Colorado Water

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Highlights

In Every Issue

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Front Cover: Horsetooth Reservoir near Fort Collins, Colorado. Photo by Lindsey Middleton
This Page: A water fountain on CSU's Natural and Environmental Sciences building. Photo by Lindsey Middleton

Editorial

by Reagan Waskom, Director, Colorado Water Institute

Each year, students funded through the Colorado Water Institute report the results of their research projects in our summer newsletter. When you see the quality of the students' work and their dedication to solving water problems as part of their graduate degree programs, you can understand why we wish we could fund more students each year and at greater levels. Training these future water scientists and managers to be problem solvers is an essential function of our graduate programs and is very gratifying for those of us involved in the process. But our real challenge through graduate education and research is to train students to solve future problems—the challenges we haven't even considered yet.

Universities have for centuries been organized by academic disciplines. It makes sense that you need a cohort of engineers with varying specialties to turn out good engineering graduates, and the same is true in history, economics, and other disciplines. But the significant problems in today's world are almost never organized by discipline. Does this mean we should abandon the disciplinary approach to training students? I would suggest that it does not. When you need an engineer or a chemist, you do not call a sociologist or an astronomer. You need depth in your discipline if you are going to work effectively in research, development, or problem solving. But today's students must grow beyond a single discipline focus in order to achieve progress on real problems.

Solutions to complex water problems are almost always some blend of changing physical conditions and human interactions. Though we know this, it seems we rarely have the foresight to anticipate the next problem, much less the tools and solutions needed. This is why being a learner is infinitely better than being a knower. The world we live in is changing at an extremely rapid pace—the learners are the ones who will be tomorrow's heroes. Those who are simply knowers will not be prepared for solving new problems; they will be knowledgeable about problems that no longer matter.

Problem solvers must find solutions in the midst of uncertainty. The public expects answers to complex water problems from scientists and engineers—not a call for more research and a long description of uncertainty. People want to be told what is it that you do know. While uncertainty exists in any research results, we must focus our science communication on what certainty does exist in order to move forward. In short, there is no perfect water plan or solution—what's needed is the information to select the best path forward and then the ability and latitude to adapt to the next increment of change.

Engaging in scientific research on current water resource problems and conflicts is not for the faint of heart—folks will often try to coerce you to their view or discredit you if you fail to line up on their side. This is why scientific independence and coherent organization of the data and its meaning are critical to get decision makers to listen. We need people high in the political chain that understand of the importance of science in making sound water decisions, but we must communicate the science effectively and without bias. The data streams available to us today are huge compared to even just a few years ago. Has this improved the signal to noise ratio? Probably not, and social ecological systems are almost always more complicated than anticipated.

Colorado is now in its third or forth year of drought, depending upon what part of the state you live in. If you look at the history of Colorado water, you will note that new supply projects and major policy changes often occur following drought. What changes are coming this time? Can we learn to better anticipate the consequences of our choices without suffering paralysis by analysis? The world that our students will face within their lifetimes portends greater water scarcity in the midst of rapid change and ever expanding technology. When I view our students, their creativity, and their ability to view problems from new perspectives, my confidence in our ability to navigate these waters is renewed.

Farmer Resiliency Under Drought Conditions

Ron Nelson, Master's Candidate, Department of Agricultural and Resource Economics, Colorado State University
Faculty Advisors: Christopher Goemans, James Pritchett

In a Nutshell

- Study: Determine via survey the resiliency of farmers and ranchers to drought
- Results: Factors like debt-to-asset ratio and location were indicative of drought resiliency

For the last two years, agricultural producers in Colorado have been faced with severe drought conditions, resulting in significant economic losses. The drought has led to widespread crop failures, damaged rangelands, and drastically reduced crop yields and livestock productivity. The financial impacts caused by the drought will be felt by agricultural producers for years to come and may threaten the long-term economic viability of some agricultural operations. Given forward and backward linkages with other industries in the supply chain, the impact of drought typically extends well beyond those sectors and communities immediately impacted. Federal and state agencies have responded to the drought by offering millions of dollars in emergency drought relief. With a changing climate, likely leading to an increased probability of extreme and recurring droughts, it is becoming an ever more important policy concern to determine the effect that drought has on the resiliency of farmers and ranchers.

The resiliency of farmers and ranchers is the ability of the agricultural producer to return to a similar state of production after they have endured a stressor such as a drought. Understanding the factors that influence the resiliency of agricultural producers is important for multiple reasons. First, understanding existing levels of resiliency can convey how adaptable agricultural producers are to extreme and changing climatic conditions. Second, it indicates how long farmers and ranchers can endure an environmental stressor such as drought until they are ultimately forced to exit the agricultural sector. Third, by understanding the determinants of resiliency, decision makers can design policies that help agricultural producers adapt to the challenges presented by natural hazards such as drought. Fourth, because farmers and ranchers are key components of rural communities, their resiliency is directly correlated with the resiliency of rural communities. Lastly, small and mid-sized farms and ranches have been found to be less resilient than large farms, which many believe decreases the adaptability of the domestic food sector and may lead to food security concerns in the future. Therefore, by determining the characteristics that influence resiliency, we can help improve food security. By investigating resiliency, we aim to provide insight into the efficacy of the current drought relief policies and identify ways to minimize the economic impacts felt by agricultural producers and regional economies.

Past studies that have examined resiliency indicate that there are multiple producer and enterprise characteristics that influence the ability to adapt to drought and the producer's decision to exit the agricultural sector. Characteristics that have been found to influence farm exit include off-farm income, the size of the operation, experience, and age. Characteristics related to drought induced exits include decreased crop yields, number of acres fallowed, the duration of drought, access to irrigation, and decreased profit. Most recently, a theoretical model was developed

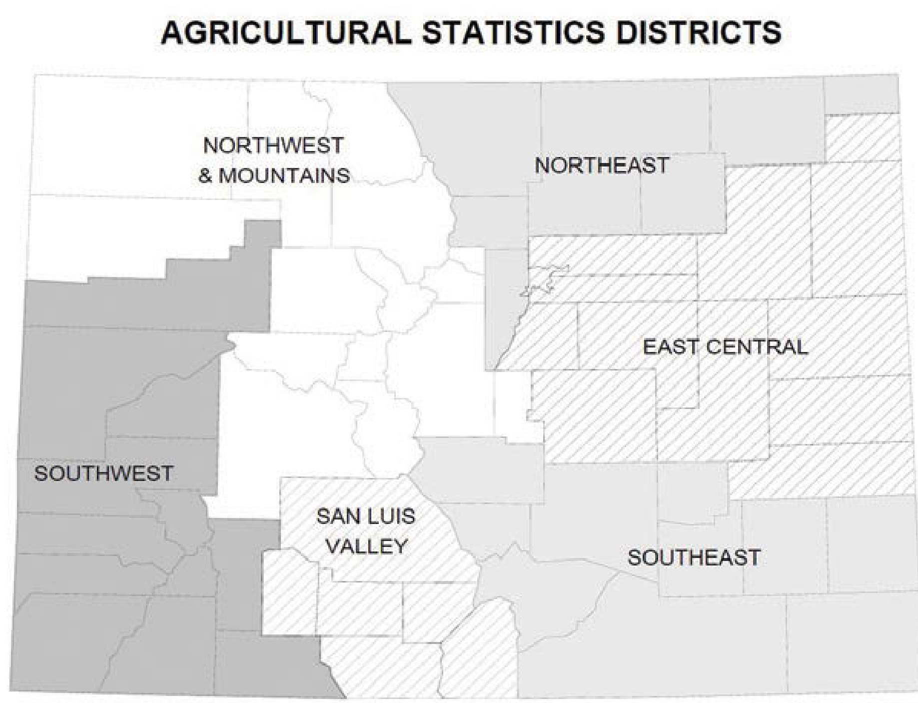

Figure 1: *National Ag Statistics Service—Colorado Agricultural Statistics Districts. Source: NASS, 2012*

Table 1: Regression Results			
Dependent Variable	**Definition**		
Resiliency	the respondent's stated probability of leaving farming in the next five years if drought continues in 2013		
Independent Variables	**Definition**	**Marginal Effect**	**P-Value**
ln(acres)	the natural log of the number of acres in an operation	-0.0009	0.955
Debt-to-asset ratio	the debt-to-asset ratio after the 2012 drought	0.0054**	0.036
Profit	profit in 2012	-0.0008	0.723
(Debt-to-asset ratio)*(Profit)	interaction variable	-0.0001	0.44
Southeast	the Southeast district of Colorado as defined by NASS	-0.1709***	0.007
Irrigation	the type of enterprise divided into those with water and those without	0.0525	0.436
Off Farm Income	the percentage of income that comes from off of the farm	-0.0008	0.426
Experience	the number of years the respondent has farmed and/or ranched	0.0011	0.594
** Significant at 5% or under *** Significant at 1% or under			

that suggested proxies for a farmer's or rancher's overall wealth, such as groundwater, since it can be thought of as a savings account during drought.

Our study explores the determinants of resiliency, but mainly focuses on the roles that wealth and the duration of drought have on farmer and rancher resiliency. To investigate resiliency, we developed an online survey that was administered to agricultural producers throughout Colorado. The survey inquired about the circumstances faced during the 2012 drought and collected information on the characteristics of producers and their production enterprise(s). As a measure of wealth, we inquired about the respondent's debt-to-asset ratio before and after the 2012 drought. Debt-to-asset ratio is defined as a producer's total liabilities divided by their total assets. And as a measure of resiliency, we asked respondents what the probability was of them leaving farming/ranching if the drought continued for another year. Respondents included all major producer types, and the sample was thought to be representative of the larger agricultural enterprises in Colorado.

Ron Nelson and his advisor Chris Goemans work on building their survey, which went out to farmers and ranchers in Colorado to determine their operations' resiliency to drought.

Photo by Lindsey Middleton

Using the data from the survey, we use regression analysis to estimate the determinants of resiliency (see Table 1 for complete results). Several key findings emerge from the analysis. First, the analysis suggests location is an important determinant of resiliency. Specifically, we found that the southeastern region of Colorado was more resilient than other regions of Colorado (see Figure 1). This finding is interesting partly because the Southeast region is in its second year of drought while most other regions of Colorado are in their first. The increased resiliency that the region possesses during drought may be due to the fact that the Southeast has a long history of drought and therefore has successfully adapted. This may indicate that the duration of the drought may not be as important as where the drought is occurring and if that area has been repeatedly exposed to similar droughts. A policy implication of this finding is that drought assistance in form of educational outreach and financial resources may be better utilized by regions less familiar with adapting and planning for drought.

Additionally, our analysis indicates that debt-to-asset ratio is a key determinant of the resiliency of a farmer or rancher. As a proxy for the wealth of the farmer or rancher, this variable reflects, in aggregate, how the farm or ranch has been financially managed over a long period of time. Debt-to-asset ratio's importance reveals that a one year drought may not be a significant factor in motivating an agricultural producer to exit the sector, since it likely will not decrease drastically in a single year. Furthermore, profit from the year 2012 was not found to influence resiliency, which furthers the claim that a one year drought may not be impacting resiliency. However, multi-year droughts will surely increase the debt-to-asset ratio of most agricultural producers, decreasing resiliency and possibly increasing agricultural sector exits. This finding has implications for policy makers, agricultural producers, and industry. First, producers and insurers need to be educated on how increasing debt can lower the resiliency of agricultural producers, and how preparing financially for drought may increase the vitality of a producer's enterprise. Second, the form of assistance currently offered, low interest emergency loans, may be decreasing farmer and rancher resiliency by increasing their debt-to-asset ratio. However, low interest emergency loans may be minimizing the negative impact felt by agricultural producers and their communities, and could be the best policy option available for the circumstances. To further determine whether or not low interest emergency loans are the best option for drought assistance, additional research could compare the exit rates of those farmers that choose to take low interest emergency loans versus those that do not. Authors gratefully acknowledge funding from CWI.

USGS science for a changing world

Recent Publications

Effect of power plant emission reductions on a nearby wilderness area: a case study in northwestern Colorado; Mast, M. Alisa; Ely, Daniel

Status and understanding of groundwater quality in the San Francisco Bay groundwater basins, 2007—California GAMA Priority Basin Project; Parsons, Mary C.; Kulongoski, Justin T.; Belitz, Kenneth

Characterization and data-gap analysis of surface-water quality data in the Piceance study area, western Colorado, 1959–2009; Thomas, Judith C.; Moore, Jennifer L.; Schaffrath, Keelin R.; Dupree, Jean A.; Williams, Cory A.; Leib, Kenneth J.

Simulation of salinity intrusion along the Georgia and South Carolina coasts using climate-change scenarios; Conrads, Paul A.; Roehl, Edwin A. Jr.; Daamen, Ruby C.; Cook, John B.

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California Groundwater Ambient Monitoring and Assessment (GAMA) Program Priority Basin Project--shallow aquifer assessment; U.S. Geological Survey

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

Describing and Quantifying Profit Risk Producers Face When Adopting Water Conserving Cropping Systems

Larisa Serbina, Department of Agriculture and Resource Economics, Colorado State University
Faculty Advisor: Christopher Goemans

In a Nutshell

- Purpose: Due to increased municipal and industrial water demands, water will potentially be transferred from agricultural use.
- Study: How does the underlying distribution of farm profits change when adopting a water conserving cropping system?
- Results: Different scenarios may be preferable to different water users based on their preferred level of risk and the amount of water needed.

Overview

Driven primarily by population growth along the Front Range, municipal and industrial (M&I) demand for water in Colorado is expected to nearly double by 2050. Throughout most of Colorado, water is already fully allocated—the majority of water being diverted for agricultural uses. These two factors make it likely that the gap between existing M&I supplies and future demands will be met, at least in part, by reallocating water out of agriculture. The Colorado Water Conservation Board's (CWCB) 2010 State Water Supply Initiative (SWSI) forecasts that as much as 20 percent of existing irrigated land, statewide, will be dried up due to meeting future urban demands. Growing concerns surrounding the impacts to rural communities associated with the permanent dry up of agricultural land have led many to advocate for alternatives to permanent transfers of water rights.

Water banks, interruptible water supply agreements, and multi-year leases are examples of such alternatives that when combined with rotational fallowing and/or alternative cropping patterns are thought to be less impactful on rural communities, while freeing up water to meet future needs. Regardless of the nature of the agreement, each requires the producer to make changes in their production practices to free up water. While identifying the optimal strategy is relatively easy to do *after the fact*, uncertainty in output prices and potential yields significantly complicates the decision process. Understanding the potential impacts apriori, both in terms of their impacts on expected profits and variation in profits, is critical not only for policy makers trying to understand the potential viability of such alternatives, but also for producers evaluating the potential efficacy of their choices. This research develops both a conceptual and analytic framework for evaluating alternative cropping systems that producers may choose when seeking to conserve water and compares them to baseline cases corresponding to existing irrigated cropping systems. The goal is to develop a tool for irrigators and policy makers that will allow them to evaluate the impact of various alternative cropping and rotational fallowing strategies on the distribution of future profits accounting for uncertainty in yields and output prices. While the tool can be applied anywhere, we illustrate its potential usefulness below with an example focused on Weld County of Colorado.

Methodology

The focus of analysis is an irrigated farm manager's question: how does the underlying distribution of farm profits change when adopting a water conserving cropping system? The Excel model developed evaluates the financial tradeoffs that exist when adopting different cropping systems under uncertain price and yield conditions.

These financial tradeoffs include differences in realized profits, the potential for losses when price and/or yields are low and the opportunity cost of unrealized financial gains.

Within the model, profits stemming from a "baseline" cropping pattern (e.g., 100 percent corn) are calculated and compared to those associated with user-specified, alternative systems (e.g, 50 percent corn, 50 percent fallow) that result in a given amount of conserved, consumptive water use (CU). Of key importance is the recognition that any particular comparison represents a potential outcome given assumed prices and yields. To represent the uncertainty faced by irrigators, the comparison is repeated 500 times under different output price and yield conditions, the suite of results providing a

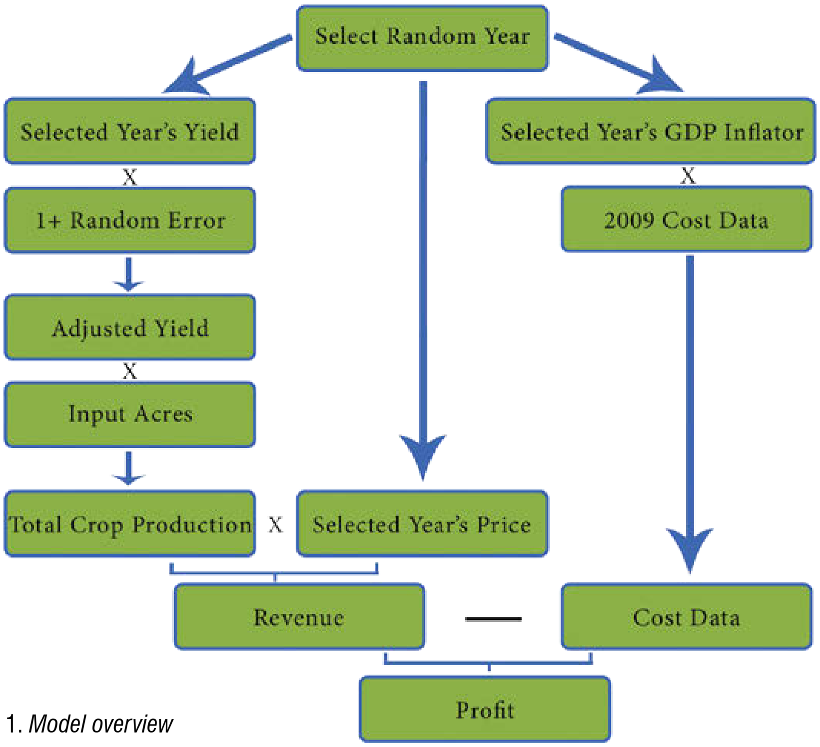


Figure 1. *Model overview*

distribution of outcomes under alternative conditions.

Figure 1 provides an illustration of the iterative process used. For each iteration, total profits are calculated under the baseline and alternative cropping systems. Total profits are equal to revenue minus the cost of production, with revenue equal to yield times prices and cost calculated based 2009 input cost data.

The iterative process begins with the selection of a random year from 1980 to 2010. The selected year (e.g., 1985) becomes the base year for that iteration. Commodity prices and the GDP deflator for the base year are used directly in the calculation, whereas the yield from that year is used to calculate an "adjusted yield." The adjusted yield is calculated by adding a random term to the selected base yield. This is done so as to not draw from the same yield frequency. This allows the model to proxy the potential variation in yields that have been demonstrated historically, while preserving the correlation between local production conditions and national output prices. Without the random error term, the sample would be drawn from the historical distribution of yields; thus, the result would be the same distribution as that of the historical data. The addition of a random percent error term allows for variability yields outside of what has been observed historically.

The number of acres in production is multiplied by the adjusted yield to calculate total yield.

The product of total yield and the commodity price equals revenue. The input costs are adjusted using the GDP ratio.

The difference between revenue and costs represents the potential profit obtained from producing a particular crop under that iteration's conditions. For a given iteration, the difference between the profit under baseline and the alternative scenarios represents potential foregone profits for the irrigator if they were to switch to the water conserving alternative.

