level attempts to deal with water conservation efforts through the newsletters of the Colorado Water Congress, an organization dedicated to influencing water policy in the state. Such a study could shed light on the ways in which competing interests worked together and against each other to influence Colorado's water conservation policy and implementation.

Science in the courtroom: As civil engineers develop their experience and expertise over the course of their careers, they become excellent sources of knowledge for lawyers who need consultants or expert witnesses to testify in a variety of lawsuits. Their scientific reports and professional testimony are meant to influence judges' decisions and can even alter future decisions about water use in Colorado. Studying materials from the papers of engineers such as Everett Richardson or Daryl Simons could illuminate a familiar but little-studied aspect of Colorado's water courts.

Biographies of water leaders: The Archive holds the personal and professional papers of several lawyers, politicians, activists, educators, and engineers whose work impacted water use and policy in Colorado and the U.S. more broadly. Most of these people are now rather vaguely associated with a mathematical formula or law with little attention paid to the political and social context in which they worked or their larger contributions to institutions or social movements. Robert Glover, an engineer for the U.S. Bureau of Reclamation from 1917 to 1954 who researched groundwater movement and dam design, is one such individual. Glover contributed to massive projects like Hoover Dam and at the same time was involved in multiple environmental organizations. His papers include sixty years of diaries, files on his research and professional career, papers related to organizations in which he took a personal interest, and images ranging from dams to wildlife. Examining the extent to which Glover's involvement in perhaps the most active time in Bureau history informed his views on the environment and conservation–and vice versa–would provide a valuable portrait of a twentieth century civil servant and the attitudes of the Bureau towards the natural environment he influenced and/or embodied.



Proceedings of First Meeting.

The first meeting of organization held at the House of N. Bovis, March 1st A.D. 1870 – for the purpose of organizing a Ditch Company under the laws of the Territory of Colorado. Said Ditch to be constructed in Weld County –
Louis Allen was appointed Chairman.
A.R. Godfrey " " Secretary.
Upon motion a committee of Three C.E. Miller. E.W. Perkins and H. Godfrey were appointed to draft resolutions and frame the necessary papers required by the Company. Said committee to meet at the County Clerks Office in Evans March 2d 1870.
Meeting then adjourned to meet at the House of A Hitschle's March 2d 1870

Section No. 3 Ditch Company, Secretary's book, 1870-1910. The Section No. 3 Ditch Company formed in 1870, drawing water out of the South Platte River in Weld County. The company was reincorporated as the Godfrey Ditch Company in 1910. Meeting minutes from 1870 to 1910 have been digitized and can be accessed through the Water Archive as a unique research opportunity.
From the Godfrey Ditch Company Records, Water Resources Archive, CSU Libraries

Women and water: The Archive's collections are dominated by men and their activities, but women are also present. Historians, rhetoricians and communications majors, women's studies students, and political scientists interested in women and water can use Archive collections as a starting point for their research. Some women found in the Archive, like Vena Pointer, Colorado's first female water lawyer, or "Dot" Carpenter, wife and assistant to Delph Carpenter, have received some attention. Others, especially those involved in mid- and late-twentieth century organizations, have not been studied. Researchers might inquire why women became involved in the Colorado Association of Soil Conservation Districts, Xeriscape Colorado or Cache la Poudre River preservation organizations. They might examine the strategies women employed within and through these organizations to effect political and social change.

Municipal water supplies and water quality: As urban communities on the Front Range continually look for ways to supply water to a growing population, research on water quality, waste water reuse, and the economic and environmental impact of reservoir construction have become increasingly important. The Archive contains hundreds of documents on these subjects. One often-debated but less-carefully-contextualized topic is water use and storage on the Cache la Poudre River. Feasibility reports and debates about Fort Collins's purchase and expansion of Joe Wright Dam in the 1970s, as well as the successful push to protect part of the Poudre as a Wild and Scenic River in the 1980s, are important references for those studying the feasibility and possible results of projects like the Glade Reservoir or the impact of Fort Collins's current water use/water conservation policy.

Students wanting to know more about these few topics, additional topics, or how to get started with archival research should contact their advisors or the archivist. Professors who want to know more should also contact the archivist. With its campus location, the Archive is convenient for CSU students, but access is open to anyone, free of charge. Though most of the Archive's materials will continue to be only accessible through its reading room in Morgan Library, an increasing amount of materials is being made available online.

For more information, see the Water Resources Archive website http://lib.colostate.edu/archives/water/ or contact the archivist (970-491-1939; Patricia.Rettig@ColoState.edu) at any time.

Cache la Poudre River National Heritage Area: Commemorating Development of Western Water Law and Complex Water Delivery Systems

Prepared using material contained in the Cache la Poudre River National Heritage Area Management Plan, submitted to the National Park Service April 2012

A national heritage area is a place where natural, cultural, historic, and scenic resources combine to form a nationally distinctive landscape—one evolved from patterns of human activity shaped by geography. The lower Cache la Poudre River Valley, within which humans crafted a legacy of western water management, is such a place!

National heritage areas are administered by the National Park Service, but are not generally owned and managed by the federal government. The Cache la Poudre River National Heritage Area is comprised largely of private land and is coordinated by the Poudre Heritage Alliance (PHA), a local entity comprised of private, government and non-profit representation.

