# Colorado Water

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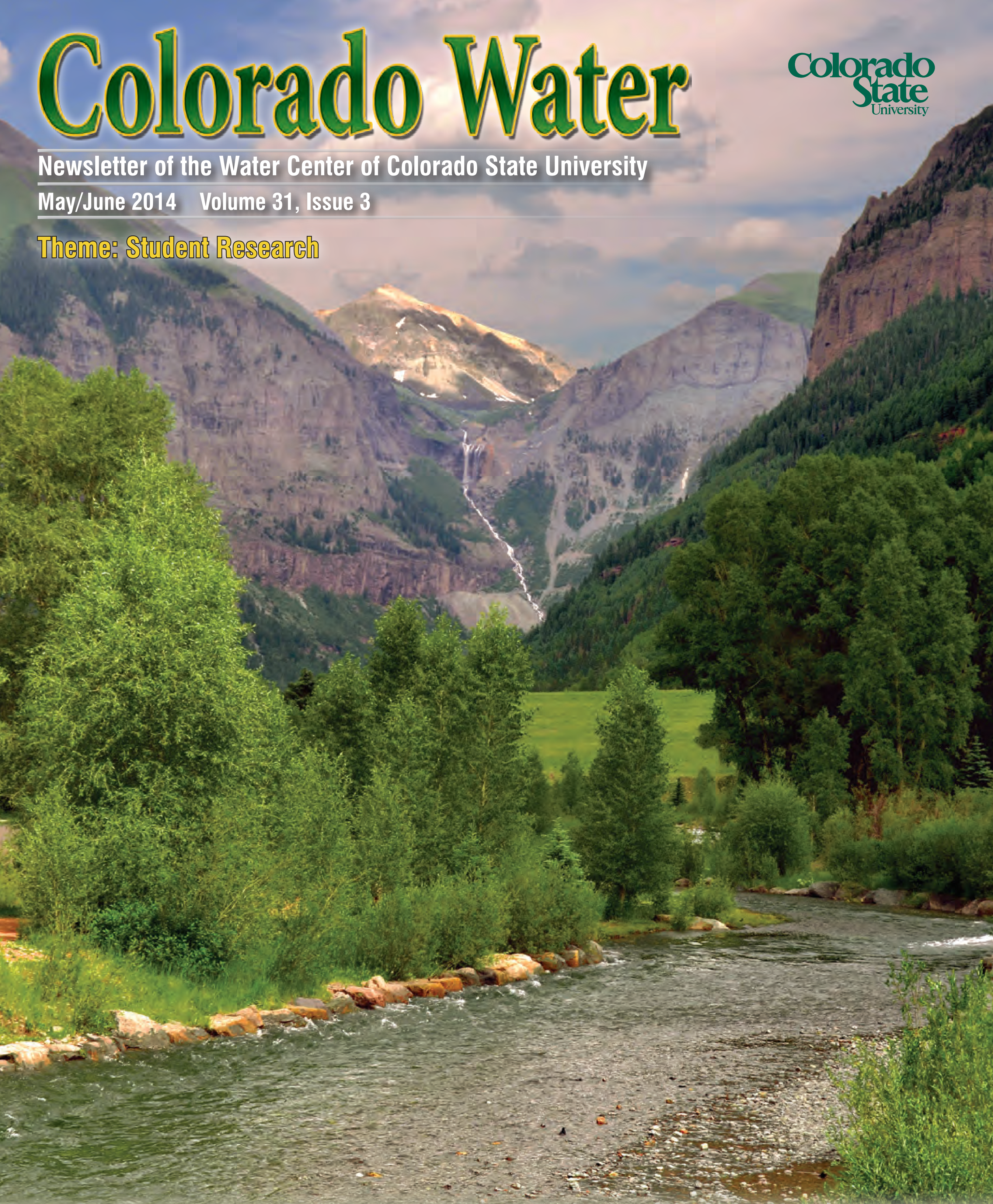

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# Highlights



# In Every Issue




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Front Cover: The San Miguel River near Telluride, Colorado. Photo by Richard Hurd
This Page: The Grand Canyon of the Gunnison, Colorado. Photo by Richard Hurd

# Editorial

*by Reagan Waskom, Director, Colorado Water Institute*

At Colorado State University (CSU), students are the heart of the university mission and activities. Although we often include student research in *Colorado Water*, each year, we devote one issue solely to student projects. When working with graduate students, it is a pleasure to learn from them, to view water problems through fresh minds, and to renew the hope that new ideas and energy will resolve the water challenges our global society faces. The blending of the experience and knowledge of seasoned practitioners with the optimism and creativity of new water professionals offers us the best combination of human ingenuity and problem solving.

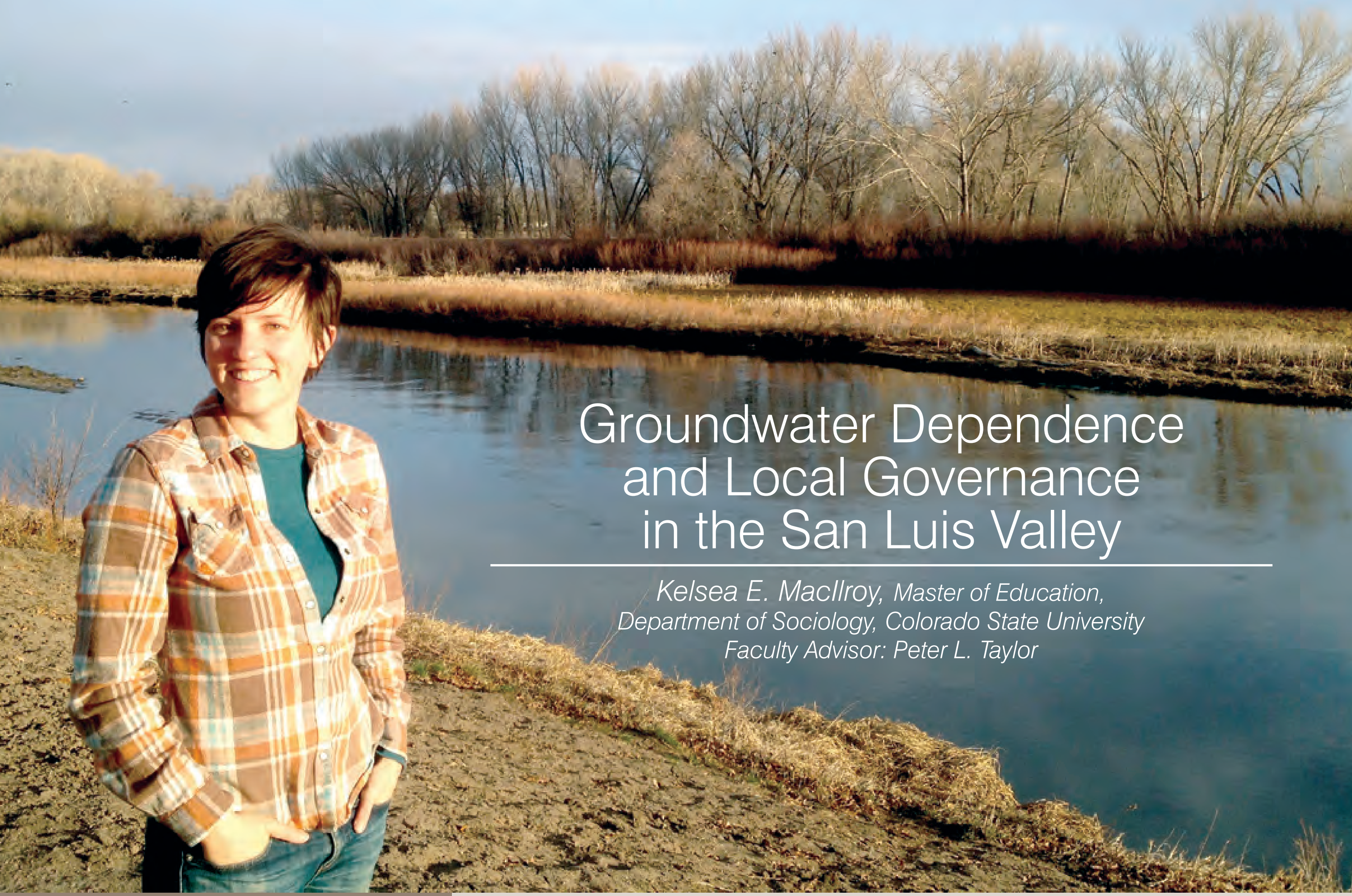
Student water research at CSU covers an amazing breadth of topics, approaches, and geographies. Some is basic research focusing on the discovery of new knowledge and scientific theories. As a landgrant university, much of our research is applied—developing new tools or approaches to solve specific problems. The topics covered in this issue are just the tip of the iceberg of hundreds of active student water projects.

The Colorado Water Institute (CWI) at CSU is devoted to applied research that addresses Colorado-specific problems and is authorized to work with all of public higher education in Colorado. The CSU Water Center has a different mission, serving to enhance water research, teaching, and outreach at CSU that spans basic and applied topics in locations across the planet. The Water Center works to enhance CSU faculty and students through a variety of activities. Since the recently reformed CSU Water Center just completed its first academic year since Provost Rick Miranda provided new funding and direction, it seems timely to report on our progress.

We jump started the new CSU Water Center with the formation of a 12 member faculty Executive Committee that reports to the Provost and provides the vision and guidance for the Center. As first steps last fall, the Executive Committee developed its bylaws, mission, and logo and hired staff and student support. They released a request for faculty proposals in September that funded eight faculty seed grants during the 2014-2015 academic year. Provost Miranda secured a space for the Water Center in Johnson Hall room 119, and efforts are underway to create a place for meetings, Center staff, and visiting scientists and fellows to be housed. A new Water Center website was developed and launched at www.watercenter.colostate.edu, as well as a Water Center Facebook page (www.facebook.com/CSUWaterCenter). Updated CSU Water Faculty biographies can be found on the Water Center website. A significant effort went into the development and delivery of CSU's first water MOOC (massively open on-line course) with over 600 students from around the world participating. Additionally, a faculty committee was formed to begin renewal of the CSU Water minor program.

The CSU Water Center was involved in a number of outreach activities this year, including an Open House in October to launch the new Center, co-hosting a weekly water resources seminar during the spring semester, co-sponsoring CSU Hydrology Days, co-sponsoring the CSU/Colorado Association of Stormwater and Floodplain Mangers Flood Forum, hosting a special presentation by *The Emerald Mile* author Kevin Fedarko, co-sponsoring the CSU Confucius Institute Symposium, and holding an all water faculty and student meeting in April to hear research activity reports. Ongoing outreach activities of the Water Center include an e-newsletter published every three weeks and the bi-monthly publication this newsletter.

Student engagement will become an increasingly important role of the Water Center. This year the Center worked with students to sponsor an art student logo design competition, sponsored 46 CSU students to attend CSU Hydrology Days, provided sponsorship for the Environmental Engineering Society Conference, sponsored a screening of "DamNation" documentary for the Student Sustainability Center and the Sustainable Undergraduate Remediation Forum, and initiated the formation of a Water Center Student Committee. Finally, the Water Center Executive Committee developed and released an FY15 request for proposals to fund new seed grant projects for the coming academic year. The CSU Water Center Executive Committee looks forward to working with faculty and students at CSU who want to apply their expertise to water-related issues.



# Groundwater Dependence and Local Governance in the San Luis Valley

*Kelsea E. MacIlroy, Master of Education,*
*Department of Sociology, Colorado State University*
*Faculty Advisor: Peter L. Taylor*

*Groundwater management is undergoing changes in the San Luis Valley. Using a grounded theory methodological framework approach and interviews of water users, social and political attitudes related to groundwater use and management in the valley were investigated.*

*Results suggest that subdistrict managers should take the varied social and historical contexts of stakeholders' interests into consideration when constructing buy-in incentives related to fallowing.*

## Introduction

In the arid American West, groundwater is vital for agriculture and municipalities, as it increasingly is used to supplement surface flows. Relatively cheap access to reliable and plentiful fresh water provides many benefits and can transform the local landscape and social structure. However, overuse or "mining" of groundwater can threaten the stability and livelihoods of communities that grow dependent on the cheap and plentiful resource. A significant shortfall in snowpack over the winter of 2001-2002 in the mountains of south-central Colorado precipitated a major drought in the summer of 2002 that continued into 2003. The effects were felt strongly in the San Luis Valley (SLV—see Figure 2), an agricultural community where groundwater pumping reached an all time high, and aquifer levels in an unconfined aquifer dropped to the lowest level since record keeping began in 1976 (Figure 3).

The drought of 2002 illuminated long dormant issues in groundwater management. In light of the significant declines in the aquifer, local state senator and farmer Lewis Entz sponsored the passage of SB04-222, which allowed the Rio Grande Water Conservation District to create subdistricts, enabling the local management of groundwater resources. Subdistrict #1 is the first site of water management implementation in the SLV.

There are two main priorities for subdistrict #1: first, to replace and prevent injurious depletions to senior surface right holders through a collective augmentation plan and fee

Above Photo: Figure 1. *Author in the field, on the banks of the Rio Grande in the San Luis Valley.*
Photo by John (Muck) Kilpatrick

scale for well users in subdistrict #1; the second priority is to return the unconfined aquifer to a sustainable level. To accomplish these goals, the subdistrict hopes to remove 40,000 of the 174,000 acres in production in the area of subdistrict #1 over 10 years through a payment for fallowing program. If the subdistrict does not demonstrate significant headway in achieving this goal, new groundwater rules developed by the State Engineer's office may take precedence, subverting local control.

## Literature

The nature of groundwater itself prevents direct property ownership of the resource, as it is located underground, follows no


Figure 2. *San Luis Valley, showing subdistrict #1.*

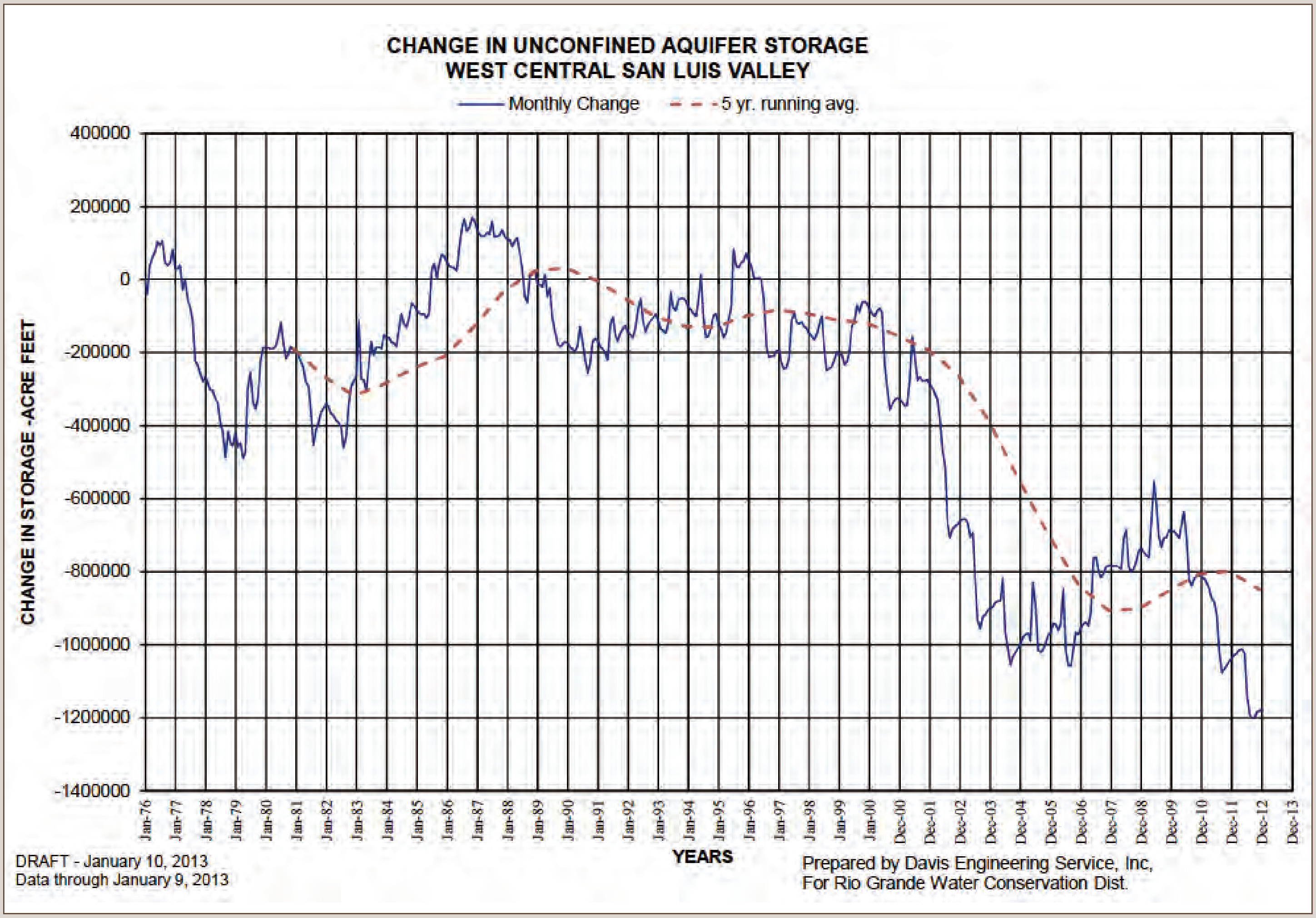



Figure 3. *Temporal change in unconfined aquifer storage in the San Luis Valley, showing record low levels in recent years.*

formalized boundaries, can be part of a complex hydraulic system, and is invisible. Groundwater is customarily understood as a common pool resource (CPR), which means that it is relatively difficult to manage—there can be many landowners who, with just a little money and a submersible pump, can access it. Garrett Hardin, in his infamous essay *The Tragedy of the Commons*, argues that communal resources will inevitably be deteriorated, as people have no incentive to limit their use of a CPR. Hardin's rationale dictates that each user will withdraw more water to increase his or her own profit, but the costs of excessive pumping are distributed to all. He maintains that the only solution is privatization or centralized government control of the resource.

