Colorado Water

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Student Research 2015

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Student researcher Tim Stephens studied fish movements in manmade whitewater parks. Courtesy of Tim Stephens

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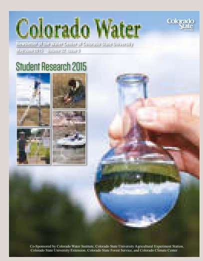
Volume 32, Issue 2

CWI Funded Projects

In Every Issue



About the Cover: *CWI-funded student research included the topics water conservation, fisheries, agricultural and horticultural use, instream woody debris, and snow research methods. Background image from Adobe Stock.*

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The Next Parshall?

Guest Editorial by Nancy J. Grice, Assistant to Director, Colorado Water Institute

The power of water. It has force and speed to carve our land, affect the economy, influence political decisions, and impact people's lives.

Student water research is a vital component in shaping our future water leaders' education, real life experiences, and engagement with the power of water. Student researchers are introduced to many educational practices and theories, become familiarized with the research and funding process, experience success, and learn from their failures. These invaluable lessons allow them to prepare for their chosen careers, and their growth is an investment that will benefit the greater water community and public in the future.

Leadership, vision, understanding, and communication of Colorado water issues by water experts, politicians, the public, academia, and students are imperative for initiatives to be identified and materialized. An example of an unresolved water challenge shared by James Kircher, former Director of the Colorado Water Science Center at United States Geological Survey (USGS), is a need for a better flood warning network and new technology to measure streamflow. "Advancements in science and technology allowed us to land a man on the moon, so let's get the man out of the stream," says Kircher. Furthermore, there is a fiduciary responsibility to tax payers and funding sponsors to use this money wisely. Collaboration plays an essential role in accomplishing this obligation and provides a platform for exciting new opportunities for students in water research. Student research funding often comes in the form of small seed grants, yet many of these have provided results that have evolved into larger research projects.

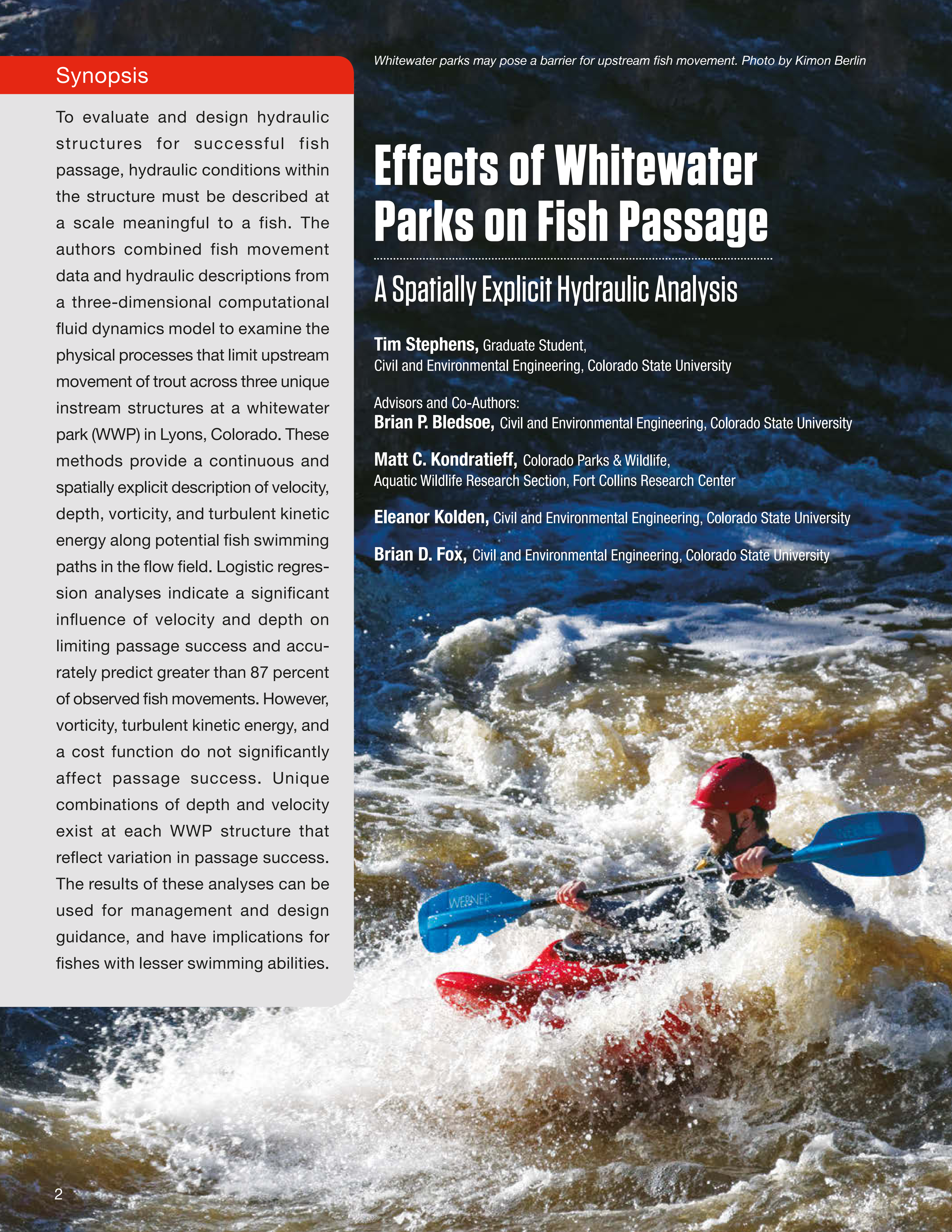
Leadership, vision, understanding, and communication of Colorado water issues by water experts, politicians, the public, academia, and students are imperative for initiatives to be identified and materialized.

The educational process enables students the interdisciplinary approach of exploring new learning opportunities with the vast wealth of knowledge and experience from water faculty at Colorado State University as well as other institutions of higher learning throughout Colorado and the world. It empowers them to hone their critical thinking skill sets to say *what if?*, and possibly be the next Darcy, Horton, Farr, or Aspinall. The advisor's commitment and active involvement in the student's research experience is of vital importance and should be one of their highest priorities. The multifaceted role of the advisor through consistent guidance and control teaches the student to conceptualize an idea, formulate research questions, master the grant writing process, implement the project's scope of work, and be cognizant of the project deliverables and deadlines. Advisors encourage them to immerse themselves into the water culture as well as to learn the professional language and jargon in order to confidently interact and communicate with the water industry and public. Additionally, students become trained in the latest technology and question best practices with fresh eyes. With proper mentoring, students can conduct professional, high quality research that is relevant to solving the challenges facing today's water community.

Nancy J. Grice

The power of the student research program has proven its capacity to profoundly impact students' educational experience. Continued support of the program by water leaders, industry, and the general public will allow more students to pursue research training, strive for their dream jobs, and be a catalyst of change. We all need to encourage students to have the Colorado pioneer spirit and take the initiative to *dream it* and then *do it* in order to tackle future water challenges. Perhaps one of the students whose research project is featured in this issue will be the next Ralph Parshall or Delph Carpenter?

Above Photo: *Ralph Parshall taking flume measurements. Courtesy of Archives and Special Collections, CSU Libraries*



Whitewater parks may pose a barrier for upstream fish movement. Photo by Kimon Berlin

Effects of Whitewater Parks on Fish Passage

A Spatially Explicit Hydraulic Analysis

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Synopsis

To evaluate and design hydraulic structures for successful fish passage, hydraulic conditions within the structure must be described at a scale meaningful to a fish. The authors combined fish movement data and hydraulic descriptions from a three-dimensional computational fluid dynamics model to examine the physical processes that limit upstream movement of trout across three unique instream structures at a whitewater park (WWP) in Lyons, Colorado. These methods provide a continuous and spatially explicit description of velocity, depth, vorticity, and turbulent kinetic energy along potential fish swimming paths in the flow field. Logistic regression analyses indicate a significant influence of velocity and depth on limiting passage success and accurately predict greater than 87 percent of observed fish movements. However, vorticity, turbulent kinetic energy, and a cost function do not significantly affect passage success. Unique combinations of depth and velocity exist at each WWP structure that reflect variation in passage success. The results of these analyses can be used for management and design guidance, and have implications for fishes with lesser swimming abilities.

INTRODUCTION

The reproductive success of migratory fishes and other organisms depends on the quantity, quality, and connectivity of available habitats that vary spatially and temporally across dimensions and scales. Human extraction of water resources has resulted in fragmentation of many rivers by dams, diversions, and other instream structures. When impassable, these structures cut off necessary habitat linkages and migration routes of aquatic organisms, particularly fishes. Successful passage for fishes of all life stages across barriers to migration is imperative to restore and maintain ecosystem function, and structures are often designed and constructed without direct knowledge of fish passage success in response to altered hydraulic conditions. Velocity, depth, turbulence, and vorticity can impact the ability of fish to swim upstream.

A whitewater park (WWP) consists of one or more instream structures primarily constructed to create a hydraulic jump that is desirable to recreational kayakers and other boaters. The hydraulic jump is typically formed by grouting a laterally constricted chute over a steep drop into a downstream pool. WWPs provide a valuable recreational and economic resource that is rapidly growing in popularity. WWPs were originally thought to enhance aquatic habitat; however, recent studies have shown that WWPs can act as a partial barrier to upstream migrating trout, and WWP pools may contain lower densities of fish compared to natural pools. Concerns have arisen that the hydraulic conditions required to meet recreational needs are contributing to the suppression of movement of upstream migrating fishes and disruption of longitudinal connectivity. Without a direct understanding of the factors contributing to the suppression of movement in WWPs, making informed management and policy decisions regarding WWPs will continue to be difficult and could have unintended consequences.