The PHA works to preserve the integrity of the landscape and local heritage of the Cache la Poudre River—the "working" Poudre, if you will—without compromising local control over the use of the land and water.

The stories of the Cache la Poudre River National Heritage Area are a microcosm of early settlers' struggles to tame the western frontier of the United States, particularly with respect to establishing mechanisms for sharing limited water resources. The relationship of the natural environment to human use of water was carefully examined during the latter half of the 1800s, as society attempted to balance human and natural water needs. The resolve and ingenuity exhibited by early white settlers in the Cache la Poudre River valley during this time resulted in an historical legacy in the fields of water law, water storage, and water delivery, and water engineering that continues to evolve today. Before the settlers, Native Americans[1] utilized the Poudre River Valley for sustenance.

The following historical overview highlights events that occurred in the lower Cache la Poudre River Basin as a part of the development of the Colorado System of water allocation. The Colorado System was used as a template for other states, and countries around the world, in establishing and/or refining their water allocation systems. Elwood Mead,[2] Benjamin Eaton,[3] and Delph Carpenter[4] were early leaders in the Poudre River Valley whose work in water rights, large irrigation project design/implementation, and water compact development, respectively, had ramifications across the western U.S. and around the world.

Overview of the Historical Poudre

The system of water allocation that evolved in Colorado was partially born from conflicts experienced along its rivers, and particularly the Cache la Poudre River. However, lessons learned in other regions also helped to shape the evolution of the system.

When the early American colonists settled the eastern seaboard, they gave little thought to a legal framework to govern water use. Their new climate and topography, with plentiful precipitation, resembled closely their native England. English water laws and customs, based upon the Riparian Doctrine, were easily put to use[5] and soon became standard practice.

Another strong influence came later in the northeastern U.S., where industrialization gave birth to the concept of 'an exclusive right to dam streams and regulate their flow" in order to power mills during the early industrial revolution.[6] Another important influence came from the California gold fields, where miners' fierce competition over water led to a system that prioritized water use by seniority.[7]

Permanent settlement along the Cache la Poudre River began in

1. Burris, Lucy. "An Ethnohistory of the Cache la Poudre River National Heritage Area, AD 1500-1880." Poudre Heritage Alliance.
2. Kluger, James R. 1992. Turning on Water with a Shovel: The Career of Elwood Mead. University of New Mexico Press, Albuquerque.
3. Norris, Jane E. and Lee G. 1990. Written in water: the life of Benjamin Harrison Eaton. Ohio University Press, Athens.
4. Tyler, Daniel. 2003. Silver Fox of the Rockies: Delphus E. Carpenter and Western Water Compacts. University of Oklahoma Press, Norman.
5. Johnson, Norman K., "The Doctrine of Prior Appropriation and the Changing West," (unpublished report, Staff of the Western States Water Council, 1987), 1-2.
6. Donald J. Pisani. Water, Land and Law in the West (Lawrence, KS: University of Kansas Press, 1996), 1.
7. Ibid., 7-37.

the 1840s. Early settlers generally avoided agriculture, primarily relying on trapping and hunting to survive. However, in 1859, the discovery of gold along Cherry Creek in Denver sparked a dramatic change throughout the Colorado Territory. The population grew suddenly and dramatically as thousands of miners and pioneers descended on the area, and some pioneers saw Colorado's agricultural potential as the more promising and enduring path to riches, especially as hungry miners turned to local farmers for sustenance.

The early Colorado farmers had to adapt to a new landscape and climate. Creating an effective and fair water delivery system was essential. Even at this early stage, Colorado settlers realized that the use of the river water needed to be controlled, and the territorial legislature passed its first law concerning water management in 1861.

That law stated that when there was not enough water to satisfy a community's needs, "the nearest justice of the peace shall appoint three commissioners … whose duties it shall be to apportion [water] in a just and equitable proportion … to different localities as they, in their judgment, think best for the interests of all parties."[8] This first law would later prove too vague to resolve any serious conflict over water, but because the territory's population was still sparse and only simple, short canals existed, there was still plenty of water for all of the irrigators. Only when the demand for water surpassed the available supply would agriculture and irrigation undergo an important transformation.

The arrival of the Union Colony in 1870 changed the nature and scale of irrigation in northeast Colorado. The Colony, located close to the junction of the Cache la Poudre with the South Platte, envisioned ditches large enough to serve all their community's members, and almost immediately after their arrival, they began construction on the first of four proposed ditches, of which they only built two—Greeley No. 3, serving the municipality and its gardens, and Greeley No. 2, for crop irrigation. The canals set powerful precedents by their size, the numbers of farmers they served, and by proving the importance of a cooperative effort to develop a water supply system.

Other farmers and entrepreneurs soon replicated the cooperative methods of the Union Colony and created their own extensive ditch networks. A new agricultural colony appeared in Fort Collins in 1872, and shortly thereafter began the construction of two new large ditches, the Lake Canal and Larimer County Canal #2. These new structures had the capacity to divert a significant portion of the river's flow and, due to their position upstream from the Union Colony ditches, they had the first opportunity to use the water.

It only took one dry spell to spark a controversy. In 1874, low river flow left inadequate water for Greeley, who suggested appointment of a river commissioner, and insisted that the city's prior water rights be recognized. Before the problem could be resolved, rains came, the drought ended, and the controversy subsided as both sides fell silent. However, the issues raised at the 1874 Eaton School meeting between Fort Collins and Greeley were still unresolved, and all parties realized that a more effective system was needed in order to avoid future conflicts.