In response to Hardin's dire predictions, Elinor Ostrom contends that Hardin's assumptions are flawed. Not only do individuals not act in isolation, they also develop internal coordination mechanisms, which serve to manage the resource—often, this takes place through unwritten social arrangements and constraints. In order for this "institutional choice" to work, trust must be developed between all members of the group. However, Ostrom's theory is not without its flaws, and the situation in the SLV provides an insightful critique of Institutional Choice.

## Methods

In order to study the social impacts of the subdistrict formation and the groundwater management plan and allow major themes among stakeholders to emerge on their own, a grounded theory methodological framework was used. A grounded theory approach relies on a cyclical process of collecting qualitative data, comparing and analyzing it, and using new information to guide the research as it moves forward. In this process, theory is emergent, which enables stakeholders' experiences to guide the direction of the research. I conducted 25 in-depth, semi-structured interviews with stakeholders in and around subdistrict #1 in the SLV during the summer of 2012 and observed participation at local board meetings. Field notes and memos were written up about each of these meetings. Interviews were transcribed, coded, and analyzed using NVivo software.

## Results

Groundwater has fundamentally reshaped the social structure of the SLV, and through the growing dependence upon it the SLV became, at its root, a groundwater based economy. People plant crops, raise cattle, marry, have children, build lives, and get up every morning based on the presumption that the water is there and will continue to be there. "I think back then it just wasn't that big of a deal, people didn't worry about it," describes Bradley, a third generation family farmer. Not only have the physical properties of groundwater shaped human systems, but the economy of subdistrict #1 is based on agriculture, making the larger community dependent on the health of the aquifer.

> *"Groundwater has fundamentally reshaped the social structure of the San Luis Valley."*

The presence of groundwater to many signaled the beginning of a new era. Center pivot irrigation came to the SLV in the 1960s and altered the structure of family farms, facilitating the planting of higher value crops and driving expansion in farmland. Larry, a second-generation farmer, will pass his farm onto his son soon, and thinks that "there's a lot of these wells and quarters out here—and I'm probably as guilty as anybody—that probably shouldn't have gone into production." A rational actor would do just like Larry did and Hardin described, setting up the SLV for a tragedy of the commons. However, as Ostrom suggests, individuals are adaptive, and their response in the form of the subdistricts shows promise for local governance. But what Ostrom fails to account for is that people are part of a larger social, historic, and geographic context that shapes their decisions.

Thus far, the subdistrict has not achieved enough buy-in in the form of land fallowing agreements. The response to the subdistrict plan is largely contingent on people's geographical and legal relationships to water as well as their perceptions of the importance of the local community and farm-based economy. The degree of dependency a farmer has on wells in relation to their surface rights factors into their feelings about the subdistrict. In spite of possessing rights to divert water, a few farmers and ranchers lack access to that water because of their geographical location. Within the subdistrict there is an area referred to as, "God's Country," or the "Holy Land." This area continues to have a high water table, while those outside this area are considered to be in the margins in terms of water access. Access to water and owning (or not owning) water rights is a fundamental part of how farmers and ranchers manage their operations and thus plays a considerable role in their perception of and interaction with the plan. For instance, Bradley, who had a house well dry up, is not sure farming is a viable option any longer—her junior water rights mean she will be paying for most of the water she pumps, since the subdistrict fees are offset by putting surface diversions into recharge pits. "For me, I don't

Figure 5. *Double Rainbow in Potato Fields, Subdistrict #1.* Photo by Kelsea E. MacIlroy

feel like my situation is sustainable… I don't feel like my water rights are senior enough to make them extremely valuable."

Choosing to support the subdistrict or participate in fallowing depends on more than the financial incentives offered by the subdistrict board. Jeff, who ranches outside the subdistrict, describes his ranch as "drought proof" because of his very senior water rights. He argues that the impact to his surface rights will not be fixed by the subdistrict plan, and that the wells should be fit in with prior appropriation; "What are the three best water rights in the SLV? First, the Rio Grande Compact; second, 'I can go out and push my button any time I want'; and three, the regulated guy on the river." He views his situation as fundamentally threatened by groundwater pumping. Meanwhile, Mike, also a surface-water-only rancher who feels that pumpers have been threatening his surface supply, takes a different approach: "I got history here. Everybody in this valley knows my family... Anyway, so you know that's the way I live."

Mike illustrates that supporting the subdistrict process is more than a rational monetary choice, and it extends to those who choose to fallow land. Most of the people I interviewed with fallowing contracts were either close to retirement, had very poor or junior water rights, or felt that their actions supported the broader community, which they valued highly.

## Discussion

Groundwater use in the Valley does not need to be Hardin's "Tragedy of the Commons" because people are creative and adaptive. However, social vulnerability is distributed unevenly across the spectrum of farmers and ranchers because they have different relationships with the problem, which means they have varying responses when it comes to solutions. The groundwater situation in the SLV speaks to the larger question of how to organize the management of resources in the face of overuse and decline when a community is dependent on them. Though the subdistrict process is an attempt to resist Hardin's recommendation for outside control, it has been fraught with challenges, and the institutional arrangement Ostrom suggests can only work when there is trust in the process.

Conclusions about the subdistrict are premature; however, based on my research, I suggest that first, the subdistrict invite and take seriously the input of all stakeholders, even those outside the defined boundaries. And second, the subdistrict should consider using distinct messaging and incentives for people in different contexts in order to increase buy-in related to fallowing contracts. Supporters and opponents of the subdistrict are embedded in particular social and historical contexts as well as social networks and relationships that shape how they see the world and their level of commitment to the community, and they do not maneuver without thought for these relationships. Thus, the recognition that it takes more than financial incentives and identifying those incentives, as well as bringing all stakeholders to the table, may aid in creating a more sustainable future for the San Luis Valley. ●

# Developing a Composite Index for Colorado's Irrigated Agriculture and Wellbeing

*Brian Quay, Ph.D. Student, Department of Agricultural and Resource Economics, Colorado State University*
*Faculty Advisors: Chris Goemans and James Pritchett*

*Changes in irrigated agriculture production may have impacts on the productivity and well-being of the food production sector. This study gauges irrigated cropping productivity and rural well-being by comparing a composite index of economic well-being across place and time to the irrigated agriculture index. Results will be published in July 2014.*

Water is a scarce resource in Colorado whose rights to ownership are, for all intents and purposes, fully allocated. In spite of this limitation, demand for water resources is expected to grow as the population expands in Colorado. Moreover, climate change is increasing the water requirements for the environment and the production of irrigated crops. How will the gap between growing demand and static supplies be met? While conservation, water pricing, and infrastructure play a role in meeting Colorado's increasing water demands, it is generally accepted that some water rights will be transferred in ownership and use from agriculture to urban water suppliers.

Agriculture is an important base industry in Colorado, generating more than $6 billion of farm gate receipts and contributing broadly to the state's economic activity—nearly 20 percent of Colorado's gross domestic product can be traced to agriculture or allied industries. It is also a sector in transition, with new markets developing and technological innovations improving productivity, and, importantly, agriculture is seeing increasing competition for key resources such as land and water. According to the Colorado Water Conservation Board's Statewide Water Supply Initiative (2010), urban growth will spur the reallocation of an additional 600,000 to one million acre feet of agricultural water to new municipal, industrial, and energy demands by 2050.

The anticipated reallocation will occur via voluntary, market based transactions. In these transactions, both the buyer and seller will be suitably compensated, else the transfer will not occur. However, third parties may be adversely impacted by reallocation, and this is a concern for many rural and urban stakeholders. One potential negative impact is a disruption of the rural, regional economy—after all, irrigated agriculture contributes to a host of allied industries supplying farm inputs (fertilizer, chemical, and seed), and in turn provides value added industries with its outputs (feed, raw products for sugar, dairy, energy, etc.). Income generated by agribusiness employee wages can be an engine of activity and growth for other Main Street firms. If irrigated cropping diminishes, this economic activity might be lost. At the same time, a reallocation may mean that future opportunities in crop production or value added enterprises fail to come to fruition due to a lack of available resources.

The negative impacts to third parties is a concern, and so too is a reduction in the value of agricultural output. Irrigated agriculture is noteworthy in its ability to innovate with technology, genetics, and new processes to improve its overall productivity and efficiency. How will water reallocation impact productivity of the agriculture sector? Less water may reduce the sector's overall value of goods produced, and some agricultural enterprises might be less competitive. Yet, the efficiency of water use in growing crops (or crop value) could potentially increase as farmers adapt to changing circumstances. The future is unclear.

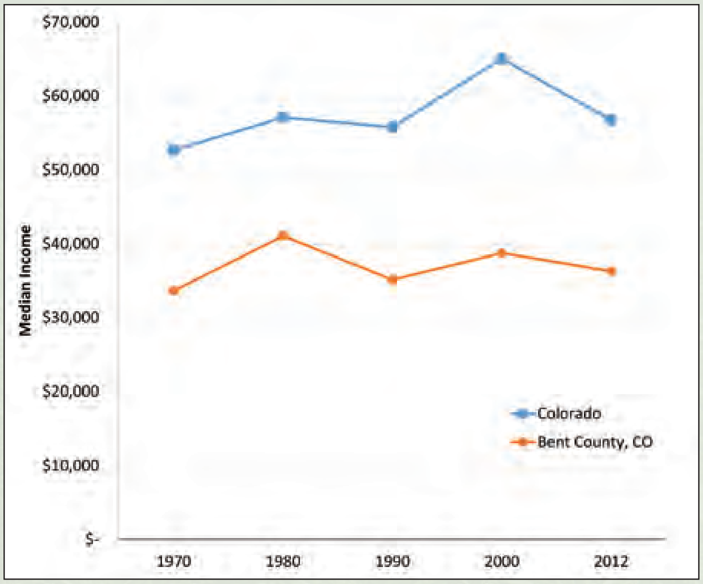
Driven by these unknowns, stakeholders and policymakers are interested in benchmarking the productivity and efficiency of agriculture's water use, forecasting the potential changes in well-being as a result of alternative transfer scenarios, and then monitoring changes in productivity and efficiency going forward.

The project on which we are working focuses on a straightforward question: "Can simple measures of production and efficiency be developed to benchmark the value of agriculture's use of water resources?" These measures will help to answer stakeholders' questions and allow for rigorous 'what-if' scenarios to be examined.

Economists use metrics and indices to gauge changes in economic activity in industries, as well as local and national economies. This study's metric will focus on gauging irrigated cropping productivity and rural well-being. The index will be comprised of a small number of easily obtained data series, and results will be made publicly available.

We have been examining a variety of approaches to find the techniques that fit Colorado's situation. Given the nature of the data (described in further detail below), an index

Background photo by Bill Cotton




*Bent County median household income is compared to Colorado median household income for 2012—an example of historical data referenced in the study.*

number—specifically, a composite index—appears to be the most suitable. This method of indexing has its origin in the field of economic development and is applied in many different situations. In particular, composite indices are useful tools in observing broad changes in a region's economic well-being.

As its name suggests, a composite index is a single output statistic that is generated by other indices, and these other indices are data series that are called dimension indices. An example of a composite index is the *Index of Leading Indicators*, which is calculated by the Conference Board for the Bureau of Economic Analysis for tracking and forecasting the U.S. economy. The *Index of Leading Indicators* includes dimension indices such as average weekly hours worked in manufacturing, new housing permits, confidence of consumer, etc. The *Index of Leading Indicators* is routinely published and is used by many as an indicator of the likely changes in store for the U.S. economy. A second composite index, the *Index of Coincident Indicators*, is used as a measure for the current well-being of the U.S. economy.

A composite index is most often calculated by taking an average of the dimension indices, but this average is a geometric average (multiplying all the dimension indices together and then taking this product to the power of 1/number of dimension indices). The geometric average creates a composite index that is not dominated by any one dimension index.

Our goal is to create a composite index that can be used for tracking and forecasting the well-being of irrigated agriculture and rural economies. The composite index can be used to show changes at two points (or more) in time, but can also be used to compare different geographic locations such as two different watersheds or several Colorado counties.

Creating a composite index requires four steps:

- Selecting the dimensions that address stakeholder concerns about water reallocation's impacts on agriculture
- Finding data that are representative proxies of the dimensions of the problem
- Calculating the dimension indices from available data for different points in time and for different locations
- Calculating the composite index as a geometric average of the dimension indices

The dimensions we have chosen, as well as their indicators, include the following:

1. Economic well-being of a farmer
   a. Mean annual farm income
2. Economic well-being of a rural community
   a. Average annual employment at the county level
   b. Average education achievement
   c. Median annual household income level
3. Productivity of agriculture (entire sector)
   a. Total agricultural output measured in value of sales
4. Economic well-being of non-farm sectors
   a. Non-agricultural output measured in value of sales
5. Irrigated agriculture
   a. Surface and groundwater withdrawals for agriculture
   b. Proportion of irrigated land to total cropland

The first four dimensions will be used to calculate a composite index of economic well-being, and eventually compared across place and time to the irrigated agriculture index, which is listed fifth. Data will be collected at the county level, dating back to the late 1970s. Data sources are the National Agriculture Statistics Service, the U.S. Census Bureau, U.S. Geological Survey, Bureau of Labor Statistics, and the Bureau of Economic Analysis. A good example of our historical data is the median household income (Figure 1), which is an important proxy for how a county is doing relative to a statewide measure.

The data series will be collected into spreadsheets for ease of use and charting. Data series will extend for as long a period as appropriate given reporting conventions and availability. Hyperlinks to online data sources will be embedded in the spreadsheet for updating.

Once we have finished compiling the index, we'll ask an expert advisory group to review it and offer suggestions. After revision, we'll publish a written report with appropriate graphics in July 2014 that provides an historical discussion of the composite index. This will be made available on the Colorado Water Institute's website.

# Mapping Water Sharing for Agriculture in the Colorado River Basin

*Faith Sternlieb, Post Doctoral Research Fellow, Hebrew University, Jerusalem Water Policy Scientist, Colorado Water Institute, Colorado State University*

*Yampa River in the Upper Colorado River Basin, Colorado.*
Photo by Chris M. Morris

*Relationships between geography, hydrology, and governance in the Colorado River Basin were studied, with an emphasis on how interest groups, water sharing, and governance patterns influence each other.*

## Introduction

This article presents the research conducted for my doctoral dissertation, entitled *Water Sharing Across Boundaries in the Colorado River Basin: Mapping Agricultural Policies, Data, and Perspectives*, presented and defended January 22, 2014 for the Department of Geosciences at Colorado State University. This research demonstrates the relationship between geography, hydrology, and governance, especially as it pertain to rules and policies about agriculture in the Colorado River Basin (CRB). This relationship is shown in three ways: through (a) an analysis of water sharing arrangements (WSAs) which resulted in a boundary typology (Chapter 2); (b) the application of the boundary typology in a geospatial environment exemplified by WSAs (Chapter 3); and (c) an analysis of social perceptions through interviews with farmers, agricultural producers, and agricultural water managers in the basin applying the boundary typology (Chapter 4).

The culmination of these analyses includes: a literature review of boundaries from a geo-political perspective; a historical account of the shifting boundaries and policies in the CRB; the spatialization (representation of abstractions and selections of reality) of agricultural (Ag) water governance highlighting the Colorado River Basin Water Governance Geodatabase; and farmers' perspectives on natural and anthropogenic boundaries, many of which were instituted by the Bureau of Reclamation. The boundary typology seeks to explain discrepancies between the physical, political, and social (special interest) landscape that shape decisions surrounding Colorado River water.

Key terms include:

- **Agricultural water governance** is the rules, policies, organizational structures, and tools that structure how people produce agriculture, including how they access and use water for agriculture.
- **Boundaries** mark both similarities and differences. They can be bonafide (anthropogenic boundaries) or fiat (natural boundaries); they can be obvious or discreet; and they can be formed by different social, political, and environmental phenomena.