It is important to note that these comparisons do not include a payment for leased water associated with the conserved CU, so profits for the alternative cropping systems are expected to be less than the baseline. Model output could be used by the irrigator to determine, given their risk preferences, the amount of leasing revenue they would need to receive to offset the foregone profit associated with switching to the alternative

Applying the Model to a Representative Farm in Weld County, Colorado

To illustrate the model's potential usefulness, results corresponding to a representative farm of 2,000 acres in Weld County, Colorado are presented below. Figure 2 illustrates the baseline and four alternative scenarios considered. The scenarios considered here were selected based on conversations with specialists at CSU and represent likely adaptations farmers would consider to reduce consumptive water use.

Table 1 presents the average, standard deviation, coefficient of variation, minimum, and maximum profit associated with the Baseline and Scenario runs generated by the model.

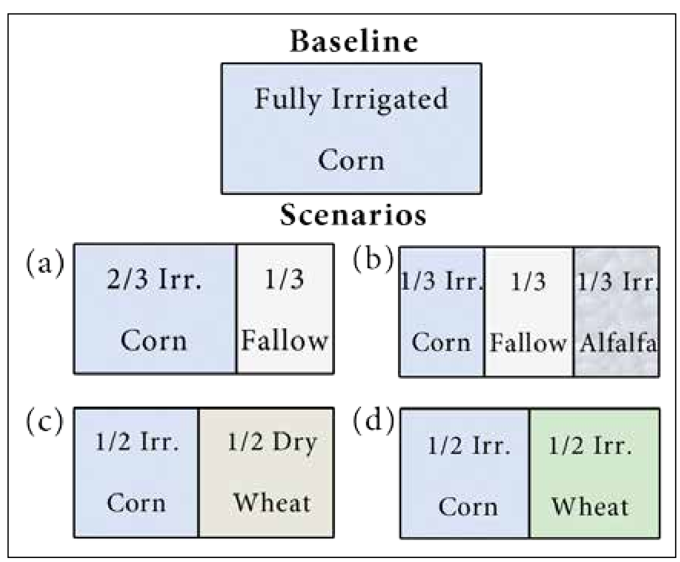


Figure 2. *Baseline cropping pattern and four potential scenarios for analysis*

Both in terms of average and relative variability in profits (i.e., coefficient of variation), Scenario D is preferred over the other alternatives and the Baseline cropping pattern. The latter is true despite recently high corn prices relative to the average over the 30-year sample period. To the extent that corn prices remain high, all else equal, the model underestimates the true value of producing corn and therefore also underestimate the opportunity cost of switching to any of the alternatives.

While the figures in Table 1 provide insight into the impact of each alternative on the distribution of profits, they are difficult to compare given that the amount of water freed up, as well as the number of acres impacted, differs across each alternatives. As an alternative, we calculate the difference in profits between the Baseline and each of the scenarios and normalize them based on the amount of acres impacted (Table 2) and the consumptive water use conserved (Table 3).

Again, it is important to keep in mind that profit estimates presented in Tables 2 and 3 represent deviations from Baseline production where potential revenue from water leases is not factored in.

Which alternative is preferred? Tables 2 and 3 each provide the irrigator (and policy makers) with a starting point for considering the type of returns they would need to get from leasing to offset losses in productivity. The preferred alternative will depend on the risk preferences of individual producers and the quantity of water needed. For more information about the project, and use of the model, please contact Larisa Serbina (larisa.o.serbina@gmail.com) or Christopher Goemans (cgoemans@rams.colostate.edu). Authors gratefully acknowledge funding from CWI.

Table 1. *Summary Statistics of Profits for a Representative Farm*

Profit	Baseline	Scenario A	Scenario B	Scenario C	Scenario D
Average	265,240	176,836	103,044	199,517	285,354
St. Dev.	138,641	92,432	90,638	94,707	130,797
Coef. of Var.	52	52	88	47	46
Min	-181,317	-120,884	-134,725	-87,893	-39,825
Max	535,758	357,190	431,053	401,131	724,882

Larisa Serbina and her advisor, Chris Goemans, discuss the simulation model.

Photo by Kim Hudson

Table 2. *Foregone Profits per Acre Converted from Corn*

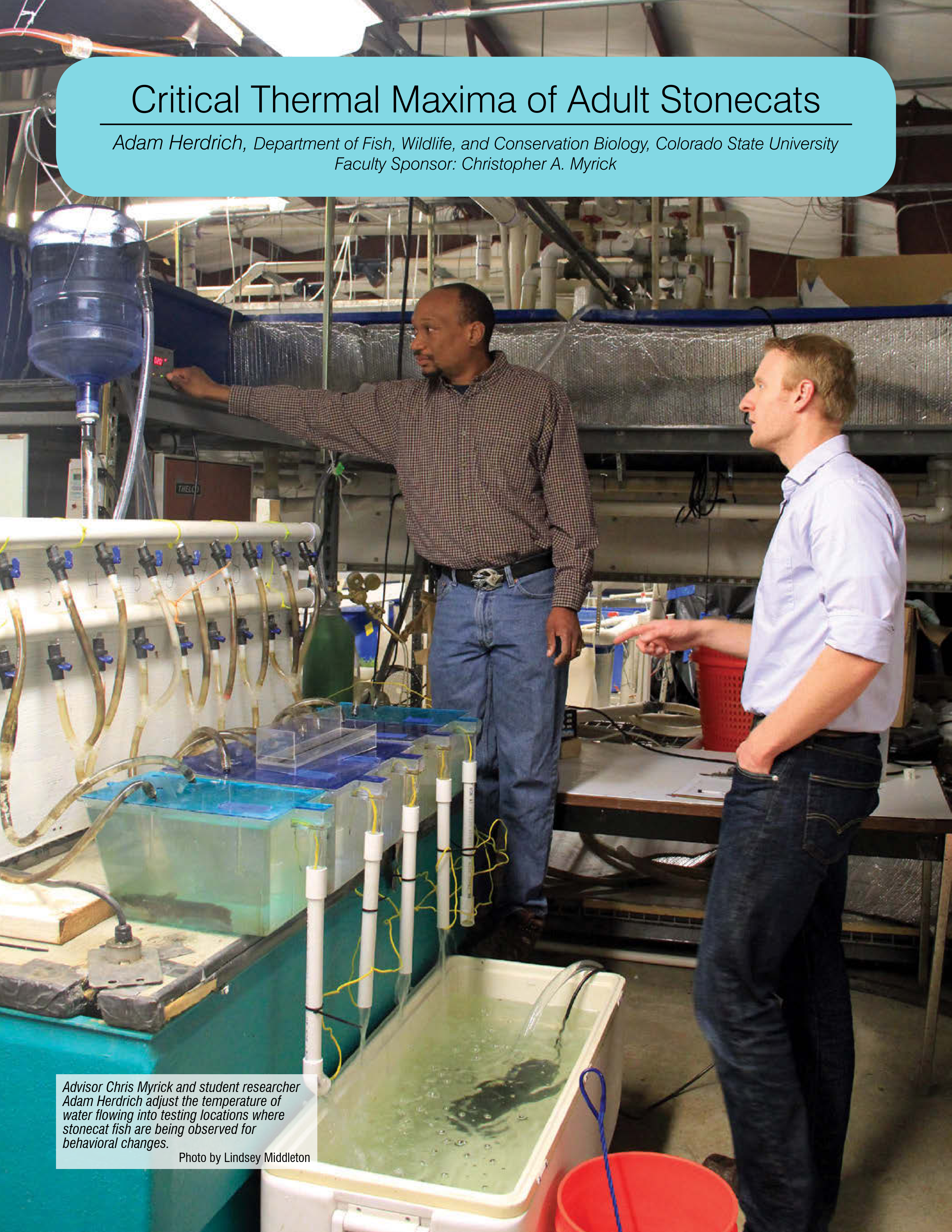
	Scenario A	Scenario B	Scenario C	Scenario D
Average	132	238	65	-24
St. Dev.	72	160	70	90
Coef. of Var.	55	67	107	-384
Min	-91	-222	-126	-466
Max	268	643	247	256

Table 3. *Foregone Profits per Acre Foot of Water Conserved (CU)*

	Scenario A	Scenario B	Scenario C	Scenario D
Average	111	569	55	-46
St. Dev.	58	363	56	199
Coef. of Var.	52	64	102	-435
Min	-76	-519	-106	-1,060
Max	224	1,504	206	583
Acre Feet Conserved	797	285	1,195	440

Critical Thermal Maxima of Adult Stonecats

Adam Herdrich, Department of Fish, Wildlife, and Conservation Biology, Colorado State University
Faculty Sponsor: Christopher A. Myrick



Advisor Chris Myrick and student researcher Adam Herdrich adjust the temperature of water flowing into testing locations where stonecat fish are being observed for behavioral changes.
Photo by Lindsey Middleton

In a Nutshell

- Study: Determine the thermal preference of stonecat fish and compare the preference to Colorado temperature standards set for their resident streams
- Methods: Used the Critical Thermal Maximum approach (Underwood et. al.) to identify temperature at which fish sustained loss of equilibrium, indicating their inability to move to cooler water
- Results: Stonecat behavior indicated that they may be less tolerant than other fish in their habitats to temperature increases and should be further researched

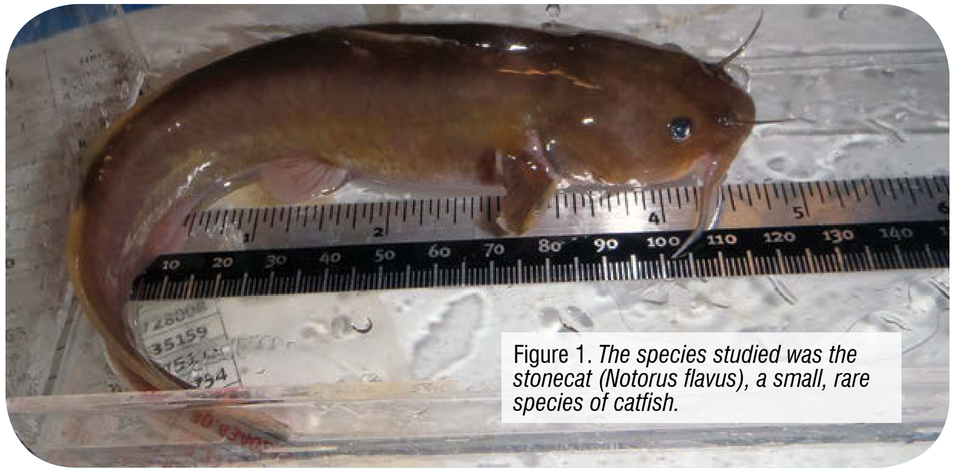


Figure 1. *The species studied was the stonecat (Notorus flavus), a small, rare species of catfish.*

Introduction

Transition zone streams, those coming off of the Rocky Mountains and transitioning onto the Great Plains along the Front Range of Colorado, are under increasing pressure from anthropogenic sources. Between the push for supplying drinking water for the growing population in this area, the invasion of non-native aquatic species, and the effects of urbanization, these streams have been and will continue to be impacted by human activities. The ecosystem-level effects inevitably trickle down to the fish and insect communities inhabiting these stream segments, and create conditions that are suboptimal, or even detrimental, to these assemblages.

Changes in the magnitude, timing, and duration of flows have serious impacts on these systems, but another factor, the temperature or thermal regime, is of equal or greater importance. Temperature is one of the most crucial factors in aquatic systems, largely because the vast majority of aquatic organisms are poikilotherms, or cold-blooded, and their biology is directly tied to the environmental temperature. All organisms have temperatures at which their fitness is maximized, and without the ability to internally control their body temperatures, poikilotherms, such as the fish in transition zone streams, are limited by the thermal heterogeneity offered by their environment.

The state of Colorado regulates water temperature through a tiered system that is based on the fish communities that are present at the site being regulated. Thermal tolerance data are reviewed, and regulations are set based on the most sensitive member of the fish assemblage present in the reach of interest. The most sensitive species is generally assumed to be the one that is most vulnerable to water temperature changes. Currently, Colorado develops independent standards for both acute (short-term) and chronic (long-term) exposure and differentiates between warm and cold-water species and flowing (e.g., streams, rivers) vs. impounded (e.g., ponds, reservoirs) bodies of water.

While thermal tolerance data are available for numerous fishes, the majority of studies have focused on fishes that are valued from a commercial or recreational fishing standpoint, or that are candidate species for protection under federal endangered species legislation. Until recently, relatively few studies looked at native non-game fishes such as those that dominate the transition zone assemblages.

My research focused on the thermal biology of the stonecat (*Notorus flavus;* Figure 1), a species of small catfish. The Colorado populations of stonecats are found in the St. Vrain River in the vicinity of Longmont, Colorado, and in the Republican River near Wray, Colorado; (Figure 2). Specifically, I am investigating whether the thermal regulations set by the State of Colorado Water Quality Control Division are sufficiently protective of these rare fish.

The section of the St. Vrain River where stonecats occur is presently categorized as a Tier-I Aquatic Warm-Life stream section with a Daily Maximum Temperature of 29°C. This means that the stream temperature cannot exceed 29°C more than once in three years. This regulation is driven by the presence of common shiner (*Luxilus cornutus*) and Johnny darter (*Etheostoma nigrum*) and is based on the assumption that these fishes are the most sensitive to drastic thermal changes in this stream.

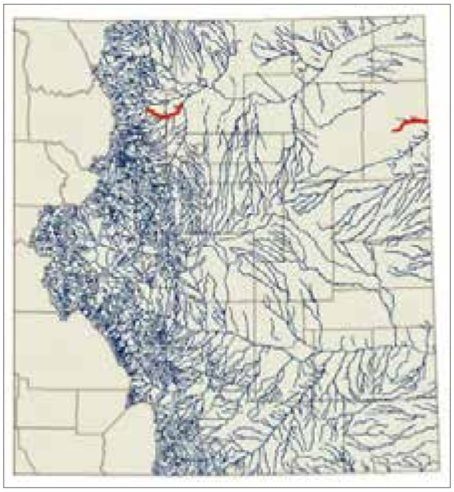


Figure 2. *Current distribution of Stonecats (Noturus flavus) in Colorado*

My research project was designed to test this assumption, and to expand the existing knowledge of stonecat thermal biology, particularly as it relates to their thermal tolerance when acclimated to summer-type temperatures. Prior research conducted at the Center for Lake Erie Area Research (The Ohio State University) on thermal tolerance of stonecats acclimated to cold temperatures (1.6° C) showed that they selected a temperature of 29 °C.

Methods

Adult stonecats (n = 20; total length: 209.75 ± 15.64 mm [mean ± S.D.]; wet weight: 105.05 ± 23.07 g) collected from the St. Vrain River by Colorado Parks and Wildlife (CPW) biologists were delivered to Colorado State University (CSU) where they were held in ambient (temperature & photoperiod) conditions at the CSU Foothills Fisheries Laboratory. Six weeks prior to the trials, the temperature was raised to 20°C at a rate of 2.0°C per week. This was done to simulate spring warming, culminating in water temperatures found in the St. Vrain River over the summer. We simultaneously and incrementally changed the photoperiod, culminating in a 14-hour day, also to mimic summer conditions (Figure 3) and to account for any additional stress effects, due to a decreased window of activity, on the thermal tolerance of the largely nocturnal stonecat. Stonecats were fed a mixed diet of live earthworms and commercial fish feed (Hikari Massivore Delite).

I used the Critical Thermal Maximum (CTMax) approach, as modified by Underwood et al. (2012) to measure the short-term thermal tolerance of the stonecats. The CTM methodology is a well-established and widely used technique for evaluating the acute thermal tolerance of fish and other aquatic organisms. The CDPHE thermal standards include specific guidance on how to translate the results of CTMax tests into thermal standards. Because of the limited availability of stonecats, I was not able to test fish at additional acclimation temperatures, nor was it possible to use a chronic and lethal test methodology such as the incipient upper lethal temperature (IULT) approach.

The test apparatus was based on the system assembled by Underwood et al. (2012), with the notable substitution of the 1.5-l aquaria with five larger 9-l aquaria (Figure 4) receiving 3 l/min of temperature-controlled water. The heated and ambient water were delivered to a mixing tank, then to aquariums to increase the tank temperature by 0.3°C per minute. Fish were measured (to nearest mm) weighed (to nearest g) and placed into the tanks (one fish per tank), and allowed to acclimate at ambient temperatures for one hour before a trial was started. Fish behavior was observed and the trials were ended after a sustained loss of equilibrium (LOE; greater than 10 s); with this loss of equilibrium, it can be assumed that fish will not be able to escape rapidly warming water temperatures in a natural setting. After LOE was observed, the water temperatures were recorded and the tanks were immediately flushed with ambient temperature water, and final temperatures were recorded. Fish were then returned to their holding tanks and monitored for 48 hours to check for delayed mortality. No

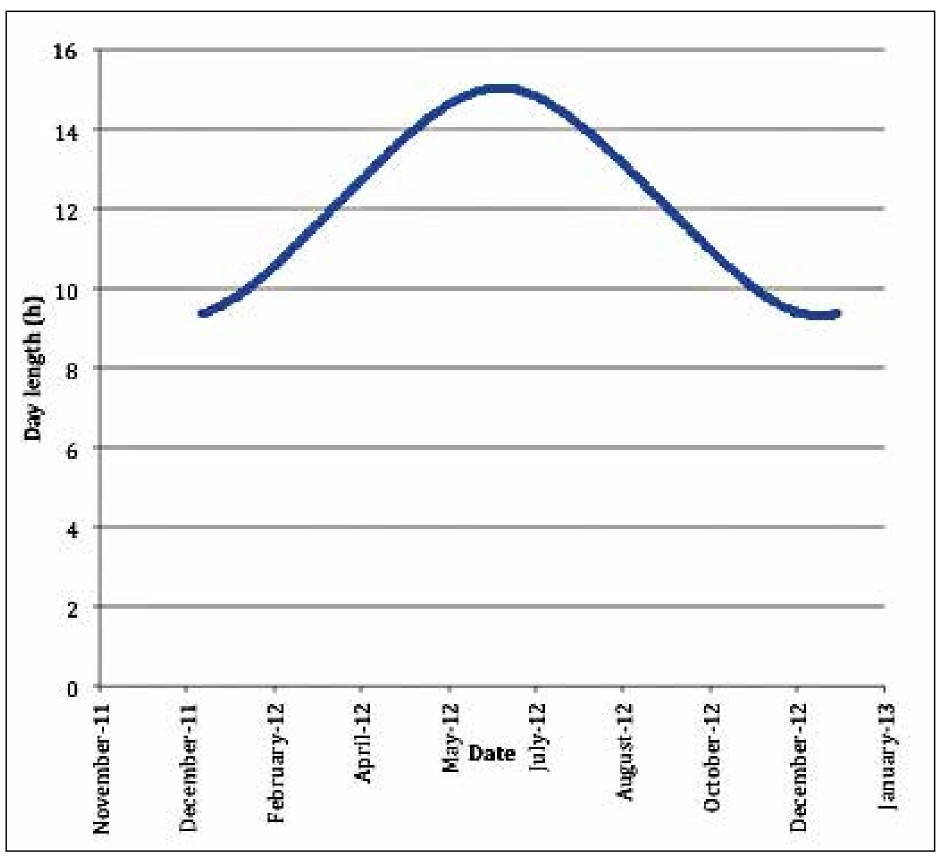


Figure 3. *Photophase (length of daylight) for the Longmont, CO, area over one year*

fish were reused, and all experiments were conducted under the protocol approved by the CSU Institutional Animal Care and Use Committee (#12-3991A).