Demands on the state's limited water resources kept growing, and the frequency of conflicts over water increased, sometimes resulting in violence. The need for a uniform system of water regulation became urgent. It also became evident that the territorial law of 1861 was inadequate to address the problems faced by irrigators. The power of the state of Colorado to regulate water had to be strengthened.

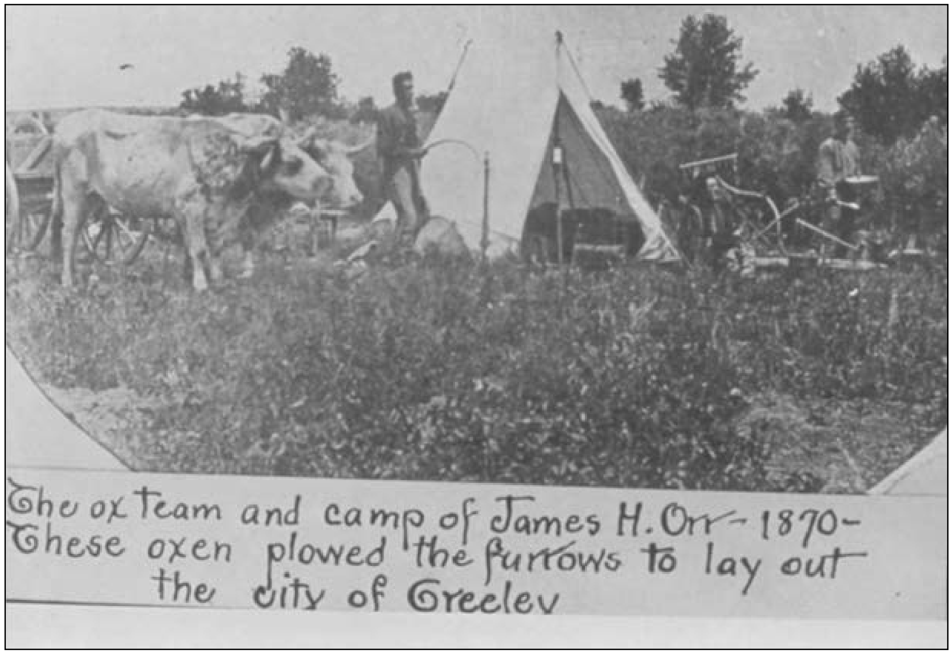
In 1876, the framers of the Colorado Constitution attempted to address water issues in the state's constitution, but ultimately it would take

Greeley #3 irrigation ditch

Courtesy of greeleyhistory.org

8. Robert Dunbar, "The Origins of the Colorado System of Water-Right Control," The Colorado Magazine 27 (October 1950), 241.

Right: *Ox team plows furrows in 1870*
Courtesy of District 6 Greeley, Colorado – Birth of a City slideshow



another conflict along the Cache la Poudre River to force the state to take effective action. That conflict occurred in 1878, when Benjamin Eaton, with backing from English investors, began construction of the massive Larimer and Weld Canal upriver from all of the other major ditches. Without regulations, the canal could divert the entire river, leaving both Greeley and Fort Collins with no water or legal recourse.

On October 1878, State legislators S. B. A. Haynes and J. L. Brush called a meeting of area farmers at Barnum Hall in Greeley to discuss the potentially devastating situation. At this meeting, the "embryo of the Colorado System" was crafted. The Barnum Hall attendees believed that legislation must be passed which: (1) created a state agency to superintend the rivers, (2) divided the state into water districts, (3) measured the flow of all streams, and (4) clarified all earlier legislation. They called for a statewide convention to address those issues in an attempt to force the Colorado legislature into action.

The convention appointed a five-member committee to draft a legislative proposal. Two members of that committee were from the Cache la Poudre region. After much deliberation and debate over the "nature of prior rights," a bill was submitted to the Colorado General Assembly in 1879.

The bill was rewritten and passed, and several essential aspects of current Colorado water law were evident in the resulting legislation, including the creation of water districts and water courts. One of the most fundamental tenants of Prior Appropriation also emerged; the idea that only enough water that could be beneficially used could be diverted from a stream. However, the legislation did not create a state commissioner or regulate the measurement of the rivers, which left many unsatisfied and would cause further problems in the future.

Another hot and dry season hit Colorado from 1879 through 1880, and the unresolved issues resurfaced. Greeley farmers again accused Fort Collins irrigators of using too much water, and turned to the new legislation for a resolution. It was then that the process of determining the dates of construction for all of the ditches began. Ditch owners' proven claims in Water Court would establish an order of priority.

Even with accepted testimony and evidence, the priorities proved impossible to enforce, because it was popularly believed that they violated the principles of the Riparian Doctrine. But the Greeley irrigators continued to push for irrigation regulation and elected state legislators James Freeman and J. L. Bush, men dedicated to changing Colorado's water legislation. Freeman became chairman of the Senate Irrigation Committee and introduced legislation that finally seemed to satisfy the needs of Colorado irrigators. It included the necessary measurement of streams and the appointment of a state water commissioner.