Figure 1. *The U.S. portion of the Colorado River Basin, Bureau of Reclamation Supply and Demand Study (2012).*

- **Governance layers** are defined by two key components: (a) mandated or naturally occurring geographic boundaries and (b) decisions made based on those boundaries, converting discreet boundaries to geospatial boundaries.
- **Water sharing arrangements** defined broadly for the purposes of this research encompass the apportionment and reallocation of water resources between two or more users from one or more uses to another through mechanisms such as water markets, transfers, exchanges, banks, and contracts through natural or physical infrastructure and policy.

## Colorado River Basin

The CRB (Figure 1) is an international transboundary river basin, measuring 2,736 km (1,700 miles) long from Green River headwaters in Wyoming to the Gulf of California in Mexico and draining an area of 63.7 million hectares (246,000 sq. miles). The Colorado River is one of the world's most highly regulated river systems, where agriculture uses up to 75 percent of the available water, according to the CRB Supply and Demand Study conducted by the Bureau of Reclamation in collaboration with the seven basin states (AZ, CA, CO, NM, NV, UT, and WY). Ag water in the CRB is currently under pressure due to projected increases in population, water demand, and water use, as well as significant uncertainty in climate and future water supply. Special districts that manage the supply of Ag water to farmers and producers are situated at the center of these pressures.

## Chapter 2 Summary and Results: Shifting Boundaries

To answer the question of how shifting political and hydrologic boundaries in the CRB have impacted agricultural water governance, the second chapter: (a) proposes a typology of boundaries based on agricultural water governance in the CRB, (b) operationalizes the typology using water sharing arrangements within the CRB, (c) analyzes the changing nature and intersection between political and hydrologic boundaries, and (d) geospatially demonstrates emerging governance patterns and processes, which facilitate or inhibit water sharing across the basin (Table 1).

This research reveals that hydro-geopolitical boundaries at the state and federal level have become fuzzy, enabling WSAs. Second, the boundary typology coupled with geospatial representation reveals both political patterns and processes, especially as they pertain to Ag water governance. Third, the application of the boundary typology leads to a clearer understanding of water sharing, its challenges and benefits, patterns and processes, and decisions at multiple scales. Such an understanding informs the mechanics of governance in the agricultural sector, compounded by the governance complexities of other sectors, opening opportunities

Table 1. *Boundary Typology and Description*

| Boundary Type | Governance Layer | Description |
|---|---|---|
| Physical | Hydrologic | Based on natural drainage systems defined by the National Hydrology Dataset (USGS) |
| | Hydrographic | Based on drainage basin delineated by each state and tribe |
| Political | Statutory | Based on federal, state and tribal laws and policies |
| | Judicial | Based on US Federal/State, District and Appellate Court system |
| | Administrative | Rules and regulations based on governmental jurisdictions (federal, state, tribe, county, municipality, city) |
| | Temporal | Based on time/history largely due to sequential legal and political decisions |
| Sectoral | Agricultural | Based on social and political interests and supported by organizations' bylaws and occasionally reinforced by state statute |
| | Environmental | |
| | Municipal | |
| | Industrial | |
| | Recreational | |

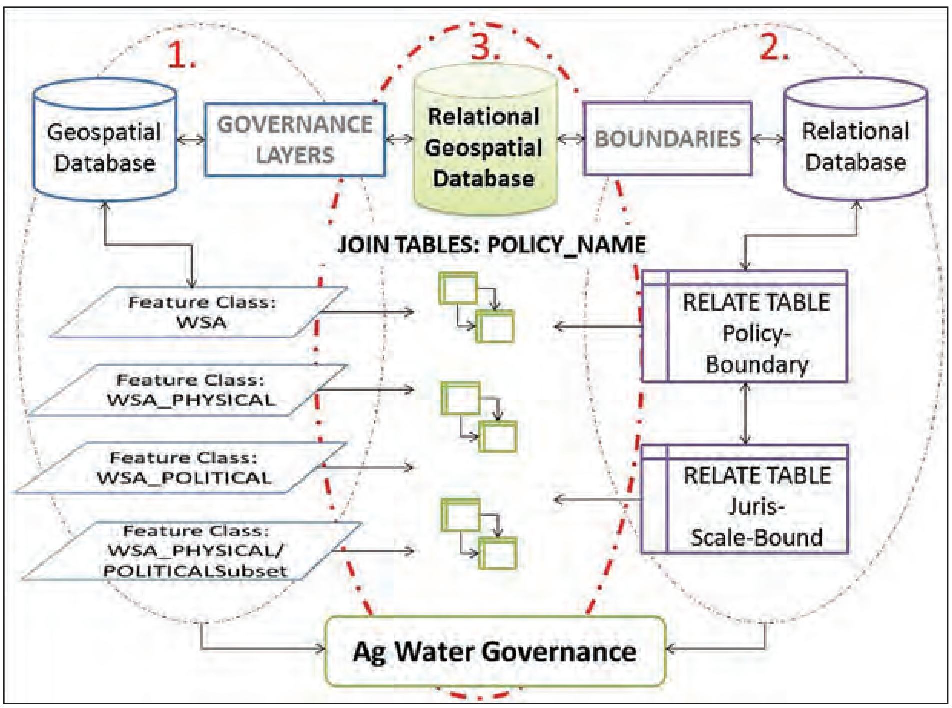


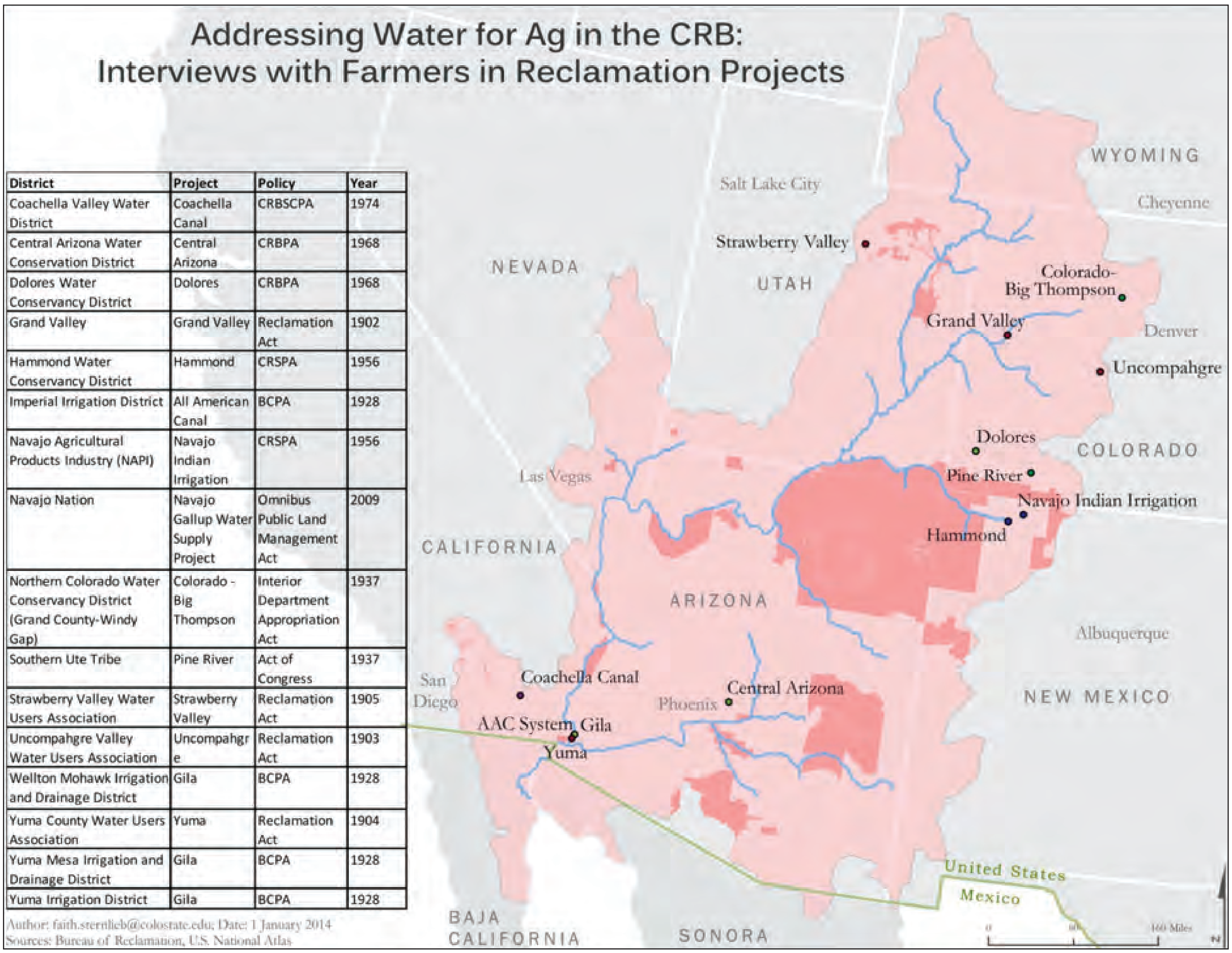

Figure 2. *The Relational Geospatial Database Architecture and Process. 1. The structure and process for the development of the geospatial database, 2. The relational database, and 3. The relational geospatial database, which is where the two databases are joined through a like item in their database tables (i.e., Policy_Name).*

for continued scholarship on transboundary water sharing.

## Chapter 3 Summary and Results: CRB Water Governance Relational Geodatabase

Chapter 3 responds to the need to better understand water governance as a geospatial phenomenon by describing the development of the CRB Water Governance Relational Geodatabase (WGRG) (Figure 2). The CRB WGRG responds to the need to better understand water governance as a geospatial manifestation by (a) applying the boundary typology (hydrologic, political and sectoral boundaries) in a geographic information system (GIS), (b) identifying geospatial governance characteristics, and (c) proposing governance layers as a method to integrate governance data in a relational geodatabase, with an emphasis on special interests—in this case, agriculture. The Environmental Defense Fund contracted the authors to initiate the development of the WGRG in 2010, which was further developed in conjunction with the USDA project, *Addressing Water for Agriculture in the Colorado River Basin*, and has been linked through the Geospatial Centroid at Colorado State University (centroid1.warnercnr.colostate.edu/flexviewers/CRB1/) since 2011. In addition to the application of the boundary typology, the WGRG is an application for the Ag water governance dataset.

Ag water governance is complex due to overlapping federal, state, and local jurisdictions in the CRB as well as




| District | Project | Policy | Year |
|---|---|---|---|
| Coachella Valley Water District | Coachella Canal | CRBSCPA | 1974 |
| Central Arizona Water Conservation District | Central Arizona | CRBPA | 1968 |
| Dolores Water Conservancy District | Dolores | CRBPA | 1968 |
| Grand Valley | Grand Valley | Reclamation Act | 1902 |
| Hammond Water Conservancy District | Hammond | CRSPA | 1956 |
| Imperial Irrigation District | All American Canal | BCPA | 1928 |
| Navajo Agricultural Products Industry (NAPI) | Navajo Indian Irrigation | CRSPA | 1956 |
| Navajo Nation | Navajo Gallup Water Supply Project | Omnibus Public Land Management Act | 2009 |
| Northern Colorado Water Conservancy District (Grand County-Windy Gap) | Colorado - Big Thompson | Interior Department Appropriation Act | 1937 |
| Southern Ute Tribe | Pine River | Act of Congress | 1937 |
| Strawberry Valley Water Users Association | Strawberry Valley | Reclamation Act | 1905 |
| Uncompahgre Valley Water Users Association | Uncompahgre | Reclamation Act | 1903 |
| Wellton Mohawk Irrigation and Drainage District | Gila | BCPA | 1928 |
| Yuma County Water Users Association | Yuma | Reclamation Act | 1904 |
| Yuma Mesa Irrigation and Drainage District | Gila | BCPA | 1928 |
| Yuma Irrigation District | Gila | BCPA | 1928 |

Figure 3. *Interview Locations*, Irrigation Districts, and Bureau of Reclamation Projects Across the Colorado River Basin. Policies include: Reclamation Act of 1902, Boulder Canyon Act of 1928 (BCPA), Colorado River Storage Project Act of 1956 (CRSPA), Colorado River Basin Project Act of 1968 (CRBPA), and the Colorado River Basin Salinity Control Project Act of 1974 (CRBSCPA)**.*

*In many locations, more than one interview was conducted.

**The map only shows CRBSCPA projects, which are under the authority of the Bureau of Reclamation. It does not include projects under the authority of the U.S. Department of Agriculture Colorado River Basin Salinity Control Program.

two different management systems in the Upper CRB and Lower CRB. Data collection reflects this complexity, posing multiple challenges for mapping scale. One such challenge is compilation from multiple sources, some of which are private and hold proprietary information such as data at the local scale regarding water rights. In addition, multiple scales of relevant data are collected for different purposes. Compounding scale challenges are the different types of data such as satellite imagery, paper maps, historical records, and field data collection as well as techniques used to collect data, including global positioning systems, surveying instruments, and photogrammetry, among others. Finally, data collection at a coarse versus fine resolution as well as disparate standards for metadata and minimal coordination in data collection efforts make it difficult to standardize datasets and to visualize governance through GIS.

## Chapter 4 Summary and Results: Agricultural Perspectives

Chapter 4 focuses on the postulation that Bureau of Reclamation projects facilitate water sharing within and outside of the irrigation districts that manage them. As part of a research team, we conducted interviews with farmers to ask what they think about the changes that are occurring around Ag water in the basin (Figure 3). A subset of interviews was extracted to specifically examine the boundaries that exist across multiple scales of Ag water governance, from the federal government to the irrigation district, specifically as they relate to Bureau of Reclamation projects. This study answers the questions:

- What are the boundaries based on farmers' perspectives?
- Can those boundaries be geospatially represented?
- Do they indicate the presence of water sharing?

By correlating interview responses to the boundary typology, responses validate the boundary typology and that physical, political, and sectoral boundaries are explicit (as well as new boundaries not previously considered). In addition, they show that farmers in Reclamation projects think about Ag water in the context of place, space, time, and scale, which constitute four dimensions of geography. In fact, farmers do not only think about boundaries—responses support the hypothesis that boundaries are not prohibitive. In other words, the political boundaries, which they identify, do not necessarily constrain their ability to engage in water sharing. Translating boundaries that were explicit in the interviews through governance layers reveals the spatial dimension of the interviews, enabling geospatial representation of the policies that may either confine or facilitate transboundary relationships.

> *"Hydro-geopolitical boundaries at the state and federal level have become fuzzy, enabling water sharing arrangements."*

## Conclusions

Transboundary analysis facilitates the study of WSAs by illuminating the role of key interest groups that are integral to decisions about Ag water governance, such as those embodied by sectoral boundaries. Fuzzy and shifting boundaries enable us to consider questions about interest groups and their role in shaping new patterns of governance, so when we consider a phenomenon like water sharing, we see boundaries in a new way. And describing the boundaries helps us understand the challenges of governance, including the need to consider overlapping boundaries and the patterns and processes they represent.

This research highlights a number of implications:

- Governance patterns and processes can be identified through transboundary analysis leading to a better understanding of the need for water sharing in water stressed systems.
- Data and geovisualization of governance patterns and processes enriches geophysical datasets and decision-making processes.
- Mapping policies, data, and perspectives about agriculture leads to better understanding about scale, place, and space.
- This database is a tool for water managers from any sector to identify how water is used and who is sharing it.

This database demonstrates the impact of policy on the landscape.

## Acknowledgements

I wish to express my eternal gratitude to my Ph.D. committee, Melinda Laituri (Chair), Reagan Waskom, Stephen Mumme, and Tanya Heikkila (University of Colorado-Denver). This research would not have been possible without funding from the Center for Collaborative Conservation, Environmental Defense Fund, and the U.S. Department of Agriculture (USDA), and the collaborative efforts of the USDA Planning Grant team.

# Social Network Analysis Techniques for Water Resources Management Workshop

*Margaret T. Herzog, Ph.D. Candidate, Department of Civil and Environmental Engineering, Colorado State University*
*Faculty Advisor: John W. Labadie*
*Co-Advisor: Neil S. Grigg*

*Shared Learning Environment at CSU.*
Photo by Kim Hudson

*The author created social network analysis workshop materials to use in an introductory workshop teaching social network analysis techniques employed in water resources management and research. Various formats were tested for effectiveness. Results suggest that SNA workshops should be expanded into a semester-long course to support more complex, multi-dimensional problem solving.*

## The Problem

Water resources issues today rarely have a clear technical solution. Competing water demands, water quality regulatory compliance, environmental flow needs, and sediment transport all contribute to the complexity of water problems. Fragmented rule-making authority spans federal, state, county, and local jurisdictions. Public, private, and leased lands intermingle, making landscape-scale wildfire, flood, and drought mitigation planning more challenging. Uncertainty in pollutant sources and their fate and transport makes it difficult to determine the most appropriate technical measures to improve water quality. Even when pollution sources and pathways are generally known, competing science and contrasting results may lead to disagreement over which corrective measures to employ.