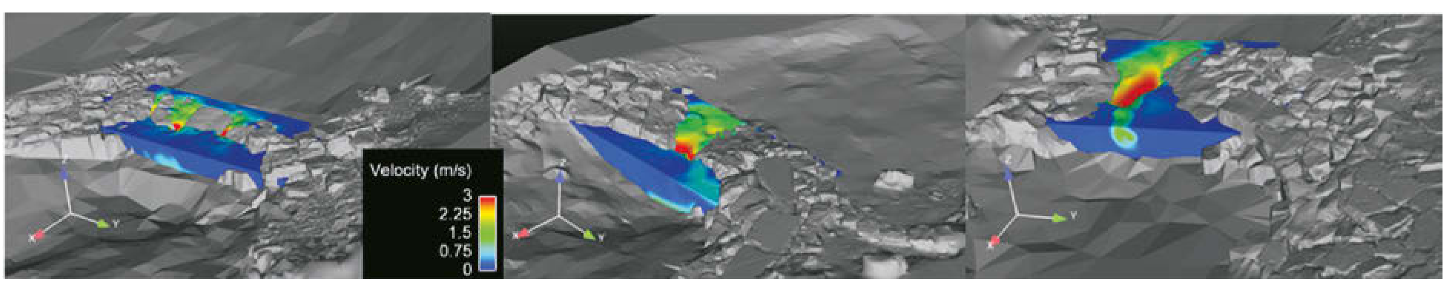
OBJECTIVES

We describe novel approaches combining fish movement data and hydraulic results from a three-dimensional (3-D) computational fluid dynamics (CFD) model to examine the physical processes that limit upstream movement of trout in a WWP in Lyons, Colorado. The objectives of this study were to:

1. Use the results from a 3-D CFD model to provide a continuous and spatially explicit description of velocity, depth, vorticity, and turbulent kinetic energy (TKE) along the flow field at WWP structures containing fish movement data
2. Compare the magnitudes and distribution of velocity, depth, vorticity, and TKE among three unique WWP structures on the St. Vrain River in Colorado
3. Determine the relationship between velocity, depth, vorticity, and TKE on the suppression of movement of upstream migrating fishes through statistical analysis of movement data from passive integrated transponder (PIT)-tag studies at the St. Vrain WWP
4. Provide design recommendations and physically-based relationships that help managers better accommodate fish passage through WWP structures

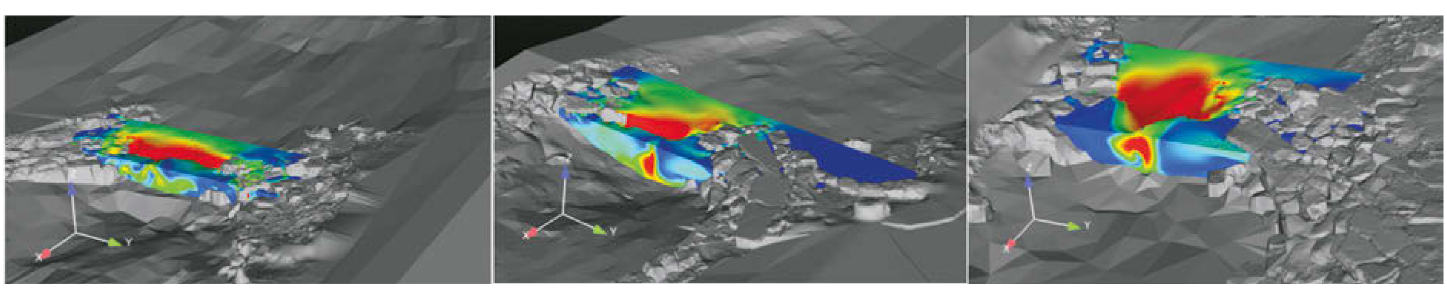
METHODS

The study site consists of nine WWP structures along a 1,300 ft reach in Meadow Park, Lyons, Colorado. The natural river morphology at the study site can be described as the transition zone between a step-pool channel and a meandering pool-riffle channel with a slope of one percent. The natural river channel is characterized by riffles, runs, and shallow pools with cobble and boulder substrates. Three of the



WWP1 WWP2 WWP3

Figure 1. *Analysis flow volume at each WWP structure for 0.42 cms (above) and 4.20 cms (below).*



WWP1 WWP2 WWP3

nine WWP structures were selected for the study to represent the range of structure types and hydraulic conditions at the site (Figure 1). WWP1 is the downstream-most structure characterized by a short, steep drop constructed by large boulders. WWP2 is the middle structure producing a wave over a longer distance with the maximum constriction at the exit of the chute into the downstream pool. WWP3 is the upstream-most structure producing a wave similar to WWP2, but over a longer chute.

Fish passage was assessed at these three WWP structures by obtaining 14 months of fish movement data. Tagged rainbow trout (*Oncorhynchus mykiss Hofer x Harrison* strain) and brown trout (*Salmo trutta*) were included in the analysis totaling 536 tagged fish ranging in size from 115 to 435 mm as total length. Passage success was evaluated over four discrete time intervals. The start of each time interval was defined by a stocking or electroshocking event in which fish were observed in the pool directly below a structure. Movements were evaluated over the duration of that respective time interval. There were 429 successful movements over the duration of all the time intervals (Figure 2).

Seven discharges were modeled in 3-D at three WWP structures containing PIT antennas (Figure 1). The modeled discharges include: 15, 30, 60, 100, 150, 170, and 300 cubic feet per second, representing a range of flows that produces various habitats throughout the year. Field measurements of water surface elevations, velocity profiles, and wetted perimeter ensured the model was performing within an acceptable range of error.

Particle traces were emitted through the modeled flow field. A particle trace consists of a series of points that track a massless particle through both time and space in the fluid domain. Releasing particle traces through the flow field and quantifying hydraulic variables along each trace provides a meaningful description of the hydraulic conditions a fish might encounter while migrating upstream. Approximately 6,500 to 20,000 particle traces were used to describe the flow field at each structure depending on the flow volume being analyzed. Each particle trace was evaluated as a potential fish movement path (flow path). Velocity, depth, vorticity, and TKE were defined in 3-D at every point along a flow path and used to define hydraulic variables that relate to fish swimming abilities. The maximum velocity relative to fish swimming ability, a cumulative cost in terms of energy and the drag force on a fish, the minimum depth, and the sum and maximum vorticity and TKE were quantified along the entire length of each flow path providing a distribution of hydraulic variables for each modeled discharge. The magnitude and distribution of these hydraulic variables were compared among WWP structures. Logistic regression analyses were used to determine the relationship between the hydraulic variables and passage success at each individual WWP structure and across all WWP structures.

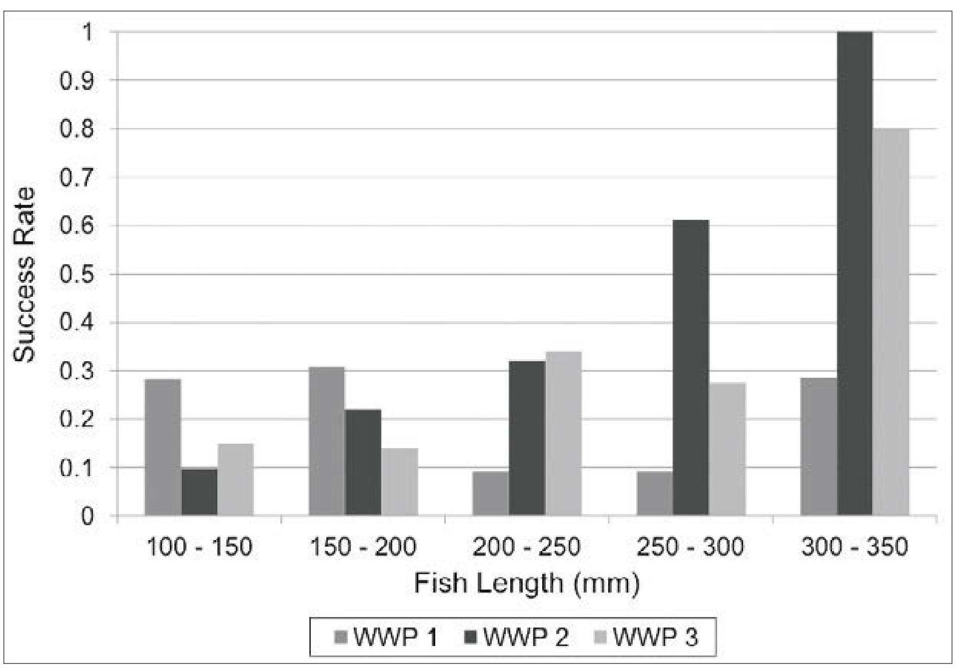


Figure 2. *The fraction of observed fish by size class at each whitewater park (WWP) structure that successfully passed that structure*

RESULTS AND DISCUSSION

Direct observations of fish movement obtained from the PIT-tag movement study indicate that fish passage success varies among WWP structures and size classes of fish. Different fractions of successful movements at each WWP structure occurred over different discharges. The magnitude and distribution of the hydraulic variables vary among WWP structures, relative to each size class of fish, and across discharges, similar to passage success. Simply averaging the hydraulic conditions over large spatial scales or evaluating point measurements does not take into account the continuous complexity of the flow field along a fish's movement path. However, quantifying the hydraulic conditions along potential fish swimming paths highlights the magnitude and distribution of potential barriers to upstream migrating trout at each WWP structure.

The logistic regression analyses indicate that velocity and depth accurately predict passage success for over 87 percent of observed trout. The fraction of flow paths that exceed a fish's burst swimming ability or do not provide adequate depth had a negative influence on passage success. Variation in statistically significant hydraulic variables among WWP structures and across discharges highlights unique hydraulic characteristics at each WWP structure that affect passage success differently. For instance, depth presents a greater challenge at WWP1 as it is characterized by a shorter, steeper drop compared to WWP2 and WWP3. Velocity

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Tim Stephens

Tim Stephens and a fellow student on the Cache la Poudre River northwest of Fort Collins test a method for surveying whitewater parks that are too difficult to wade.

is more limiting at WWP2 and WWP3 compared to WWP1 due to longer chutes with minimal roughness and constricted flow. Variation among the chute configuration at similar structure types, such as WWP2 and WWP3, dictates variation in the magnitude of velocity vectors and heterogeneity within the flow field among structures. The evaluation of depth, velocity, and their combined influence on passage success by size class and discharge emphasizes the importance of site-specific characterization of subtle differences in structure design. It is important to consider both velocity and depth concurrently as a potential movement path might meet the minimum depth criteria but serve as a velocity barrier and vice versa.

Logistic regression analyses did not indicate a significant influence of cost or turbulence on passage success. The cumulative effects of velocity a fish experiences while crossing a structure have the potential to influence passage success. Studies have shown that as the swim speed of a fish increases the time to fatigue decreases. The fact that our models did not indicate turbulence as significant could be an issue of scale. The magnitude or intensity of vorticity and TKE do not account for the spatial scale at which fish experience turbulent eddies relative to body length.

This study examines hydraulic conditions as physiological barriers to migration and does not take into account fish behavior. Accessible movement paths might exist at a structure. However, a fish might feel the cumulative effects of fatigue or lack motivation after several failed attempts to locate accessible movement paths. It is important to consider the timing of fish migrations and other life-cycle processes.

Evaluating additional hydraulic structures is highly recommended to determine the range of hydraulic conditions that fish are required to pass. Further, assessing passage success of non-salmonid fishes with different swimming abilities or behaviors could highlight the need for lower velocity zones or higher topographic diversity within hydraulic structures. Additionally visual observations of successful and failed attempts of individual fish will allow for a more-detailed comparison of the hydraulic conditions that affect passage success and shed light on behavioral limitations.

CONCLUSIONS

This study used the results from a three-dimensional computational fluid dynamics model to provide a continuous and spatially explicit description of the hydraulic conditions along potential fish movement paths and examine their influence on fish passage at a WWP on the St. Vrain River in Lyons, Colorado. Quantifying the hydraulic conditions in this manner captured important and unique hydraulic characteristics at each WWP, and described velocity and depth throughout the flow field at a scale meaningful to a fish. Logistic regression indicated a significant influence of velocity and depth on passage success, and accurately predicted 87 percent of individual fish movement observations. However, cost, vorticity, and turbulent kinetic energy did not have a significant effect on passage success. When designing hydraulic structures for fish passage, it is imperative that continuous movement paths exist, providing adequate depth and velocities that do not exceed fish swimming capabilities. Similar hydraulic analyses coupled with fish movement data can be utilized to evaluate the effects of hydraulic conditions on passage success at other types and sizes of hydraulic structures. This study lays the groundwork for a novel and powerful approach to mechanistically evaluate the effects of hydraulic structures on fish passage. Further, the results of this study can serve as a reference for managers and policy makers, provide design guidance for future hydraulic structures, and be used to evaluate existing structures of similar size, design type, and hydrologic regime.