The accurate measurement of streams was a problem that would not be solved until 1922 when Ralph Parshall, a graduate of the Colorado Agricultural College (later Colorado State University), designed a flume that has been described as "the most commonly used device for measuring flow in irrigation channels all over the world." [9]

The Colorado system of water allocation, and particularly the concept of Prior Appropriation, evolved to fit the needs of the arid west throughout the 1870s and 1880s. The concept of Prior Appropriation asserts the simple principle of "first in time, first in right," and further defines it with the caveat of beneficial

9. Herman J. Finkell, ed., CRC Handbook of Irrigation Technology, vol. 1 (Boca Ratón: CRC Press, Inc., 1982), 151.

use, which means that the first party that diverts the natural flow of the river and puts the water to beneficial use has the right to its use. The diversion must be a physical feature that alters river flow, and the beneficial use must be for social or economic reasons, with as little waste occurring as possible.

In Colorado, as established in the State Constitution, water is considered public property and the state has the duty to regulate its management. A system of priorities based on the dates (seniority) of the creation and use of irrigation structures regulates Colorado's rivers.

Those who hold senior water rights receive their share of water before anyone else and, as long as there is enough water, the right to use the river's water moves down the list to junior claimants. The type of use also affects the seniority of a water right. The state gives preference to domestic use, then to agriculture, and finally to manufacturing. Water commissioners are appointed by the state to assure fair access to, and use of, the limited water resources.

The Colorado System of water allocation and the process of prior appropriation briefly alleviated pressure on the rivers, but irrigation was becoming increasingly complex as more and larger ditches were built. There was a constant need to find new ways to manage water. The proliferation of canals and irrigated acreage attracted more population to the Cache La Poudre River Basin and soon its water resources and the state's fledgling system of water management were again taxed to their limits.

In addition, Colorado's consumer tastes and market economics were changing. Farmers were growing new crops to satisfy consumer demand. Water was the key to the success of those crops, but orchards need water all summer; potatoes need water until late summer; and alfalfa needs water in early spring.

The Colorado climate, the river, and the irrigation ditches could not consistently provide enough water during each season to allow all products to flourish. Irrigators needed to store water that fell during non-growing seasons and during times of flood. To do that, in the 1880s and 1890s, a network of reservoirs linked to canals, ditches, streams and rivers, and a system of water exchange were established.

The reservoirs stored "surplus" water from the rivers that could be released into the river's flow for delivery to the proper ditch when needed. Water exchange allowed a ditch in need of water, but located upriver from a reservoir, to take another ditch's water from the river at the point where it is needed, and replace that ditch's water with water from the reservoir at the appropriate point down river. This system enabled the reservoirs to operate successfully.

Skyline Ditch, Columbine Ditch, Wilson Supply Ditch, and the Laramie Poudre Tunnel are well-known landmarks that document the shift of water from the Pacific to the Atlantic watershed as they divert water from the Laramie River into the Poudre. Transmountain diversions using the Michigan Ditch and Grand Ditch were also created at this time

Reservoirs constructed throughout the Cache la Poudre Basin in the 1890s captured runoff from heavy winter snows, storing it and allowing it to be used when most needed. Although always junior to direct irrigation rights, the Prior Appropriation Doctrine was applied to the reservoirs, with each having a specific priority. The system of water exchange increased the reservoir system's efficiency by permitting the maximum benefit from stored water, extending water resources even farther.

Early irrigation ditch providing water to the Akin farm in Fort Collins

Courtesy of history.poudrelibraries.org

Today, the river is still an important part of life in Larimer and Weld Counties. A larger, more diverse population is forcing the re-examination of the values inherent in the river and has begun to impact local and regional growth and development policies. Understanding the history of how the Poudre River arrived at its current water allocation system is critical to addressing today's water conflicts and addressing future human and ecosystem water needs. The Cache la Poudre River National Heritage Area strives to provide insight into the region's natural, cultural, historic, and scenic resources that combined to form a nationally significant heritage in western water allocation and management.

For More Information

In 2011, the PHA produced a guidebook that summarizes the story of the river and describes ways to explore the Heritage Area's history, particularly via maps of the roadways in the region and the Poudre River Trail. The guidebook is available by contacting PHA at www.PoudreHeritage.org.

In addition, the Heritage Area's website provides an easily accessible overview of the region and its water history.

The PHA, a 501(c)3 nonprofit organization, recently prepared a management plan for the Heritage Area and much of its content can be viewed on the new website.

Hopefully, this very brief introduction to the western water history being celebrated via the Cache la Poudre River National Heritage Area will entice readers to visit and experience the natural, cultural, historic, and scenic resources of the lower Cache la Poudre River Basin.

USGS science for a changing world

Recent Publications

Real-time monitoring of landslides; 2012; FS; 2012-3008; Reid, Mark E.; LaHusen, Richard G.; Baum, Rex L.; Kean, Jason W.; Schulz, William H.; Highland, Lynn M.

Principal aquifers can contribute radium to sources of drinking water under certain geochemical conditions; 2012; FS; 2010-3113; Szabo, Zoltan; Fischer, Jeffrey M.; Hancock, Tracy Connell.

The National Land Cover Database; 2012; FS; 2012-3020; Homer, Collin H.; Fry, Joyce A.; Barnes, Christopher A.