## How SNA Training Can Help

Social network analysis (SNA) is a method for studying relationships and transactions between people, organizations, or other entities. By helping to analyze stakeholders involved in water and land use decisions, their competing interests, and underlying values, SNA may help resolve complex water issues. SNA can be used to plan stakeholder engagement processes to work toward shared understanding. Robust coalitions may then be built to address complex issues as a team. Knowledge, resources, and funds can be pooled toward more creative, longer-term solutions than any one group could accomplish on its own. Regulatory effects may also be better

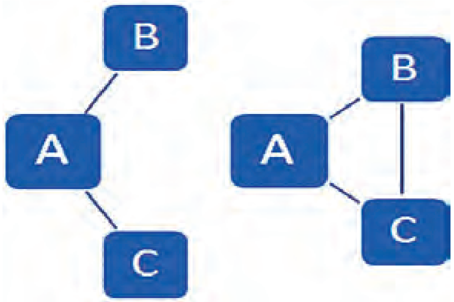



Figure 1. *Triadic closure: Friend A introduces Friends B & C, creating a relationship triad.*

aligned to reduce the economic cost of compliance.

SNA simplifies study of relationships as nodes (entities) connected with links (relationships). Software has been developed to manage data in a matrix format to permit statistical analysis of social network structural characteristics. This helps determine which nodes are the most important ones in each cluster, which nodes serve as brokers between clusters, and where gaps exist that may need to be bridged.

For example, one of the simplest social network concepts is the relationship that often develops among three friends. One friend may be friends with two others, who don't know each other yet. However, over time it's likely they'll be introduced and become acquainted, and maybe even start doing things together (Figure 1).

This happens often in reality because friends typically have much in common, so their friends tend to be similar, too. This makes it easy to create a group of likeminded individuals. At the group level, different environmental groups may have a lot in common, so they may also meet together at annual events or through community volunteer efforts. Oil and gas companies, though competitors, may also get together at trade shows and professional events. However, oil industry and environmental groups often have opposing interests and tend to avoid one another, unless facing off in a courtroom or other public proceedings. This tendency to conglomerate in groups of like-minded community and business interests further complicates the issue of fragmented regulation and land management. In contrast, brokers that can bridge these different interests toward mutual benefit can create more dynamic structures. As more groups bridge the divides, information and resources have more ways to flow, and transactions can be executed with fewer intermediaries. Stronger, community-wide relationships may also permit more rapid, coordinated response to unexpected events. By creating more cohesive groups more strongly tied to a wider variety of other organizations, such improved core-periphery social structure can support more effective water and natural resource management. Consciously focusing on this goal is difficult without formal analytical methods, which SNA provides. By training more technical professionals in SNA techniques, they may be able to more systematically foster the antecedents necessary for more effective, joint decision making. Technical professionals will also learn that actively seeking a diversity of knowledge about complex social-ecological systems from community members will improve their own ability to plan and design civil projects for systems-wide improvement.

## Methods

To achieve improved cooperation, it is important for technical disciplines to learn new strategies like SNA. However, no CSU course in engineering, agriculture, or natural resources includes SNA methods. Therefore, after extensive SNA methods research, the utility of SNA was tested in a watershed-scale nutrient management case study. Then results were used to create a half-day workshop with support of CSU TILT instructional designers and research-based instructional methods. In the fall of 2013, two offerings of the SNA workshop were provided to interested Colorado State University (CSU) students, faculty, and community members. A few experts in SNA-related application were invited to each session to provide more real world insight. In the spring of 2014, SNA training techniques were further tested in three additional formats. First, SNA results were provided in a 20-minute segment of a three-person expert panel on SNA applications. Next, a shorter version of the half-day workshop was presented during one class period of a communications course for Metro Denver, One World-One Water (OWOW) undergraduate students. Finally, a full-day introduction to SNA software methods was provided to CSU Natural Resources, Conservation Leadership through Learning (CLTL) program students.

## Results

About 30 participants attended the two, four-hour fall seminars rather evenly divided among engineering, agriculture, natural resources, and other technical disciplines. Twenty people attended the spring panel, and 11 OWOW and 19 CLTL students attended their sessions. Thus, over 80 people received training through this study grant. Most came to solve work-related or community participation problems or for research or personal interests.

Having the fall workshops set around a large, oval table was more conducive to shared learning than the spring classroom sessions. Attendees enjoyed high interaction, guest speakers, and developing greater consciousness of sociology concepts and social network features. Two common takeaways were focusing on bridging groups and encouraging constant, incremental structural improvement in practice.

One frequent comment was a desire to learn SNA software, which could not be introduced in the half-day session. Therefore, the SNA workshop was expanded to a full-day session for CSU CLTL students to try to include software training. Students could select from one of four demos to explore for each collaborative they had studied in class in previous weeks. Although the software introduction was not as effective as hoped, lessons learned by the group can be applied to make future software sessions more effective.

## Discussion

As an initial SNA introduction, a small group session format was quite successful. Conducting the SNA introduction around a central meeting table and including a shared meal seemed to be the most effective shared learning environment.

SNA workshop participants agreed that SNA was a useful framework to improve management of complex social-ecological systems. However, there was less agreement that employing SNA software to more systematically analyze relationships and transactions would be worth the learning curve. Perhaps, if training were provided in shorter sessions throughout a college semester, students could more easily digest each new concept. SNA software could then be introduced in a more stepwise fashion as each new SNA concept was introduced.

## To Learn More About SNA

If you are interested in SNA, please visit the SNA workshop companion website at sna.wateractionnetwork.org for online software, textbooks, and course links, or to schedule an SNA workshop for your class, organization, or community group.


*Student facilitator teaching SNA workshop at CSU, October 29, 2013.* Photo by Kim Hudson

# Conjunctive Use of Groundwater Extraction and Rainwater Catchment to Sustain Community Living on Micronesian Atoll Islands

*Corey Wallace, Master's Candidate, Department of Civil and Environmental Engineering, Colorado State University*
*Faculty Advisor: Ryan Bailey*

*Water supply in Federated States of Micronesia atoll islands was quantified, including the temporal variability of groundwater supplies and the necessary rainwater catchment supplies for drought. The author is traveling to Micronesia in fall 2014 to present results of the groundwater modeling study and educate on the use of the rainwater catchment model.*

In regard to freshwater supply, communities on atoll islands are some of the most vulnerable in the world. Island residents rely primarily on rooftop rainwater catchment systems (Figure 1) to fill their domestic water needs, with fresh groundwater used as a secondary water source. However, during intense El Niño induced drought, both groundwater and rainwater supply can become depleted, requiring the island communities to import water from neighboring islands, many of which can be hundreds of miles away. The objectives of this project are to quantify the temporal fluctuation of stored rainwater and available, extractable fresh groundwater for atoll islands in the Federated States of Micronesia, particularly during times of major drought. A numerical groundwater flow and transport model is used alongside a rainwater catchment water balance model to quantify time-varying stored groundwater and rainwater, respectively, and results are compared to observed field data and conditions. Also, the rainwater catchment model is used to determine required rooftop and storage tank dimensions to sustain communities during a major drought. As such, this project provides communities living on these atolls with information and guidance to ensure adequate water supply derived from both ground and rainwater sources.

## Study Area

The Federated States of Micronesia is an insular nation in the western

*Coast of a Micronesian island in the South Pacific.*
Photo by Hadi Zaher

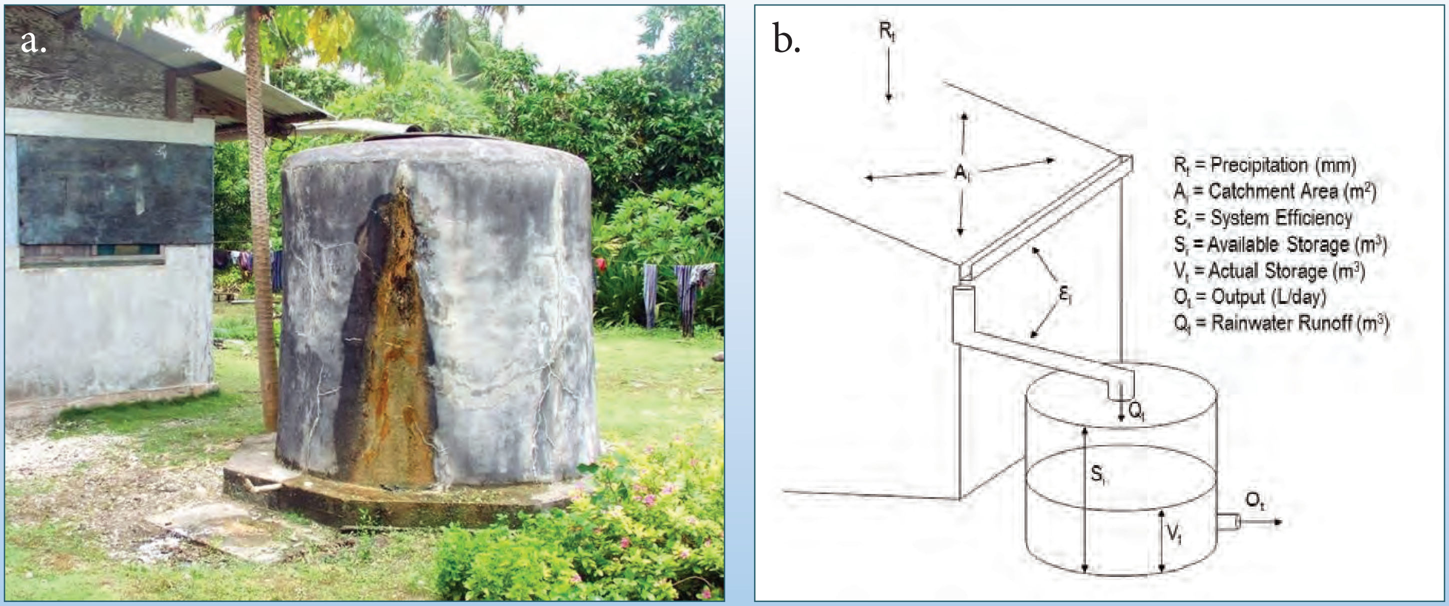



Figure 1. (a) *Example of a currently used household rainwater catchment system on Ulithi Atoll that employs a ferro-concrete tank in a state of minor disrepair;* (b) *shows a rainwater catchment system schematic detailing the various parts of a functioning system, including the roof catchment area, water transmission system, and storage tank.*

Pacific Ocean (Figure 2) comprised of four volcanic islands and 32 coral atolls. These atolls, each consisting of several small islands surrounding a shallow lagoon, have extremely small land surface areas and therefore cannot support populations greater than a few hundred people. Due to the high porosity of surface sediments, atoll islands are incapable of sustaining surface water sources such as streams or lakes. The absence of surface water sources necessitates the use of both groundwater extracted from the freshwater lens and rainwater collected using rooftop catchment systems.

## Groundwater Supply

A freshwater lens develops beneath the atolls as rainfall infiltrates through the sandy surface sediments. The density difference between rainwater and the heavier, highly alkaline seawater creates a freshwater zone directly beneath the land surface, shown in Figure 3, with a brackish transition zone between it and the seawater. Average annual rainfall depths in Micronesia range from three to five meters, with a general increase in depth from the western to the eastern regions. El Niño conditions, defined by seasonal temperature and precipitation fluctuations, can result in prolonged drought conditions, occurring mainly in the winter and spring months. Because the freshwater lens is dependent exclusively on precipitation for recharge, it is highly sensitive to fluctuations in climate, and fresh groundwater can become completely mixed with seawater during times of heavy drought. If stored rainwater volumes also become depleted (see next section), as happened during the 1998 drought, communities must rely on the import of water to sustain community living.

The behavior of the freshwater lens beneath atoll islands has been modeled in regions worldwide in an effort to understand and predict the quantity of groundwater under various rainfall patterns. To accurately model the atoll hydrologic system, density-driven groundwater flow models are used to simulate the interaction between higher density seawater and lower density infiltrated rainwater. In this project, we apply the Saturated Unsaturated Transport (SUTRA) model, developed by the U.S. Geologic Survey, to generic Micronesian atoll islands of varying

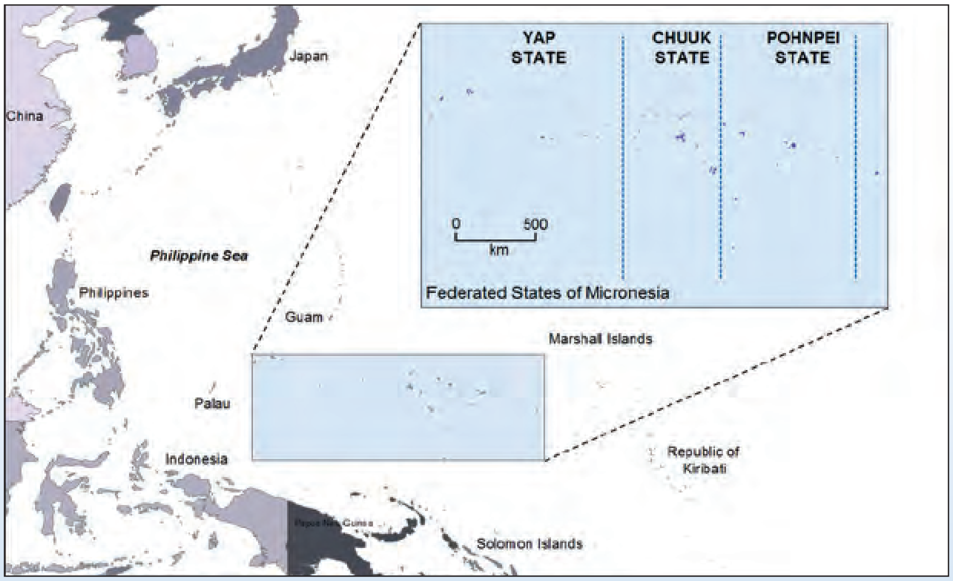



Figure 2. *Map of the western Pacific Ocean showing the location of the Federated States of Micronesia and three of the major states within the region.*

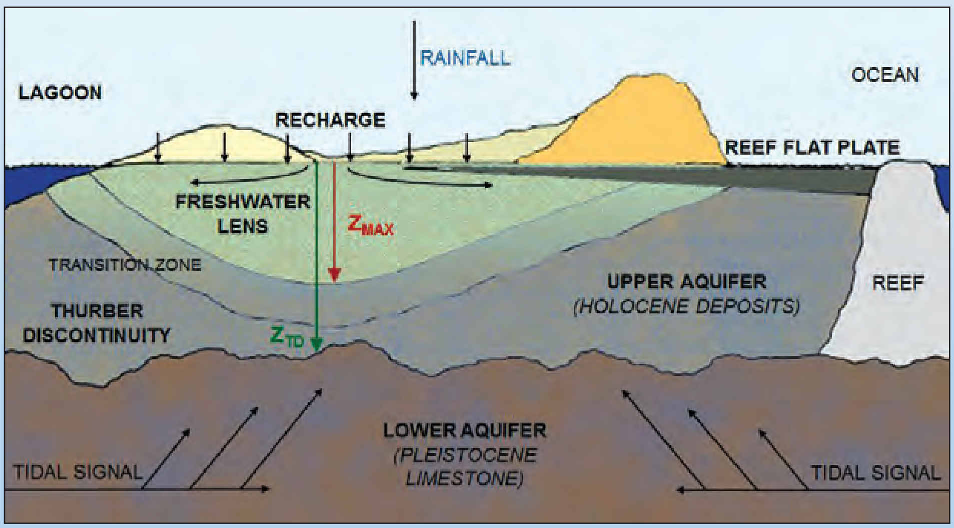



Figure 3. *Diagram of the hydrologic structure of atoll islands, with a freshwater lens developing beneath the atoll subsurface.*

widths and geologic characteristics, with a finite element mesh created for each island model. Then, using both variable historic and simulated future climatic conditions (tides, rainfall, sea-level rise), we examine the daily, annual, and decadal response and behavior of the freshwater lens. The freshwater lens delineation from a typical model simulation is shown in Figure 4, with areas of blue corresponding to fresh groundwater. Historical rainfall data is used to calibrate the SUTRA model parameters to more accurately reproduce observed values, which is essential to ensure the model functions properly. Using the calibrated model parameters, simulated future rainfall (from Global Circulation Models) is then used to study how the thickness and volume of the freshwater lens may change in the coming decades. Of keen interest is the effect of sea-level rise, which causes shore-line recession, thereby decreasing the width of the island, and an accompanying thinning of the lens. Preliminary results indicate that, while the freshwater lens can often sustain community life, its periodic depletion during times of drought must be supplemented by rainwater supply if residents are to maintain their current lifestyles.

## Rainwater Supply

Rooftop rainwater catchment is used extensively worldwide as a means to collect and store freshwater when surface or groundwater is not readily available, accessible, or is too heavily contaminated to treat economically. As seen in Figure 1, systems typically consist of a roof to act as the catchment area, a gutter system to deliver collected runoff from the roof, and a cistern to store the rainwater. Though tight restrictions are in place for implementation in Colorado due to conflicts with existing water rights, in regions that experience a pronounced wet season and dry season, such as Southeast Asia and on islands in the Pacific Ocean, rainwater catchment can play a vital role in filling public water demand.