ACKNOWLEDGMENTS

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Impact of Limited Irrigation on Health of Three Ornamental Grass Species

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Advisor: **James Klett,** Horticulture and Landscape Architecture, Colorado State University

This is a two-year study. All data reported in this paper serve as a preliminary report of data from year one. No conclusive results have been made from this first year of research.

Synopsis

This work is part of a two-year study looking into the impacts of dry conditions on several ornamental grass species. For the first year, a water use study included recording stress measurements and ornamental quality measurements for four species at zero, 25, 50, and 100 percent of bluegrass evapotranspiration (ET_o), recorded using an atmometer, with irrigation treatments calculated and applied weekly. A lysimeter study included one species with treatments, including four dry down periods in which plants reached critical stress levels. Findings included that generally, ornamental grasses receiving 25 percent ET_o have similar aesthetics to 100 percent ET_o plants, indicating that these grasses may be watered less while still achieving the same quality. Plants watered less (25 percent of actual plant evapotranspiration) and subjected to dry down periods are more at risk for stress symptoms than plants watered more.

LITERATURE REVIEW

Water availability in the U.S. has decreased in the past twenty years as populations have steadily increased. Populations coupled with diminishing growing grounds and widely used unsustainable growing practices are reducing water availability across the country. Colorado is considered a dry state, with annual precipitation averaging 15.47 inches per year. To combat this drought, attention to irrigation efficiency has the greatest potential for water conservation for most residents. Ornamental grasses tend to go hand-in-hand with the principles of water-wise growing. They are regarded as problem-free, and highly drought tolerant. For this reason, it is essential to find species that require minimal irrigation for survival in the hot and dry environment of Colorado. This information will have a great impact on the horticulture industry, affecting large industry growers as well as individual landscapers and homeowners.

INTRODUCTION

The purpose of this study is to quantify a feasible irrigation standard at which ornamental grasses should be watered. More generally, it is important to know if deficit irrigation is feasible with ornamental grasses. In Colorado's climate, is this deficit irrigation feasible once periods of drought are introduced? While studies have touched on growing these grasses, this study serves as a pioneer in linking ornamental quality with physiological stress and growth. Discovering critical water potentials and other aspects of plant stress will help give a baseline for the levels of stress these plants can

endure while maintaining aesthetic quality. A final goal lies in quantifying the actual evapotranspiration (ET) that these plants undergo. Industry personnel and researchers tend to base a majority of irrigation practices on ET, and this is why effective quantification of ET is a key aspect of precise irrigation management.

…this study serves as a pioneer in linking ornamental quality with physiological stress and growth.

MATERIALS AND METHODS

Two studies are being performed, termed the **water use study** and **lysimeter study**. The **water use study** examined three species of ornamental grasses: *Panicum virgatum* 'Rotstrahlbusch' (Rotstrahlbusch Switchgrass) (*Panicum*) (Figure 1), *Schizachyrium scoparium* 'Blaze' (Blaze Little Bluestem) (*Schizachyrium*), and *Calamgrostis brachytricha* (Korean Feather Reed Grass) (*Calamgrostis*). The study consisted of four treatments: zero percent, 25 percent, 50 percent, and 100 percent bluegrass ET (ET_o). ET_o was recorded using an atmometer. Irrigation treatments were calculated and applied once per week.

Two generalized categories of data were collected—plant stress and ornamental quality. Plant stress parameters include predawn water potential, infrared canopy temperature, and dry weight. Plant ornamental quality parameters included height, width, circumference, green-up date, flowering date, floral impact, landscape impact, overall habit/lodging, color, self-seeding, and representative photographs.

The **lysimeter study** examined one species of ornamental grass: *Schizachyrium scoparium*—Blaze grass—chosen for its vigorous growth, lack of extreme deep rooting, and ornamental popularity. After establishment, plants were placed in the field in a pot-in-pot system. The three treatments applied were 25 percent, 50 percent, and 100 percent of actual plant ET (ET_s). The same plant stress and aesthetic measurements were chronicled in the lysimeter study as in the water use study. In addition, four dry down periods were conducted. This consisted of providing each treatment with its relative level of irrigation, and then allowing plants to dry out to critical stress levels. During dry down periods, entire pot and plant weight was measured on a daily basis, recording weight loss, and in turn ET_s (Figure 2). Photographs and water potential readings were also taken daily.

Figure 1. *Decorative grass species Panicum virgatum underwent four comparative watering treatments. From top left to bottom right, the treatments were 0%, 25%, 50%, and 100% of the amount of water consumed by the benchmark species bluegrass.*

Sam Hagopian

Figure 2. *Sam Hagopian uses the mini-lysimeter to measure pot and plant weight during dry down periods, in which plants were dried to critical stress levels.*

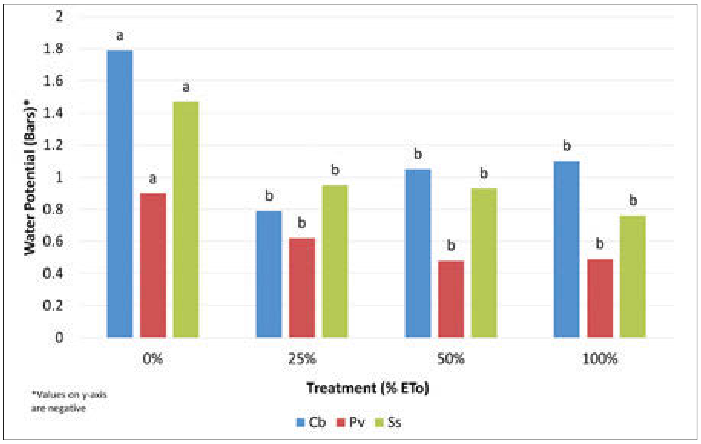


Figure 3. *Water use study: 2014 water potential on 9/7/14 (trend is representative of five out of 10 measured dates)*

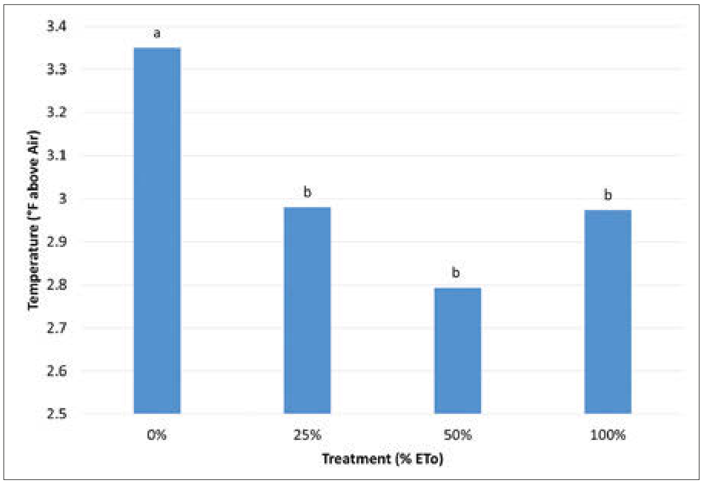


Figure 4. *Water use study: infrared plant temperature averages of Calamagrostis, Panicum, and Schizachyrium*

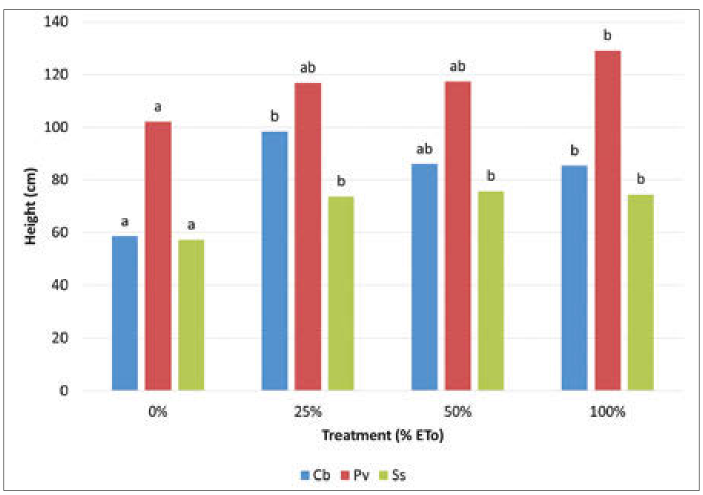


Figure 5. *Water use study: End of season height*

RESULTS

WATER USE—STRESS MEASUREMENTS

For water potential, five of the 10 dates showed the trend of the zero percent treatment being significantly lower than the other three treatments (Figure 3). Infrared canopy temperature showed the same trend, with the zero percent treatment being significantly higher than the other three treatments (Figure 4). End of season dry weight was calculated, showing no differences between treatments for *Panicum* and *Calamgrostis*. *Schizachyrium* showed less dry mass between the zero percent treatment and all others.

WATER USE—ORNAMENTAL MEASUREMENTS

End of season height showed differences between treatments for each species. *Calamgrostis* heights were lower for the zero percent and 50 percent treatments, and significantly higher for 25 percent and 100 percent treatments. *Panicum* values showed that zero percent was shorter than 100 percent. *Schizachyrium* heights were lower for zero percent than all three other treatments (Figure 5). End of season width also showed differences between treatments for each species. *Calamgrostis* widths were lower for zero percent than all three other treatments. *Panicum* values showed the zero percent treatment to have smaller widths than 100 percent treatment, and the 25 percent treatment was smaller than the 50 percent treatment. *Schizachyrium* values showed that all three lower treatment plants are

David Staats

Figure 6. *Sam Hagopian and advisor James Klett use frequency domain reflectometry (FDR) to determine where the plant accesses water (vertically), as well as where the plant ceases to access water, as part of a plant stress and aesthetics watering study.*

smaller than the 100 percent treatment. End of season circumference showed that *Calamgrostis* values in zero percent had a smaller circumference than those in the 50 percent and 100 percent treatment. *Panicum* values showed that zero percent was lower than 50 percent and 100 percent, and the 25 percent was smaller than the 50 percent treatment. *Schizachyrium* values showed that zero percent was lower than all three other treatments.

Self-seeding showed no differences between treatments. Floral impact for *Calamgrostis, Panicum,* and *Schizachyrium* showed that zero percent was lower than all other treatments. Landscape impact and overall habit follow the same trend. Each ornamental category had slight differences between treatments on certain dates, but they are negligible with one year of data.

LYSIMETER—STRESS MEASUREMENTS

Stress measurements were recorded using a pressure chamber to evaluate the amount of pressure required for water to appear on a cut leaf (Figure 6). The third dry down resulted in ET of 25 percent being the same as 50 percent, but less than 100 percent. The 50 percent treatment was also significantly less than the 100 percent. The fourth dry down showed that the 25 percent was lower than both 50 percent and 100 percent (Figure 7). When evaluating water potential, dry down 1 showed no differences between treatments until day 7, where 25 percent has lower values that both 50 percent and 100 percent (Figure 8). Dry down 2 showed no differences between treatments. Dry down 3 resulted in 25 percent being similar to 50 percent but lower than 100 percent, and 50 percent was lower than 100 percent. Dry down 4 showed no differences until the sixth day, in which 25 percent was lower than both 50 percent and 100 percent. There were no differences between treatments for end of season plant dry weight.