Results

The mean ± S. D. CTMax for the 20° C-acclimated stonecats was 32.6 ± 0.44° C ($n = 20$). A 1-way ANOVA (JMP) showed a significant effect ($P < 0.05$) of total length on CTMax (Figure 5), and a non-significant trend ($P = 0.09$) wherein wet weight also influenced CTMax. No delayed mortality was observed.

Discussion

This study demonstrated that stonecats are capable of tolerating temperatures that are slightly lower than those tolerated by other transition zone and eastern plains fishes such as the Johnny darter and common shiner when acclimated to summer-type temperatures. Smith and Fausch (1997) reported that the mean ± SE CTMax for Johnny darter acclimated to 20°C was 34 ± 0.32° C; Beitinger et al. (2000) reported that the CTMax for common shiner acclimated to 26°C was 35.7 ± 0.39° C. Based on these results, it appears that stonecats should receive serious consideration as one of the sensitive species that can influence thermal classifications, particularly when their limited distribution is considered.

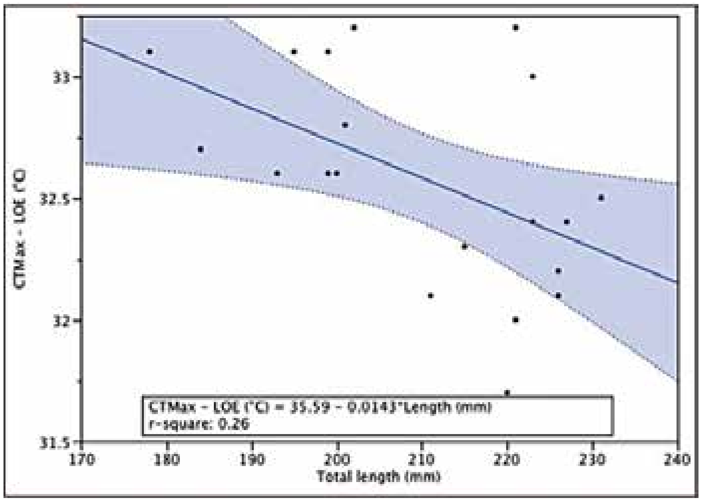
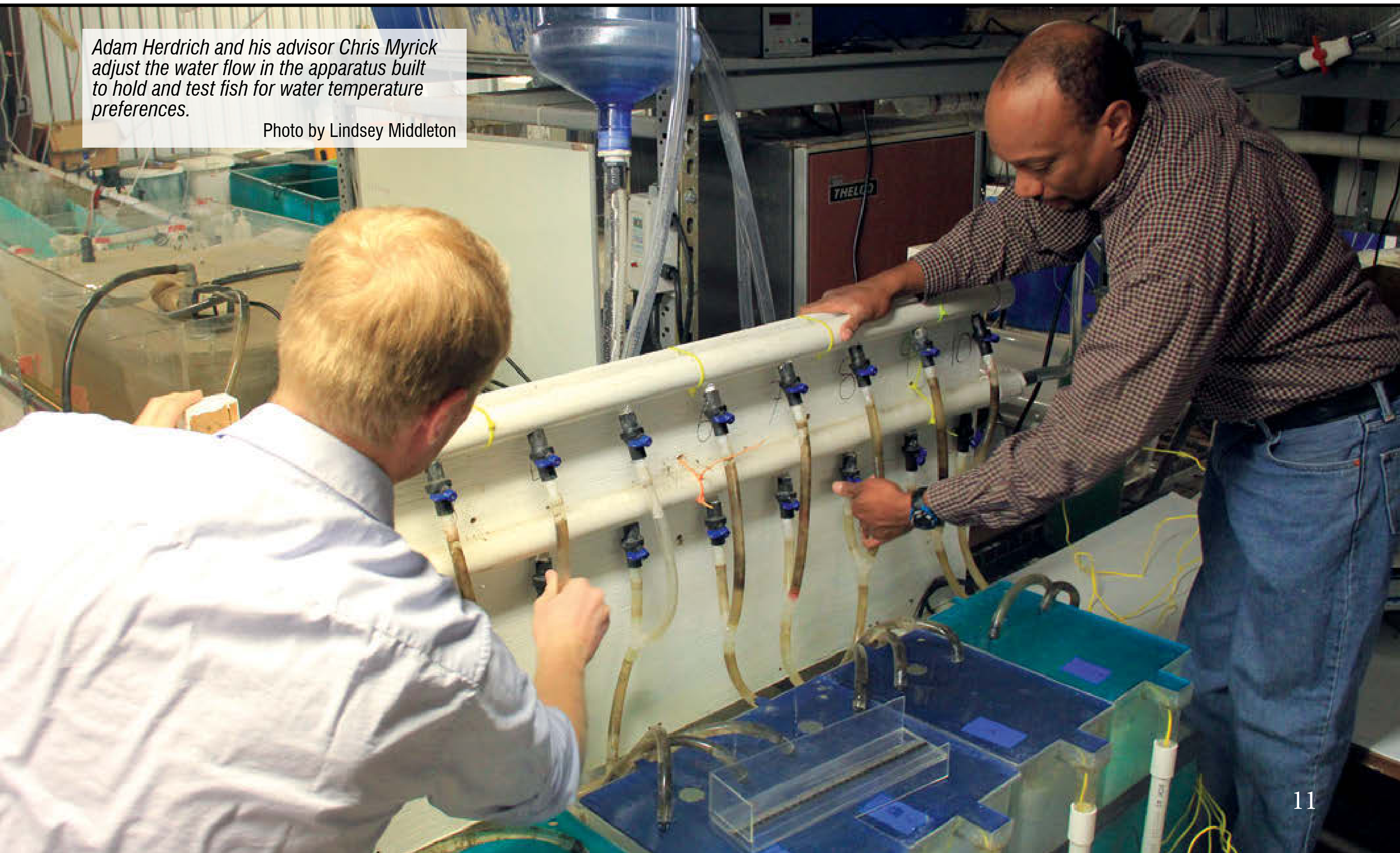


Figure 5. *Effects of fish size (TL, in mm) on the critical thermal maxima - loss of equilibrium (CTMax-LOE) of adult stonecats (Noturus flavus) acclimated to 20°C. The shaded area shows the 95 percent confidence interval for the fitted regression line.*

Additionally, the presence of a size effect highlights the importance of follow-up studies to determine whether there are ontogenetic changes in the thermal tolerance of stonecats; if the larger adult fish are indeed more sensitive to elevated temperatures, perhaps more protective standards are required to protect them. From this study, it is clear that further research is warranted, both to better understand the effects of fish size on thermal tolerance, and to complete a thermal tolerance polygon (a figure showing the absolute thermal limits, upper and lower, for a fish species) for the stonecat. Authors gratefully acknowledge funding from CWI.



Adam Herdrich and his advisor Chris Myrick adjust the water flow in the apparatus built to hold and test fish for water temperature preferences.
Photo by Lindsey Middleton

3-D Modeling of Fish Passage in Colorado Whitewater Parks

Brian Fox, MS Candidate, Department of Civil and Environmental Engineering, Colorado State University
Nell Kolden, MS Candidate, Department of Civil and Environmental Engineering, Colorado State University
Faculty Advisor: Brian Bledsoe

In a Nutshell

- Study: Determine the effect of whitewater parks (WWPs) on aquatic and riparian habitat and on the movement of fish
- Method: Data was collected from WWP sites and control sites using a hydraulic modeling software package
- Results: WWPs may be a partial barrier to fish movement, and further study is needed to determine habitat changes

Electroshocking surveys were used to determine fish biomass in WWP reaches and control reaches. Captured fish were tagged with Passive Integrated Transponder tags, measured, and weighed before being released.
Courtesy of Brian Fox

Introduction

Whitewater parks (WWPs) have become a popular recreational amenity in cities across the United States, with Colorado being the epicenter of WWP design and construction. WWPs contribute to local communities by providing revenue from tourism, promoting public interest in rivers and creating exciting new recreational opportunities. However, no comprehensive studies have been completed to assess how these structures affect the ecological environment.

An initial pilot study was completed by the Colorado Parks and Wildlife (CPW) to monitor a small number of WWPs in Colorado. They identified a number of concerns surrounding WWPs, including the potential for impaired aquatic organism passage and loss of aquatic and riparian habitat. These concerns were developed through observations of the altered hydraulic conditions at WWPs. Field measurements of a high velocity zone within the structures indicate that conditions may exceed fish swimming ability and limit upstream passage, while complex flow patterns and recirculation below the structures could be creating unfavorable habitat conditions.

CPW and Colorado State University (CSU) initiated a comprehensive field study to assess the effects of WWPs on upstream fish passage, and to determine potential positive or negative effects of WWPs on aquatic habitat quality. Central to both research goals is to increase our understanding of the hydraulic conditions present in WWPs and how this relates to fish passage and habitat quality. The authors collaborated to develop a hydraulic dataset using FLOW-3D® and then used this data set as part of separate analyses aimed to address the two research goals. Brian Fox incorporated this data set to assess the effects of WWPs on fish passage, while Nell Kolden used this data set to assess effects of WWPs on habitat quality.

Study Sites

A study site was selected at a WWP in the Town of Lyons, Colorado on North Fork St. Vrain River. A WWP was constructed at this site in 2003 and consists of nine WWP structures representing a range of design types. Three of these structures and three control sites were selected for detailed study of fish passage and habitat. The selected control sites were intended to provide a baseline for comparison of habitat and fish passage conditions (see map).

Hydraulic Model Development

FLOW-3D® is a commercially available hydraulic modeling software package. This model outputs a dataset of detailed information on flow velocity, direction and depth, which can be used to evaluate fish passage and habitat at relevant spatial scales over a range of flow conditions.

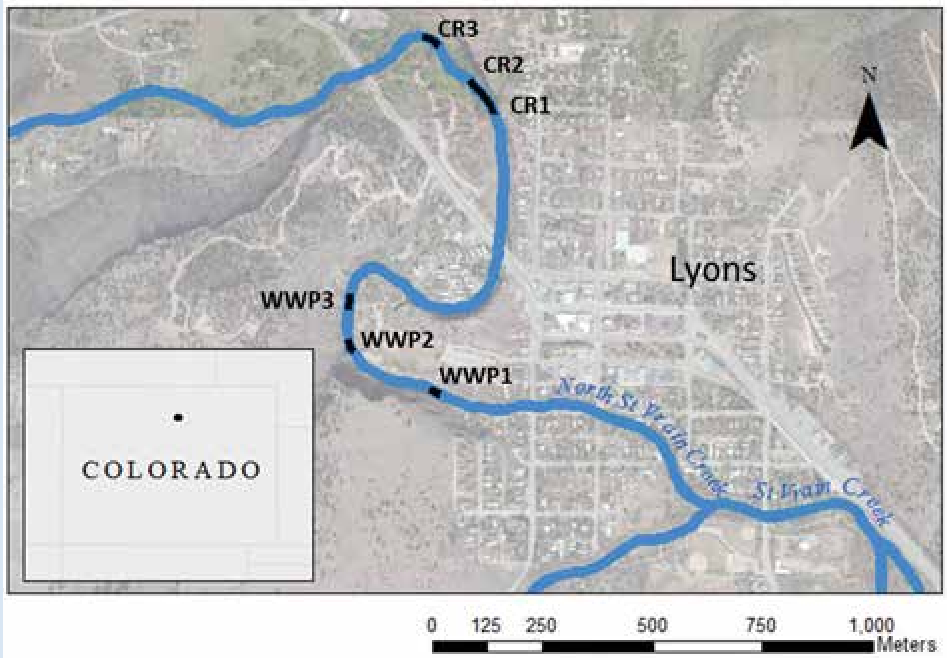
To build the model for each WWP reach and control reach, we collected detailed channel bed and bank topography, upstream and downstream flow conditions, and a channel bed roughness to approximate the effects of boulders and cobbles in the stream to be specified in the computer model. We validated the accuracy of the model by comparing predicted velocities and depths with field measurements.

Multiple simulations were performed at different of flow rates that matched the low, medium, and high flow conditions for each of the study sites.

Fish Passage Study

We used a Passive Integrated Transponder (PIT) telemetry system to track fish movement and directly assess the effects of WWPs on upstream fish movement. PIT telemetry is a type of passive radio frequency identification (RFID) with the capability to detect uniquely coded radio tags that pass within the vicinity of fixed antennas. Because PIT tags are small (<32mm) and operate without batteries, they are ideal for studies involving a number of individuals over relatively long time periods.

Approximately 2,500 individual fish including brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus*



The study site was located on the St. Vrain River in Lyons, Colorado. Courtesy of Nell Kolden

mykiss), longnose sucker (*Catostomus catostomus*) and longnose dace (*Rhinichthys cataractae*) were tagged and released within the vicinity of the project. A total 12 fixed PIT antennas were installed to monitor upstream movement across three WWP and three control sites.

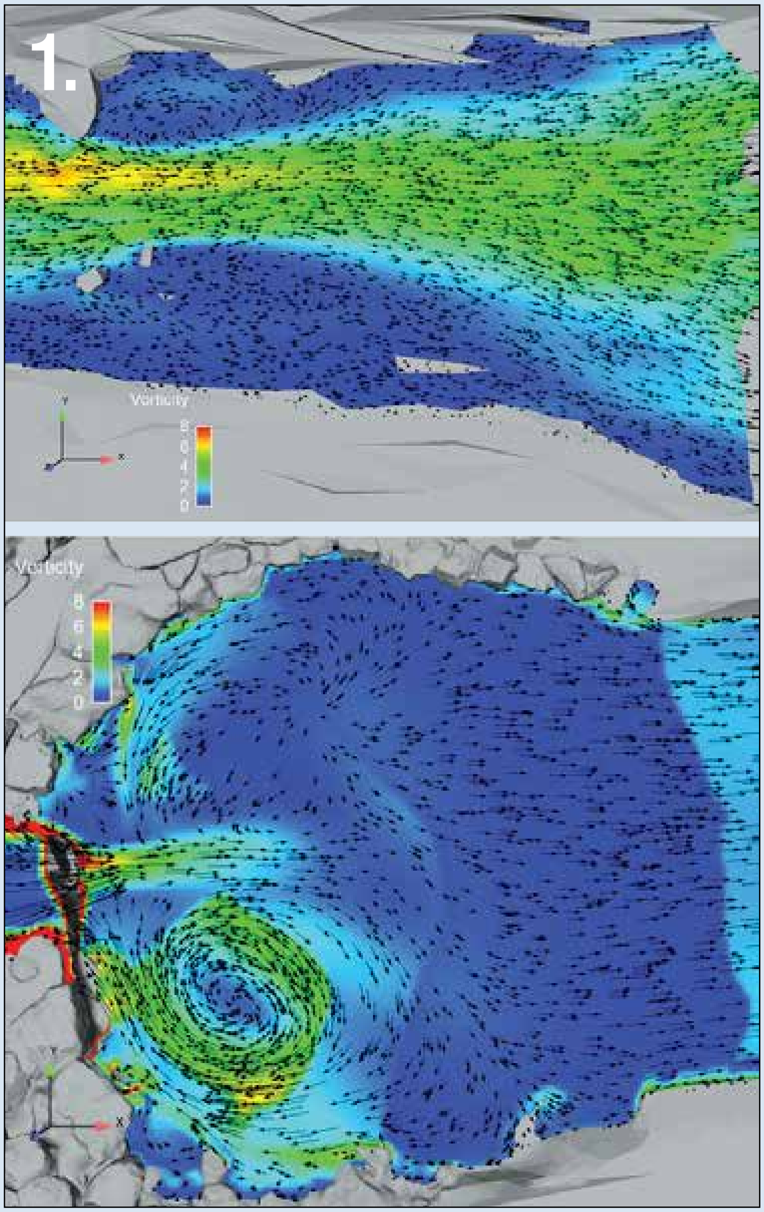
We collected PIT telemetry data for approximately 14, and totaled over 10 million individual detections of tagged fish. Results show that this WWP is not a complete barrier to upstream movement, but differences in WWP and control movement may indicate a partial barrier. Proportions of fish moving upstream differed by up to 30 percent based on 359-494 individuals observed at each sampling location. Maximum water velocities observed in the chutes of WWP structures exceeded three m/s in some instances, while those within the control reach were typically below one m/s.

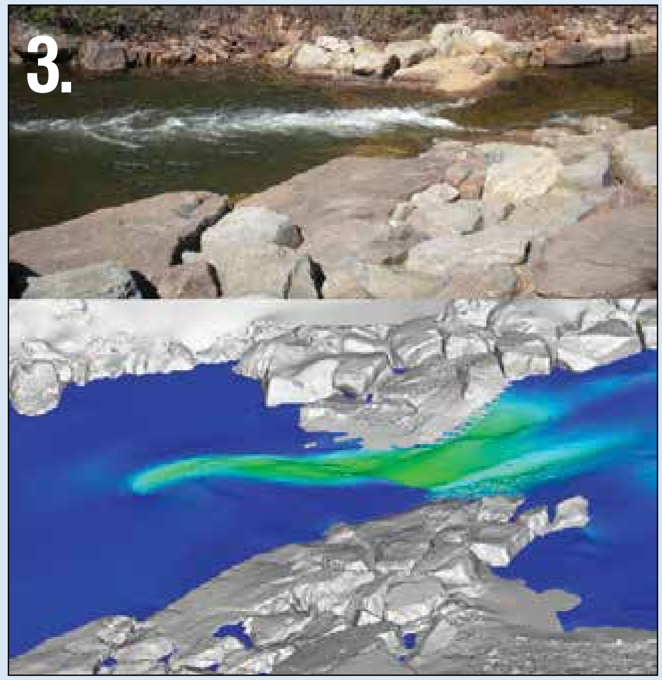
Further analysis is currently underway to assess this difference in movement rate and how it may be related to the hydraulic conditions at the WWPs. We are using the PIT data and a mark-recapture statistical model to assess differences in movement probability between the WWP and control sites. We will also be assessing the effects and interactions between species, body length and hydraulic conditions using the FLOW-3D® modeling results. The results of this analysis will assist future research needed in developing design guidelines to optimize the recreational and ecological benefits of WWP structures.

Fish Habitat Study

We used the output of the FLOW-3D® models to calculate predicted habitat quality in the WWP pools and control pools. Habitat suitability equations were used for this process, which relate the 2-D hydraulic variables depth and depth-averaged velocity to habitat suitability for specific fish species and life stages. Predicted habitat suitability in the WWP pools based on these equations was on par with control pools for all species and life stages; however, CPW conducted fish biomass estimates in the same WWP pools and control pools and found more adult brown trout and rainbow trout biomass per volume in the control pools during two years of surveys, which directly contradicts the prediction of habitat suitability models for these species.

This contradiction suggests that the habitat suitability analysis is not accurately predicting habitat suitability





1. *Flow-3D model results show the different flow patterns present in whitewater parks pools and control pools. The top graphic is CR3 and the bottom graphic is WWP2. Color contours show 3-D vorticity and arrows show flow direction.* Photo by Nell Kolden. 2. *Nell Kolden and Brian Fox discuss their whitewater parks research site with their faculty advisor, Brian Bledsoe.* Photo courtesy of authors. 3. *Visual comparison of actual river flow through whitewater park drop structure (top) and modeled flow through the same structure (bottom).* Courtesy of Brian Fox.

in the WWP pools, and there are many possible explanations for the discrepancy. First, the habitat suitability equations are based solely on the 2-D variables of depth and depth-averaged velocity. It is clear from the FLOW-3D models of the WWP pools that there is substantial flow complexity in the vertical direction, and this 3-D flow complexity could affect fish habitat in a way that is not reflected in the habitat suitability equations. Secondly, the predictions take into account only hydraulic conditions, while there are many other factors that affect habitat quality including competition, predation, food availability, water quality, and recreational use.