Analysis of existing rainwater catchment systems in terms of daily captured and stored water volume is important for several reasons. First, understanding the performance of rainwater catchment systems currently used by communities can illuminate what issues exist and typify daily freshwater usage patterns. Second, knowledge of which system variables are most important to stored water volume allows for optimizing the system in terms of roof area and/or storage tank size, thereby helping to ensure future adequate stored rainwater supply. By improving the performance of the systems under different climatic conditions, issues such as inadequate storage during periods of low rainfall or potential contamination and degradation of collected rainwater can be prevented.

A number of past studies in regions around the world have used water balance algorithms to perform quantitative assessments of daily rainwater volumes and provide suggestions for improving rainwater catchment system sustainability. These water algorithms are based on the system variables shown in Figure 1B; are applied at daily, weekly, or monthly time scales; and typically analyze only individual household rainwater catchment systems without expanding the model to include catchment at a community scale. Moreover, no studies have quantitatively assessed the performance of rainwater catchment systems on small Pacific islands, for which rainwater is one of the primary sources of freshwater. This project applies the water balance model to Micronesian atoll islands, with the aims of (1) investigating the daily stored volumes of rainwater, particularly in time of major drought, and (2) identifying the parameters influential to system performance and providing design guidelines for adequate future storage on Micronesian atoll islands.

Using daily measured rainfall for the years 1997-1999, during which a major drought occurred in 1998, and including each of the household catchment systems of Nikahlap Island, Pohnpei State, in the water balance algorithm, the total daily end-of-day stored water volume is calculated, with results shown in Figure 5. Though currently the systems perform adequately only during wet periods, optimization of the rainwater catchment systems could potentially result in adequate rainwater supply year-round, a necessary trait if rainwater supply is to supplement groundwater during drought periods. As with the groundwater modeling study, future decadal rainfall conditions will be imposed on the rainwater catchment systems to determine if rooftop area and storage tank size are adequate to maintain sufficient water for the island community.

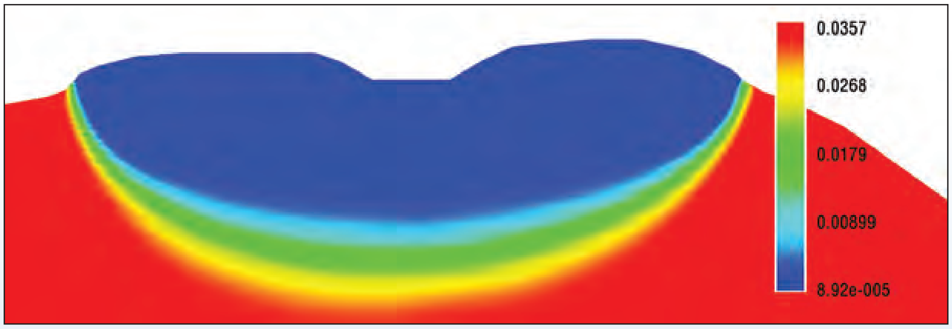



Figure 4. *Contour plot of the freshwater distribution beneath a 400 meter atoll island. Blue indicates areas where freshwater is present, while red represents salt water. A brackish transition zone is seen between the freshwater and seawater.*

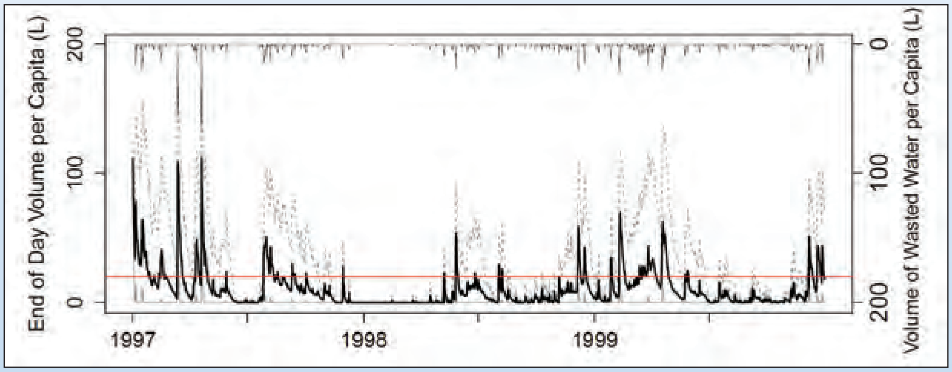



Figure 5. *Time series of simulated daily total volume of stored rainwater for a generic FSM atoll. The black line indicates the average of all scenarios, with the red line on the figure indicating the United Nations water use standard of 20 L/day per capita. The volume of wasted water is inversely plotted to show the relationship between the periods with a large amount of storage and the associated volume of water lost when storage tank capacity was exceeded.*

## Summary and Future Work

Future research for this project will include the development of a three-dimensional atoll island model that can be used to predict the volume of water contained within the freshwater lens as compared to the current two-dimensional model, which can predict only the depth to which freshwater extends. Results from these model simulations will not only allow for more accurate prediction of groundwater volume during times of prolonged drought, but also provide the opportunity to incorporate rainwater catchment systems into the model to simultaneously tabulate the volume of rainwater stored under simulated conditions. In addition to rainfall patterns, future sea level rise will also be incorporated and analyzed. Utilizing predicted rise rates under several different future climate scenarios, the potential reduction in groundwater volume beneath the atoll islands can be estimated. Sea level rise poses a significant threat to the sustainability of island communities, because even a minor reduction in the surface area of low-lying atoll islands can considerably reduce the width of the island, and therefore the volume of water the aquifer is capable of storing.

Integrating the use of groundwater and rainwater supply is vital to ensuring adequate water supply on Micronesian atoll islands. This fall I will travel to Micronesia to educate island communities on the use of the rainwater catchment model and to present results of the groundwater modeling study. By conjunctively using groundwater and rainwater supply, and designing rainwater catchment systems to optimize storage, it is hoped that community life can be sustained on low-lying atoll islands and that proper water resources planning can occur for future climate conditions.

# Estimating Sublimation in the Upper Colorado River Basin

*Morgan C. Phillips, Ph.D. Candidate, Department of Atmospheric Science, Colorado State University*
*Faculty Advisor: Nolan J. Doesken*

## Introduction

Water reserves stored in the form of mountain snowpack provide the primary source of water for the population, agriculture, and many high and middle elevation ecosystems throughout much of the western United States, particularly in the Upper Colorado River Basin (UCRB), where at least 70 percent of annual flow originates from snowmelt alone. While loss of mountain snowpacks through the process of sublimation is recognized as an important factor in the removal of water throughout the winter season, there is little information on the magnitude and spatial variability of sublimation losses.

Quantifying sublimation is problematic due to the difficulty in obtaining direct observations. The task is further complicated by the uneven vertical distribution of snowfall within forest canopies and redistribution by wind, both of which complicate obtaining accurate measurements of snow accumulation and loss.

## Research Questions

The main objective of this investigation is to provide reasonable estimates of sublimation over a large mountain catchment for multiple years. This includes variations on both the inter-annual and sub-annual timescales, and across spatial gradients of elevation and land cover. In light of the effects of the recent mountain pine beetle outbreak on forest cover, particular emphasis will be given to the influence of vegetation on sublimation characteristics.

## Methods

Due to the difficulty in measuring sublimation and the remote nature of high mountain catchments, a physically based snow evolution model was used to simulate snow processes and provide an estimate of sublimation. This study employed SnowModel, which has been used extensively in the past to simulate snowpack evolution in a number of different environments and locations.

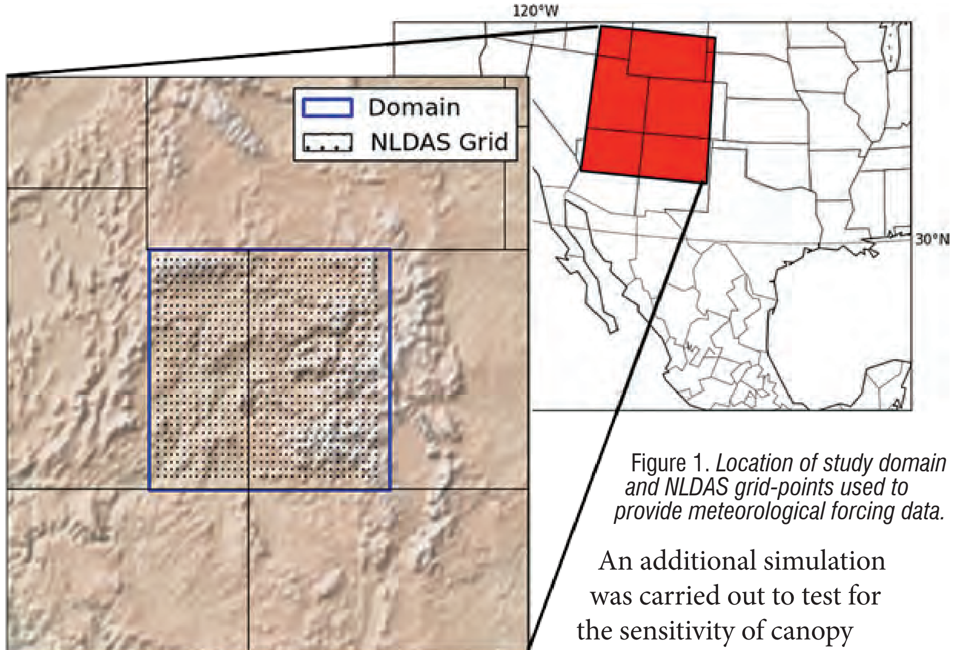



Figure 1. *Location of study domain and NLDAS grid-points used to provide meteorological forcing data.*

The study domain was chosen to be a square region roughly centered over the UCRB covering an area of approximately 180,000 km$^2$ and ranging from an elevation of 1,115 m to over 3,500 m at the highest mountain peaks. Meteorological input for the model was obtained using gridded reanalysis data from the North American Land Data Assimilation System (NLDAS). The model was then run using hourly time steps for 10 years, from October 1, 2001 through September 30, 2011. The model grid size was chosen to be 250 m in order to best capture the small-scale effects of slope and aspect on snowpack evolution.

An additional simulation was carried out to test for the sensitivity of canopy sublimation by modifying the leaf area index (LAI) of the conifer land-cover type in the model to follow observations of needle loss on Lodgepole Pine stands (*Pinus contorta*) impacted by the Western Mountain Pine Beetle in western North America. LAI for the conifer land type was reduced by 30 percent, and a one-year simulation for WY 2004-2005 was then run using the altered values of LAI and output saved at the end of each model day.

## Results

The majority of the sublimation estimated by the model resulted from canopy loss, with sublimation from blowing snow only contributing a small amount to the overall amount of sublimation. Despite sublimation from blowing snow only consuming a small amount of the overall sublimation budget, the small area over which it occurred in the simulations attests to the efficiency at which blowing snow is capable of returning water from the snowpack back to the atmosphere.

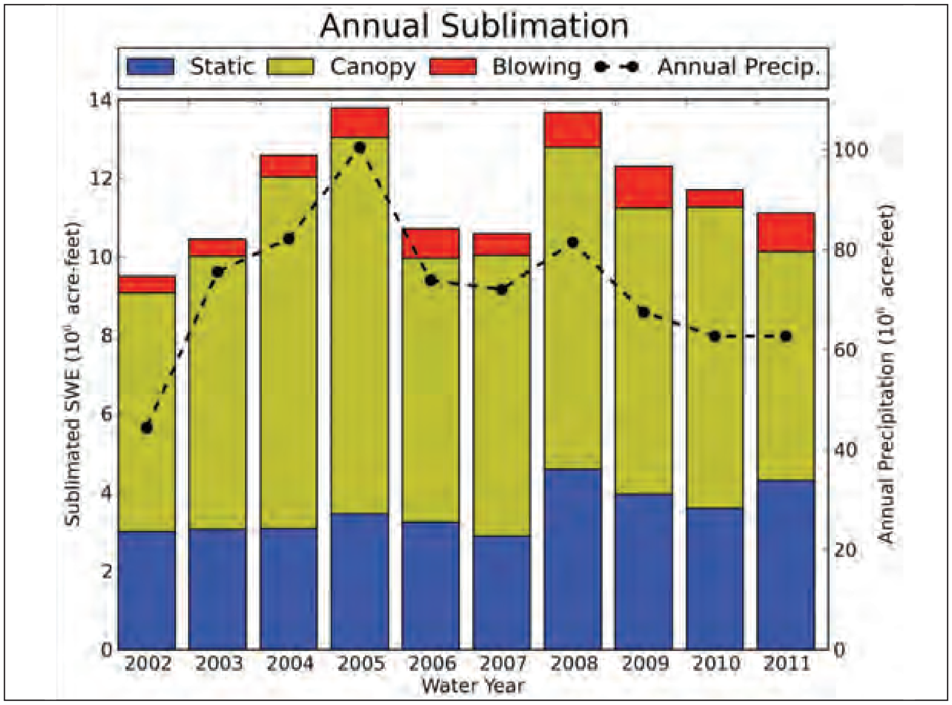



Figure 2. *Annual Domain total sublimation by type from October 1, 2001 through September 30, 2011.*

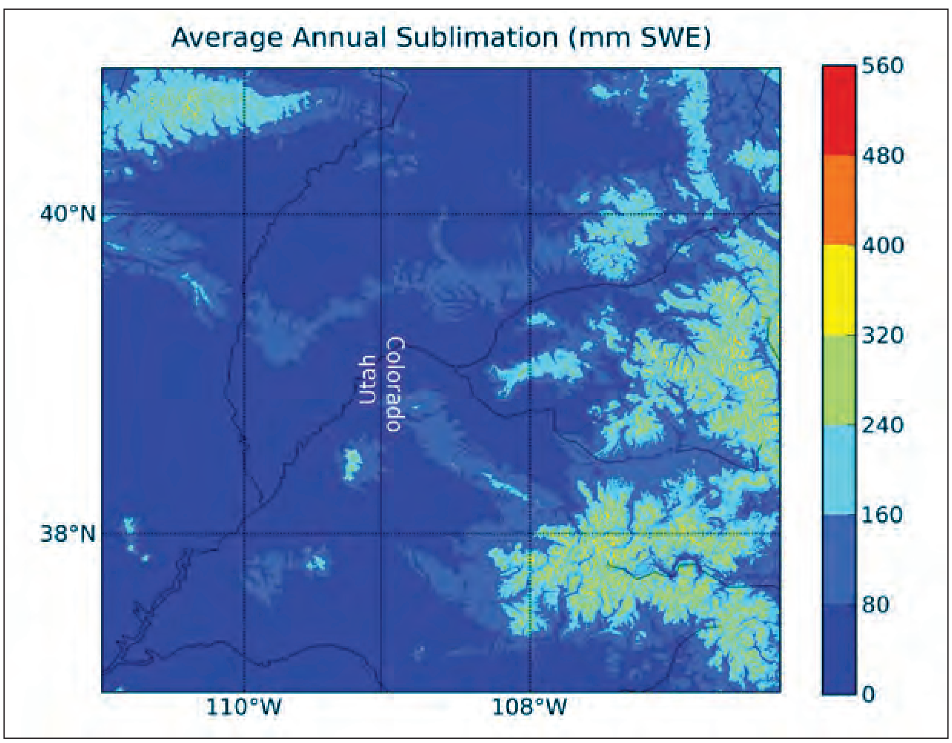



Figure 3. *Average annual sublimation simulated from October 1, 2001 through September 30, 2011.*

Average annual simulated total sublimation shows a distinct elevation gradient, maximizing on the windward slopes of high elevation alpine regions in central and southern Colorado and minimizing in the drier valley locations. The magnitude of annual average sublimation ranges from 1-10 mm in the sheltered valleys, to isolated amounts exceeding 500 mm on preferred upwind aspects of high alpine terrain.

### Canopy Sensitivity Simulation

Results from the canopy sensitivity simulations show an overall change in total sublimation for the sensitivity run of five percent less than that estimated in the control run. Reduction in LAI also resulted in an increase in snow that falls from the canopy after first being intercepted and a decrease in average canopy storage throughout the study area. Additional runs were made for the same water year with a 15 percent and 60 percent reduction in LAI to test the models sensitivity to various LAI values, with a near linear trend in resulting sublimation changes.

## Discussion

### Spatial and Temporal Variability

Sublimation peaks during the late winter and early spring period when wind speeds are greatest and average RH values begin to decline. This is important, because it roughly corresponds to the time of peak snow water equivalent (SWE) accumulation when most water supply forecasts are being made. As a result, sublimation loss at this time of year has the potential to lead to overestimation of water stored in the snowpack.

On sub-annual timescales, results show that sublimation has a tendency to occur during discrete time periods of increased sublimation, which are then followed by corresponding periods of little or no sublimation. Sublimation events tend to occur in cycles of about three to five days when dry and windy meteorological conditions lead to efficient removal of water vapor by turbulent mixing and large vapor pressure gradients between the snow surface and the atmosphere. These 'sublimation storms' resulted in removal of approximately 3 mm of SWE in this simulation, but have been reported by other investigations to consume up 9 mm of SWE from the snowpack during a single event.