LYSIMETER—ORNAMENTAL MEASUREMENTS

There were no significant differences for height, width, circumference, floral impact, landscape impact, or overall habit between treatments.

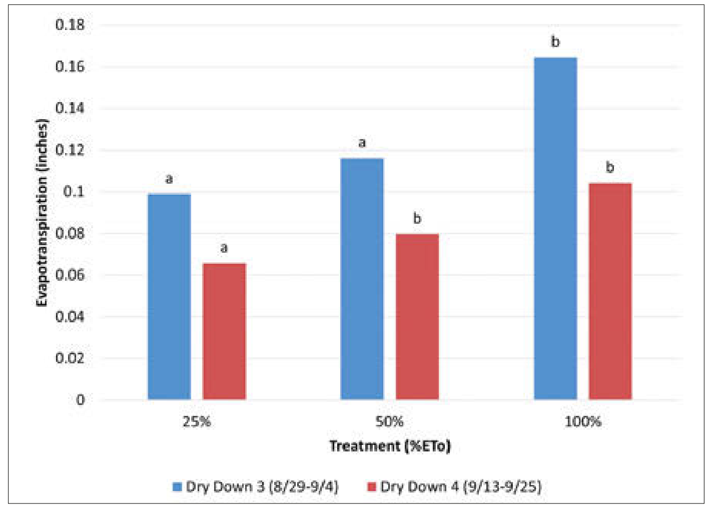


Figure 7. *Lysimeter study: Evapotranspiration of Schizachyrium scoparium during two dry down periods*

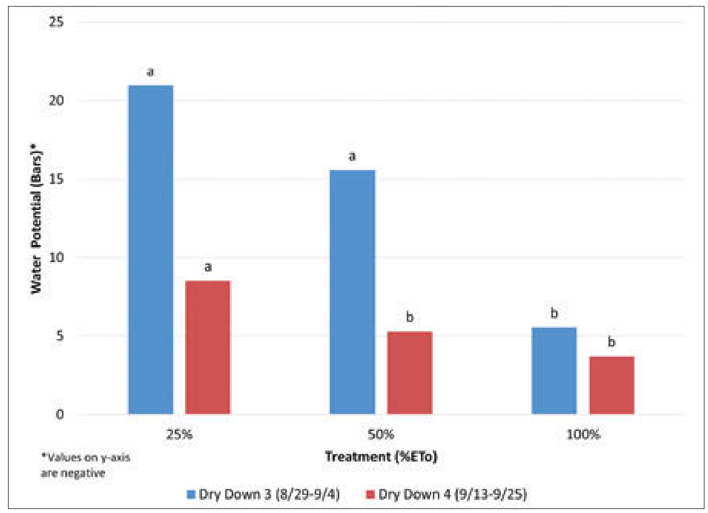


Figure 8. *Lysimeter study: Water potential of Schizachyrium scoparium on two dates during dry down periods*

For water potential, five of the 10 dates showed the trend of the zero percent treatment being significantly lower than the other three treatments (Figure 3).

DISCUSSION

WATER USE STUDY

Water potential and Infrared Thermometer values indicates that 25 percent plants are under the same levels of low stress as 100 percent plants. Dry weight of *Schizachyrium* indicates that this species will have less mass when given no water, and 25 percent plants will be the same size as 100 percent plants. These three parameters combined suggest that zero percent plants are significantly more stressed, while plants receiving 25 percent water are just as stress-free as those receiving 100 percent. This suggests that plants receiving 25 percent ET are as physiologically healthy as plants receiving 100 percent ET, suggesting strong implications for dry conditions.

Schizachyrium scoparium

Height measurements indicate that zero percent treatments will result in smaller plants, no matter the species. Regardless of species, all plants grew the most in 25 percent and 100 percent treatments. Width measurements indicate that zero percent treatments result in narrower plants. Circumference, floral impact, and landscape impact hold true to the same trends as width. This suggests that zero percent plants will be smaller and less showy than their watered counterparts. Overall habit showed that zero percent treatment results in more prostrate plants, while 100 percent treatment results in very upright plants. These results are also very promising, as plants receiving 25 percent ET are as ornamentally pleasing as plants receiving 100 percent ET.

LYSIMETER STUDY

Evapotranspiration during dry down 3 showed that 25 percent and 50 percent will use less water than 100 percent. Dry down 4 showed that 25 percent used less water than 50 percent and 100 percent. These results together indicate that 25 percent plants will use much less water than 50 percent or 100 percent. Water potential during dry downs 1, 3, and 4 indicate that 25 percent plants are more stressed than their well-watered counterparts.

Calamagrostis brachytricha

All ornamental measurements showed that there is no difference between treatments. Coupling this information with the physiological data implies that plants are aesthetically pleasing regardless of irrigation amount; however, 25 percent plants are much more stressed than 50 percent or 100 percent plants. This is perhaps very harmful if plants receiving lower amounts of water are ever subject to periods of drought.

When combining the results of both studies, plants grown in the 25 percent treatment are as aesthetically pleasing and ornamentally healthy as those in the 100 percent treatment. However, if these plants are ever subject to periods of drought, they are much more likely to succumb to physiological stress than those in the 100 percent treatment. This implies that ornamental grasses put on a deficit irrigation schedule must be constantly watered to ensure health and aesthetics.

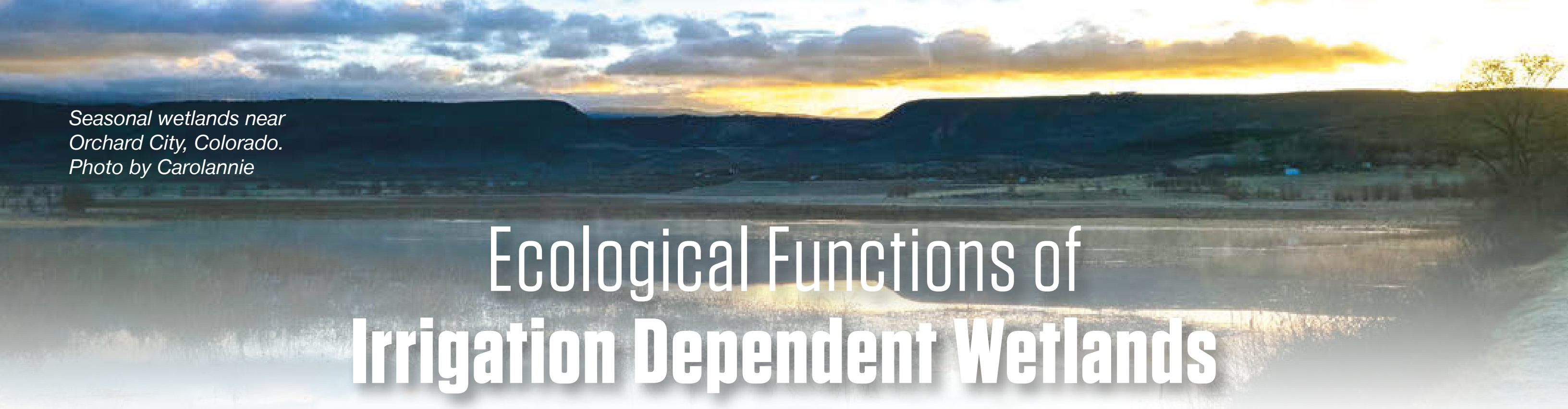
FUTURE WORK

This study will continue in the summer of 2015. Data will be combined with one year of previous work to formulate conclusions regarding a feasible level of irrigation under which ornamental grasses maintain long-term health and aesthetics.

Panicum virgatum

ACKNOWLEDGEMENTS

Funding for this project came from the Agricultural Experiment Station, the Colorado Horticulture Research and Education Foundation, and the Department of the Interior–Geological Survey, through the Colorado Water Institute.



Seasonal wetlands near Orchard City, Colorado. Photo by Carolannie

Ecological Functions of **Irrigation Dependent Wetlands**

Nitrate Mitigation

Erick A. Carlson, PhD Student, Ecology, Colorado State University

Advisor: **David Cooper,** Forest and Rangeland Stewardship, Colorado State University

Synopsis

A pilot project was conducted at four sites in Weld County, Colorado to explore hydrology as well as wetland nitrate dynamics near agricultural fields. Trends were seen in water table rise following rain events and assumed irrigation events, and water tables rose gradually over the growing season, indicating a correlation with irrigation. However, water table levels and precipitation were weakly correlated over the growing season. Denitrification was tested in soil incubation chambers using the acetylene block technique, and results showed that the incubation time used (five hours) was not enough to block most of the denitrification, which will inform future work in the field. Future work will continue to look into the fate of nitrate and will also include analyzing soil temperature, soil pH, soil bulk density, soil type, soil carbon, and microbial biomass.

BACKGROUND

Nitrate has been reported in Weld County, Colorado irrigation, drinking water, and monitoring wells in agricultural areas at levels exceeding the EPA drinking water standard. Improvements to irrigation and fertilizer application efficiency have not yet significantly reduced groundwater nitrate levels in the region. We propose investigating the functioning of wetlands created by irrigation runoff to trap and process nitrate.

The goal of this pilot project was to locate and instrument sites to explore the hydrology of these irrigation dependent wetlands and test methods of investigating the potential fate of nitrate (NO_3^-) exiting the field as runoff and shallow groundwater. The primary objective was to test the acetylene block technique for inhibiting microbial denitrification. In anaerobic (waterlogged) conditions, some microorganisms use nitrate in the absence of oxygen (O_2) for respiration. The presence of acetylene gas (C_2H_2) blocks the chemical process that moves the intermediate nitrous oxide (N_2O) to elemental nitrogen gas (N_2). In a controlled experiment, nitrous oxide can be measured accurately and used to determine the denitrification activity in the soil, a potentially significant component to nitrogen cycling in wetlands. This method, however, is not commonly performed in the field, and experimental equipment and procedures needed to be tested for efficacy.

METHODS

Site selection from aerial imagery of wetlands near irrigated crop fields was conducted, and several dozen potential sites were initially considered. Networking with Colorado State University research scientist Troy Bauder narrowed the potential sites. Site visits with David Cooper and discussions with the landowners to explain the project and walk through the properties were conducted in May 2014. All three farmers contacted agreed to participate in the research in 2014, which led to the development of four field sites in Weld County (two near Ault and two near Gilcrest, Colorado) with a diverse set of physical characteristics, irrigation type, crop type, and wetland vegetation represented (Figure 1).

Figure 1. *Map of the field sites, presented at a scale to protect the landowner's privacy*

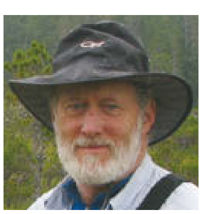
Figure 2. *A groundwater well and piezometer set in a wetland near Ault, Colorado.*

Figure 3. *Soil incubation chamber in the field near Gilcrest. Notice the gas exchange port and stockcock for taking samples.*

Erick Carlson (3)

Figure 5. *The marginally productive crop land with high water table and the invading wetland vegetation (cattail), a potential location for denitrification.*

Erick Carlson



David Cooper

HYDROLOGY

The hydrologic setting was monitored in 2014 (June-November) using shallow groundwater wells (two inch by 60 inch PVC and automated water level sensors—Rugged Troll 100-InSitu). Piezometers were also installed and water depths recorded to help determine groundwater flow paths (Figure 2). For comparison, nearby publically available daily rain gage data were used to examine the effects of precipitation on the water table.