The results of this habitat analysis show that more research is needed to understand the specific ways that WWPs affect aquatic habitat quality. 3-D modeling has the potential to be very useful in this research, especially as we increase our understanding of how habitat quality is correlated to 3-D hydraulic variables such as turbulence, vorticity, and circulation.

Acknowledgements

The authors would like to acknowledge and thank the contributions of the many people who made this study possible. Colorado Parks and Wildlife, Colorado Water Conservation Board, and the Colorado Water Institute all contributed funding and resources. We would all also like to give special thanks to Jordan Anderson, Brian Avila, Larissa Bailey, Dan Cammack, Eric Fetherman, Ashley Ficke, Dan Gessler, Adam Herdrich, Matt Kondratieff, Joel Sholtes, and Ben Swigle for their contributions to this study.

Structural and Functional Controls of Tree Transpiration in Front Range Urban Forests

Edward Gage, PhD Candidate, Ecology, Department of Forest and Rangeland Stewardship, Colorado State University
Faculty Advisor: David J. Cooper

In a Nutshell

- Study: Urban vegetation was classified in Aurora, Colorado to determine predictors of structure and composition, relational variation between tree diversity and broader land cover patterns and social structure, and other factors.
- Methods: Remote sensing analysis with added layers was accompanied by a tree inventory and data collected on transpiration rates.
- Results: Several patterns emerged, including that land use and zoning parameters correlated with the abundance of vegetation types.

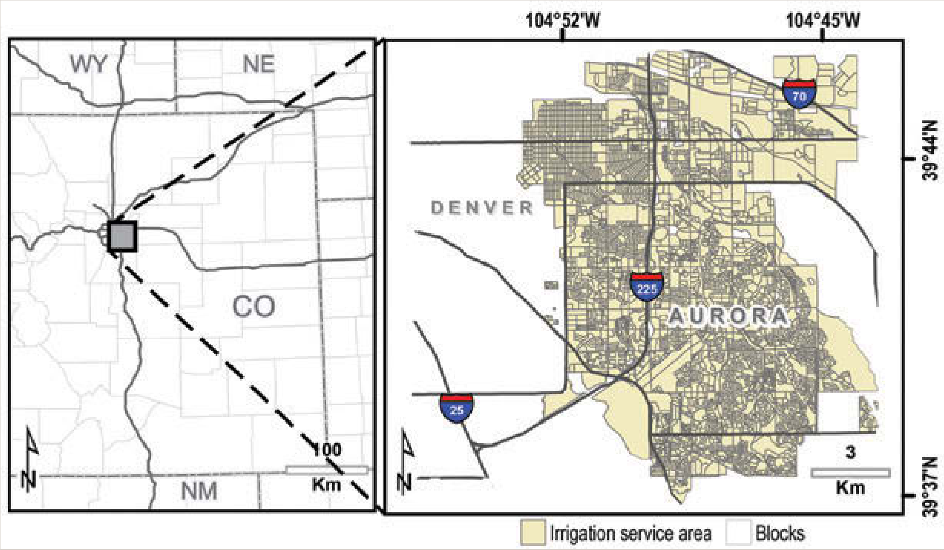


Figure 1. *Map of Aurora, Colorado study area.*

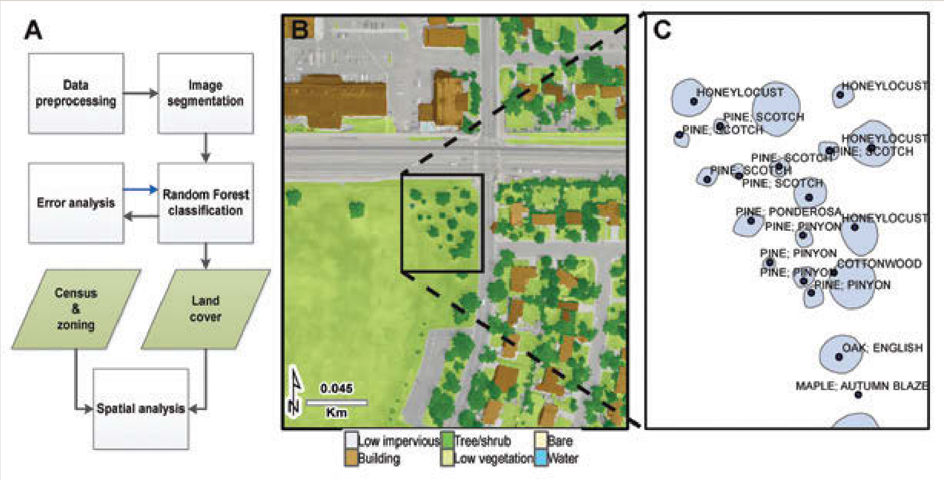


Figure 2. *Flowchart illustrating main steps in development and analysis of land cover data (panel A); example of land cover product (panel B) for an Aurora Park also used in field measurements of tree sap flow (inset box, panel B; panel C).*

Introduction

A few basic land cover (LC) classes dominate the urban landscape, but just as a painter can coax varied hues from a few primary colors, basic LC types such as trees, turfgrass, and pavement are arranged in complex patterns in cities. The abundance and spatial arrangement of LC classes forms a city's physical structure, which, in contrast to natural ecosystems, is largely the product of human agency. Socioeconomic, demographic, and land-use factors (e.g., zoning regulations) contribute to a city's legal and social structure. Combined, these shape a city's basic character and influence phenomena important to water managers, such as evapotranspiration (ET) and residential water demand.

Vegetation, especially trees, strongly influences urban structure and function. Front Range cities are built largely on native grasslands, and on the pre-settlement landscape, trees were generally restricted to riparian areas. An LC change commonly accompanying urbanization is the establishment of irrigation-dependent vegetation types. Water applied to support these communities often accounts for the majority of summer water demand, so an improved understanding of factors influencing plant water requirements and outdoor watering behavior is critically important to water management.

The urban forest is particularly varied, supporting trees differing in age, size, and basic functional characteristics. For example, transpiration rates and stomatal sensitivity to atmospheric drivers of ET vary among species and functional groups, due to differences in plant physiology, xylem anatomy, root distribution, and phenology. If functional differences can be generalized and inferences made to landscape-scale distribution patterns, a truer accounting of vegetation's role in urban ecohydrological processes may be possible.

Research Questions

Our broad research objective is to explore landscape-scale spatial variation in vegetation characteristics potentially important as drivers of outdoor water consumption in a typical Front Range urban area. Our motivation is to develop information applicable to studies of the urban water balance and outdoor residential water demand. Specifically, we ask:

- What socioeconomic, demographic, and historical land-use history variables best predict measures of urban vegetation structure and composition?
- Does the compositional diversity of trees in the urban forest vary in relation to broader LC patterns and social structure?
- Can tree compositional diversity be reduced meaningfully by identifying functional types?

Edward Gage with his advisor, David Cooper.
Photo by Kim Hudson

Methods

Land Cover Mapping and Landscape Analysis

At the broadest scale, we used remote sensing analyses to map and characterize LC characteristics for our Aurora, Colorado study area (Figure 1). Accurate LC data of sufficiently fine grain is a prerequisite for analyses in urban areas. Existing LC data are too coarse to be used for parcel-scale analyses, so we developed our own dataset using an object-oriented segmentation and random forest classification approach on primary and derived high spatial resolution (0.5 m GSD) multispectral imagery and lidar layers. Lidar is an active remote sensing technology similar in principle to radar that uses pulsed laser light instead of microwaves to produce point clouds characterizing the 3-D structure of what is being sensed. Six classes were mapped: trees, buildings, low vegetation, low impervious, bare soil, and water (Figure 2).

We calculated the proportional area of each LC class, as well as various image and lidar-derived structural variables (e.g., mean tree height, NDVI, etc.), for study area parcels, census blocks, and census block groups using zonal statistics tools in ArcGIS. A similar procedure was used with socio-economic, demographic, and historical land-use data from the 2010 U.S. Census, Arapahoe County Assessor's Office, and the U.S. Geological Survey. Agglomerative cluster analysis was used define natural groupings of sampling units

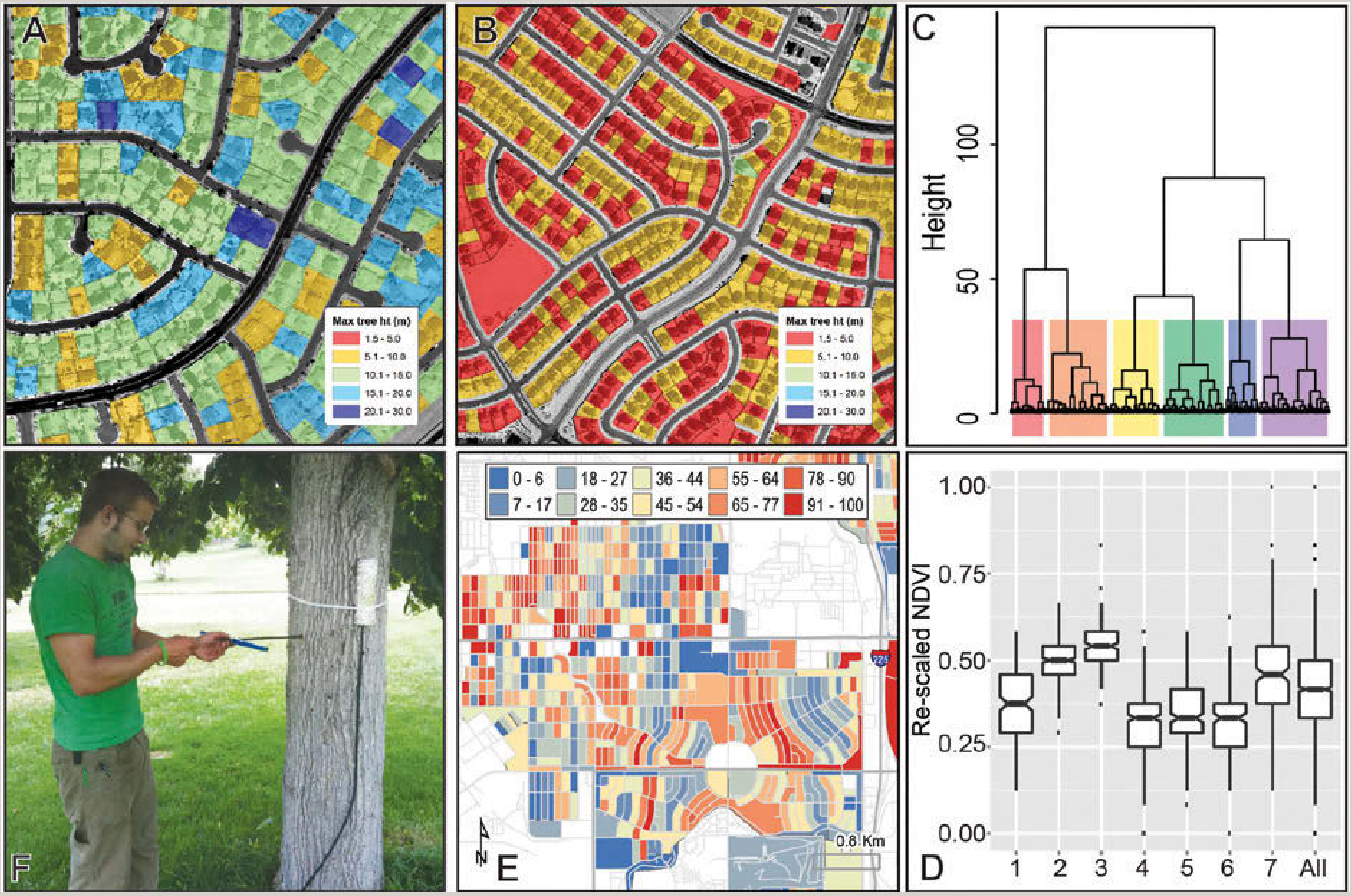


Figure 3. *Clockwise from the top left: parcel level maximum tree height for an older neighborhood built in the early 1960s (panel A); maximum tree height in a newer neighborhood constructed in the early 2000's (panel B); dendrogram illustrating clustering of census blocks based on agglomerative cluster analysis of physical structure variables (panel C); box plot of mean census block Normalized Difference Vegetation Index (NDVI) clusters (panel D); intermediate-scale map illustrating the proportion of all trees in individual census blocks with ring-porous xylem anatomy (panel E); Andrew Carlson, CSU Research Associate, collecting tree core from green ash tree outfitted with sap flow sensor (panel F).*

at a given scale and to provide a means of identifying portions of the landscape exhibiting similar structure.

Models predicting structure variables were then constructed in the R statistical program, with separate analyses constructed for parcel, block level, and block group level units. We used Random Forests, an ensemble method commonly used in data mining because of its predictive accuracy and ability to work with highly dimensional and nonlinear data. Variable importance plots were used to identify variables most useful for prediction.

Analysis of Urban Tree Composition and Functional Variation

Our LC data are precise enough to effectively discriminate among broad LC classes. However, the data sets we used contain insufficient information from which to discriminate individual tree species, so we used a tree inventory layer provided by Aurora. These data were used to evaluate spatial distribution patterns and assess the relative abundance of tree functional types defined by wood xylem anatomy (e.g., conifers, diffuse-porous and ring-porous angiosperms), a factor shown in previous studies to influence ecohydrological function.

Most studies documenting ecohydrological consequences of xylem anatomy have been conducted outside of the Front Range. To evaluate whether previous findings apply to the tree species and environmental conditions here in Colorado, we measured tree transpiration using thermal dissipation sap flow sensors at five Aurora parks. Data are still being analyzed, but will help quantify differences in tree transpiration rates among species with different physiological characteristics. Our intent isn't to directly scale-up field-based transpiration to the study area—there are too many confounding and unmeasured variables; rather, data will be used to contextualize landscape-scale tree distribution patterns and evaluate the utility of incorporating tree functional type into future sampling and modeling

Results

Our land cover maps reveal complex spatial patterns across our study area. The relative abundance of different land cover classes varies dramatically depending on land use and zoning parameters. For example, the highest impervious cover is found in commercial settings, while vegetation cover is greatest in city owned parks, open space, and golf courses. Residential areas generally show intermediate characteristics between those found in commercial and park settings.

Total tree cover and the proportional share of vegetation cover from trees is greatest in the Northwestern portion of the assessment area, and is directly related to the age of the neighborhood (Figure 3; panels A and B). Tree height and canopy volume layers are correlated with each other and with absolute tree cover, showing similar spatial trends over the assessment area, with the greatest mean and maximum height and volume seen in older portions of the city.

Tree inventory analyses reveal additional complexity in the urban forest. Of the 48,957 trees in the assessment area, 51.8 percent were classified as diffuse-porous, 41.3 percent as ring-porous, and 6.8 percent as conifer (Figure 3). Our sap flow measurements reveal significant tree to tree variability in transpiration. Some is due to micro-site and size variation among trees, but data also suggest differences among trees with different wood anatomy.

Discussion

Our research highlights the complexity of urban land cover patterns, particularly with regard to vegetation. Results suggest numerous socio-economic variables are correlated with physical structure characteristics (e.g., percent tree cover, mean tree height, etc.), a finding consistent with previous research. Our LC classification captures broad differences in LC, but fails to discriminate among tree types. Traditional tree inventories complement data from remote sensing analyses by providing species and functional type-specific information. Preliminary results from sap flow analyses support the notion documented elsewhere that tree functional types respond differently to climatic drivers of ET.

Individually, the different scales of analysis provide interesting insights on urban land cover patterns of direct importance to water managers. In future analyses, we will work to elucidate controls on these patterns, and importantly, link patterns and processes across varying scales. Results also suggest that time since development is an important conditioning factor shaping vegetation structure, but more work is needed to understand how temporal changes in structure affects urban microclimate, water and energy demand, and ecological services. Authors gratefully acknowledge funding from CWI.

Assessing the Benefits and Drawbacks of Different Institutional Arrangements to Enhancing Forest and Water Ecosystem Services and Ecosystem Services Markets in Colorado

Heidi Huber-Stearns, PhD Student, Department of Forest and Rangeland Stewardship, Colorado State University
Faculty Advisors: Antony Cheng, Joshua Goldstein

In a Nutshell

- Study: Several Payments for Watershed Services (PWS) programs have been developed in recent years; this study characterized and mapped PWS programs in the western U.S.
- Results: After collecting and characterizing data, a map for publication, a spatial database, and an initial Web map are the project's outcomes.

Introduction

The forested watersheds of the western U.S. are critical to the supply of clean drinking water to myriad downstream users, including agriculture and urban population centers. Intensifying watershed risks, inadequate public and private funding, loss of land stewardship capacities, and limitations of existing policies are all converging on the matrix of state, federal and private lands across the region. These challenges, combined with opportunities arising from expanding cross-sector collaborations, provide a fitting context for the development of programs that incentivize the stewardship of public environmental resources across land types. Such incentive programs are geared toward linking ecosystem service providers (e.g., landowners or a federal agency improving water quality or quantity upstream) with those who depend on those services (e.g., downstream utilities, breweries). Incentive-based programs targeting watershed ecosystem services, often broadly classified as Payments for Watershed Services (PWS), have expanded rapidly in the western U.S. over the last decade. PWS is a policy tool that can be used in order to address environmental issues of concern, such as water supply and security. While relevant reports have highlighted many of these programs, until now, no comprehensive report existed that detailed characteristics for all PWS programs in the western U.S. As these programs continue to expand, a window of opportunity exists to use lessons learned from these programs to shape future design and implementation of new programs, and also to improve the effectiveness of existing programs.

Study Area

Our study region included the western U.S., encompassing: Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Utah, Washington, and Wyoming. The western U.S. provides an appropriate study site for this project, due both to the sheer number of PWS-type programs emerging across the region, as well as the increasing watershed and natural resource concerns, such as wildfire risk and effects, overall forest health, source water protection, and increasing water quality regulations.

Research Objectives

The purpose of our investigation was to characterize PWS programs in the western U.S. region by understanding: 1) the key design elements of these programs, and 2) how experimentation on-the-ground relates to and differs from what we know of PWS literature and related theory.

Methods

We began our project with a literature and document review in order to generate an informed understanding of existing documentation of PWS programs in the west, as well as to identify which program attributes we should include in documenting programs. To inform our approach, we used sources such as Ecosystem Marketplace's 2010 State of Watershed Payments report and Watershed Connect Web-platform, as well as Carpe Diem West and EcoAgriculture reports, all of which identified a varying number and type of PWS programs in the region.

Survey Development and Data Analysis

For survey design and administration, we partnered with Ecosystem Marketplace, an online source of news, data, and analytics on ecosystem services projects around the globe (see www.ecosystemmarketplace.com/). Our survey was administered online to all identified relevant programs in the study area. Survey follow-up was conducted by phone. We conducted quantitative data analysis in SPSS ("Statistical Package for the Social Sciences" from IBM) with the resulting survey data.