Model simulations reveal an increase in sublimation across gradients of elevation throughout the domain. Not only do high elevation areas lose the most water from solid phase transition, but they lose it at a greater rate than low elevation areas. This relationship of increasing sublimation with altitude has profound implications on the role that sublimation plays in the water balance of mountain environments, indicating that the greatest impact from sublimation is felt in areas with the highest concentration of snow pack water. The highly ventilated environment of these high elevation alpine zones provides adequate driving force to efficiently transition mass from the solid to vapor phase, and also has a large reservoir of water to act upon in the form of deep snowpacks that remain exposed to the atmosphere for much of the year.

### Canopy Sublimation

The relatively high contribution of sublimation from snow intercepted by the forest canopy to the overall sublimation budget illustrates the importance of accurately simulating the correct vertical distribution of snow in the model, and is of particular interest given the widespread pine forests found in the snow accumulation zones of the UCRB. Reducing the LAI leads to less interception and increases the amount of snow stored on the ground, where lower wind speeds and smaller surface area acts to limit the amount of water lost to sublimation. In terms of the local water balance, retaining this water would result in at least some additional runoff, and could represent a net contribution to the overall water supply in the UCRB; however, this effect is tempered by the non-uniform pattern of infestation. Furthermore, any additional runoff generated by reduction in LAI is unlikely to persist in the long term due to re-growth and replacement of forest cover.

### Model Performance

While the estimates of sublimation found in this study fall within the bounds of previous observations, there was no direct validation of the modeled sublimation from this particular study to provide any degree of certainty in the sublimation estimates. Validation of precipitation and Snow Water Equivalent (SWE) with Snow Telemetry (SNOTEL) observations indicated that the model generally followed trends observed in the real world, but fell short of matching real world observations of snow metrics at statistically significant levels.

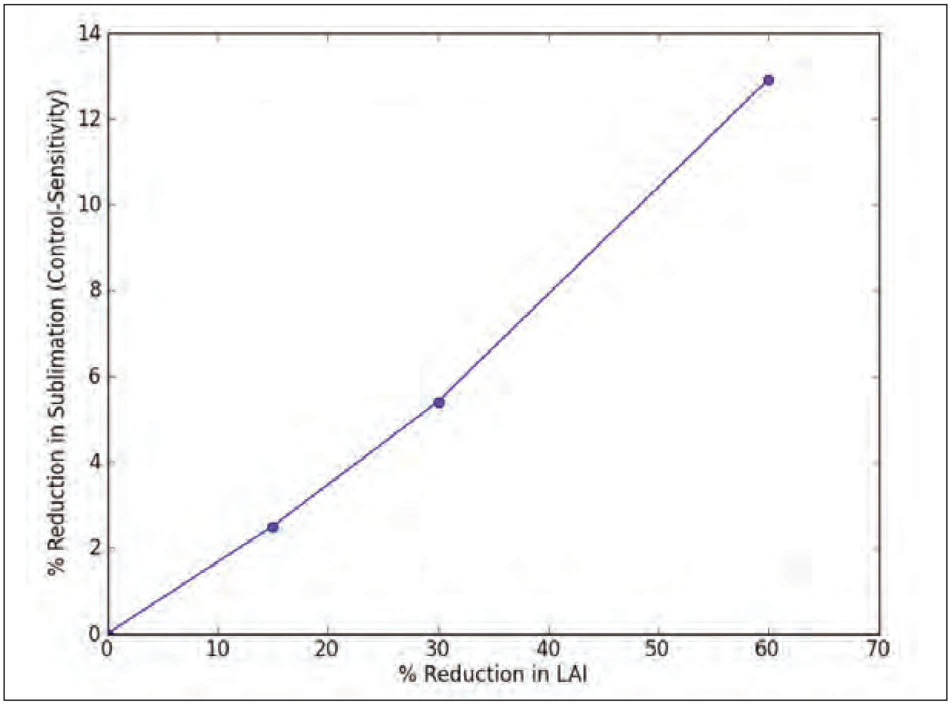



Figure 4. *Percent reduction in leaf area index vs. percent reduction in total sublimation from control year.*

## Conclusions

Based on the results of this study, the author concludes that

1. Sublimation is a major component of the water balance within the UCRB, and results in a significant loss of snowpack water
2. Sublimation generally increases at higher elevations, with a sharp increase in sublimation above 3,500 m elevation
3. Model derived sublimation is most efficient when snow is blowing or saltating
4. The magnitude of sublimation varies greatly on inter-annual timescales
5. On daily time scales, sublimation appears periodic in nature, with 'events' of enhanced sublimation resulting in substantial loss of water from the snowpack for short periods (a few days at a time)

The results from this study offer many new questions about the nature of sublimation and the processes that control snow pack evolution in general. Of particular interest is the response of sublimation to changes to the forest canopy in conjunction with the ongoing bark beetle infestation. The resulting net decrease in overall sublimation found in the sensitivity run illustrates that even subtle differences in the land surface can have profound implications on the water balance.

Future work will need to focus on obtaining accurate measurements of sublimation in order to validate the current models depiction of snowpack mass loss and gain a better understanding of this important part of the water balance.

# Discovering an Untapped Resource

*Janell A. Byczkowski, Water Resources Archive, Colorado State University Libraries*

As a graduate history student, I knew that one day I would need to make several trips to various archives to conduct primary research. This thought filled me with excitement as I pictured myself sifting through documents, images, and maps locating the perfect sources that preserved interesting stories and answered all of my research questions. But the thought of visiting an archive also caused some anxiety as I had never been given instruction on correct protocol, how to search for potential sources, organization of archives, and terminology. Like many current students, I decided to first jump online; I was either overwhelmed by all the information on archives' websites or frustrated with limited descriptions. Eventually I could not postpone visiting an archive any longer—I dove in, and through trial and error began traversing the archive world.

For the past year, I have had the opportunity to experience archives from the other side of the door, as an archive assistant for the Water Resources Archive (WRA) at Colorado State University. Learning the guidelines and methodologies that direct archive activities including acquiring donations, processing collections, creating finding aids, digitization, and promoting the various collections and archives has had a direct influence on my work as a researcher.

First, I have learned that not all archives are the same or equal. While this statement may seem too obvious to merit mentioning, the more one understands the factors that influence the creation, development, and management of an archive, the more realistic a researcher's expectations can be. For example, the WRA is housed within a land-grant university system, and has one full-time, professionally trained archivist, along with a few student assistants. The WRA's purpose—to collect and preserve materials from individuals and organizations that have been instrumental in the development of water resources in Colorado and the U.S. West—is topical and geographically defined. Availability to researchers is a central priority of the WRA, which is reflected in its detailed and informative finding aids and digitization projects.

In contrast, a local history archive created in conjunction with a local museum on the Colorado plains may not have the same resources to devote to full processing and creating a detailed finding aid. Collections may also be more limited to a very specific physical area or people. I have learned that understanding how different archives can be helps me have more realistic expectations in terms of how accessible the collections may be, how thorough the information online is, how helpful the finding aids are, and how long I may need to spend at the archive.

Another research strategy I have learned by working at the archive is to save valuable time by contacting the archivist. As a student coming from a generation that is dependent on the Internet for information, I forget the effectiveness of communicating with people. Archivists know the ins and outs of their collections and are a very useful source in targeting specific series, subseries, and boxes within a collection that may be relevant to one's research. Archivists are also part of a greater web of archives; a good archivist will work to stay informed as to where related collections are housed so they can point researchers to other useful repositories. As many archives have off-site storage, communication with an archivist prior to a visit can ensure a collection is accessible and at the reading room for the researcher.

Archivists create finding aids for the benefit of researchers, so use them—all parts of them! Of course, each archivist will format finding aids differently and provide varying levels of detail and

*A researcher examines photographs of a ditch repair project. The photographs are a part of a ditch company's collection housed at the Water Resources Archive.*
Courtesy of Water Resources Archive


*Ditch company minute books, letters, maps, and more contain ample research opportunities.* Courtesy of Water Resources Archive

*Water Resource Archives student assistants, Janell Byczkowski and Alan Barkley, analyze the different materials—maps, photographs, and ledgers—found in a Front Range ditch and reservoir company's collection and how potential researchers might utilize these sources.* Courtesy of Water Resources Archive

description, but when finding aids are available online, take note of all the information included. Before working at the WRA, I would conduct a quick keyword search to determine if anything of use existed. While this is not a poor strategy, I would have saved myself time if I would have read the series descriptions, how the archivists determined to arrange the material, the bulk dates, and history of the individual or organization.

I have also realized the importance of personally visiting the archive to view and touch the materials. I realize the constraints of time, money, and geographic location, but if at all possible, go to the archive to sift through the collection yourself. Many times collections arrive at archives with no apparent order. Through careful consideration, archivists assign order and arrange the materials based on what they deem to be the most logical. Practically, the archivist usually cannot itemize each document or object in the finding aid, but must make a judgment call on how much information to include. Therefore, it is important that the researcher comb through the boxes and folders in order to know if the material can be of any use to their projects.

Finally, I have come to understand that many archivists, particularly Patty Rettig at the WRA, want researchers to come and use the collections to inform their research projects. Archivists have invested time and energy into collecting, preserving, and processing collections they believe have value, and they want researchers from all disciplines to utilize the information stored in the documents and objects.

There are numerous and rich stories waiting to be found and told at the WRA. One such story is the interaction between ditch companies and towns along the Front Range like Fort Collins and Loveland after World War II. As these once primarily agricultural centers began expanding and transitioning to urban centers, new housing developments needed to be built. This extension came into contact with the established irrigation system—canals, ditches, and dams. Within irrigation company collections are the proposed maps of neighborhoods and the correspondence between the ditch companies and housing developers that record this shift from agriculture to urban.

The WRA especially wants to be available to CSU students—graduate and undergraduate. Engineering, liberal arts, natural resources, agricultural sciences, business, and natural sciences students may all find visiting the WRA to be beneficial in their variety of research topics. With all of the collections housed at Colorado State University, this resource is too convenient not to be considered by CSU students trying to identify a research or thesis topic. I encourage all scholars to take advantage of the WRA—contact Patty Rettig, read through the finding-aids, and come in to see for yourself the valuable information held within the rich collections.

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

# Rivers and *The Republic of Nature*

*Mark Fiege*, *History, Colorado State University*

I had always wanted to come to this magical confluence of water and time. For years I had felt the pull of the current and known that it would bring me here one day. It began when I was a boy and my dad read out loud from the great American novel by the author after whom I was named, and I experienced that dreadful moment when Huck and Jim realize that they had missed the turn in the foggy dark and now the river was bearing their little raft deep into an unknown country and to an uncertain fate.

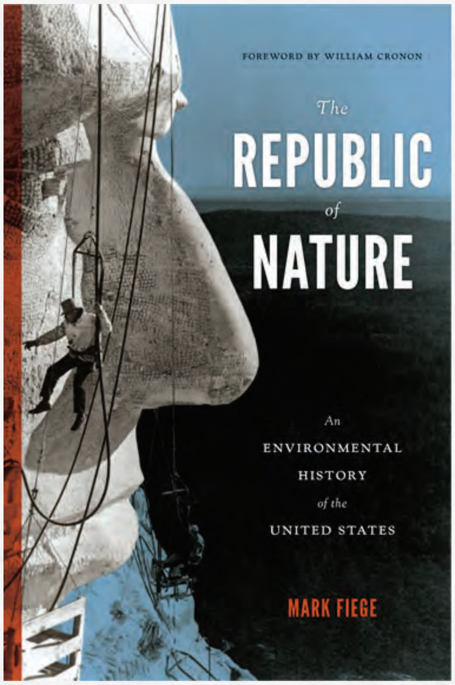
Decades later, the big book I was struggling to write became my own raft of sorts, and the current caught it and brought me to this place. If you write about the United States, sooner or later you will come to this confluence, or some other like it. It's hard to fight the current, and, like Huck and Jim, once you're in it, you have little choice but to go with it.

And so it carried me—and my wife and daughter, who joined me on the adventure—through mile after mile of cornfield and humid green forest, through the little town of Cairo ("kay-ro"), and down to the point defined by the converging waters of the Ohio on the left and the Mississippi on the right. The Ohio Valley was in severe drought that summer, and the river was so low that it stalled a good portion of the barge traffic. Under the hazy sky, in the air that felt like warm wet cotton, just beyond the mud flats, the hulking steel boats waited for the water to rise. It had taken me a long time, but at last, here we were, here *I* was, at a place where past and present collapse into one, a site that contains multitudes, a wondrous spot on the map of America where all things seem to begin, and to end.

I never anticipated how many rivers would run through the stories I wanted to tell, and how many of those rivers fed larger streams that flowed together at the point just south of Cairo. My book was about famous events in American history, about witches and declarations of independence, cotton and constitutions, atomic bombs and automobiles, soldiers and battles, laborers and iron rails. It was about a president, the best we ever had, stricken with grief by the violence that nearly shattered the nation. It was about an innocent child at a bus stop, caught in the pincers of historical movements that she scarcely could understand. The big point of this big book was that to tell big stories, the historian really had to bring in that wondrous, capacious thing called nature, the plants and animals, weather and microorganisms, hill and dale, flesh and soil that give physical form and substance to all earthly events. And yes, to tell those stories, the historian really had to pay attention to rivers.

Here is a sampling of the river stories that flow through America and that I navigated with *The Republic of Nature*. In the beginning, Madison, Washington, Jefferson, and others imagined a future in which rivers integrated in one secure, enlightened nation the vast productive powers of diverse regional environments. Little did the Founders imagine, though, how the currents swirling around the point at Cairo also served as instruments of oppression that carried untold thousands of people, many of them in chains, on fearsome journeys deep into a land of forced labor. In search of that story, I travelled up the Red River from its confluence with the Mississippi and along a lonely bayou lined with palmettoes to the forgotten place where Solomon Northup, the captive New Yorker depicted in the recent film *Twelve Years a Slave*, fought despair and waited for a chance at freedom.

Northup's story is a powerful reminder of how easy it is to forget, in our




era of highways, jet aircraft, and the Internet, how much past people's fates were channeled through rivers. So it was with Abraham Lincoln, who once steered a flatboat down the Mississippi past Cairo, past the mouth of the Red and the cotton plantations that would imprison Northup, and to New Orleans. The young Lincoln was a boatman as much as he was a rail-splitter, and like the Founders he admired, he imagined rivers as sources of prosperity, avenues of freedom, and the sinews of a great republic.

To understand Lincoln is to picture him on a river—to know his origins, head up the Mississippi from Cairo, up the Illinois, to the waters of the Sangamon as it drains the heart of the Illinois country. There, in 1831, at New Salem, Lincoln deftly horsed a flatboat over a milldam on which the craft had become stuck. A crowd of townspeople gathered to watch, and for the first time in his life, Lincoln got what politicians crave—the attention and approval of their fellow citizens. In my telling, his work on "the cool waters of the Sangamon gave birth to his political career."

The calluses on Lincoln's hands measured the significance of rivers to American history, but even the modern railroad systems that he advocated ran in tandem with those great streams. Go up the Mississippi from Cairo again, but this time, don't go as far as the Illinois. Just above St. Louis, on your left, is the mouth of the Missouri—the Mighty Mo, my dad called it. Follow the Missouri upstream to Nebraska, to the mouth of the Platte, and to Omaha. There, in the 1860s, railroads—and rivers—opened a mechanized path across the West. The Union Pacific, building out of Omaha, and the Central Pacific, laying track from Sacramento, followed routes created by the Platte, the Weber, the American, the Truckee, the Humboldt, and more. And not only did the railroads follow these riverine paths of least resistance, but locomotives also needed the fresh water in the streams. (Coffee made from the alkali ground water of the Great Basin desert formed "the meanest compound man has yet invented," wrote Mark Twain, but the alkali was as corrosive to boilers as it was to stomachs.) Thus flows the historical lesson: to build railroads in the nineteenth century was to mingle the nation's future with rivers.

"A river runs through it," Norman Maclean famously wrote, and what was true for his family on the Big Blackfoot in Montana was just as true for families everywhere else. Downstream from Omaha is Kansas City and the mouth of the Kansas River. Turn and head west, upstream to Topeka. In the late nineteenth century, thousands of African American families boarded steamboats and railroads and left the South for a better life somewhere else. Kansas was promising, but far from perfect, and those imperfections helped provoke the famous national desegregation case to which one Topeka family lent its name: *Brown v. Board of Education* (1954). The conditions that stirred the civil rights movement in the city were not merely social. A river and creek ran through Topeka, and the names of poorly drained, flood-prone black neighborhoods—Sandtown, Mudtown, and the Bottoms—revealed that the city's inequalities also were environmental.