DENITRIFICATION USING ACETYLENE BLOCK TECHNIQUE

Microbial denitrification was tested in the field using soil incubation chambers and the acetylene block technique. PVC tubes (three inches by 20 inches) were pounded into the ground 17 inches deep, leaving about three inches of headspace (Figure 3). Caps with a gas port were installed and sealed onto the tubes. Acetylene gas (C_2H_2) was injected into the headspace to comprise about 10 percent of the volume. The equal amount of air was removed just prior to injection such that the end result was a neutral pressure. Samples were taken pre-injection and again every hour after incubation began for up to five hours. Thirty milliliters of gas was extracted and 30mL of N_2 was injected to maintain neutral pressure. Gas samples were analyzed on a Shimadzu GC14B gas chromatograph with FID, methanizer ECD, and autosampler. This measured the amount of methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O).

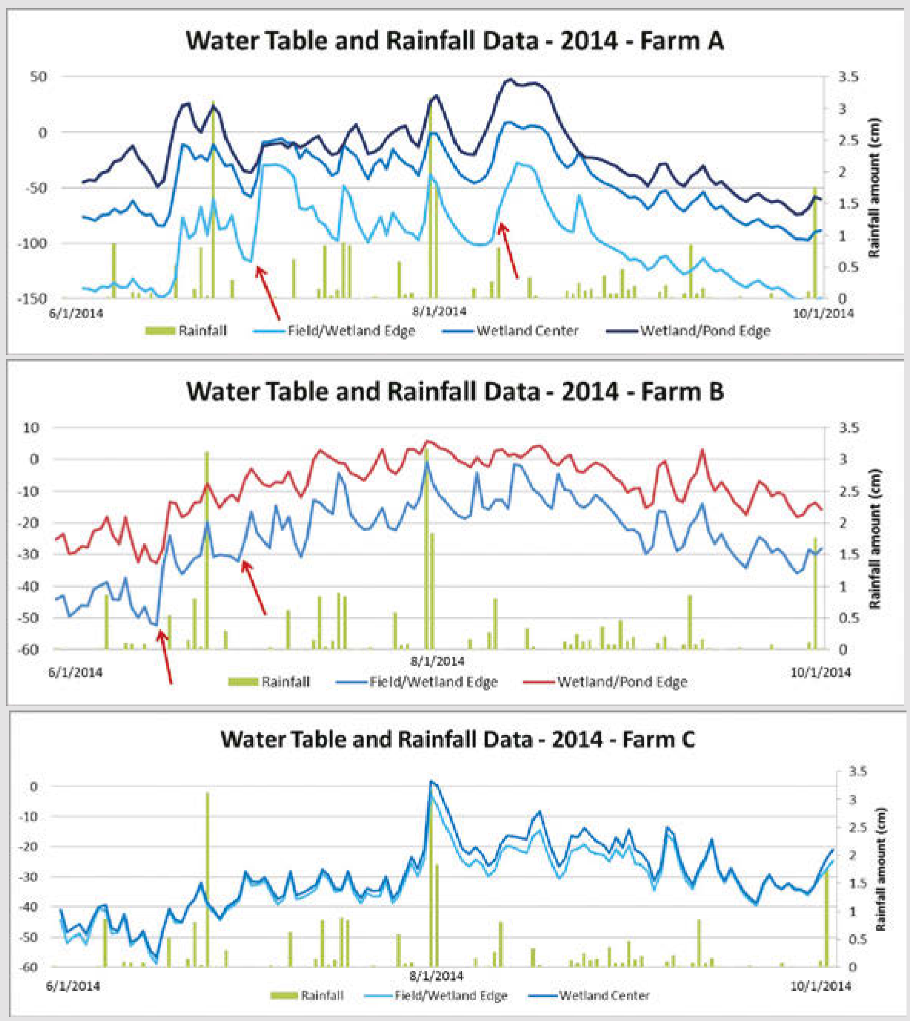


Figure 4. *Water table data from wetland adjacent to flood irrigated alfalfa field (top), flood irrigated corn field (middle), and sprinkler irrigated corn field (bottom). Red arrows represent likely flood irrigation events.*

RESULTS AND DISCUSSION

HYDROLOGY

Observation of the hydrologic setting of the four sites was illuminating, even during an anomalously wet summer. Clear trends in water table rise with rain events and assumed irrigation events took place (Figure 4). Farm A and B were used for base level control as they were adjacent to open water ponds. The stability of water level in the ponds can be seen from the nearest well. Farm A showed a wide range of variability in pond level—over one meter during the reported period—while Farm B only varied 30cm. Farm C represents a sprinkler irrigated system in very sandy soil. The groundwater wells were located the same distance apart as in Farm A and B (10m), but the soil was very sandy with high hydraulic conductivity, while farms A and B were clay dominated soils.

All three sites showed a gradual rise in water tables during the growing season, which would suggest irrigation water as major cause of the trend. Additionally, correlation was weak between water table levels and precipitation at all sites (<0.25 with 1.0 being a perfect correlation). The summer was exceptionally wet, however, with frequent substantial rains limiting many farm operators to irrigating half as often. Water table analysis of an average year might show irrigation events more prominently.

DENITRIFICATION USING ACETYLENE BLOCK TECHNIQUE

The experimental component of the research was to test efficacy of the acetylene inhibition technique in the field. This method is commonly used a laboratory setting to determine *potential* denitrification. I was interested in the actual denitrification under field conditions (Figure 5). The size of the incubation chamber and incubation time were unknown variables. The goal was to determine the maximum N_2O levels that could be obtained from blocking the denitrification chemical reaction. My results showed that five hours (three hour incubation presented) was not enough time for the acetylene to diffuse into the soil and block most denitrification (Figure 6). The slowing CO_2 accumulation suggests that the commonly observed reduction in microbial respiration was occurring, which supports that some diffusion was occurring and denitrification was impeded. The ideal result would have been a line that would begin to level off as most denitrification had been blocked at the nitrous oxide intermediate. We estimate this could take as long as 24 hours in dense, saturated clay soils after further literature review.

CONTINUED WORK

Additional funding through the Colorado Corn Growers Association and the U.S. Geological Survey (through the Colorado Water Institute) will continue to support this investigation into the question of wetland nitrate dynamics near irrigated agricultural fields. An additional site has been developed (Site E in Figure 1) and intensive sampling is planned for summer 2015. Analysis on other physical parameters likely to affect denitrification will be measured and analyzed for influence including soil nitrate, soil temperature, soil pH, soil bulk density, soil type, soil carbon, and microbial biomass. Plant uptake is another pathway that will be investigated with measurements of total plant nitrogen at the end of the growing season. The goal is an estimate of the amount of nitrogen endogenous to the wetland (cycling locally with plant tissues and soil reserves) and the amount entering the wetland through surface flow and shallow groundwater.

The work conducted with the Colorado Water Institute grant was essential to characterizing the systems, testing experimental equipment, and adjusting and understanding the need for data collection on additional physical parameters of the system. I want to sincerely thank the Colorado Water Institute for its continued support.

Acetylene Block N_2O Accumulation Over Time

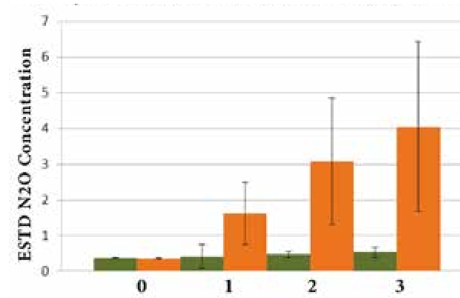
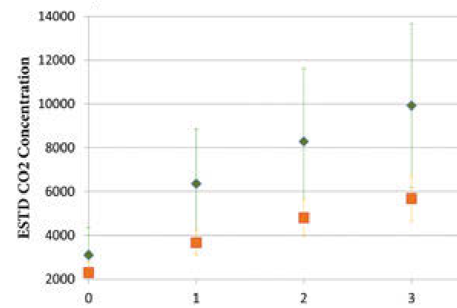


Figure 6. *Accumulation of nitrous oxide (N2O, above) and carbon dioxide (CO2, below) over a three hour incubation. Orange is the experimental chambers (C2H2 added); green are the control chambers.*

Acetylene Block CO_2 Accumulation Over Time



Additional funding through the Colorado Corn Growers Association [and the Colorado Water Institute] will continue to support this investigation into the question of wetland nitrate dynamics near irrigated agricultural fields.

Student researcher David Kamin adjusts instruments on the meteorological tower, which records temperature, humidity, and wind speed.

Exploration of a Geometric Approach for Estimating Snow Surface Roughness

David Kamin, MS Student, Watershed Science, Colorado State University

Advisor: **Steven Fassnacht,** Ecosystem Science and Sustainability, Colorado State University

BACKGROUND

In cold climates, the snow surface is often the interface between the atmosphere and the earth. Changes in this surface can have important effects on the hydrologic process, but it is difficult to characterize and model these changes. One measure used to understand the flow of air, temperature, and moisture over a surface is called surface roughness length (Z_0). This is a measure of the vertical turbulence that occurs when a horizontal wind flows over a rough surface. The greater Z_0, the greater the magnitude of turbulence that arises when wind passes over a roughness element. Due mainly to the difficulty and cost of obtaining estimates of Z_0, most land surface models and climate models do not address the variability of this value due to changing snow surfaces. This research, funded by a grant from the Colorado Water Institute, compares methods for estimating Z_0 and tests the viability of an approach that does not rely on expensive wind tower instrumentation.

METHODS

The traditional method for estimating Z_0 is an **anemometric** approach. This method relies on field observations of wind turbulence movement to generate a logarithmic wind profile and solve for aerodynamic parameters such as Z0. The anemometric method can be used for any surface or roughness elements, but its disadvantage is the expense and difficulty involved in installing and operating a wind tower to obtain measurements. In contrast, the **geometric** method uses algorithms relating aerodynamic parameters to measures of surface roughness elements. Geometric methods have the advantage that values of Z_0 can be determined without tower instrumentation. However, most geometric methods are based on empirical wind tunnel tests that do not account for changing wind directions and irregular roughness elements like boulders and trees. This project obtained Z_0 values from both procedures and used the more standard anemometric approach to test and validate the geometric method.

Synopsis

Experiments were conducted to compare the effectiveness of two methods for measuring snow surface roughness length. This measure is used in hydrologic analyses, and is important in colder climates—when surface roughness length is higher, wind turbulence is greater. The anemometric approach is more commonly used but a wind tower must be installed to collect observations. The geometric approach, which uses algorithms, is compared as an alternative. Work is still ongoing, and preliminary trends indicate that while the approaches do not yield the same values, they follow the same trends.