Results

We found 41 programs in operation, 14 programs in design, and 12 programs that were either inactive or did not have data to report. In this section, findings are reported for only the 41 programs identified as currently in operation since the programs in development do not yet have complete data.

Overall Program Characteristics

Geographically, the number of programs varied by state, with at least one program in each state. The highest concentration of programs was found in the Pacific Northwest (Oregon and Washington). The programs ranged in age, with the oldest programs ($n = 9$) established in 1970-80s. In the past decade, the number of operating programs doubled, reaching 41 programs in 2012. The majority of programs (88 percent) include private land. By comparison, approximately 35 percent of programs include (mainly federally managed) land.

Our results demonstrate that a variety of actors are involved in these programs, including, for example, states (Water Resources, Ecology, Forestry, Fish and Wildlife departments) and water utilities as ecosystem services buyers, NGOs as program administrators (those managing program funds), and private landowners and federal agencies as sellers. The collaborative nature of these arrangements is evident from the number and differing sectors of participants. Most programs involved

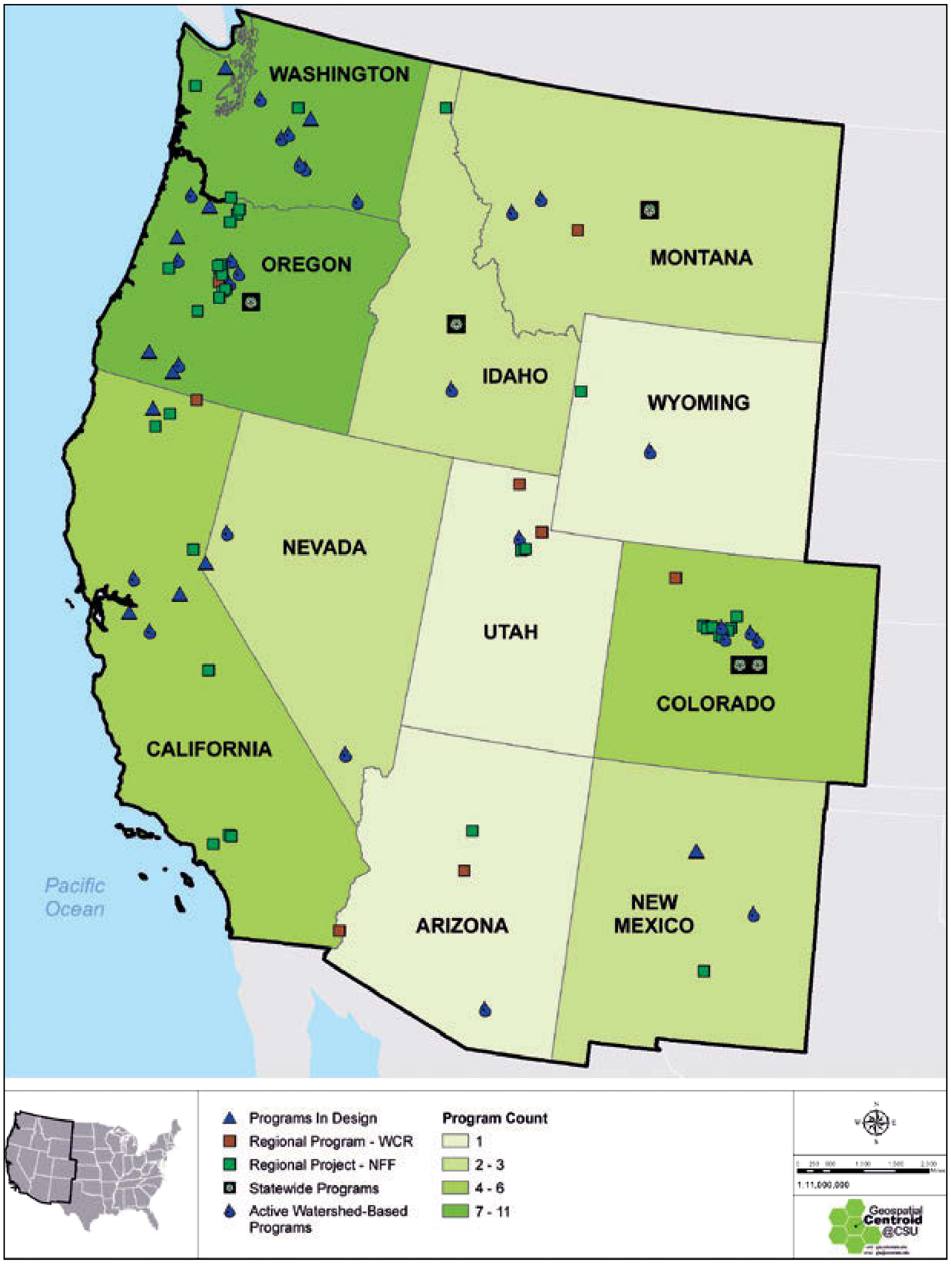


Figure 1. *Incentive-based Watershed Programs in the Western United States*

voluntary participation on the part of ecosystem-service sellers, but contained some regulatory driver(s) for those participating as buyers. Drivers for the programs stemmed mainly from meeting state and federal regulations, including state-specific propositions and statutes, particularly instream flow requirements. Other federal regulatory drivers include the Clean Water Act and Endangered Species Act. Seventy-six percent of programs focused on water quality ecosystem services, including a subset of programs (20 percent) that focused on phosphorous and/or nitrogen specifically. Seventy percent of the programs concentrated on flow restoration ecosystem services, which demonstrates that many programs were aimed at dual water quality and quantity goals. Programs were found to conduct different management actions in order to achieve targeted ecosystem services. Most programs (66 percent) employed water rights transactions, including acquisition of temporary leases and permanent water rights transfers. Several programs (27-34 percent) also used restoration and protection actions to achieve program goals. Other program actions included reforestation, alterations to agricultural and operational procedures, and fire suppression.

Mapping Project Results

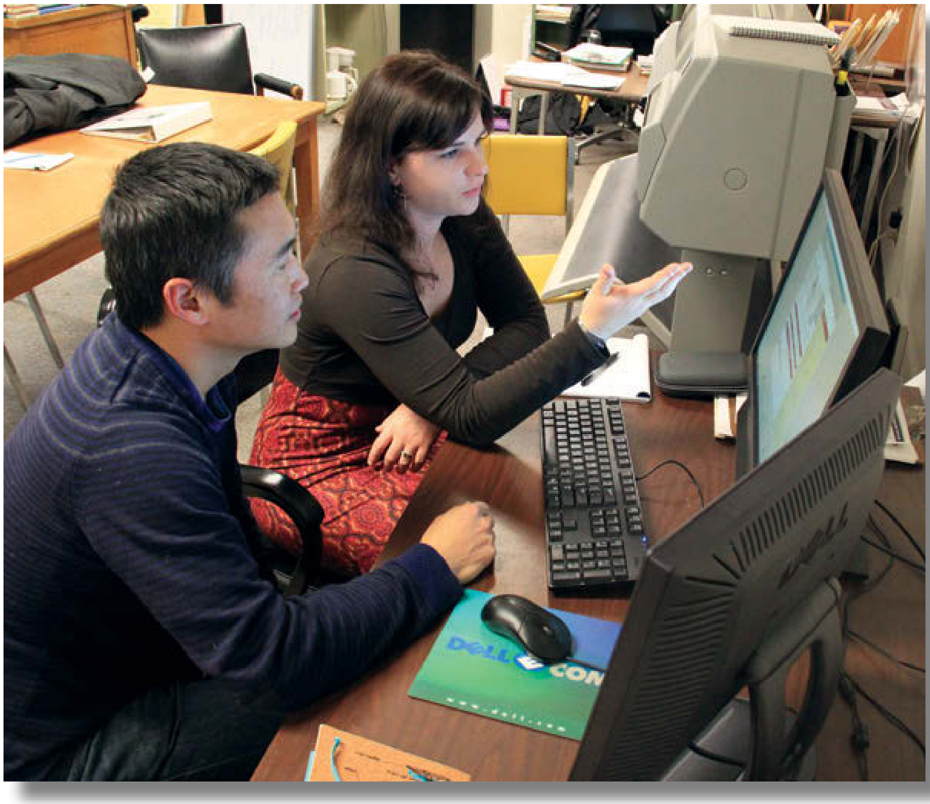
In collaboration with the Geospatial Centroid at Colorado State University, we are in the process of using the survey data and results to organize and distribute spatial data and map products. This portion of our project contains three products: 1) a map for publication, 2) a spatial database, and 3) an initial Web map. The map for publication purposes displays the programs and their respective watersheds within the study region (Figure 1). The development of a spatial database includes detailing the spatial extent of each watershed project and attributes of each program, such as the previously described program characteristics. For the final product, the Centroid will publish the data (from the developed database) as a Web map service and will create a website where the data can be viewed. The anticipated completion date for the spatial database and web map service is April 30, 2013.

Conclusion/Implications

As is evidenced by the substantial increase in programs implemented across the landscape, and the programs in design at the moment, it is clear that these types of PWS programs are continuing to grow in our region. It is important to understand how to appropriately design programs, which actors to target as potential participants, and the types of social-ecological contexts and drivers for which this type of policy tool is suitable. Another finding from our data analysis is the identification of differences between programs, dividing our dataset into subgroups. Some key differences between programs include geographic distinctions, management actions, types of sellers, and program objectives. For example, in the Pacific Northwest, many programs are focused on increasin g instream flow in rivers through water rights and leases from individual private landowners. In the more arid parts of the west (e.g., Colorado, New Mexico, Arizona), programs are focused on protecting watershed health and reducing wildfire risk by employing restoration and protection actions, typically on public land (e.g., National Forest System lands managed by the U.S. Forest Service). We are currently further developing these program typologies using survey results. These distinctions can expand both practitioner and academic awareness of the differences and similarities between programs, thus generating a more mutual understanding of the types of programs, as well as where and how they operate. Understanding what and how actors, policies, and communication influence the design, implementation, and outcomes of these projects across the landscape is essential to providing lessons learned for future program design.

Acknowledgements

We would like to thank the Colorado Water Institute (CWI) for sponsoring survey and mapping development for this project. This support allowed us to speed up the development and administration of our survey through funding research hours and encouraged the development of new collaborations with external partners. CWI funding also provided us the opportunity to work with the Geospatial Centroid to develop maps and related products. We thank the CSU Colorado Agricultural Experiment Station for its support of our larger research project. We also thank other project collaborators including, Genevieve Bennett and the Ecosystem Marketplace team, and AES project collaborator Ted Toombs.



Heidi Huber-Stearns works with her advisor, Tony Cheng, on her spreadsheet characterizing Payments for Watershed Services programs in the western U.S.
Photo by Lindsey Middleton

Andrew Muniz works with his faculty advisor, Nolan Doesken, on a portion of his precipitation analysis.
Photo by Henry Reges

Relating Streamflow Amounts to Various Climate Indices and Quantifying Spatial Differences in Snowpack in Colorado

Andrew Muniz, Earth Science: Meteorology, University of Northern Colorado
Faculty Advisor: Nolan Doesken

In a Nutshell

- Study: To analyze latitudinal precipitation patterns in Colorado and construct a more accurate model for forecasting snowpack and runoff
- Methods: Snowpack and streamflow from diverse sites were collected and compared to historical El Niño Southern Oscillation (ENSO), North Atlantic Oscillation (NAO), and Pacific Decadal Oscillation (PDO) data
- The resulting model showed that ENSO was a weak but potential predictor, and that NAO and PDO may be more accurate predictors

Introduction

Skillful snowpack, streamflow, and water supply prediction with reasonable lead times is essential to water management and planning not only in Colorado, but around the U.S. With drought so widespread and severe in 2012, the interest in snowpack and streamflow prediction is at an all time high in Colorado for municipal water management, agriculture, and outdoor recreation.

The Rocky Mountains of Colorado receive a majority of their annual precipitation during the winter season, mostly as snow. The snowfall that has accumulated at elevations above 9,000 feet by mid-April each year becomes the source of most of the growing season's runoff and water supplies. This exemplifies the need and opportunity to improve forecast models to assist water management officials.

Climate teleconnections are one tool used in seasonal predictions around the world. The El Niño Southern Oscillation (ENSO) has been the most popular climate predictor here in Colorado, in terms of seasonal snowpack variability. For the purpose of this study, ENSO, North Atlantic Oscillation (NAO), and Pacific Decadal Oscillation (PDO) will be used in combination to identify correlations with snowpack and streamflow and to attempt to improve seasonal water supply forecasts.

Research Objectives

Many studies have been conducted investigating seasonal patterns and year to year variations in the magnitude and timing of precipitation in the Rocky Mountain region and relating these to streamflow discharge in Colorado's major river basins. The relationship of these variations to the phase of ENSO and other modes of large scale atmospheric and oceanic circulations indicates some potential for skill in streamflow forecasting. Analyses of Colorado precipitation data, especially winter season precipitation, reveal that there are many years where precipitation anomalies (wet versus dry) appear out of phase between the northern and southern mountains of Colorado. The objective for this research is to better recognize characteristic latitudinal precipitation patterns and document their association with large scale climate indexes such as ENSO, NAO, and PDO. The end result of this project is to develop a model with more skill in forecasting snowpack and runoff to further assist water management officials.

Methods

In order to document the impact each teleconnection has in Colorado, snowpack and streamflow data from diverse geographic regions of Colorado were selected. We first obtained snowpack data from 49 individual locations provided by the Natural Resources Conservation Service (NRCS), each of which has snow water equivalent, or SWE, readings dating back to 1950 or earlier. The 49 locations were separated into 11 mountainous regions throughout the state, based on geographic location and similar year to year variations in SWE. Then, one site from each of the 11 regions was selected to represent each region, which was solely based upon similar elevation. April 1 SWE data were selected since this is close to the maximum seasonal snowpack water

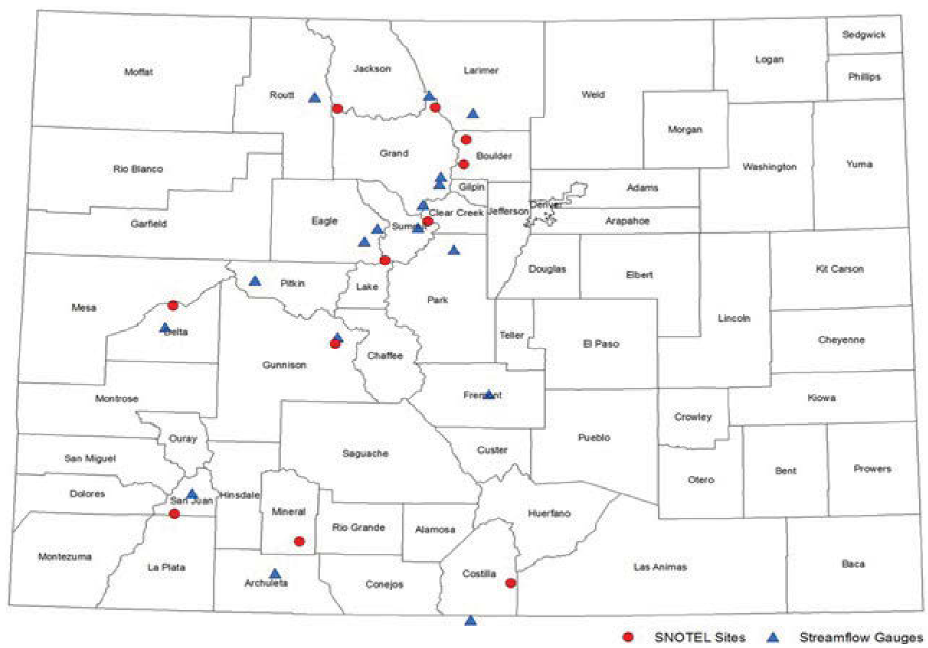


Figure 1. *Eleven SNOTEL sites denoted with a red circle and 17 streamflow gauge sites denoted with a blue triangle*

Table 1. *Correlations between April 1 SWE and April – July streamflow discharge amounts*

SNOTEL with Streamflow (Nearest City, State)	April - July (R Value)	April - July (R^2Value)
Cascade with Animas River (Silverton, CO)	0.5078	0.2578
Columbine with Fish Creek (Steamboat Springs, CO)	0.6908	0.4772
Copeland Lake with Big Thompson (Estes Park, CO)	0.4471	0.1999
Culebra#2 with Costilla Creek (Costilla, NM)	0.6956	0.4838
Fremont Pass with Eagle River (Red Cliff, CO)	0.7529	0.5668
Grizzly Peak with Bobtail Creek (Jones Pass, CO)	0.7368	0.5428
Lake Irene with Michigan River (Cameron Pass, CO)	0.6488	0.421
Park Cone with Taylor River (Taylor Park, CO)	0.7423	0.551
Park Reservoir with Surface Creek (Cedaredge, CO)	0.8899	0.7919
University Camp with Ranch Creek (Fraser, CO)	0.3433	0.1179
Upper San Juan with San River (Pagosa Springs, CO)	0.8987	0.8077

content and is best correlated with subsequent runoff and streamflow volumes. These 11 locations, Figure 1, represent spatial differences in snowpack in Colorado from the original 49.

Seventeen streamflow gauge sites were then chosen from the United States Geological Survey (USGS) and the Colorado Division of Water Resources (CDWR). A total of nine of the overall 17 stream gauge locations are naturalized streamflow sites, meaning not influenced by human activity. We only wanted to use naturalized sites, but not enough were readily available with close proximity to each SNOTEL location. This is why eight of the total 17 gauge sites are not naturalized sites. Streamflow discharge for these 17 sites was totaled from April 1 – July 31 and measured in cubic feet per second. It was then compared against snowpack from nearby SNOTEL stations to confirm how well correlated snowpack is with runoff in various regions across the state (Table 1).

Lastly, ENSO, NAO, and PDO monthly index values were obtained from the Climate Prediction Center and National Climatic Data Center, each of which dated back to 1950. A monthly time series of each index value was obtained starting at the beginning of each water year. (October – March, Figure 2) Also, a yearly time series beginning at the point of which recording of the stream gauge began until 2012 (Figure 3).