Digital surfaces and hydrogeologic data for the Mesozoic through early Tertiary rocks in the Southeastern Coastal Plain in parts of Mississippi, Alabama, Georgia, South Carolina, and Florida; 2012; DS; 662; Cannon, Debra M.; Bellino, Jason C.; Williams, Lester J.

Evaluation of long-term water-level declines in basalt aquifers near Mosier, Oregon; 2012; SIR; 2012-5002; Burns, Erick R.; Morgan, David S.; Lee, Karl K.; Haynes, Jonathan V.; Conlon, Terrence D.

Understanding earthquake hazards in urban areas - Evansville Area Earthquake Hazards Mapping Project; 2012; FS; 2012-3014; Boyd, Oliver S.

A new method of calculating electrical conductivity with applications to natural waters; 2012; Article; Journal; Geochimica et Cosmochimica Acta; McCleskey, R. B.; Nordstrom, D. K.; Ryan, J. N.; Ball, J. W.

Characterization of major-ion chemistry and nutrients in headwater streams along the Appalachian National Scenic Trail and within adjacent watersheds, Maine to Georgia; 2012; SIR; 2011-5151; Argue, Denise M.; Pope, Jason P.; Dieffenbach, Fred

Assessment of potential migration of radionuclides and trace elements from the White Mesa uranium mill to the Ute Mountain Ute Reservation and surrounding areas, southeastern Utah; 2011; SIR; 2011-5231; Naftz, David L.; Ranalli, Anthony J.; Rowland, Ryan C.; Marston, Thomas M.

Lee MacDonald

Lee MacDonald, *Department of Forest and Rangeland Stewardship, Colorado State University*

Dr. Lee MacDonald, a professor of Watershed Science, is retiring from active teaching after 22 years at CSU, a post-doctoral appointment at the University of Washington, and more than five years setting up research and training programs in developing countries. We've asked him to summarize lessons learned over his career.

Lessons Learned After 30 Years in Watershed Science

We don't teach hydrology, we teach physics. The basic principles of hydrology are relatively well known: 1) water runs downhill, 2) inputs equal outputs plus the change in storage, and 3) flowing water flows faster as it gets deeper. These are all just applications of basic physics, once one understands the underlying principles. Often water is going up in direction, such as when it evaporates from the soil or a plant, but this is downhill in energy terms because the atmosphere has such a strong pull on liquid water (vapor pressure deficit).

Obeying the second principle ("continuity equation") is critical to any hydrologic analysis, as water generally can't be created or destroyed. So inputs (usually precipitation) have to be balanced by the outputs (usually runoff, evapotranspiration, and any change in storage). Similarly, energy has to be conserved, so water flows faster when it is deeper, because there is less resistance along the bed and banks. Understanding and following these basic principles is the heart of hydrology. Knowing that hydrology is physics makes the basic principles easier to understand and apply.

The basic principles are easy, but the application is hard! The first principle is that water flows downhill, but predicting the direction and amount of flow requires information on the amount of energy that water has in different places, and the resistance to flow. So to predict evaporation we have to know how tightly water is held in the soil, air temperature and humidity, how much energy is available, and turbulence at the water-atmosphere interface. To determine the water balance, we have to accurately measure the different components of the water balance, but it is impossible to accurately measure precipitation, evapotranspiration, runoff, and water storage on large plots, much less an entire watershed (Figure 1).

Figure 1. *Most precipitation gages do not measure snow very accurately.*
Courtesy of Wendy Ryan, Fort Collins weather station

Spend time in the field, and learn from that. Hydrology is a data-based science, yet almost all of our education is conducted indoors. Without a field component, people are too prone to believe that hydrologic data are perfectly precise (to a computer, 10 cubic feet per second is 10.0000….), models accurately represent the underlying processes, and we can accurately characterize the variability in time and space. Students need to spend time in the field making measurements in order to appreciate the uncertainty in the underlying

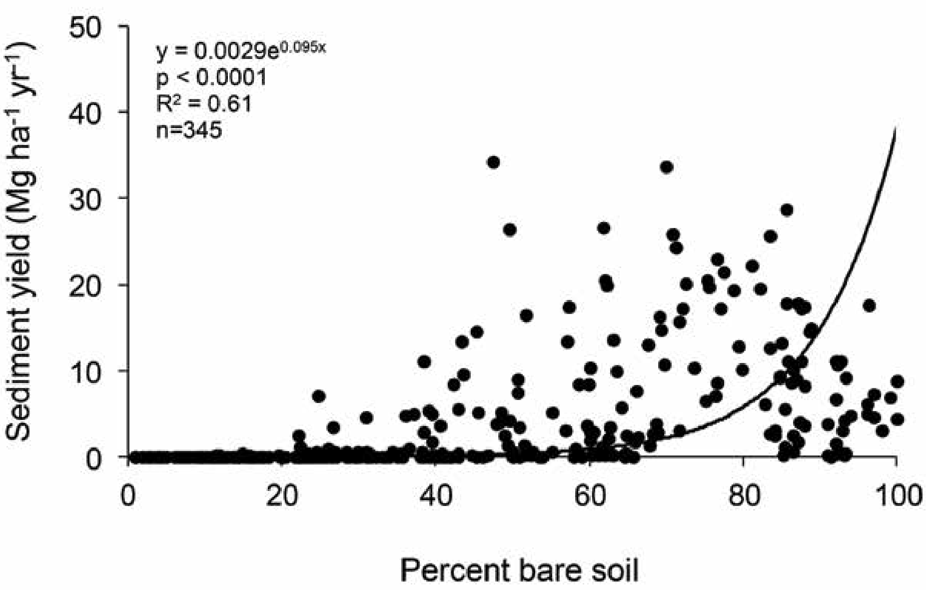


Figure 2. *Sediment yield versus percent bare soil for burned and unburned hillslopes in the Colorado Front Range (Larsen et al., 2009).*