Table 1. Preliminary results

Surface Condition and Snow Covered Area (SCA)	Anemometric Z_0 (m)	Geometric Z_0 Lettau Method (m)	Geometric Z_0 Counihan Method (m)
Unplowed Field, 100% SCA	0.0005 ± 0.001	0.00006	0.003
Unplowed Field, ~30% SCA	0.0006 ± 0.001	0.0003	0.009
Plowed Field, 100% SCA	0.0024 ± 0.002	0.0014	0.036

David Kamin (2)

Above Left: *Ph.D. student Rosemary Records (left) and Steven Fassnacht, Professor of Snow Hydrology, construct the meteorological tower.* ***Above Right:*** *Furrows were dug on the upwind fetch of the experimental site to induce roughness.*

Data collection took place during the winters of 2013-2014 and 2014-2015 at an experimental site east of Fort Collins, Colorado at the Colorado State University Horticultural Farm. A meteorological tower was constructed and instrumented on the east end of a 100m by 35m field in an area with prevailing winds from the west. The upwind fetch was left undisturbed for part of the winter then plowed with regular furrows orthogonal to the prevailing wind direction in order to induce surface roughness.

The meteorological tower was instrumented at ten levels over a five meter height with anemometers, temperature, and humidity sensors. Data were quality controlled so that the only wind profiles used were those which best met the theoretical conditions for aerodynamically rough flow. In practice, this means profiles where wind speed was above four meters per second, winds were coming from the upwind fetch, and the profile showed strong correlation (r>0.95). A least squares linear regression fitted to these profiles yielded slopes and intercepts which were in turn used to compute the aerodynamic roughness length Z_0. For the geometric evaluation, ground-based light detection and ranging (LiDAR) technology was used to generate a point cloud of the upwind fetch being measured by the meteorological tower. Multiple scans were conducted during the winters to capture changing snow conditions. The geometric approach is limited by the accuracy of the description of roughness elements, so this LiDAR scanning is a good solution because it can describe the surface at sub-centimeter resolution. These surface scans were evaluated using the Lettau and Counihan methods to empirically compute Z_0 based on the height and area covered by the roughness elements.

RESULTS

Work is still ongoing to process and analyze the LiDAR scans, but preliminary results are promising. Table 1 shows examples of the Z_0 values and comparisons between the different approaches.

At any specific location, the physical roughness of the snow surface changes over the season and can be affected by snow redistribution and changes in wind direction. These results are encouraging because they show the responsiveness of the geometric methods to changing surface conditions. The Lettau and Counihan methods use different formulations to take into account the roughness of the surface, so it is expected that they yield different results. The geometric results do not match precisely with the anemometric Z_0 values, but they do follow the correct trends with changing surfaces, and further analysis is expected to strengthen the correlation between the two approaches.

CONCLUSIONS

Gaining a better understanding of snow surface roughness is a key component to improving models of the snow surface interaction with the atmosphere. Snow surface roughness is a complicated metric, and improvements to methods for estimating Z_0 will aid researchers and modelers working on this subject. Climate models like the flagship Community Land Model (CLM4) rely on metrics like Z_0 to estimate snow sublimation and melt. The results of this work indicate the effectiveness of evaluating Z_0 on diverse surfaces using geometric techniques and LiDAR technology. Other work in this field is starting to show the potential for mobile LiDAR and passive microwave remote sensing as methods to evaluate surface roughness on a larger scale. The present work informs these future efforts by demonstrating a tested geometric method for analyzing surface roughness lengths. A question for further research is how to scale this method into study of larger areas. The geometric method in this research relies on the accuracy of the ground-based scanner, but sub-centimeter resolutions are impossible over larger scales. Future work must address these questions of scale in order to deliver accurate Z_0 values over larger areas to feed into climate models.

ACKNOWLEDGEMENTS

We thank the Department of the Interior–Geological Survey, through the Colorado Water Institute, for funding support.

Management of Large Wood in Streams of Colorado's Front Range

Figure 2. Instream wood deposited by the Fall 2013 flooding in Ralph Price Reservoir, Colorado.

Natalie Anderson (2)

Figure 1. Student awardee, Natalie Anderson (center left with co-authors Brian Bledsoe (left, Civil and Environmental Engineering), Ellen Wohl (center right, Geosciences) and Mike Gooseff (right, Civil and Environmental Engineering). Not pictured are co-authors Kurt Fausch and Kevin Bestgen (Fish, Wildlife, and Conservation Biology).

Natalie Kramer Anderson, PhD Candidate, Geosciences, Colorado State University

Advisor: **Ellen Wohl,** Geosciences, Colorado State University

Synopsis

Student Natalie Kramer Anderson was part of a Colorado State University research team that researched decision-making on leaving or removing instream woody debris deposits. The team met with and advised city and county water professionals from the fall of 2014 to spring of 2014 and based on feedback from the meetings, they created a technical guidance document for water managers, with the overall goal of advising to leave wood in streams for the benefit of waterways unless a risk is posed to human health or safety. Technical tools, such as a structural stability analysis spreadsheet, were introduced to aid decision-making.

Large wood in rivers provides numerous physical and biological benefits to river corridors, but may also pose risks to inhabitants, infrastructure, property, and public safety. This project provided managers with a framework and tools to be able to assess the benefits and risks of leaving wood in river corridors via a technical report titled: "Management of Large Wood in Streams of Colorado's Front Range: A Risk Analysis Based on Physical, Biological, and Social Factors." The authors of the report included Colorado State University water faculty: Ellen Wohl (fluvial geomorphology, Department of Geosciences), Kurt Fausch (Department of Fish, Wildlife, and Conservation Biology), Kevin Bestgen (Department of Fish, Wildlife, and Conservation Biology), Mike Gooseff (ecohydrology, Department of Civil and Environmental Engineering), and Brian Bledsoe (Department of Civil and Environmental Engineering) as well as a graduate student, Natalie Kramer (Department of Geosciences) (Figure 1). The team met and advised water resources professionals at the city and county levels in Boulder and Larimer Counties during the fall of 2013 and the spring of 2014. These meetings provided valuable feedback to the academic team on how to design guidelines for assessment and monitoring that would be practical and regularly implemented by staff in stormwater utilities, floodplain management, and natural resources programs. Based on this feedback, the team wrote and distributed the technical guide in the fall of 2014. Informal feedback in the form of emails and verbal communications has indicated that the report has been widely circulated among interested parties and is now being used by private consulting firms and non-profit watershed groups, as well as by local governmental agencies.

The project was initiated after the September 2013 Front Range floods, which deposited large amounts of wood within the river corridors and onto the floodplains of the Colorado Front Range (Figure 2). The goal of the project was to be able to assist managers in deciding whether individual wood pieces or jams must be removed, can be stabilized and left in place, or can simply be left alone, as opposed to the current default of always removing wood. It was the hope of the team that the report would lead to the decision to leave in place wood that poses little to no risk to human infrastructure and safety, to the benefit of river ecosystems. This project was featured in the July/August 2014 issue of this newsletter wherein the project justification and background were fully discussed. Thus, the focus here will be on some of the tools developed and the results of the project.

Within the report, a decision process for managing large wood is outlined, particularly for assessing the relative benefits and risks associated with individual pieces and with accumulation of wood. The process is designed so that varying levels of effort can be applied, from a cursory visual assessment to detailed numerical modeling, and is usable by individuals with diverse technical backgrounds working in a range of rivers, from urban to natural.

The report begins with background information on the physical and biological benefits of wood followed by a summary of the hazards that wood may create for inhabitants, infrastructure, and recreational users. The decision of whether to retain, remove, or modify wood is highly dependent on context. Thus, several technical tools are introduced, including a large wood structure stability analysis spreadsheet, flow and habitat models, and a framework of easy-to-use decision bands that facilitate assessment of risk for three categories: ecological, recreation, and public safety. Figure 3 shows an example of a decision band. Eight decision bands were designed, and an overall decision band score sheet was developed to easily compare relative risks for any piece or accumulation of wood within any context (Figure 4). The report also outlines seven reasonable management responses based on the risk analysis: no action, monitor, stabilize, signage/outreach, remedial pruning, close reach, and move wood. Figure 5 shows a flow chart for steps in the decision making process included in the report.

The risk assessment designed in the report has been enthusiastically taken up by the management community, especially by Boulder County Parks and Open Space. Local government agencies and consulting firms across the Front Range are currently using the document to help design and implement new waterways master plans. The success of this project is partially due to swift response of the team from concept to publication following the 2013 flooding. To reach a broader national and global audience, a version of this report has been submitted to the peer-reviewed Journal of American Water Resources Association. It is currently in review, with expected publication date in the fall of 2015.

Funding was provided in part by the Department of the Interior–Geological Survey, through the Colorado Water Institute, as well as the CSU Water Center, Warner College of Natural Resources, and City of Fort Collins Natural Areas.

Figure 3. Example decision band

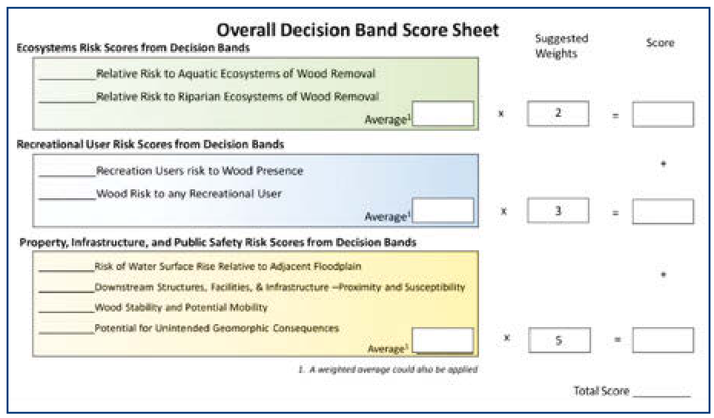


Figure 4. Decision band score sheet that allows a user to assess risk for wood removal or retention

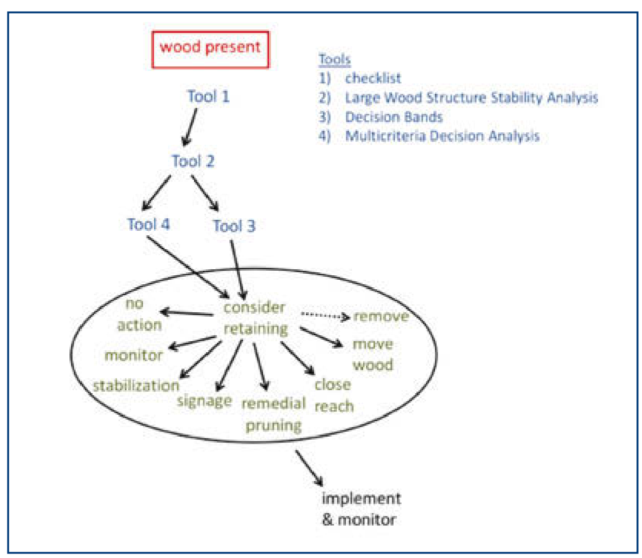


Figure 5. Decision-making flow chart for assessing risk and management of wood in streams

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

Adam Herdrich, Graduate Research Assistant, Department of Fish, Wildlife, and Conservation Biology, Colorado State University
Advisor: **Dana Winkelman,** Unit Leader, Colorado Cooperative Fish and Wildlife Research Unit, Colorado State University

Synopsis

Woody debris is thought to provide beneficial habitat to fish in streams, but much of the work studying the impacts of instream wood have taken place in environments that are dissimilar to the Colorado Rocky Mountains. This work is part of an ongoing project to analyze stream habitat in the Rocky Mountains, including an analysis of the health of brook trout populations. Field studies have been completed, and several fish were collected for analysis—this lab work is currently taking place, and will include growth rate analyses, diet content, and lipid analyses. Preliminary results include that lipid content varies seasonally, that growth rates are similar among the sites, and that whether brook trout live in environments with large wood deposits significantly affects both the amount and type of macroinvertebrate prey consumed.