Results

Data provided for each of the preceding six monthly climate indices was correlated with seasonal (April-July) streamflow for that year using Statistical Analysis System, or SAS, and independently verified with

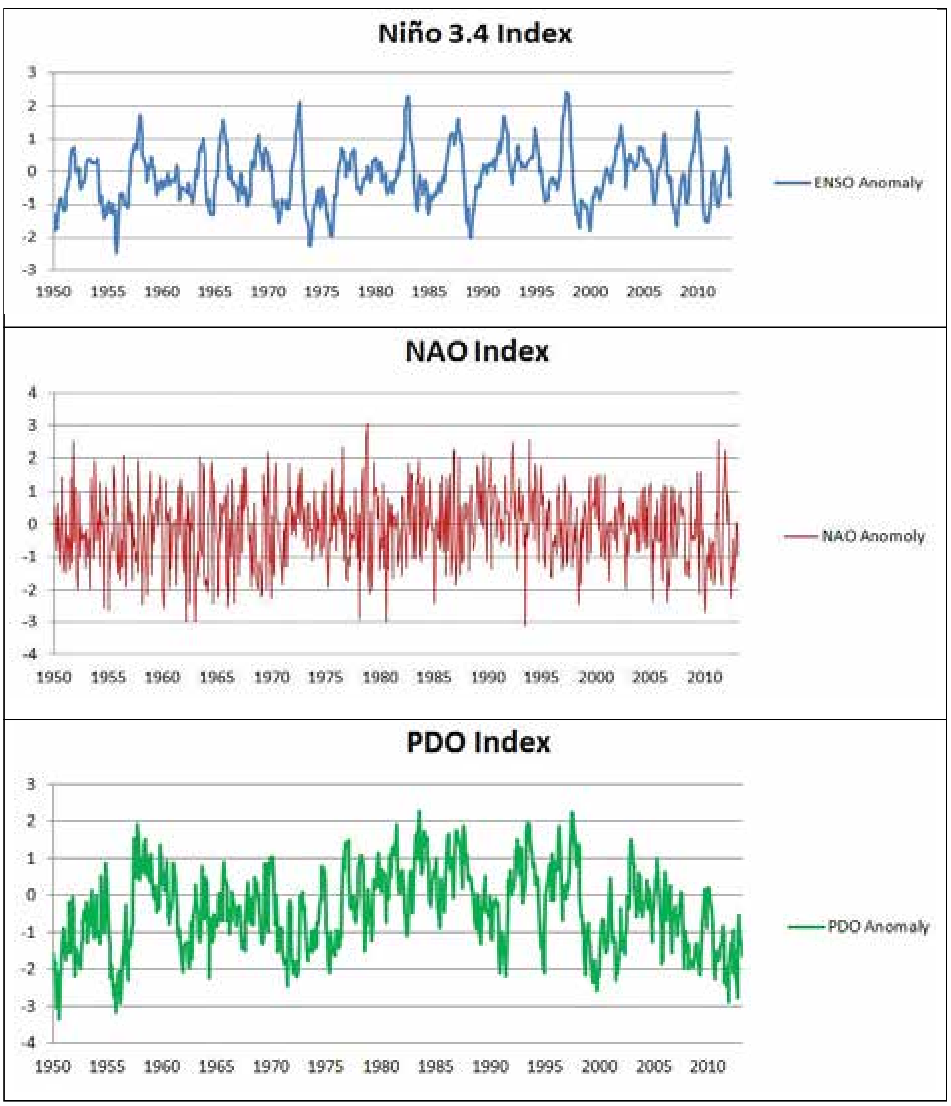


Figure 2. *The ENSO, NAO, and PDO monthly anomaly series from October 1950 – March 2012*

Table 2. *The number of times each climate index (ENSO, NAO, and PDO) contains the largest single month correlation value for each gauge site*

	ENSO	NAO	PDO
Best Correlation	2	9	6
Middle Correlation	3	7	7
Worst Correlation	12	1	4

Table 3. *Forecasted total streamflow discharge amounts from April 1 – July 31, 2013*

	Forecasted Streamflow
Animas River	2505
Arkansas River	2731
Big Thompson River	30944
Bobtail Creek	92.3
Costilla Creek	30.5
Crystal River	2183
Eagle River	213.6
Fish Creek	701.1
Fraser River	129
Gore Creek	134.3
Michigan River	28.5
North Fork South Platte River	14363
Ranch Creek	87.5
San Juan River	2726
Snake River	459.3
Surface Creek	166.4
Taylor River	956.6

Microsoft Excel. Streamflow versus SWE correlation show differences (Table 1) for a multitude of reasons that cannot fully be explained by climate forcings. However, most of the sites are well correlated and explain one another. The month with the highest correlation for each climate index was identified. Then the index values best correlated with streamflow were combined using multiple regression to provide a model to determine how well the three best single month correlations compared with the observed streamflow discharge values.

The results are shown in Table 1. Correlations are generally weak, even for ENSO. However, there is just enough correlation with several month lead time to possibly provide some useful predictive skill.

> "Analyses of Colorado precipitation data, especially winter season precipitation, reveal that there are many years where precipitation anomalies (wet versus dry) appear out of phase between the northern and southern mountains of Colorado."

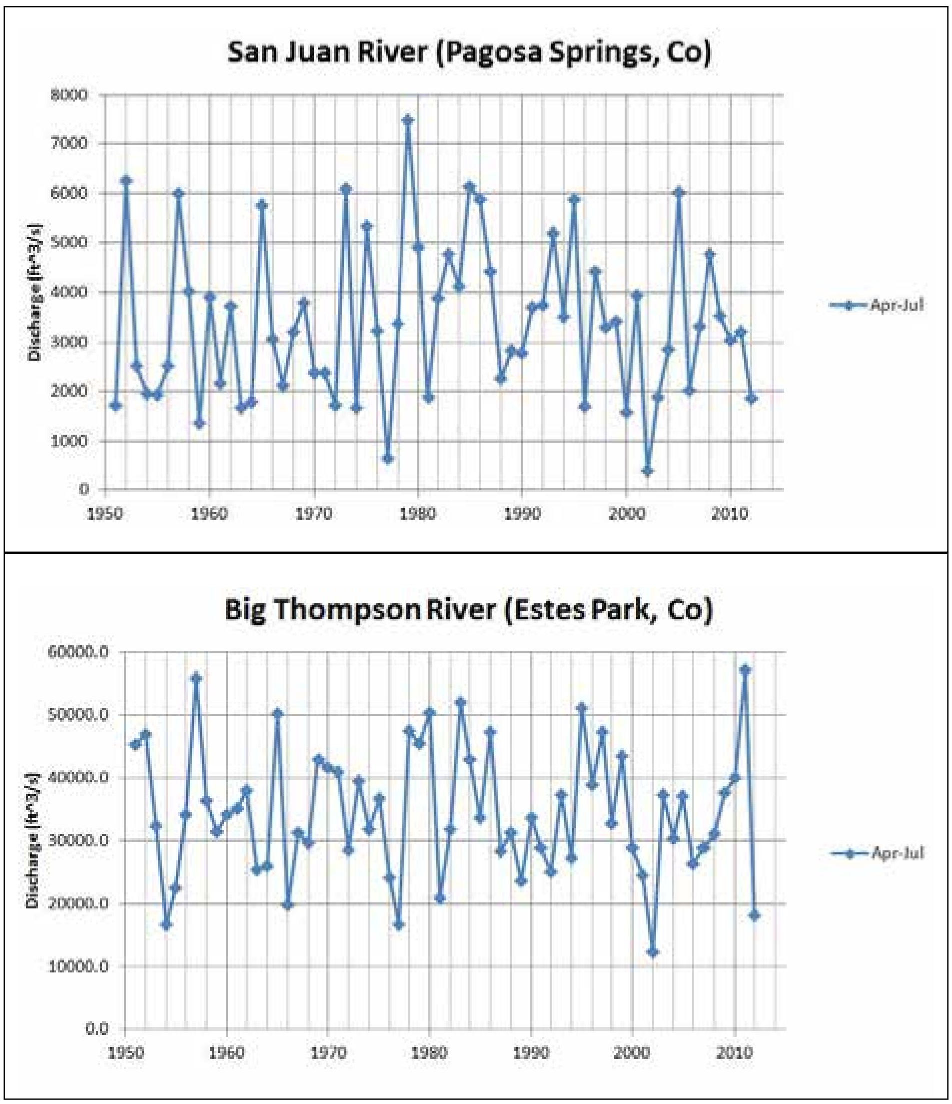


Figure 3. *Streamflow time series of the San Juan River in Pagosa Springs, Colorado and the Big Thompson River above Lake Estes in Estes Park, Colorado*

Interestingly, for most regions the NAO showed better correlation than ENSO. The NAO was more highly correlated during the month of November (13) than all other months combined (four) and the PDO was more highly correlated during March (14) than all other months combined (three).

Based on the results in this study, it can be concluded that for the period of the years tested, ENSO is ultimately the weakest climate predictor with NAO and PDO performing better. Since many forecasters have relied more on ENSO when making their upcoming winter snowpack predictions, using a model equipped with NAO and PDO may improve forecast accuracy. To show this, (Table 2) illustrates how many times a specific climate index is the best, worst, and average predictor, based on the R^2 value.

Future research for this project is to construct a full scale model, of which will include observed yearly discharge rates from April 1 – July 31 and compare it to each monthly climate index from October through March on a year to year basis. So this full model will include all six months from each climate index and total to 18 variables as compared to only three used previously. This may improve streamflow forecasts in the future and better assist water management officials in decision making. Lastly, we would like to show our forecasted values for each streamflow location based on our best three month correlation model (Table 3).

Acknowledgements

We would both like to thank the Colorado Water Institute and Colorado State University for funding this research.

Quantifying Streamflow Accretion by Conjunctive Use at the Tamarack Ranch State Wildlife Area

Jason Roudebush, MS Candidate, Watershed Science, Colorado State University
Faculty Advisor: John D. Stednick

Jason Roudebush and his advisor, John Stednick.
Photo by Lindsey Middleton

In a Nutshell

- As part of Colorado's Tamarack Ranch State Wildlife Area groundwater recharging initiative, a new model was created in this study to incorporate the most up-to-date data concerning the geology of the aquifer

Introduction

The presence of four threatened or endangered species—the whooping crane (*Grus americana*), interior least tern (*Sterna antillarum*), piping plover (*Charadrius melodus*), and pallid sturgeon (*Scaphirhynchus albus*)—on the Platte River in Nebraska prompted the states of Colorado, Wyoming, and Nebraska to enter into a cooperative Tri-State Agreement with the U.S. Department of the Interior to implement recovery efforts by improving riverine habitats. The Platte River Recovery Implementation Program (PRRIP) began on January 1, 2007, still allowing state water use and development to continue. Wyoming's obligation under PRRIP is met by operating an environmental account in Pathfinder Reservoir to retime flows during periods of target flow shortages. Nebraska operates a similar environmental account in Lake McConaughy to retime flows while also providing additional land habitat in the Lexington to Chapman reach of the Platte River. Colorado's contribution is groundwater recharge at Tamarack Ranch State Wildlife Area (TRSWA) near Crook.

Managed groundwater recharge at TRSWA is designed to meet the state of Colorado's obligation to increase streamflow in the Platte River by an average of 10,000 acre-feet per year. This obligation is met by pumping alluvial groundwater (in priority and during times of surplus) upgradient to recharge ponds where the water seeps into the ground and returns to the river at a later time. Under designed conditions, recharge water flows through the subsurface with a timing that supplements streamflow during periods of critical low flow. The South Platte River flow regime is dominated by snowmelt in the late spring and early summer, so the target window for streamflow accretions is designed to occur between August and November.

Modeling Approach

The three most common approaches for estimating the effects of groundwater pumping on streamflow are the Glover solution (Glover and Balmer, 1954), stream depletion factor (SDF) method (Jenkins, 1968), and numerical methods such as MODFLOW (McDonald and Harbaugh, 1988). The Glover and SDF analytical methods are both used in water rights decisions but oversimplify physical conditions (Fox et al., 2002). MODFLOW, a widely used code for numerical modeling, is capable of simulating fully three-dimensional flow in systems that are horizontally and vertically heterogeneous and have complex boundary conditions (Barlow and Leake, 2012).

The original groundwater model for TRSWA was developed by Colorado Parks and Wildlife, formerly the Colorado Division of Wildlife (Halstead and Flory, 2003). This MODFLOW model was developed and calibrated based on aquifer conditions in the vicinity of the recharge wells to evaluate groundwater-surface water exchange (1996CW1063, 2012). Much of the aquifer characterization was based on earlier work utilizing drill log data (Hurr and Schneider, 1972). Additional work by Colorado State University (CSU) has better determined these physical conditions.

The modeling results will form the basis of an MS Thesis in Watershed Science at CSU and can subsequently be used to facilitate the design and placement of future conjunctive use sites.

For instance, CSU hydrology research at TRSWA inferred groundwater flow pathways from the recharge ponds to the river by contouring the water table elevation from measurements taken at a network of piezometers (Beckman, 2007). Further research confirmed this local groundwater flow direction with a fluorescein tracer study (Donnelly, 2012). Hydrogeophysical investigations into the subsurface stratigraphy of the eolian sands, alluvial sediments, and shale confining unit suggested the presence of a paleo-channel beneath the recharge ponds that could influence the flow pathways of recharge water (Poceta, 2005). In order to better map the potential flow pathways and quantify streamflow accretion, a groundwater flow model using MODFLOW is being constructed to utilize the existing onsite hydrologic and geophysics research.

The geometry of the South Platte alluvial aquifer is more complex than previously suggested. A recent surface Electrical Resistivity Tomography (ERT) survey defines a detailed topography of the confining bedrock surface in the area located between the recharge ponds in the eolian sand hills and the river (Lonsert et al., 2013). The ERT data were used in combination with additional drill logs to create a subsurface bedrock map (Figure 1), which revealed steeper topographic relief compared to previous interpretation of the shale bedrock (Hurr and Schneider, 1972). The incorporation of the new geophysical data into the model allows a better understanding of the potential flow pathways from the recharge ponds back to the river.

The three-dimensional model of the unconfined aquifer consists of three layers. The uppermost layer represents the eolian sand hills and the bottom two layers represent the alluvium. The alluvium was divided into two layers to

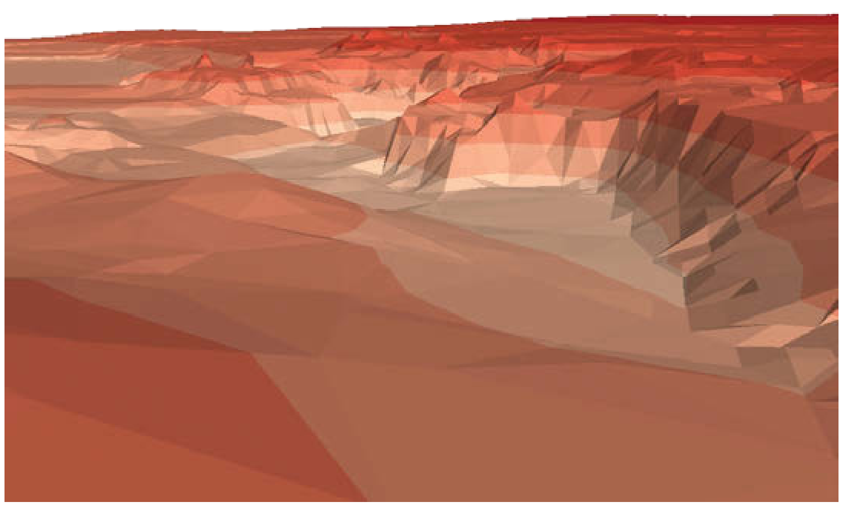


Figure 1. *Topographic bedrock map (five times vertical exaggeration) in the vicinity of the recharge ponds based on the additional geophysical investigation*

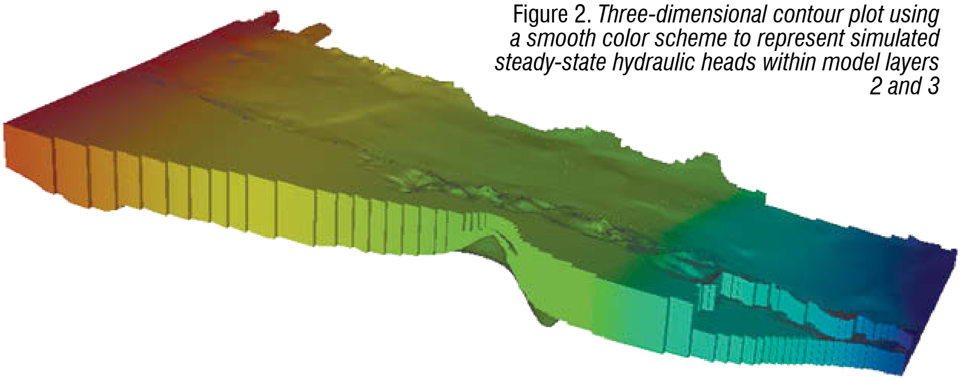


Figure 2. *Three-dimensional contour plot using a smooth color scheme to represent simulated steady-state hydraulic heads within model layers 2 and 3*

allow for the simulation of vertical gradients. The model domain is 17 kilometers (east to west) by 10 kilometers (north to south) by an average of 42 m deep and contains approximately 120,000 active cells. Grid spacing was refined in the area of the recharge ponds to account for the steep vertical hydraulic gradients. The lateral boundaries to the north and south are formed by the edges of the alluvial deposits digitized from USGS Geologic Maps of the area (Scott, 1978) and are considered to be no-flow boundaries. The western edge of the model is located along State Highway 55 where the Colorado Division of Water Resources (CDWR) operates a streamflow gaging station; the eastern edge is 25 kilometers downstream.

The South Platte River is simulated as a partially penetrating stream in Layer 2 using the Streamflow-Routing (SFR1) package. The SFR1 package calculates stream baseflow and groundwater-surface water exchange for each of the stream cells that are independent of the groundwater budget (Prudic et al., 2004). Advantages of using the SFR1 package include: the model computes baseflow within each cell internally, and stream stage does not need to be specified for each cell. The Gage package (GAGE) is used to designate cells in the model for monitoring so that separate output files are written for graphical post processing of the calculated data. The western model boundary is aligned with the CDWR gaging station and defines the uppermost reach of the river. This provides for an accurate representation of streamflow entering the model; subsequent contributions to base flow downstream of the gage represent streamflow accretions from recharge operations and irrigation return flow.

Expected Outcomes and Impacts

Using new hydrogeophysical data, model calculations of baseflow and groundwater-surface water exchange will provide an enhanced understanding of how recharge water reaches the stream and where streamflow accretion is occurring. Achieving a more fully informed understanding of these physical processes is critical in evaluating the efficiency of recharge operations at TRSWA, and is an essential component in accomplishing the goal of accurately augmenting streamflow in the desired period. The modeling results will form the basis of an MS Thesis in Watershed Science at CSU and can subsequently be used to facilitate the design and placement of future conjunctive use sites.

Acknowledgements

Funding for this research is provided by the Colorado Department of Parks and Wildlife and the Colorado Water Institute. Professor Michael Ronayne of CSU provided helpful suggestions on the modeling.

Please contact the author or Colorado Water Institute for references.

Tamarack Ranch State Wildlife Area.

Photos by John Stednick

Biowin Simulation to Assess Alternative Treatment Units for a Local Wastewater Treatment Plant to Meet the New Effluent Nutrient Regulations

Keerthivasan Venkatapathi, Civil and Environmental Engineering, Colorado State University
Faculty Advisor: Pinar Omur-Ozbek

In a Nutshell

- Study: Analyze ability of retrofitted wastewater treatment plant units to meet new regulation standards for total phosphorus and nitrogen in water (specifically, the Loveland plant)
- Results: Using BioWin software simulations, treatment process and equipment recommendations are made (see "Conclusions") for how to meet the regulations

Table 1. *CDPHE's Regulation 85 discharge limits*

Parameter	Existing Discharges Annual median	Existing Discharges 95th percentile	New Discharges Annual median	New Discharges 95th percentile
Total Phosphorus	1.0 mg/L	2.5 mg/L	0.7 mg/L	1.75 mg/L
Total Inorganic Nitrogen	15 mg/L	20 mg/L	7 mg/L	14 mg/L

Table 2. *Influent and effluent concentrations for City of Loveland WWTP*

Parameters (Annual Average)	Influent Values-units	Effluent Values-units
Flowrate	6.29 MGD	6.19 MGD
BOD_5	312 mg/L	7.6 mg/L
TSS	273 mg/L	6.9 mg/L
TKN	37.4 mg/L	2.2 mg/L
pH	7.49	6.9
NH_3	24.7 mg/L	0.4 mg/L
Total Inorganic Nitrogen	N/A	19.38 mg/L
Total Phosphorus	6.6 mg/L	4 mg/L

Introduction

Wastewater treatment plant (WWTP) effluents may contribute significant levels of nutrients (i.e., nitrogen and phosphorus) to the surface waters. Elevated levels of nutrients lead to eutrophication of the water bodies and may result in algal blooms during summer and fall. This becomes a major concern if the water body is used as a drinking water source. Algae may store and release problematic metabolites during the blooms, which include taste-and-odor compounds (e.g., geosmin and 2-methylisoborneol), toxins (e.g. microcystins), and other organic compounds that may lead to disinfection by-product formation during water treatment.