I don't know if I will ever go back to the point where the Ohio and the Mississippi flow together, where water and history converge so powerfully. There are many other stories that I want to track down and tell, and I'm not sure any of them will carry me back to the muddy bank below Cairo. But if I do return, I will feel as I did the first time I was there—that I'm home, that I'm at the heart of an enormous natural heat pump, a vast hydrological engine that drives American history. Clinging to my raft, I will experience once more that irresistible current and the truth that it teaches, that *The Republic of Nature* is a republic of rivers. ●



# Kevin Fedarko and CSU's Confucius Institute Join CSU Hydrology Days

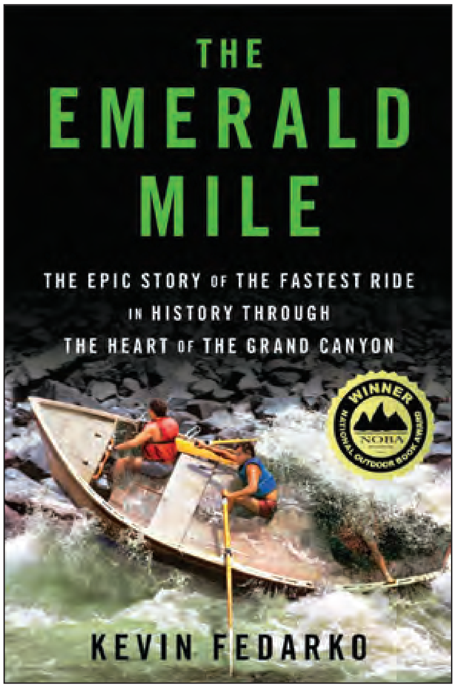
*Julie Kallenberger,* *Research and Outreach Coordinator, CSU Water Center*
*Jorge Ramirez,* *Professor, Department of Civil and Environmental Engineering*
*Emilie Abbott and Ajay More,* *Student Intern, CSU Water Center*

In conjunction with Colorado State University's (CSU) 34th Annual Hydrology Days, the CSU Water Center hosted Kevin Fedarko, author of *The Emerald Mile: The Epic Story of the Fastest Ride in History Through the Heart of the Grand Canyon* on Monday, March 24 at the Lory Student Center Theater. Over 130 campus and local community members gathered to hear Fedarko share this riveting story.

Fedarko first described his personal and professional backgrounds and how he was inspired to write about *The Emerald Mile*, a dory rafting boat, which in June 1983, accomplished the fastest journey down the Colorado River. Fedarko spoke about how he became a river guide so that he could experience firsthand the countless intricacies of the Colorado River and channel his experiences into his writing. During his journeys down the river, he, along with his fellow boatmen and rafting passengers, shared stories around the evening campfire about the river and its canyon, their majestic past, and their uncertain future. A particular campfire story that resonated with Fedarko described the historical flooding that occurred in June 1983 and the events that unfolded simultaneously over a few short days. He then decided to write and narrate his book based on the story of *The Emerald Mile*.

During the winter of 1983, the Upper Colorado River Basin experienced an unprecedented amount of snowfall, and with the onset of spring, a sudden surge in temperature and heavy spring rain caused all of the snow to melt in a very short period of time. Fedarko spoke in detail about the Glen Canyon Dam, situated at the upper end of the Grand Canyon. Its outlet works consisted of four 14-foot diameter pipes and two emergency tunnel spillways, each 41 feet in diameter. He described how the runoff had destroyed its emergency tunnel spillways, and consequently created the potential for uncontrolled releases which could exceed the dam's crest. This disaster was avoided by increasing the capacity of the reservoir by constructing plywood flashboards around the tops of the spillway gates, buying engineers precious time to evaluate the integrity of the dam. Still, enough water had passed through the emergency spillways to create the largest flood the Grand Canyon had experienced in the past 25 years. On Saturday, June 25, 1983, downstream rafters would soon experience the wrath of the water as it rushed down the canyon. One life was lost, and many more were forever changed that day. That same evening, three experienced rafters launched *The Emerald Mile* to experience the fastest journey down the Colorado River—a trip usually measured in days or weeks, not in hours. This reckless and defiant trip has been described by Fedarko as "one of the purest and most perfect journeys the Grand Canyon has ever seen, a voyage that embodied the essence of the river by moving through its corridor under conditions that were not only beset by immense

*The Colorado River near Marble Canyon in Arizona.*
Photo by Denny Armstrong




*The Emerald Mile* book cover.

*Troy Bauder (CSU, Department of Soil and Crop Sciences) demonstrates farm equipment used for experimental tilling to Chinese visitors.* Photo courtesy of Glenn Patterson

*Kevin Fedarko greeting community members and signing copies of The Emerald Mile before his presentation.* Photo by Kim Hudson physical challenges, but more important, were freighted with the extraordinary power of metaphor."

Fedarko shared many different perspectives that he encountered while writing his book, especially the damming of the Colorado River at Lake Powell. Even though many had a deep desire for the Colorado River to remain free flowing, Fedarko personally learned to appreciate the creative and brave efforts of the U.S. Bureau of Reclamation officials who were responsible for avoiding a catastrophic failure of the Glen Canyon Dam. He also described the fleet of boats whose names were fashioned after natural landmarks that were negatively impacted by humans. These names serve as a stark reminder that we must minimize our footprint on our natural environment, especially this beloved river.

Fedarko was formerly a staff writer for *Time* magazine. His work has been featured in *Esquire* and *Outside* magazines and has been included in *The Best American Travel Writing*. He lives in Santa Fe, New Mexico, and works as a part-time river guide in the Grand Canyon National Park.

Visit books.simonandschuster.com/Emerald-Mile/Kevin-Fedarko/9781439159859 to view more information about *The Emerald Mile*.

## Hydrology Days

The 34th Annual American Geophysical Union Hydrology Days conference was held March 24-26 at Colorado State University. More than 110 papers and posters were presented in sessions on topics addressing hydrologic and climatic variability and change, eco-hydrology, watershed science, emerging contaminants, water quality, fluvial geomorphology, erosion and sedimentation, snow hydrology, urban hydrology, and hydro-epidemiology. In addition, there was a special session on the hydrologic, meteorological, eco-hydrologic, and socio-economic aspects of the September 2013 Colorado floods.

*Fedarko speaking the Colorado River during his presentation.*
Photo by Kim Hudson

The Hydrology Days Award Lecturer was Professor William W-G. Yeh of the University of California at Los Angeles who gave the lecture, "Optimization of hydro-system management and operation." Other special presentations included the Borland Lecture in Hydrology, "Role of the environment in shaping malaria transmission in Africa," by Professor Elfatih A.B. Eltahir of the Massachusetts Institute of Technology, and the Borland Lecture in Hydraulics, "Eulerian and Lagrangian approaches in sediment transport, biogeochemistry and environmental law," by Professor Martin Doyle of Duke University.

In addition, the NSF-funded I-WATER program (I-WATER.ColoState.edu/) held its annual research symposium as an integral part of Hydrology Days where I-WATER fellows and faculty mentors presented their research projects. Topics included: flood, drought, energy development, watershed health, air and water quality, and ecosystem services.

Among the Hydrology Days participants was a delegation of faculty and water experts from China associated with the Confucius Institute at CSU. During the afternoon of March 26, The Confucius Institute and the CSU Water Center hosted a symposium on water and environmental sustainability which featured presentations from CSU and China researchers, as well as a discussion about potential joint research projects between CSU and China institutions. More information about the Confucius Institute can be found online at international.colostate.edu/cicsu/.

Proceedings and abstracts of Hydrology Days are available online at HydrologyDays.ColoState.edu/. Next year's Hydrology Days will be held the week of March 23.

Learn more about the CSU Water Center and upcoming events by visiting our website at www.watercenter.colostate.edu.

# CSU's Water Center Hosts Gathering for Water Faculty, Staff, and Students

*Julie Kallenberger,* Research and Outreach Coordinator, CSU Water Center
*Emilie Abbott and Ajay More,* Student Intern, CSU Water Center

On April 17, 2014, over 50 water faculty, staff, and students joined together to discuss water research, education, and outreach at CSU. Participants heard a series of presentations from faculty researchers, discussed the recently announced request for proposals (RFP), and shared ideas for water-related campus activities and next steps for the CSU Water Center.

Provost Rick Miranda welcomed the attendees and spoke about the mission and importance of a strong and vibrant Water Center at CSU. Miranda expressed his expectations of seeing the Center flourish and provide an important resource for faculty and students. Reagan Waskom, director of the Colorado Water Institute and chair of the CSU Water Center Executive Committee, moderated the meeting. Waskom first shared several accomplishments of the CSU Water Center since its reinvigoration last fall, including: the CSU Water MOOC (Massive Open Online Course), the weekly seminar series held during both the spring and fall semesters, the Water Center's involvement with CSU's Hydrology Days, the Confucius Institute Symposium, a presentation by Kevin Fedarko—author of *The Emerald Mile*, and co-sponsoring a forum on floods. The Water Center also publishes regular e-news mailings and a newsletter every other month, which reaches over 2,000 subscribers.

This was followed by presentations by faculty who had their proposals funded under the first cycle of CSU Water Center grant funding:

- Ashley Anderson, Department of Journalism and Technical Communication
  *Floods, Communication, and Climate Change: Exploring the Role of Media Use and Interpersonal Discussion in Connecting Water-Related Extreme Weather Events to Perceptions about Climate Change*
- Mary Stromberger, Department of Soil and Crop Sciences
  *Drought Stress Adaptation in Winter Wheat through Soil Microbial Interactions and Root Architecture*
- Mike Gooseff, Department of Civil and Environmental Engineering
  *Exploring the Water-Energy Nexus at CSU: Hydrologic Fate and Transport of Chemicals Used in Oil & Gas Development*
- Sheryl Magzamen, Department of Environmental Health and Radiological Sciences
  *Characterizing Biological Pollutants in Agricultural Runoff at Colorado Dairies*
- Dale Manning, Department of Agricultural and Resource Economics
  *Storage, Markets, and the Inter-Temporal Allocation of Colorado Water*
- Ed Hall, Natural Resource Ecology Laboratory
  *Developing Scholarly Excellence Across the Aquatic-terrestrial Interface: Understanding the Hydro-bio-geo-chemistry of Extreme Events*
- Sybil Sharvelle, Department of Civil and Environmental Engineering
  *Evaluation of Urban Nutrient Loading and Recommendations for Cost Effective Treatment Technologies*

*Alicia Shogbon, graduate student of Mike Gooseff, performs viscosity testing for their research on hydrologic fate and transport of chemicals used in oil and gas development.*
Photo courtesy of Molly McLaughlin

- Ellen Wohl, Department of Geosciences
  *WOOD: Windows of Opportunity for Debris Retention in Response to 2013 Front Range Flooding*

The presentations depicted the breadth of water research occurring at CSU and demonstrated how resources can be leveraged for larger projects and efforts. The presentations are available online at www.watercenter.colostate.edu/faculty_resources.html.

In addition, Melinda Laituri (Department of Ecosystem Science and Sustainability) provided an update on the redevelopment of the CSU Water Minor curriculum. Laituri is chairing a committee that has been tasked with assessing the current water minor's program and learning objectives, and to develop plans for additional courses and activities. The interdisciplinary minor is designed to offer undergraduate students of all majors the opportunity to engage in the many aspects of the water resources field. The curriculum consists of 21 credits in core and elective courses that are relevant to today's water challenges and taught by CSU water experts.

One of the Water Center's initiatives includes providing funding for projects which catalyze water research, teaching, and engagement through interdisciplinary collaboration and creative scholarship among faculty and students. These awards provide opportunities to accelerate progress in research and enable the academic and experiential realm of water resources for faculty and researchers at CSU. Three types of grants are available: Multi-disciplinary Proposal Team, Multi-investigator Project Team, and Water Faculty Fellow. Please visit the CSU Water Center website to download the full RFP.

The CSU Water Center has many exciting activities planned for the upcoming year. In addition to funding additional research proposals, the Water Center has plans to host and co-sponsor multiple water-related events on campus; organize a CSU Water Center Student Committee; foster strong partnerships with other CSU departments, centers, and institutes; and collaborate with local organizations and other water centers across Colorado on synergistic activities. The Water Center also plans to identify and foster opportunities for collaboration on international water issues.

*Ashley Anderson shares findings from her project focused on the role of social media in connecting extreme weather events to perceptions about climate change.* Photo courtesy of Ajay More

*To learn more about the CSU Water Center and its research, education, and outreach activities please visit us online at www.watercenter.colostate.edu.*

## Determination of Consumptive Water Use of Corn in the Arkansas Valley (Year 2)

*Allan A. Andales, Soil and Crop Sciences, Colorado State University*

*Co-PIs: Michael E. Bartolo and Lane Simmons.* This project will continue the long-term research to date, to more accurately calculate the $ET_c$ of major irrigated crops in the basin, by defining the crop coefficients ($K_c$) used to convert $ET_r$ to $ET_c$ values and by validating (ground-truthing) the $ET_r$ values calculated by the ASCE-PME for local conditions in the Arkansas River Basin. The more accurate calculations of $ET_c$ will improve estimates of river flow that are used to determine compliance with the Arkansas River Compact.

## Modeling the Influence of Conjunctive Water Use on Flow Regimes in the South Platte River Basin Using the South Platte Decision Support System Groundwater Flow Model

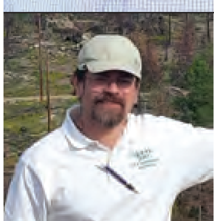
*Ryan Bailey, Civil and Environmental Engineering, Colorado State University*

The overarching goal of this project is to provide the Colorado Water Conservation Board (CWCB) with an independent evaluation of the SPDSS groundwater flow model, highlighting model capabilities, strengths and weaknesses. The proposed project is carried out over a three-year period.

## Continuation of Project Funded in 2013: Assessing the Agronomic Feasibility of Single-season Irrigation Deficits on Hay as Part of a Western Slope Water Bank

*Joe Brummer, Soil and Crop Sciences, Colorado State University*

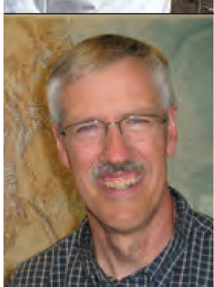
*Co-PIs: Calvin Pearson and Abdel Berrada.* Using side-by-side, i.e., "deficit" versus "business as usual" irrigation treatments, this project will answer basic questions about these approaches: 1) What is the likely impact on hay stand life, productivity (tons per acre), and quality due to a single-season deficit? 2) What is the potential range of marketable, saved (otherwise consumed) water per acre of single-season deficit irrigated hay in Western Colorado? and 3) Are there any obvious environmental benefits or concerns?



## Developing an Unmanned Aerial Remote Sensing of ET System

*José L. Chávez, Civil and Environmental Engineering, Colorado State University*

The proposed research will integrate proven remote sensing (RS) sensors into a small unmanned aerial system (sUAS). Data derived from the aerial RS platform will be used to develop a suitable RS of crop evapotranspiration (ET) method for Colorado.



## Improving Data Quality for an Enhanced Climate Data Delivery System for CoAgMet (Colorado Agricultural Meteorological) Network

*Nolan J. Doesken, State Climatologist, Colorado State University*

*Co-PI: Wendy A. Ryan.* With this funding request, the Colorado Climate Center will continue to develop, improve, and maintain a climate data system for Colorado. These funds will be used to build more robust data quality control into the CoAgMet database so that users are aware of potential problems with data inputs and to update equipment to be used throughout the network.

## Data Collection and Analysis in Support of Improved Water Management in the Arkansas River Basin

*Timothy K. Gates, Civil and Environmental Engineering, Colorado State University*

*Co-PI: Jeffrey D. Niemann.* For over fourteen years in the Lower Arkansas River Basin and three years in the Upper Arkansas River Basin, CSU has conducted extensive field monitoring to build a database to characterize the stream-aquifer system and to undergird existing and future modeling tools. The purpose of this project is to collect and analyze key field data in representative regions of the Arkansas River Basin needed to maintain and enhance the database.

## Development of Visualization Tools for the South Platte

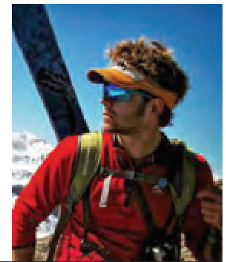
*Steve Malers, Chief Technology Officer, Open Water Foundation*

This project will build on South Platte Decision Support System (SPDSS) data and tools to create reusable and operational data visualization tools that can be used to educate the public, public servants, and professionals about water resource issues in the basin.

# FY14 CWI Funded Projects

March 1, 2014 - February 28, 2015

## Ecological Functions of Irrigation Dependent Wetlands

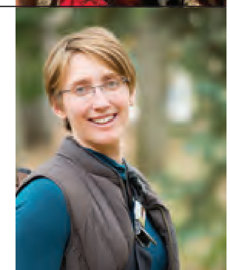


*Erick Carlson, Wetland Ecology, Colorado State University*

*Faculty Advisor: David Cooper*

This research will quantify and compare the ecological functions of natural and agricultural wetlands at study sites in Larimer and Weld counties in Colorado. Wetland profiles will be combined with information about the irrigation infrastructure and potential alterations or net reduction in water allocations. Carlson will develop a spatially explicit method to assign risk levels to wetlands under a scenario of reduced water.