INTRODUCTION

Streams of the southern Rocky Mountains suffer legacy effects of beaver trapping, wood removal, timber harvest, log floating, and other activities that have greatly reduced the size and frequency of large wood (LW) and resulting log jams. Historical studies of LW and effects on fish and habitat have focused on streams in the wet coastal forests of the Pacific Northwest. However, differences in precipitation rates, geology, flow regimes, forest composition, tree sizes, LW sizes, and LW decay rates exist between coastal forest ecosystems and the Southern Rocky Mountains of the Front Range in Colorado. For example, while abundance of LW pieces have been found to be similar in undisturbed sites in Colorado, Alaska, and British Columbia, overall volume of LW in the Rocky Mountains can be two to 10 times less than the Pacific Northwest. Further, large-scale studies of jam effects on watersheds are lacking, with most previous studies limited to the 10-100m scale, or occurring in the Pacific Northwest. Few other studies have attempted to link land management/disturbance to wood load and animal production in headwater streams.

Construction of instream structures to increase habitat heterogeneity has become one of the most common techniques in stream restoration. However, previous studies of stream restoration via LW replacement have shown variable results in increasing fish communities, and LW additions are not beneficial for all species or all developmental stages. Previous studies in Rocky Mountain streams have shown that the addition of LW increases fish populations through immigration of individuals from relatively long distances and not by increasing forage, habitat, or survival. Also, studies propose that a lack of a priori endpoints and post-project monitoring make it difficult to classify most restoration projects a success or failure.

OBJECTIVES

The objective of our study was to determine population and individual level effects of instream large wood on brook trout populations residing in streams located on the eastern slope of the Rocky Mountains. Specifically, the project goals were to address differences in trout (i) population size, (ii) population biomass, (iii) individual growth rates, (iv) individual fish condition, and (v) individual diet across a gradient of wood loading.

SUMMARY OF PROGRESS: METHODS AND PRELIMINARY RESULTS

SAMPLING DESIGN AND HABITAT MEASUREMENTS

Twenty-four separate reaches were sampled on 13 distinct streams across a gradient of wood loading in Northern Colorado and Southern Wyoming during the summers of 2013 and 2014. Streams and reaches were selected based on size, elevation, amount of LW, and dominant fish species. We measured average stream width (using wetted width), average stream depth, pool volume and number, and volume and number of large wood pieces at each site (provided by Ellen Wohl [CSU] who is collaborating on the main project).

__Facing Page:__ Adam Herdrich and advisor Dana Winkelman lead an electrofishing crew while sampling a stream in Rocky Mountain National Park. Photo by Pam Sponholtz, USFWS

POPULATION SAMPLING

Population sizes were estimated using multi-pass depletion sampling. Sampling was accomplished using backpack electrofishing equipment set at approximately 900V. At least three passes were made in each reach and stunned fish were captured with handheld dipnets. Fish were then identified to species, measured, weighed, and returned to the stream. Approximately 40 fish were sacrificed at each site for individual metrics (see below). Population estimates were then calculated using a Huggins' removal estimator in ProgramMARK. It appears that population density is not a simple function of wood load but is also controlled by other site-specific factors. Analyses of other factors such as resource availability and temperature are ongoing. However, wood loading does seem to stabilize fish density at approximately 20 cubic meters per hectare of wood loading (Figure 1).

INDIVIDUAL SAMPLING

Approximately 40 individual fish were removed at each sampling reach for analysis of growth rates, lipid contents, and diets. Growth rates are being examined using otoliths from individual fish. Both right and left sagittal otoliths were removed, cast in epoxy, and cut on the transverse plane on either side of the otolith core to remove excess otolith and epoxy material. Sections were then polished and photographed using a camera attached to a microscope. Growth rings were counted and measured using ImageJ by two separate readers to ensure accuracy. Preliminary analyses indicate that growth rates are similar among sites (Figures 2 and 3).

Individual fish condition is being analyzed using length-weight regressions (in progress), and by extracting lipid contents from whole fish collected at a subset of sampling reaches. Lipid level is being analyzed using the Folch method. Lipid content was determined by homogenizing whole fish, extracting lipids, and comparing the weight of total lipids to the weight of the original sample. To date, we have analyzed 38 individual fish lipid samples

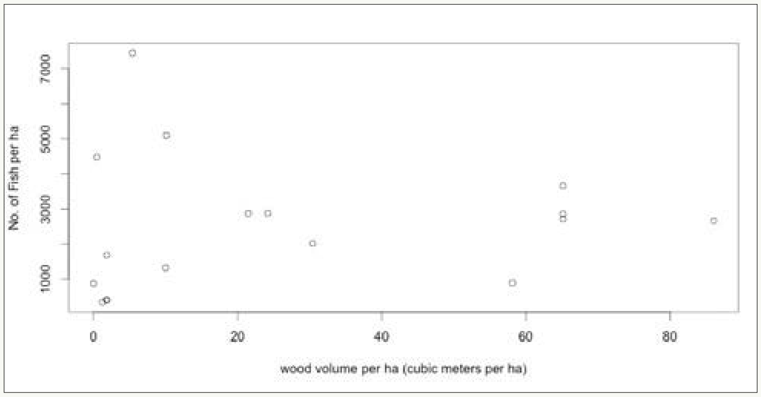


***Figure 1.** Population densities as a function of large wood loading at 16 field sites.*

***Figure 2.** Average lengths at ages for two sites, North St. Vrain and Glacier Creek in Rocky Mountain National Park, Colorado. Glacier Creek is a very low large wood loading site and low elevation (~8,500 ft above sea level), and North St. Vrain Creek is a high large wood loaded site and high elevation (~10,500 ft above sea level). Similarities in these growth rates suggest large wood is not directly affecting growth rates.*

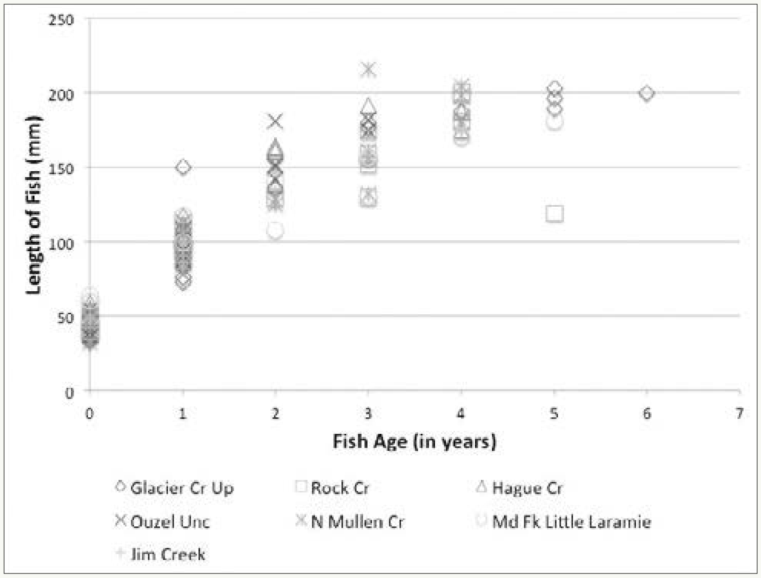


***Figure 3.** Average lengths at ages for seven other sampled reaches across a gradient of large wood loading. This plot indicates a similarity in average growth rates across these sites.*

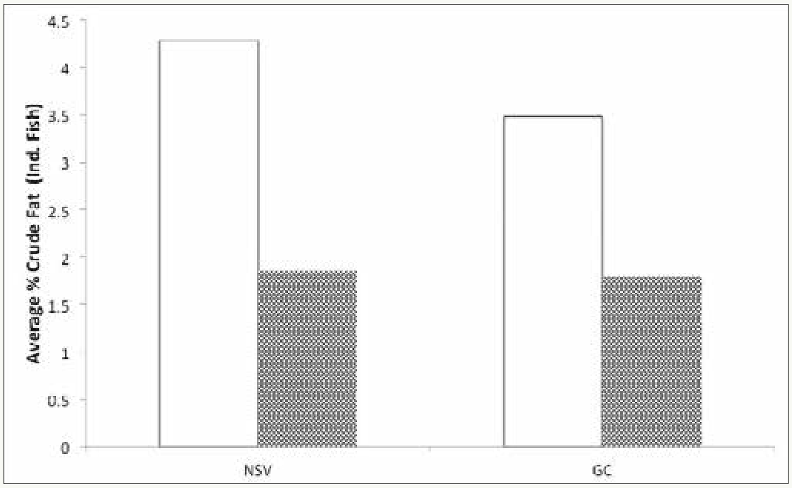


Figure 4. *Average percent crude fat for individual fish from a high wood site ("NSV"-North St. Vrain Creek) and a low wood site ("GC"-Glacier Creek), sampled in summer 2013 (open bars) and fall 2014 (shaded bars)*

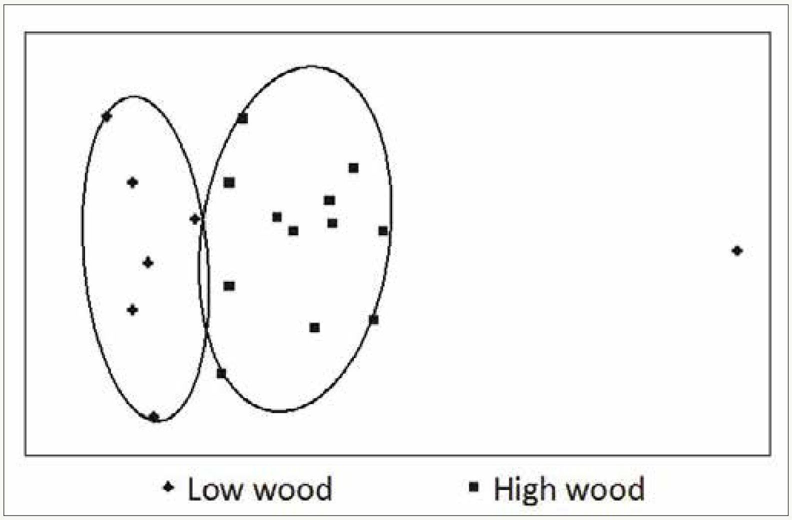


Figure 5. *Multi-dimensional scaling of fish diets from a low wood site ("Low wood," Glacier Creek) and a high wood site ("High wood," North St. Vrain Creek). Diets are statistically different (p=0.002). Plecopteran larvae were most abundant in the diets at the low wood site.*

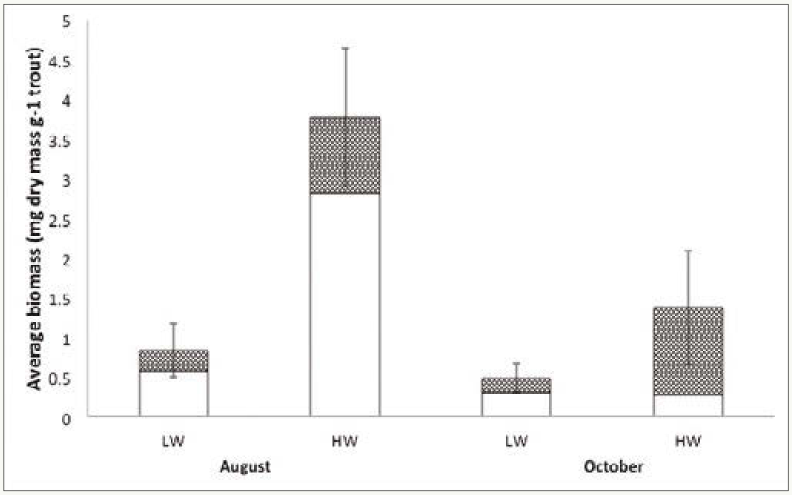


Figure 6. *Average biomass contained in individual stomachs from a low wood site ("LW," Glacier Creek), and a high wood site ("HW," North St. Vrain Creek). Open areas indicate proportion of aquatic insects, and shaded areas indicate proportion of terrestrial insects in trout diets at these sites.*

iStock.com

The project goals were to address differences in trout (i) population size, (ii) population biomass, (iii) individual growth rates, (iv) individual fish condition, and (v) individual diet across a gradient of wood loading.

from seven different sites and further analyses are contingent upon evaluation of diet analyses. Preliminary results suggest a highly seasonal change in lipid contents at each site (Figure 4).