To prevent issues due to elevated levels of nutrients in surface waters, effluents from WWTPs are monitored. Colorado Department of Public Health and Environment (CDPHE) regularly updates WWTP effluent regulations to satisfy U.S. Environmental Protection Agency (EPA) guidelines. CDPHE has recently adopted a new regulation, Nutrients Management Control Regulation (Regulation 85) in June, 2012 to be effective starting in September, 2012. Two levels of discharge limits are shown in Table 1: one for the existing and another for the new WWTPs.

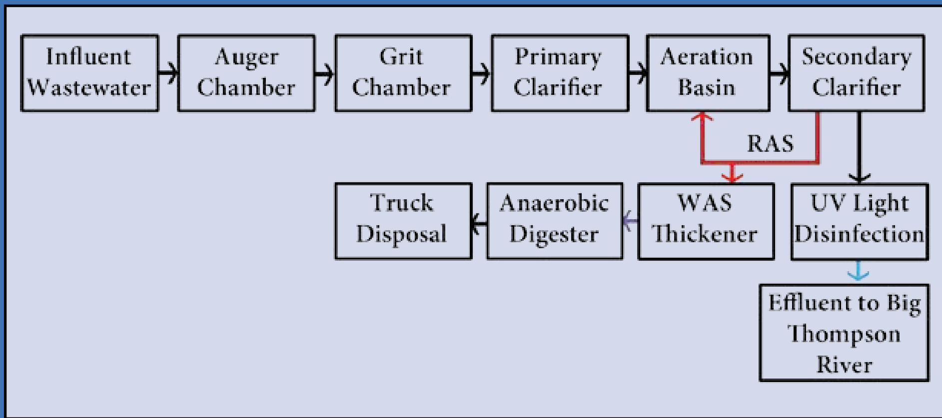


Figure 1. *Flowchart of City of Loveland WWTP*

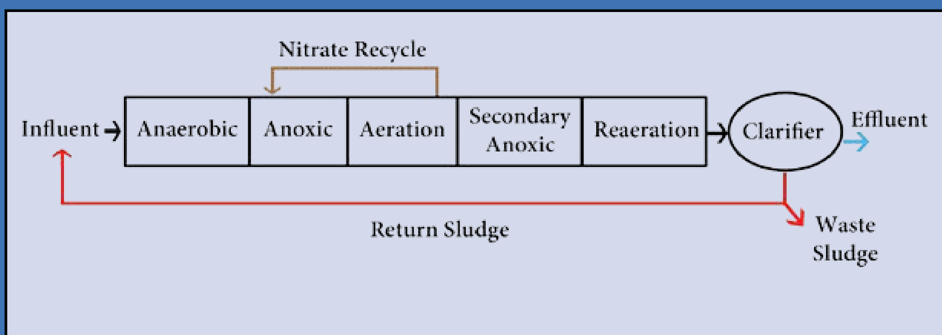


Figure 2. *Flow diagram of the 5-stage Bardenpho process*

Table 3. *Effluent concentrations from the plant and BioWin model*

Parameters	Actual Plant Effluent (mg/L)	BioWin Model Effluent (mg/L)
BOD_5	5.30	4.71
Total Suspended Solids	6.19	10.43
NH_3	0.26	1.31
Total Kjehldahl Nitrogen	2.01	3.83
Total Phosphorus	3.91	3.85

Table 4. *5-stage Bardenpho process hydraulic detention times (HRT) and basin volumes*

Basin	Lower Design HRTs		Higher Design HRTs	
	HRT (d)	Volume (Mil.gal)	HRT (d)	Volume (Mil.gal)
Anaerobic	1	0.96	2	1.92
Anoxic 1	2	1.92	4	3.84
Aerobic 1	4	3.84	6	5.76
Anoxic 2	2	1.92	4	3.84
Aerobic 2	0.5	0.48	1	0.96

City of Loveland WWTP, selected as the model system for this research, is located 50 miles north of Denver, Colorado and employs a step feed activated sludge process with a treatment capacity of 10 million gallons per day (MGD). With new regulations, Loveland WWTP has to comply with the limits by the next permit round in 2017. The effluent data, shown in Table 2, clearly indicate that Loveland WWTP will not be able to meet the new regulation limits. To address this problem, existing Loveland WWTP should be retrofitted or upgraded. Since upgrading is an expensive and time consuming process, retrofitting the existing units was explored by this study to meet Regulation 85 by reducing the total phosphorus (TP) to below one mg/L, and the total inorganic nitrogen (TIN) to below 15 mg/L.

Methods

Loveland WWTP was modeled and simulated using BioWin, proprietary software developed by EnviroSim Associates Ltd. Loveland WWTP has units found in a conventional WWTP; the main difference is the two identical treatment trains for the step feed activated sludge (AS) process (containing three basins each). For the AS process, primary effluent is divided among the three anoxic/aerobic basins in a predetermined ratio, with return activated sludge (RAS) (from the secondary clarifier) fed into the first basin only. The effluent from the AS trains are sent to the secondary clarifiers. Figure 1 depicts a simplified flowchart of Loveland WWTP.

Existing step feed AS process that already contains three basins may be updated with the addition of two more basins to convert to a five-stage Bardenpho process to achieve further nutrient removal. The Bardenpho process utilizes a series of anaerobic, anoxic, aerobic (aeration), secondary anoxic and aerobic (reaeration) basins (Figure 2). The goals of the Bardenpho process are: i) to release phosphorus in the anaerobic basin and enhance its take up in the aerobic basins; and ii) to obtain nitrogen removal through nitrification and denitrification by recycling effluent from aerobic to anoxic basin.

For this research, the five-stage Bardenpho process was modeled with only one treatment train instead of the two trains. To ensure the validity of the preset parameters in the BioWin software, the existing step feed AS process was simulated, and Table 3 shows the measured and modeled effluent concentrations. The model was accepted to be reliable in predicting the effluent concentrations for the five-stage Bardenpho process.

Simulations were performed at 13.5°C and 18.5°C to mimic winter and summer wastewater temperatures, respectively. A higher influent wastewater flowrate of 12 MGD was modeled to accommodate for population growth and future plant expansion. Basin volumes were varied based on the ideal minimum and maximum hydraulic retention time (HRT) guidelines provided by Wastewater Treatment Plants Task Force of the Water Environment Federation and the American Society of Civil Engineers. Table 4 shows the HRTs and volumes of the basins that were selected to simulate the 5-stage Bardenpho process.

Internal recycle flowrate (IR) of mixed liquor suspended solids (MLSS) (i.e. microorganisms performing biological treatment and other solids) was kept at the same flowrate as the original influent wastewater flowrate (12 MGD). To determine the optimal basin volumes for a given temperature and selected HRTs, waste activated sludge (WAS) flowrate, which controls the sludge age, was varied from 0.2 MGD to 1 MGD. Methanol was added to the secondary anoxic basin as an additional carbon source for microorganism growth, to improve denitrification. BioWin

Keerthivasan Venkatapathi and his advisor, Pinar Omur-Ozbek, compare outputs from various simulations using the BioWin software.
Photo by Kim Hudson

controller (similar to process control equipment available in a WWTP to have real time control over aeration rate, pump speed and chemical additions) was used to determine the optimal methanol dosage by averaging the methanol flowrate determined by the software after a dynamic simulation for 24 hours, a flowrate of 250 gal/d was selected for the simulations.

Results and Discussion

The goal of the simulations was to determine the optimum HRTs, basin volumes and WAS flowrates to meet the Regulation 85 by reducing the TP to below 1 mg/L, and the TIN to below 15 mg/L. The results from the simulations performed for summer and winter temperatures for selected HRTs and basin volumes (Table 4) are provided in Figures 3 and 4 for varying WAS.

Results showed that desired effluent concentrations for TP and TIN are obtained with higher design HRTs and basin volumes. Hence other effluent parameters determined using the higher design HRTs are provided in Table 5 for an influent flowrate of 12 MGD, IR of 12 MGD and methanol flowrate of 250 gal/d, for both summer and winter temperatures. As expected, the treatment efficiency is lowered during winter due to slowed metabolic reactions of the microorganisms used in the biological treatment units.

TP removal increases by increasing WAS flowrate for summer, however maximum efficiency was obtained at 0.6 MGD for winter. For TIN removal, efficiency was inversely related to WAS flowrates for both summer and winter, and hence lower WAS flowrates should be selected. It should be noted that, except for the WAS flowrate of 1 MGD for winter temperatures, all other simulated WAS flowrates meet the regulations for TIN concentrations in effluent with 0.2 MGD just making the limit for TP.

Conclusions

BioWin simulations are helpful in guiding the WWTPs in determining how to improve and update their existing processes with minimal capital and operational costs. It should be noted, however, that the effluent results should be evaluated with a factor of safety as the preset simulation parameters for BioWin may not exactly match the conditions in the simulated WWTP. This study determined that, for Loveland WWTP, retrofitting the existing plant with two additional basins and converting the treatment process to 5-stage Bardenpho will enable them to meet the new effluent nutrient regulations.

The suggested design parameters for the new process and the obtained effluent nutrient levels are as follows: WAS flowrate of 0.6 MGD results in optimal effluent concentration of 0.31 mg/L for TP and 1.49 mg/ TIN for summer (18.5 oC) and 0.32 mg/L for TP and 3.37 mg/L for TIN for winter (13.5 oC). Design HRT of 2 days for anaerobic, 4 days for anoxic, 6 days for aerobic, 4 days for secondary anoxic and 1 day for reaeration was chosen with corresponding volumes of 1.92 mil. gal, 3.84 mil.gal, 5.76 mil.gal, 3.84 mil.gal and 0.96 mil.gal, respectively. SRT was approximately 14 days for both summer and winter conditions. Authors gratefully acknowledge funding from CWI.

Sunrise over Lake Loveland, Colorado.
Photo by Jeffrey Pomranka

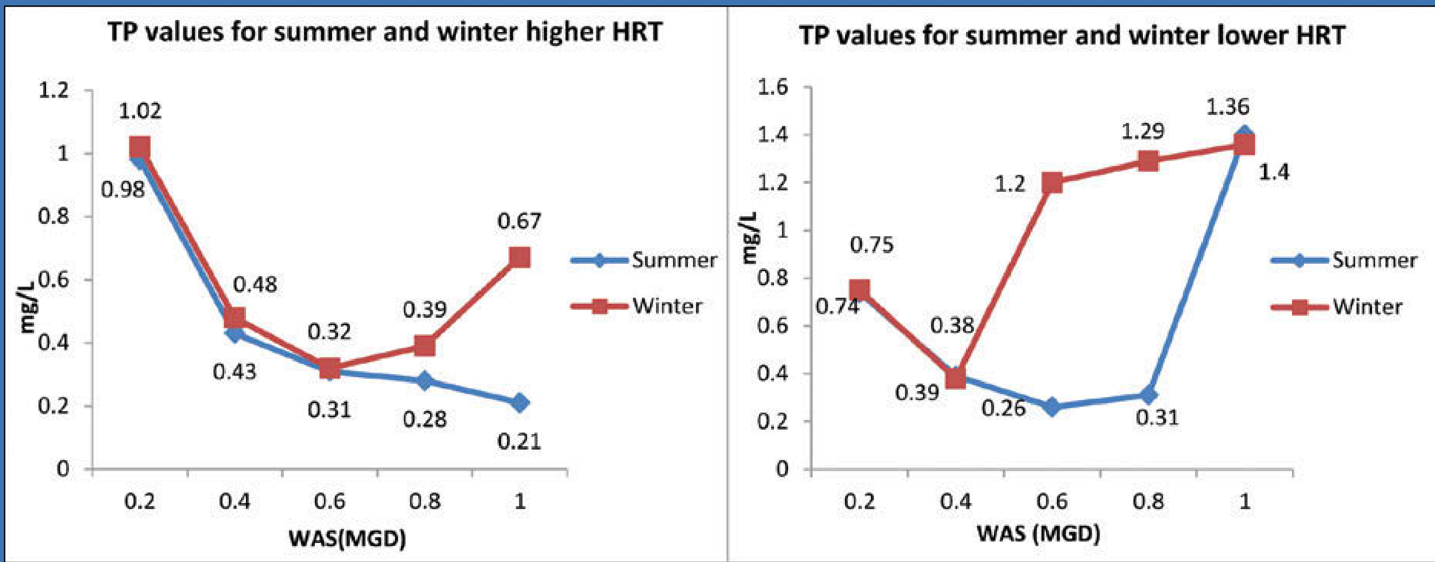


Figure 3. *Effluent TP concentrations for various WAS flow rates*

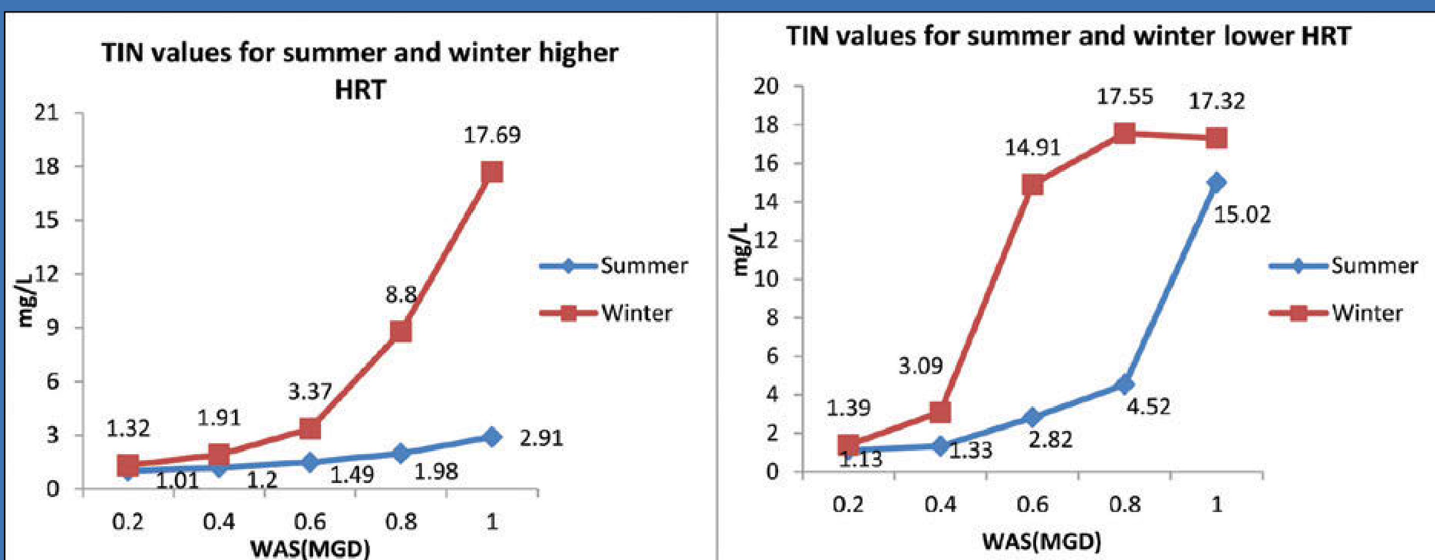


Figure 4. *Effluent TIN concentrations for various WAS flowrates*

Table 5. *Effluent concentrations determined by BioWin simulations for higher design HRTs*

WAS (MGD)	Summer				Winter			
	TIN (mg/L)	TP (mg/L)	BOD_5 (mg/L)	TSS (mg/L)	TIN (mg/L)	TP (mg/L)	BOD_5 (mg/L)	TSS (mg/L)
0.2	1.01	0.98	3.98	11.83	1.32	1.02	4.15	11.95
0.4	1.2	0.43	3.18	7	1.91	0.48	3.33	7.06
0.6	1.49	0.31	2.74	5.05	3.37	0.32	3.29	5.04
0.8	1.98	0.28	2.57	3.97	8.8	0.39	2.96	3.95
1	2.91	0.21	2.81	3.32	17.69	0.67	3.13	3.26

A Flood of Recent Donations to the Water Resources Archive

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

Like precipitation in Colorado, archival donations are difficult to predict much in advance, but they are always welcome. Donations also have their unexpected periods of drought and abundance. Early in 2013, a flood of newly donated boxes full of historically important water documents arrived at the Colorado State University Water Resources Archive. Three of those donations, described here, show the depth and breadth of Colorado's water history

Ditch Company Activities

Across Colorado, ditch companies are the oldest extant water organizations. Many have records dating back to the 1860s, sometimes in good shape, sometimes in need of extensive care. In January, a large set of records in need of a great deal of care arrived at the Water Resources Archive.

The board of the Consolidated Home Supply Ditch and Reservoir Company decided at their January meeting to donate more than 130 years of their accumulated records. They had invited me to the meeting to inform them about the Archive and what we could do for them. As a sample of their records, they brought to the meeting an early minute book, complete with a sturdy hardcover binding, distinctive cursive handwriting—and a distinct odor. Upon one whiff, I knew it was mold, and opened the cover to see the evidence.

It was clear the item, and any others they had like it, needed cleaning to remove the mold and prevent more from growing. I talked about how the Archive conducts mold cleaning and then organizes and inventories materials. Online inventories

The Water Resources Archive received eight boxes of ledgers and papers from the Consolidated Home Supply Ditch and Reservoir Company—with some materials in better shape than others.

Courtesy of the Water Resources Archive, Colorado State University

Above photo: *Boxes from the Colorado Attorney General's Office. Though numbering over 100, they will not take long to prepare for public access.*

Courtesy of the Water Resources Archive, Colorado State University

facilitate access to materials, and digitization of unrestricted materials can take place as funding allows.

Within weeks, company board members delivered eight large boxes of ledgers and files, a box stuffed full of rolled maps and plans, and a garbage bag containing a stock certificate book in need of serious preservation attention. As Archive staff looked through the materials in the following days, we found moldy ledgers, mud-caked papers, and thousands of pages of unorganized documents. While working on this sizeable collection with numerous preservation problems will pose a challenge, we would much prefer to have that challenge and preserve history than to let it rot away.

The Consolidated Home Supply Ditch and Reservoir Company diverts from the Big Thompson River west of Loveland, and their main ditch runs south and east into Weld County. Three reservoirs—Mariano, Lon Hagler, and Lone Tree—provide storage for the system. With water rights dating back to 1861 and storage rights to 1881, the company has a lengthy history worth preserving.