data, and better understand the controlling processes (c.f., MacDonald, 1993). Teaching field-based courses is expensive in terms of equipment and time, but essential to the advancement of the science (NRC, 1991). Only by spending time in the field can we appreciate the differences between the reality in the field and the simplified approximations of our models, and the uncertainties in the data that underlie hydrologic science and our predictions.

Recognize the uncertainty, and watch your significant figures! The difficulties of measuring water movement and storage, when combined with the variability in time and space, means that our measurements are only approximations. Hence most of our hydrologic data are only accurate to within 1-30 percent, and many measurements, such as infiltration, have much lower accuracy at larger scales due to the tremendous variability in time and space. This has important implications for the accuracy of our models and predictions, and two significant figures are all we can reasonably report!

Climate change is creating even more uncertainty. When I started teaching in 1990, I taught climate change as a hypothesis that needed to be tested. With another 22 years of data, the warming trends in the lower atmosphere and oceans, and the rise in sea levels, are uncontestable. The warmer atmosphere and oceans are changing water movement and hence the amount and type of precipitation, Arctic ice cover, and evapotranspiration rates. These changes have tremendous effects both locally and globally ("teleconnections"), and we no longer can simply extrapolate from the past in order to project the future (e.g., Milly et al., 2008). The result is even more uncertainty in our models and predictions! The trends and persistence of the human-induced changes in the atmosphere and oceans is my biggest fear with respect to the future of humanity and our blue planet.

Hydrology and watershed management are both a science and an art. We know the basic principles of hydrology, but have trouble applying these in the field because of the uncertainties in the magnitudes of the underlying processes, the interactions between processes, and how the relative importance of different processes change under different conditions (e.g., the nonlinear increases in surface runoff with increasing rainfall intensity and soil moisture). Given our imperfect knowledge and measurements, we inevitably must estimate certain components, and then use our judgment to evaluate the accuracy of model structure, model parameters, and model results. This judgment is a learned art that comes from experience, preferably from working in different environments under a range of different conditions. All hydrologists must learn to discern what is real versus what is just a model estimate.

Learn what is big and what is little. Although the specific details are complex, often there are only a few dominant controls on the movement and storage of water for a given situation. Practicing hydrologists need to learn what is big and what is little, and spend time on the dominant controls relevant to the problem of concern rather than trying to refine a number or an input that ultimately doesn't greatly affect the result.

Land use can have a bigger effect on erosion and sedimentation rates than runoff. I began my career as a forest hydrologist, studying how timber harvest affects the amount and timing of runoff. After studying how forest management activities affect stream channel characteristics, I found that increasing management was associated with an increase in fine sediment rather than channel incision, indicating that erosion and sedimentation were bigger concerns than the changes in runoff. I then began studying erosion rates in forested areas, and quickly realized that roads, fires, and channel erosion due to urbanization can each increase erosion rates by several orders of magnitude. Timber harvest, if done carefully, usually has very little effect on runoff and erosion. Bottom line is that in forested areas erosion and sedimentation is the biggest concern, and one should focus on roads, fires and urbanization—most everything else is just noise!

Soil cover is the key to watershed management. The primary task of the watershed manager is to minimize the increases in runoff and erosion, and this means maintaining or increasing the infiltration rate in order to minimize the amount of surface runoff. Numerous studies in different environments indicate that erosion rates are minimized if there is at least 60-70 percent surface cover (Figure 2). Hence the primary task of the watershed manager is to maintain or establish a good surface cover, as this helps maximize the infiltration rate.

Think globally, act locally. This is a well-known bumper sticker, but it applies to watershed management. If one takes care of local issues by maximizing infiltration, minimizing overland flows, and reducing local pollution sources, this should largely eliminate downstream cumulative effects (MacDonald, 2000).

If you want to help, work in developing countries. The U.S. and other developed countries have rich data sets, tremendous technical expertise, strong legal controls, and have largely solved the basic issues with respect to water supply, pollution, and human well being. In contrast, developing countries typically have very few data, limited technical expertise, and such limited resources that they can only focus on the most basic resource management issues related to human health and survival. So if you want to make a difference, think about working in developing countries.

References

Larsen I.J., L.H. MacDonald, E. Brown, D. Rough, M. J. Welsh, J.H. Pietraszek, Z. Libohova, J.D. Benavides-Solorio, and K. Schaffrath, 2009. Causes of post-fire runoff and erosion: water repellency, cover, or soil sealing? Soil Science Society of America Journal 73: 1393-1407.

MacDonald, L.H., 1993. Developing a field component in hydrologic education. Water Resources Bulletin 29(3):357-368.

MacDonald, L.H., 2000. Evaluating and managing cumulative effects: process and constraints. Environmental Management 26(3): 299-315.

Milly, P.C.D., et al., 2008. Stationarity is dead: whither water management? Science 319: 573-574.