## WOOD: Windows Of Opportunity for Debris Retention in Response to 2013 Front Range Flooding

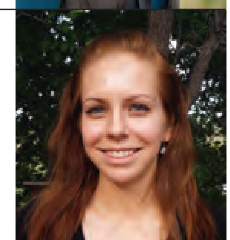


*Natalie Anderson, Department of Geosciences, Colorado State University*

*Faculty Advisor: Ellen Wohl*

This study will provide guidelines on instream wood risk assessment and management that will be disseminated to practitioners in the Front Range (May 2014) and a peer-reviewed journal article summarizing the project and the guidelines (Dec 2014). These guidelines will help water and natural resources managers make decisions about instream wood.

## The Effect of Normative Trends on Water Conservation

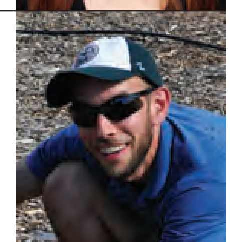


*Anastasia Bacca, Psychology, Metropolitan State University of Denver*

*Faculty Advisor: Chad Mortensen*

A past study found that communicating that the number of people conserving water was increasing led to people using significantly less water. This study will test a different conservation method and determine whether results are similar when the number of people conserving is a numerical minority, but still increasing.

## Impact of Limited Irrigation on Health of Three Ornamental Grass Species



*Samuel Hagopian, Horticulture, Colorado State University*

*Faculty Advisor: James Klett*

This study will determine the growth response of three ornamental grass species that are commonly marketed throughout Colorado nurseries and garden centers. Researchers will evaluate water requirements, drought tolerance, visual appeal, and overall performance of three commonly used ornamental grass species.

## Nutrient Retention and Productivity in Rocky Mountain Streams Under Alternative Stable States

*Adam Herdrich, Department of Fish, Wildlife, and Conservation Biology, Colorado State University*

*Faculty Advisor: Dana Winkelman*

As part of a larger project examining loss of large woody debris (LWD), this project focuses on how trout populations in high elevation streams are affected by comparing streams with high and low amounts of instream LWD. The study will compare individual growth rates, population growth rates, biomass, individual lipid content, length/weight regressions, and diet with the goal of creating endpoints for restoration projects.

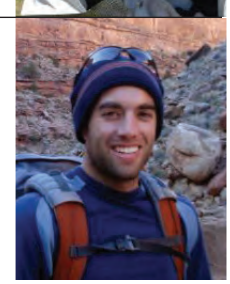
## Investigation of the Effects of Whitewater Kayak Parks on Aquatic Resources in Colorado

*Timothy Stephens, Hydraulic Engineering, Stream Restoration, and River Mechanics, Colorado State University*

*Faculty Advisor: Brian Bledsoe*

This study will utilize fish movement data and the hydraulic results from 3-D computational fluid dynamics software to statistically examine the effect of multiple hydraulic parameters on fish passage at a whitewater kayak park (WWP). Expected outcomes include evidence of movement suppression of migrating salmonids, design recommendations for WWPs, and the range of velocities that occur at WWPs in Colorado.

## Exploration of Morphometric Approaches for Estimating Snow Surface Roughness



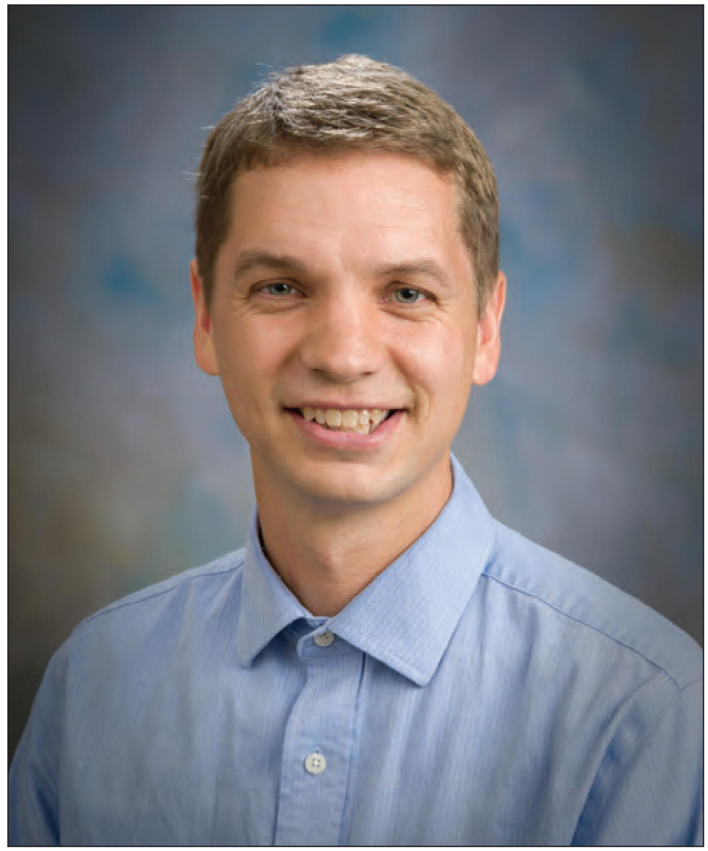
*David Kamin, Watershed Science, Colorado State University*

*Faculty Advisor: Steven Fassnacht*

Snow surface roughness length is used to understand the flow of water, temperature, and moisture over a surface. The goal of this research is to compare methods for estimating surface roughness length and test the viability of both main approaches available—the micrometeorological (anemometric) and morphometric (or geometric) methods.

# Ryan T. Bailey

*Lindsey Middleton, Editor, Colorado Water Institute*



In July of 2013, Ryan T. Bailey officially joined Colorado State University (CSU) as an Assistant Professor in the Department of Civil and Environmental Engineering. Bailey had completed his Ph.D. and a 1-year post-doctoral position at CSU under the supervision of Drs. Timothy Gates, Domenico Baù, and Mazdak Arabi, and says he was glad to have been given the opportunity to stay with CSU—Bailey says he and his family enjoy the city and the university, and are glad to call Fort Collins home.

"CSU is one of the top universities in water resources, and the faculty and students are great to work with," says Bailey. "I didn't want to go anywhere else."

Bailey earned his Bachelor of Science in Civil and Environmental Engineering from Brigham Young University in Provo, Utah with an emphasis in groundwater hydrology in 2006, and from there, he moved with his family to Guam to pursue his Master of Science in Environmental Science at the Water and Environmental Research Institute of the Western Pacific, located at the University of Guam. While on Guam, his research focused on groundwater resources of small coral islands and the management and modeling of such resources. Upon completion of his master's thesis, he was able to travel to several islands to present his research results to local government officials.

Bailey returned to the continental U.S. after earning his master's degree, and he ultimately chose CSU to complete his Doctorate in Civil and Environmental Engineering with an emphasis on Groundwater Hydrology and Water Quality. His dissertation work focused on the occurrence, reactive transport, and remediation of selenium and nitrate in irrigated agriculture groundwater systems, specifically in the Lower Arkansas River Basin in southeastern Colorado.

Prior to earning his upper-level degrees, Bailey says he gained valuable experience in groundwater modeling while interning with the Army Corps of Engineers at the Waterways Experiment Station in Vicksburg, Mississippi.

Much of his research still deals with contaminants and nutrients in regional-scale groundwater systems. In Colorado, Bailey's work focuses on fieldwork and computer models, largely in southern Colorado, to simulate the movement of contaminants in groundwater, and also the remediation of those contaminants, which include nitrates, selenium, and salts. Bailey sees contaminants as a large-scale issue in the state, with the potential to cause future problems in regard to water resource quality, but says he is confident that the resources and personnel exist to tackle the issue. In addition to working with Colorado's irrigated groundwater systems, Bailey also has continued his research dealing with water resources of Pacific islands. A current project in the Federated States of Micronesia involves assessing current and future groundwater resources and rainwater storage. He also recently completed a project with the World Bank to assess groundwater resources in the atoll islands of the Republic of Maldives.

So far, Bailey has taught an introductory Statics course (fall of 2013) and is teaching a graduate-level course on methods for sustainable water systems, with an emphasis on water systems in developing countries, a course he developed and began teaching spring semester of 2014.

"It was fun to work with new students and get them excited," he says of teaching the undergraduate Statics course, an early requirement for engineering students. "One of my goals is to be a great teacher—I knew early on that I wanted to pursue a Ph.D. because I wanted to teach."

In addition to his teaching and research pursuits, Bailey oversees the research of several graduate students in Civil and Environmental Engineering. One of his Ph.D. students is working on salt transport in groundwater, and two master's candidates are working on separate projects in the Arkansas River Basin measuring nitrogen and phosphorous mass transport in riparian-stream systems and studying the remediation of selenium and nitrates in groundwater, respectively. Another of his master's students is working on the assessment of rainwater catchment systems and groundwater resources of several islands in the Federated States of Micronesia and the Republic of Marshall Islands in the western Pacific.

**Ryan T. Bailey, Ph.D.**
Assistant Professor

Colorado State University

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# Recent Publications

Characterization of hydrodynamic and sediment conditions in the lower Yampa River at Deerlodge Park, east entrance to Dinosaur National Monument, northwest Colorado, 2011; Williams, Cory A.

Interactions between hyporheic flow produced by stream meanders, bars, and dunes; Stonedahl, Susa H.; Harvey, Judson W.; Packman, Aaron I.

Shallow groundwater and soil chemistry response to 3 years of subsurface drip irrigation using coalbed-methane-produced water; Bern, Carleton R.; Boehlke, Adam R.; Engle, Mark A.; Geboy, Nicholas J.; Schroeder, K. T.; Zupancic, J. W.

Methane occurrence in groundwater of south-central New York State, 2012: summary of findings; Heisig, Paul M.; Scott, Tia-Marie

GWM-VI: groundwater management with parallel processing for multiple MODFLOW versions; Banta, Edward R.; Ahlfeld, David P.

Landslides in the northern Colorado Front Range caused by rainfall, September 11-13, 2013; Godt, Jonathan W.; Coe, Jeffrey A.; Kean, Jason W.; Baum, Rex L.; Jones, Eric S.; Harp, Edwin L.; Staley, Dennis M.; Barnhart, William D.

Regression models for estimating salinity and selenium concentrations at selected sites in the Upper Colorado River Basin, Colorado, 2009-2012; Linard, Joshua I.; Schaffrath, Keelin R.

Simulation of water-table aquifers using specified saturated thickness; Sheets, Rodney A.; Hill, Mary C.; Haitjema, Henk M.; Provost, Alden M.; Masterson, John P.

Variables that affect agricultural chemicals in groundwater in Nebraska; Tindall, James A.; Chen, Abraham

U.S. Geological Survey Colorado Water Science Center: co.water.usgs.gov

# Water Research Awards

## Colorado State University (March 16, 2014 to May 15, 2014)

**Arabi, Mazdak**, Civil & Environmental Engineering, Hydro Research Foundation, Small Hydro Power Innovation Portal, $8,400

**Bestgen, Kevin R**, Fish, Wildlife & Conservation Biology, DOI-Bureau of Reclamation, Evaluating Effects of Non-Native Predator Removal on Native Fish in the Yampa River, Colorado, $87,847

**Bestgen, Kevin R**, Fish, Wildlife & Conservation Biology, DOI-Bureau of Reclamation, Identification and Curation of Larval and Juvenile Fish by Colorado State University Larval Fish Laboratory, $233,280

**Bestgen, Kevin R**, Fish, Wildlife & Conservation Biology, DOI-Bureau of Reclamation, Interagency Standardized Monitoring Assessment of Endangered Fish Reproduction in Relation to Flaming Gorge Operation in the Middle Green and Lower Yampa Rivers, $118,815

**Bestgen, Kevin R**, Fish, Wildlife & Conservation Biology, DOI-Bureau of Reclamation, Monitoring Effects of Flaming Gorge Dam Releases on the Lodore/Whirlpool Fish Community, $64,545

**Brummer, Joe E**, Soil & Crop Sciences, Colorado River Water Conservation District, Colorado River Compact Water Bank Feasibility Study, $46,127

**Caldwell, Elizabeth D**, CEMML, DOD-ARMY-Corps of Engineers, Clean Water Act Inspection and Stormwater Mapping Support, Joint Base Elmendorf-Richardson, Alaska, $156,860

**Chavez, Jose L**, Civil & Environmental Engineering, Brigham Young University, Decision Support Tools, Drought Tolerance, and Innovative Soil and Water Management Strategies to Adapt Semi-arid Irrigated Cropping Systems to Drought, $202,246

**Cooper, David Jonathan**, Forest & Rangeland Stewardship, DOI-National Park Service, Restoration Design and Plans for Lulu Creek, Colorado River Valley and Lulu City Wetland Complex, Rocky Mountain National Park, Colorado, $76,917

**Cotrufo, Maria Francesca**, Soil & Crop Sciences, Brigham Young University, Decision Support Tools, Drought Tolerance, and Innovative Soil and Water Management Strategies to Adapt Semi-arid Irrigated Cropping Systems to Drought, $509,922

**Doesken, Nolan J**, Atmospheric Science, Province of Manitoba, Web and Database infrastructure for CoCoRaHS Canada, $42,000

**Fink, Michelle**, Colorado Natural Heritage Program, Colorado Department of Natural Resources, Models for Evaluating Sage Grouse Habitat, $30,318

**Grunau, Lee**, Colorado Natural Heritage Program, DOI-Bureau of Land Management, Statewide Climate Change Vulnerability Assessment, $45,000

**Hawkins, John A,** Fish, Wildlife & Conservation Biology, DOI-Bureau of Reclamation, Evaluation of Smallmouth Bass and Northern Pike Management in the Middle Yampa River, $283,759

**Jha, Ajay K**, Horticulture & Landscape Architecture, World Learning, Training for Pakistan: On-Farm Water Management Training, $95,921

**Khosla, Rajiv**, Soil & Crop Sciences, Universite Laval, Variable Rate Irrigation Based on Water Management Zones and Soil Moisture Sensors, $95,864

**Omur-Ozbek, Pinar**, Civil & Environmental Engineering, University of Colorado, Impact of Wildfires on Source Water Quality & Implications for Water Treatment & Finished Water Quality, $9,200

**Roesner, Larry A**, Civil & Environmental Engineering, Urban Drainage & Flood Control District, Develop the Colorado Center for Stormwater Management, $34,720

**Sharvelle, Sybil E**, Civil & Environmental Engineering, City of Fort Collins, Ideas for Dual Water System, $50,600

**Shields, Martin**, VP Engagement, Roaring Fork Conservancy, Economic Impacts of Recreational Angling on the Ruedi Reservoir and Lower Fryingpan River, $34,000

**Thilmany, Dawn D**, Agricultural & Resource Economics, USDA-National Institute of Food and Agriculture, Place Based Innovation: An Integrated Look at Agritourism in the Western US, $499,627

**Weiner, Cary S**, CSU Extension, State of Colorado-Governor's Energy Office, Colorado Irrigation and Dairy Efficiency Analysis, $10,000

# Calendar

## July

**28-30** **NWRA 2014 Western Water Seminar; Flagstaff, AZ**
National Water Resources Annual Conference
www.nwra.org

## August

**20-22** **Colorado Water Congress Summer Conference; Snowmass, CO**
The high-energy summer conference is packed with great topical content. It's a don't-miss event for those who wish to stay informed about water issues in Colorado while engaging in numerous professional development activities.
www.cowatercongress.org/cwc_events/Summer_Conference.aspx

**28** **Documentary Film: *The Grand Valley and its Rivers*; Grand Junction, CO**
The first public screening of a 30 minute documentary on the Grand Valley and its Rivers created by CMU's Water Center and Gen9 Productions. This film will explore the relationship of the Grand Valley to its rivers, how that relationship has changed over time, and what forces may affect the region's water future.
www.coloradomesa.edu/WaterCenter/Documentary.html

## September

**7-10** **2014 RMSAWWA/RMWEA Joint Annual Conference; Albuquerque, NM**
Joint annual conference of the Rocky Mountain Section of the American Water Works Association (RMSAWWA) and the Rocky Mountain Water Environment Association (RMWEA).
http://bit.ly/1pdIsim

**7-10** **29th Annual WateReuse Symposium; Dallas, TX**
Water professionals attend to learn about the latest innovations in water recycling and desalination, to network with colleagues, and to find solutions to critical water supply issues.
www.watereuse.org/symposium29

**19** **Colorado River District Annual Water Seminar; Grand Junction, CO**
www.crwcd.org

**24-25** **4th Annual Natural Gas Symposium 2014; Denver, CO**
naturalgas.colostate.edu/symposium

## October

**7-9** **2014 Sustaining Colorado Watersheds Conference; Avon, CO**
*Come Hell or High Water!*
This conference expands cooperation and collaboration throughout Colorado by informing participants about new issues and projects while focusing on the community resiliency in the wake of the 2013 floods, wildfires, and other risks to our watersheds.
www.coloradowater.org/Conferences

## November

**5-6** **4th Annual Upper Colorado River Basin Water Forum; Grand Junction, CO**
*Seeking a Resilient Future*
www.coloradomesa.edu/watercenter/UpperColoradoRiverBasinWaterForum.html

*Basin overlook of the Colorado River.*
Photo by Geoff Llerena

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CSU Water Center: www.watercenter.colostate.edu

*San Miguel River in the Upper Colorado River Basin, Colorado.*
Photo by Michael Johnson