Left Photo: Bill Martin, Ray Nixon, and Charles L. Thomson sign a contract for the Fryingpan-Arkansas Project in 1981. From the Papers of Ray Nixon.
Courtesy of the Water Resources Archive, Colorado State University

Federal Reserved Water Rights

Moving motivates cleaning, no question about it. Last year, as the Colorado Office of the Attorney General was preparing to move out of their building, they decided to clean out their files. They contacted me about one set of files in particular: those relating to court cases dealing with federal reserved water rights in Water Division 1. The U.S. Forest Service had claimed certain water rights for national forests, including instream flow rights, and the state of Colorado and a number of other water users opposed those claims. One river—the Platte and its tributaries—and four national forests were involved: Arapaho, Pike, Roosevelt, and San Isabel. After years of preparation and a 100-day trial, the case was decided in 1993 and considered a victory for Colorado's water users.

Days before the Attorney General's office was set to move in mid-January, the Archive hired a moving truck to pick up the boxes and transport them to Fort Collins. That day, more than 100 boxes were moved into our storage facility. Largely comprised of pleadings and exhibits for the cases, the voluminous but clean and well-organized materials will take less work on our part than smaller, more chaotic collections.

Municipal Water Infrastructure

Inheriting someone's estate can bring many challenges. An unexpected challenge often arises when a cache of historical materials is discovered. What to do with everything? Distribute to family members or give to an historical repository? If a repository, which one? Who will best take care of and honor Grandpa's legacy?

Andrea Nixon asked herself and family members these questions, shopped around for the right repository, and selected the Water Resources Archive as the place to gift her grandfather's papers. Ray Nixon, best known as longtime director of Colorado Springs Utilities, was a visionary who played a significant role in Homestake Reservoir, the Fryingpan-Arkansas Project, and many more infrastructure accomplishments.

I visited with Ms. Nixon at the family house she was cleaning out in early February. She showed me various materials of her grandfather, letting me choose what would be of interest to the Archive. What I drove back from Colorado Springs that day included five boxes of documentation on Ray Nixon's work life as well as some of the many awards he received. Among the plaques, photos, and paintings is the Colorado Water Congress Aspinall Award painting he received in 1988. More materials may be added to the collection as the family sorts through them.

Ray Nixon died in 2001 at the age of 95. The power plant bearing his name is just south of Colorado Springs, visible from I-25.

Big or small, dirty or clean, all water-related collections of historical importance will get the care they deserve at the Water Resources Archive. Legacies will be honored and unique materials will be available for future research. For more information about all of the collections in the Water Resources Archive, as well as how to donate materials, see the website (lib.colostate.edu/water/) or contact me (970-491-1939; Patricia.Rettig@ColoState.edu) at any time.

Q&A: Partnership Works Across Boundaries to Restore South Platte River's Urban Waters

Ryan Lockwood, Public and Media Relations Coordinator, Colorado State Forest Service

The Colorado State Forest Service sat down to have a conversation with Devon Buckels, American Institute of Certified Planners (AICP), who was recently hired as the South Platte River Urban Waters Partnership coordinator. Prior to her new position, Buckels' work in the public, private and non-profit sectors has focused on creating healthy and sustainable communities. Her work for URS Corporation and more recently for the City and County of Denver has included community and land-use planning, river corridor planning, infrastructure financing, civic engagement, and the creation of strategic partnerships for project funding. She has a master's degree in Urban and Regional Planning from the University of Colorado at Denver and a Certification in Sustainability Leadership and Implementation from the Daniels College of Business at Denver University.

Buckels next to the South Platte River near Confluence Park in downtown Denver.
Courtesy of CSFS

First, tell us a little about the South Platte River Urban Waters Partnership (SPRUWP).

We are a collaboration of organizations, working across governmental and disciplinary boundaries, to protect and restore lands and waters in the South Platte River watershed. We emphasize stewardship and community connection, linking urban areas with forested watersheds, and people with nature. This partnership involves more than 40 groups, ranging from federal and state government to municipalities, NGOs, and private businesses, all coming together for the benefit of the silent partner, the South Platte River.

So there are a lot of different stakeholders involved with this group?

This is a very diverse group. To put it into perspective, I report to someone at the Colorado State Forest Service, my salary is paid by U.S. Forest Service funds and I have office space in the Environmental Protection Agency building downtown. At first I thought, 'How can I pull all these various groups together?' But it actually provides a lot of opportunity. I think it's very exciting.

How did the partnership get started?

It ties back to the Urban Waters Federal Partnership. The South Platte River through Denver is one of seven areas in the country selected to participate in a national program to revitalize our urban waterways, raise awareness of their value and engage local communities in their protection. The main goals are water conservation, reconnecting people to their waterways, improving water quality, and using urban water systems as a way to promote economic revitalization, particularly in areas along the river that are economically distressed.

Why is this partnership important?

This partnership is all about resource efficiency—leveraging human capital and financial resources to accomplish the most we can, in terms of river restoration, community education, and improving watershed health. My position is right at the nexus of all these important issues.

Briefly explain your new role with SPRUWP.

To provide direction, focus, structure and community presence to the partnership. In some ways I support the partners, and in other ways I help lead the group. I'm a matchmaker who tries to help link partners with funding opportunities. I also further improve efficiencies by recognizing where we can better work together to achieve greater outcomes with scarce resources.

Why did the partners create this position?

Most of the other Urban Waters pilot sites have ambassadors like me. This group wanted to make sure they had someone to shepherd them and make it work. I'm coming in at chapter two—they've already had about two years without me and have initiated some great projects.

Such as?

Last spring, the Colorado State Forest Service awarded $100,000 to four projects to restore and protect Denver-area waterways. Mapping projects also are underway to develop tools for the partnership. Other Urban Waters funding from the EPA has gone toward brownfields planning, green infrastructure design work, and an Urban Waters Green Jobs pilot project.

Why did you apply for this job? What are your own goals?

Because it builds on work I've done on the river corridor in the past, and it allows me to use skills from almost every job I've had to this point. Most importantly, it's such a unique opportunity to work on the river and its communities in a holistic fashion.

What is most valuable about the SPRUWP?

It's essential that we take care of our forests and waterways for the health of the ecosystems and their adjoining communities. Water is such a scarce resource in our region, which makes our forested watersheds and waterways even more valuable. It's critical that we take care of them, and collaborating with a group like this allows us to integrate solutions to complex problems.

Do you think most urbanites care about their waterways?

I don't think the average person gives much thought to their waterways on a daily basis, but when they do think about them, I think they really do care. Where there are combinations of natural and recreational environments, they're phenomenally successful. Just look at the Cherry Creek corridor and the Confluence Park area. I think people appreciate viewsheds and having access to nature in town.

What do you think concerns the average person most?

Probably the water coming out of their faucets. When people understand that their drinking water is tied directly to the health of the South Platte River, I think it means more to them. Part of the purpose of this group is to make sure people are aware their urban waterways exist, and help them understand their value.

Do you think the recent years of drought in Colorado have had an impact on how Denverites view water?

I do. I think drought has an impact, and I think it will continue to have an impact. Long-term drought impacts everybody, affecting our food sources, our ability to generate energy, our urban and non-urban ecosystems, our household water use, and our ability to sustain trees and other landscaping. Communities are already struggling with how to provide adequate water for residents.

Is anything unique about SPRUWP, compared to similar programs in other urban areas?

The other six pilot sites in the federal Urban Waters Partnership are all different in their geographic focus and project priorities. Our South Platte organization is unique in that we tie forested headwaters with urban waters.

How do forestry principles tie into restoring and protecting urban waters?

Community forestry in urban areas plays a key role in air and water quality, wildlife habitat and river corridor health. Community forestry projects provide opportunities for kids to understand these benefits by planting trees to restore degraded waterways. Also, at the headwaters of a river like the South Platte, forestry practices are integral in keeping waters downstream healthy. Forest health is directly related to the quality of the water consumed by residents in the Denver metro area.

Who benefits the most from SPRUWP?

It ought to be everybody in the region. Communities and ecosystems in the headwaters benefit when people in the metro area are aware of the value of the headwaters. Conversely, people in the metro area benefit by having high-quality water sources, improvements in their communities related to access and recreation, and economic benefits.

What sort of economic benefits?

The Greenway Foundation estimates that $100 million invested in green improvements to the South Platte River and its tributaries has facilitated more than $10 *billion* in residential and commercial development throughout the Denver metro area. That's a pretty good return on investment. And that doesn't even include the additional dollar value of air and water quality and public health benefits from green infrastructure.

What do you hope to accomplish in the short-term?

Within the next couple of years, I hope the group has a clearly defined mission and a more clarified structure so everyone knows how they will work together, and that we have made progress toward our top goals. We will identify one or two projects to get started on and go from there.

So you want to help get them headed in the right direction?

I want to get them off the ground. We really hope to be able to take steps toward providing people a better understanding of their water sources and the benefits of urban waterways. I also want to find a way to capitalize on the headwaters-urban waters connection, and create a platform for communication.

What do you want to say to citizens, stakeholders and decision-makers about the partnership?

Join us! The challenges surrounding water, resource protection, and connecting people and nature are complex and really can't be effectively handled by local or federal action alone. They require and deserve the extra attention they're getting through this multi-sector alliance. The diversity of this Partnership is its strength, and there's a role for each individual, community, business and agency, so please join in!

For more information about urban and community forestry in Colorado, go to csfs.colostate.edu/pages/communities.html.

For more information about the Urban Waters Federal Partnership program, go to www.urbanwaters.gov.

Coping with Extremes

First Annual Western Water History Symposium

Mary Swanson, Marketing and Development Coordinator, Public Lands History Center

On March 1, the Public Lands History Center (PLHC) and the Water Resources Archive at CSU Libraries brought four prominent historians of the American West to the Morgan Library Event Hall for "Coping with Extremes," the PLHC's First Annual Western Water History Conference, an event that encouraged the community to consider several new ideas about how water shaped the American West. PLHC director, Mark Fiege, introduced the speakers to the audience.

In a humorous lecture that established the tone for the afternoon, Patty Limerick, Professor of History at the University of Colorado at Boulder and Director of the Center of the American West, asked audience members to rethink six common assumptions about water and development in the American West. The first, and perhaps most common, was that water supply and population growth are "inherently and inevitably" intertwined. This statement, Limerick explained, does not reflect what she found while researching her latest book *A Ditch in Time: The City, The West, and Water* (Fulcrum, 2012). Rather, Limerick cited evidence that indicated water availability is only one factor in population growth and by no means the most important one. She encouraged the audience to think of the relationship between water and population growth as casual, not causal, and reminded attendees that water issues in the American West confound and contradict precisely because environmental and political conditions vary widely by from place to place.

Similarly, Louis Warren, the W. Turrentine Professor of Western History at University of California, Davis, reexamined a familiar historical event—the Ghost Dance of 1890— in his talk, "Ghost Dance in the Gilded Age: Messianic Politics and the Crisis of the American West." Because the Ghost Dance triggered the infamous Wounded Knee Massacre in 1890, historians usually describe it a final act of Indian resistance on the American frontier. This interpretation of the Ghost Dance, Warren explained, ignores how the economic hardship and arid landscape of the Great Basin region informed the messianic prophecies of Jim Wilson, the movement's Paiute leader. According to Warren, the 1890 Ghost Dance originated near Walker Lake, Nevada during a time of unusual economic and environmental strain. Many of the mines that had employed the Paiutes in the 1870s and 1880s had shut down, forcing the Paiute people to rely on traditional subsistence practices, such as gathering freshwater mussels, fishing for trout, and cultivating wild vegetation such as pine nuts. Unfortunately, the water settlers had diverted for mining caused severe erosion and killed many of the freshwater mussels and river trout, making it difficult for the Paiutes to feed themselves and their livestock. Therefore, when Jim Wilson correctly predicted that it would rain for the first time in months in the fall of 1890, his prophecy resonated with the Paiutes not only for spiritual reasons, but for

An audience gathers to attend the first annual Western Water History Conference.
Courtesy of the PLHC

Jay Taylor speaks at the first annual Western Water History Conference. Courtesy of the PLHC

practical and economic ones as well. By looking at the Ghost Dance in this way, Warren explained, one sees how the Ghost Dance was not primarily a response to American militancy or loss of Indian tradition, but a rational reaction to the challenges posed by a severe water shortage.

Jay Taylor, Professor of History at Simon Fraser University, echoed Warren and Limerick's point that the popular memory can often distort past realities. He urged audience members to see federal conservation and preservation not as a success, but as a series of problematic policies implemented by government officials who often had little knowledge of the landscapes they were protecting. He provided numerous examples of how federal mismanagement led to ecological disasters. Taylor suggested that while a more localized, less bureaucratic approach to public lands management may have prevented some of these environmental catastrophes, such policies were rarely implemented because preservation and conservation were caught in a struggle between state and federal power. Taylor traced these political struggles through the life his great-grandfather, Edward T. Taylor, the architect of the Taylor Grazing Act of 1934 and a man who, in many ways, embodied the conflicting impulses of Progressive Era politics.

Disaster and the political wrangling were also central to Donald C. Jackson's lecture on the 1928 St. Francis Dam failure. Built between 1924 and 1926 by the Los Angeles Department of Water and Power, the St. Francis Dam collapsed two and a half minutes before midnight on March 12, 1928—killing more than 400 people. As Jackson, Professor of History at Lafayette College, explained to the audience, competition over water rights and political corruption led the dam's architect, William Mulholland, to build the St. Francis dam without accounting for uplift—the force of the water pressure that pushes up on a dam in the absence of drainage. This error caused the dam's collapse, but for political reasons, was not identified as the cause of the dam's failure in the official report. Like Taylor's lecture, Jackson's speech served as a reminder that resources are best protected when not used as pawns in a larger political game.

The Public Lands History Center (publiclands.colostate.edu) and the Water Resources Archive at CSU Libraries would like to thank all four speakers for sharing their work with a gathering of scholars, students, water managers, and citizens in this dynamic event at CSU. The PLHC and Water Resources Archive hope that by gaining a better understanding the past water challenges, that faculty, students, and larger CSU community will continue to work together to ensure sustainable water issue across the Front Range. The PLHC is seeking sponsors for next year's symposium. If you would like more information, please contact Maren Bzdek at maren.bzdek@colostate.edu.

Speakers' books are arranged on a table at the first annual Western Water History Conference.
Courtesy of the PLHC

Water Research Awards

Colorado State University
(March 16, 2013 to May 15, 2013)

Berg, Wesley K, Atmospheric Science, NASA - National Aeronautics & Space Admin., Intercalibration and Rainfall Intensity Characterization for a Diverse GPM Radiometer Constellation, 3/27/13 $46,804

Brummer, Joe E, Soil & Crop Sciences, DOI-USGS-Geological Survey, Assessing the Agronomic Feasibility of Partial and Full Season Fallowing as Part of a Western Slope Water Bank, 3/22/13, $20,000

Cooper, David Jonathan, Forest & Rangeland Stewardship, Science Systems and Applications, Inc., Hydrology, Peat Body Characterization, Vegetation Ecology, and Vegetation Production of Bofedales in the Bolivian Altiplano, 4/5/13, $28,500

Jha, Ajay K, Horticulture & Landscape Architecture , USDA-Foreign Agricultural Service, Pakistan Water Dialogue Program: Scientific and Scholar Exchange, 4/29/13, $66,081

Johnson, Jerry J, Soil & Crop Sciences, Syngenta, Influence of Agrisure Artesian water-optimization alleles on hybrid performance and response to plant density, 3/29/13, $33,347

Labadie, John W, Civil & Environmental Engineering, DOI-USGS-Geological Survey, Social Network Analysis Technique for Water Resources Management Workshop, 3/22/13, $4,500

Rathburn, Sara L, Geosciences, USDA-USFS Rocky Mtn. Research Station – CO and City of Fort Collins, Mechanisms & Controls on Post-Fire Sediment Delivery: The High Park Burn in South Fork Cache la Poudre Basin, 5/15/13, $70,402

Schorr, Robert, Colorado Natural Heritage Program, DOI-USFWS-Fish & Wildlife Service, Preble's Meadow Jumping Mouse Populations at the USAF Academy, 5/8/13, $57,131

Sharvelle, Sybil E, Civil & Environmental Engineering, City of Fort Collins, Graywater Reuse in the State of Colorado, 4/9/13, $75,000

Sharvelle, Sybil E, Civil & Environmental Engineering, City of Fort Collins, Ideas for Dual Water System, 4/15/13, $99,400

Venayagamoorthy, Subhas K, Civil & Environmental Engineering, NSF- National Science Foundation, CAREER: Internal Waves, Turbulence and Diapycnal Mixing in Oceanic Flows, 5/7/13, $2,997

Waskom, Reagan, Colorado Water Institute, Great Western Institute, Regional Water Conservation Plan Southeastern Colorado Water Conservancy District for Colorado Water Conservation Board, 3/26/13, $7,653

Waskom, Reagan, Colorado Water Institute, DOI-USGS-Geological Survey, Technology Transfer & Information Dissemination, 3/22/13, $21,025

Waskom, Reagan, Colorado Water Institute, Colorado Water Conservation Board, CWCB/CWI Cooperative Intern Program, 4/17/13, $3,072

Waskom, Reagan, Colorado Water Institute, Colorado Cattleman's Association, Upper Gunnison Ranchers Self-Assessment Tools and Results Focused Dialogue of Agricultural and Environmental Stakeholders, 3/20/13, $36,000

Waskom, Reagan, Colorado Water Institute, Bohemian Foundation/Pharos Fund, The Poudre Runs Through It Study/Action Work Group, 3/27/13 $10,000

Waskom, Reagan, Colorado Water Institute, DOI-USGS-Geological Survey, Program Administration Project, 3/22/13, $10,000

Webb, Colleen T, Biology, Boston University, An Integrative Investigation of Population Connectivity Using Coral Reef Fish, 4/22/13, $140,544

Calendar

July

17-19 **Western State Colorado University 38th Annual Colorado Water Workshop; Gunnison, CO**
Planning For The New Normal
www.western.edu/academics/water

29-31 **2013 Western Water Seminar; Stevenson, WA**
www.nwra.org

August

17 **Eagle River Watershed Council 2013 Riverfest; Eagle, CO**
Riverfest 2013 is a celebration of the new access points on the Colorado through rafting, food, music, and dancing.
www.erwc.org

21-23 **Colorado Water Congress Annual Summer Conference; Steamboat Springs, CO**
Summer Conference and Membership Meeting
www.cowatercongress.org

September

15-18 **28th Annual WateReuse Symposium; Denver, CO**
The world's premier conference devoted to sustaining supplies through water reuse and desalination
www.watereuse.org/symposium28

October

7 **Valuing Colorado's Irrigated Agriculture: A Workshop for Water Policy Makers; Colorado Springs, CO**
The conference hosts will bring prominent economists of national renown to share expertise on policies, methods and approaches to the valuation of irrigation water as it is managed in the endeavor of agriculture.
www.coagwater.org

8-10 **2013 Sustaining Colorado Watersheds Conference; Avon, CO**
Water: What is the New Normal?
www.coloradowater.org/Conferences

November

6-7 **2013 Upper Colorado River Basin Water Conference; Grand Junction, CO**
Sharing Experiences Accross Borders
www.coloradomesa.edu/watercenter/UpperColoradoRiverBasinWaterForum.html

13-15 **NWRA Annual Conference; San Antonio, TX**
www.nwra.org

January

29-31 **2014 Colorado Water Conference Annual Convention; Denver, CO**
www.coloradowatercongress.org

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Electroshocking surveys were used to determine fish biomass in whitewater park reaches and control reaches for a study on the effects of such parks. Captured fish were tagged with Passive Integrated Transponder tags, measured, and weighed before being released.
Courtesy of Brian Fox