NRC, 1991. Opportunities in the hydrologic sciences. National Research Council, National Academy Press, Washington, D.C. 348 pp.

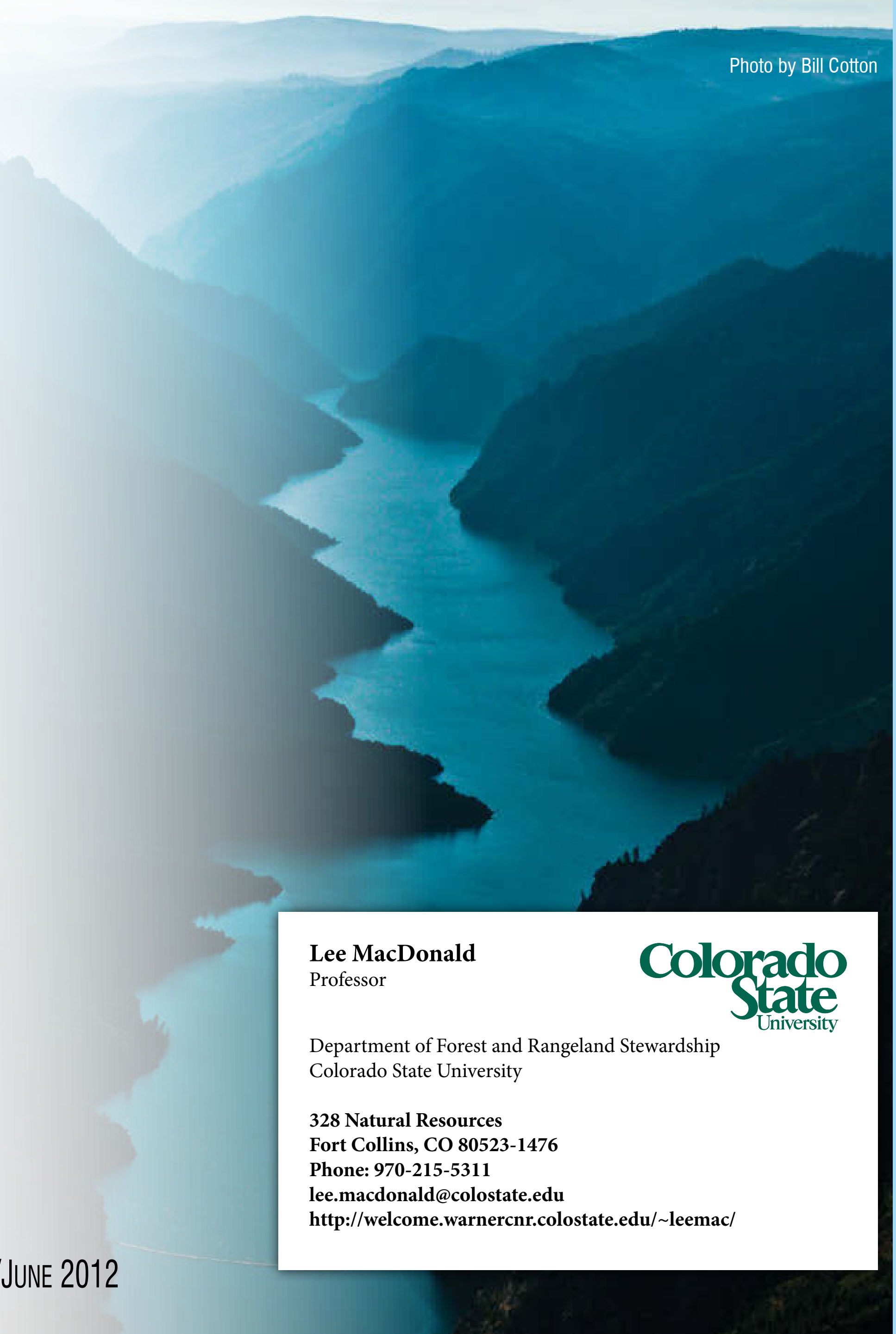


Photo by Bill Cotton

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Water Research Awards

Colorado State University (March 16, 2012 to May 15, 2012)

Aldridge, Cameron, DOI-NPS-National Park Service, Identification of Critical Winter Habitat Requirements for Gunnison Sage-Grouse, $7,000

Bestgen, Kevin R, DOI-Bureau of Reclamation, Monitoring Effects of Flaming Gorge Dam Releases on the Lodore and Whirlpool Canyon Fish Communities, $80,211

Binkley, Daniel E, USDA-USFS-Rocky Mtn. Rsrch Station – CO, Impacts of Mountain Pine Beetle & Spruce Beetle on Forest Carbon & Water Balance, $25,850

Carlson, Kenneth H, DOE-NREL-JISEA-Joint Institute for Strat, JISEA NG Study - Water-related Data and Analysis, $5,000

Cooper, David Jonathan, DOI-NPS-National Park Service, Wetland Ecological Integrity Monitoring in Glacier National Park, $62,013

Fiege, Mark T, City of Fort Collins, Fort Collins Water Utility History Update, $13,000

Jacobi, William R, DOI-USGS-Geological Survey, Impacts of Mountain Pine Beetle Infestations on Forested Ecosystems Along the Colorado Front Range, $47,000

Johnson, Brett Michael, Colorado Department of Public Health & Enviorment, Characterizing Bioaccumulation of Mercury in Sport Fish: Informing TMDL Development & Modeling Mitigation Strategies in Front Range Reservoirs, $286,353

Johnson, Brett Michael, DOI-Bureau of Reclamation, Chemically Fingerprinting Nonnative Fishes in Reservoirs (Project No. C-18/19), $6,000

Johnson, Jerry J, Syngenta, Influence of Agrisure Artesian water-optimization alleles on hybrid performance and response to plant density, $29,915

Laituri, Melinda J, Environmental Defense Fund, Colorado River Basin Governance Geospatial Layer for Agricultural Water Users, $34,505

Matsumoto, Clifford R, DOC-NOAA-Natl Oceanic & Atmospheric Admn, Hydrologic Research and Water Resources Applications Outreach Coordination, $99,196

Myrick, Christopher A, University of Washington, Cost-Effective, Alternative Protein Diets for Rainbow Trout that Support Optimal Growth, Health, and Product Quality, $2,600

Omur-Ozbek, Pinar, City of Loveland, Colorado, BIOWIN Modeling/Simulation for Biological Nutrient Removal Expansion Improvements to the Loveland WWTP, $19,293

Reich, Denis A, Colorado Water Conservation Board, Ag Transfers: Investigation of Water Savings, Water Quality Benefits and Profitability of Sub Surface Drip on Alfalfa in Grand Valley, $8,841

Reich, Denis A, Colorado Water Conservation Board, Agricultural Weather Data Delivery Improvements to Uncompahgre Valley Irrigators, $112,000

Reich, Denis A, Colorado Water Conservation Board, WSRA: Investigation of Water Savings, Water Quality Benefits and Profitability of Sub Surface Drip on Alfalfa in Grand Valley, $46,894

Sale, Thomas C, DOD - US Department of Defense, Basic Research Addressing Contaminants in Low Permeability Zones, $249,978

Sale, Thomas C, Town of Castle Rock, CO, Extended Studies Supporting Sustainable Use of the Denver Basin Aquifers, $25,000

Schneekloth, Joel, Monsanto, DroughtGard Irrigation Timing - Reproductive Growth Stages, $75,600

Schorr, Robert, DOI-USFWS-Fish & Wildlife Service, Preble's Meadow Jumping Mouse Populations at the USAF Academy, $53,791

Vieira, Nicole K M, Colorado Division of Wildlife, Developing Flow Recommendations for Turquoise Reservoir and Establishing Riparian Monitoring Points for the Upper Arkansas River and the Lake Fort, $42,023

Calendar

June

12 **Ruedi Dam Hydroelectric Tour; Basalt, CO**
Join City officials to tour and learn about Ruedi Hydroelectric facility.
www.roaringfork.org/events

25-27 **Contaminants of Emerging Concern in Water Resources II: Research, Engineering & Community Action Conference; Denver, CO**
www.awra.org/meetings/

July

10 **South Platte Roundtable; Longmont, CO**
cwcb.state.co.us/Pages/CWCBHome.aspx

11 **Southwest Roundtable; Durango, CO**
cwcb.state.co.us/Pages/CWCBHome.aspx

17-19 **2012 UCOWR/NIWR Conference; Santa Fe, NM**
Managing Water, Energy, & Food in an Uncertain World. www.ucowr.org

17-20 **Hydrovision International 2012; Louisville, KY**
The 2012 HydroVision International Conference features more than 70 sessions and over 450 speakers. www.hydroevent.com/index.html

18 **Yampa/White Roundtable; Craig, CO**
cwcb.state.co.us/Pages/CWCBHome.aspx

18-20 **37th Annual Colorado Water Workshop; Gunnison, CO**
Water Taboos: Addressing our most challenging issues. www.western.edu/academics/water

August

1-3 **2012 Western Water Seminar; Sun Valley ID**
"Future Threats to Water Supply Deliveries in the West." www.nwra.org

15-17 **Colorado Water Congress Summer Conference; Steamboat Springs, CO**
Summer Conference and Membership Meeting. www.cowatercongress.org

19-23 **StormCon Denver 2012; Denver, CO**
The North American Surface Water Quality Conference & Exposition
http://www.stormcon.com/index.html

September

13 **Colorado River District Annual Water Seminar; Grand Junction, CO**
Featuring a presentation on the history of the Colorado River District from George Sibley.
www.crwcd.org/page_115

16-20 **Dam Safety 2012; Denver, CO**
The 5th Annual National Dam Security Forum will provide State dam safety officials, owners, operators and additional stakeholders with a unique opportunity to discuss a variety of technical and non-technical issues pertaining to the safety, security and resilience of the Nation's dams and related infrastructure.
http://damsafety.org/conferences/?p=a5db6ea2-9f93-4629-a41c-6ef46ed02727

19-20 **2012 CWCB Statewide Drought Conference; Denver, CO**
Building a Drought-Resilient Economy through Innovation
http://cwcb.state.co.us/Pages/CWCBHome.aspx

24-26 **BIT's 2nd Annual World Congress of Environmental Biotechnology; Taiyuan, China**
Theme: Healthier, Safer, and Environmental Friendly. www.bitconferences.com/wceb2012/

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Hanging Lake, Glenwood Springs, Colorado.

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