Individual diets are being analyzed from stomach contents taken from fish that were sacrificed for otolith aging. Stomachs were removed in field and stored in 95 percent ethanol. Stomach contents are being identified to lowest possible taxonomic level, and data analysis has begun with comparisons of biomass per gram of fish in the diet and multivariate approaches. To date, diet analyses have been completed for two sites: North St. Vrain Creek (representative high large wood loading site) and Glacier Creek (representative low large wood loading site). Preliminary results suggest that increased large wood loading significantly affects both the amount and type of macroinvertebrate prey consumed by brook trout (Figures 5 and 6). Further stomach content analyses are currently taking place (with emphasis placed on specific sites related to high and low wood loading) and are expected to be completed by Fall 2015. Additionally, the diet data will be compared with prey availability that is being analyzed by our collaborators. All field sampling has been completed and only laboratory analyses are being performed.

ACKNOWLEDGEMENTS

We would like to acknowledge the National Science Foundation and the Department of Interior–Geological Survey through the Colorado Water Institute for providing funding.

Anastasia Bacca gave instructions for the "Toothpaste Taste Test Study," which was used to discretely measure water conservation study participants' water use while brushing. Photo by Chad Mortensen

The Effect of Normative Trends on Water Conservation

Chad Mortensen

Anastasia M. Bacca, Undergraduate Student, Psychology, Metropolitan State University of Denver

Advisor: **Chad R. Mortensen,** Psychology, Metropolitan State University of Denver

Synopsis

Water conservation efforts include the important social aspect of convincing the public to take part in conservation. Past research has looked into the effectiveness of conveying social norms (e.g., a majority of people participate), but there may be a limitation to this approach when only a small percentage of people take part. To overcome this limitation, this study conducted experiments and found that both conveying a small but increasing percentage (e.g., 48 percent, up from 37 percent) and asking participants to think about how popular water conservation would be in the future encouraged water conservation behaviors.

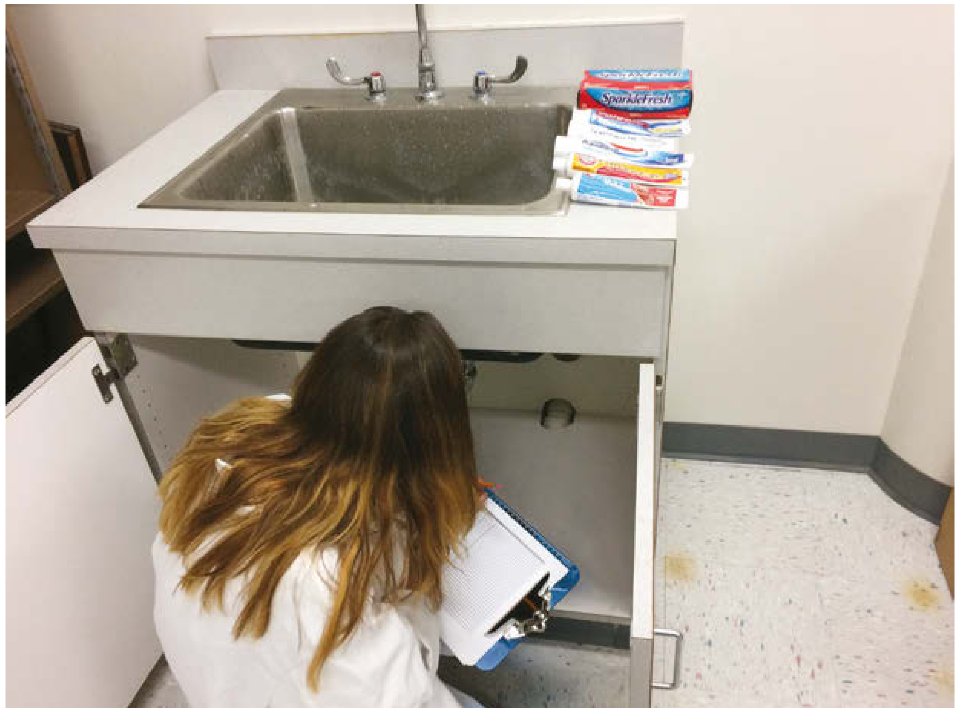
BACKGROUND

Colorado's proclivity for drought and the fact that it is the only state other than Hawaii in which water flows out, but not in, makes conservation of water resources in the state vitally important. Encouraging socially responsible behaviors—like conservation of water resources—among the population can be successfully carried out in many ways, such as fines for improper water use or financial incentives for conservation. However, communication campaigns are a relatively inexpensive way to further reduce water use through more psychological means. Recent campaigns have already sought to do so, but perhaps harnessing the powerful influence of group behavior can further increase the effectiveness of these types of communication campaigns.

The effect of social norms on individual behavior has been frequently documented. Studies have found that messages reporting pro-environmental behaviors as normative (i.e., commonly done) increases the likelihood others will perform these behaviors more than messages containing only appeals to help the environment. For example, communicating a norm that the majority of guests participate in towel reuse at hotels increases reuse beyond just asking guests to help the environment. However, what has not been properly researched is the additional effect that can potentially be had by providing information regarding changes in these norms, which may even further engender increases in conservation behavior.

People from Western cultures tend to believe that change over time will continue in the same direction. Because most Colorado residents subscribe to Western thinking, we hypothesized that communicating a norm for engaging in water conservation behaviors is increasing in popularity would have a greater effect on water conservation behaviors than presenting a norm alone. To test this in previous research, we first exposed participants to conservation statistics then asked these participants to take part in what they believed to be a separate study on toothpaste preferences. As they sampled the toothpaste, a hidden water meter measured their water use. As expected, communicating that the number of people conserving water was increasing (i.e., 63 percent engage in the behavior, and this is up from 52 percent) led people to use significantly less water than presenting a norm alone (i.e., 63 percent engage in the behavior).

Two experiments were proposed in our grant application; however, we completed an additional third experiment as well. The project had two objectives. First, we sought to conceptually replicate our previous research using a different conservation behavior (i.e., washing hands). Second, previous research has found that people



Chad Mortensen

Anastasia Bacca recorded the amount of water used by a participant on a hidden water meter during water use and conservation studies.

> *We found that messages communicating social norms are even more effective when communicators include trend information stating that these social norms are becoming more popular.*

will not be likely to perform behaviors they believe most others are not performing. However, communicating that a numerical minority is *increasing* in size may be able to overcome this problem. We hoped to find that this could provide people wishing to promote a conservation behavior a way to leverage social norms even when most people do not engage in conservation behavior, as long as the minority engaging in it is sufficiently increasing. Our final experiment examined whether explicitly asking participants to think about the popularity of water conservation behaviors in the future after being exposed to trending norm information may render these messages even more effective.

METHODS

Three experiments were conducted. In each, participants were told they would be participating in two short studies conducted by separate researchers. In our first experiment, participants were told the first study examined the relationship between personality and editing skills, and they read a brief statement regarding fellow students' water conservation behaviors and edited the message. The statement included the experimental manipulation. While some the participants read that 63 percent of students at their university engaged in one or more of several listed water conservation behaviors, the remaining participants also read that participation in these water conservation behaviors had increased from 52 percent the year before. Participants then completed several personality surveys and were directed to what they believed was the second, separate study. A second experimenter informed the participant that they would be participating in a study examining the relationships between characteristics of hands and personality. Participants were asked to hold out one hand palm up and the experimenter applied washable ink after which the participants placed their palms on a piece of paper to make a handprint. The researcher then excused herself, supposedly to store the handprints, while the participants were told they could use the sink in the room to wash off the ink. Participants were then debriefed, after which the researcher recorded a water meter reading to measure how much water participants had used.

The second experiment was identical to the first, except the second study in the experiment was presented as a toothpaste taste-test study instead of a study related to characteristics of hands. Additionally, the percentages used in this second experiment were all numerical minorities (48 percent of students engage in water conservation behaviors, which those in the trending norm condition read had increase from 37 percent the year prior), and a control condition was added in which participants read about trends unrelated to water conservation.

The third experiment was identical to the second, but added conditions in which participants made explicit predictions about the popularity of water conservation in the future.

RESULTS

In the first experiment, there was a tendency for participants to use less water after being exposed to a trending norm (63 percent of students engage in water conservation behaviors, up from 52 percent; Mean = 0.486 gal) compared to the norm alone (63 percent of students engage in water conservation behaviors; Mean = 0.496 gal). However, statistical analyses were not significant, indicating there was a high possibility that this could have been due to random chance alone.

The second and third experiments we more successful, however. In the second experiment, we examined whether communicating a trending norm can make a message urging water conservation effective even when only a minority of others engage in the behavior, and used tooth brushing as the behavior under investigation. We found that those who read the norm only (48 percent of students engage in water conservation behaviors) used the same amount of water (0.44 gal) as those who did not read about water conservation at all (0.44 gal). So, when a numerical minority of people engages in water conservation behaviors, communicating this information is ineffective in reducing water usage. However, when information regarding an increasing trend was added to this normative message (48 percent of students engage in water conservation behaviors, up from 37 percent), participants *did* reduce water usage (0.26 gal). Statistical analyses showed that this effect was large and statistically significant (unlikely due to chance). The results also showed that participants believed water conservation to be more popular if they read the trend information than if they didn't.

The third experiment was similar to the second except that it also explicitly asked some of the participants to answer how popular they thought water conservation behaviors would be in the future. Results from this experiment showed that after reading the trending norm message, water usage in the tooth brushing task was even lower if participants were asked to think about popularity of these behaviors in the future than if they weren't. Statistical analyses determined that this was a medium-sized effect and that it was significant (unlikely due to chance).

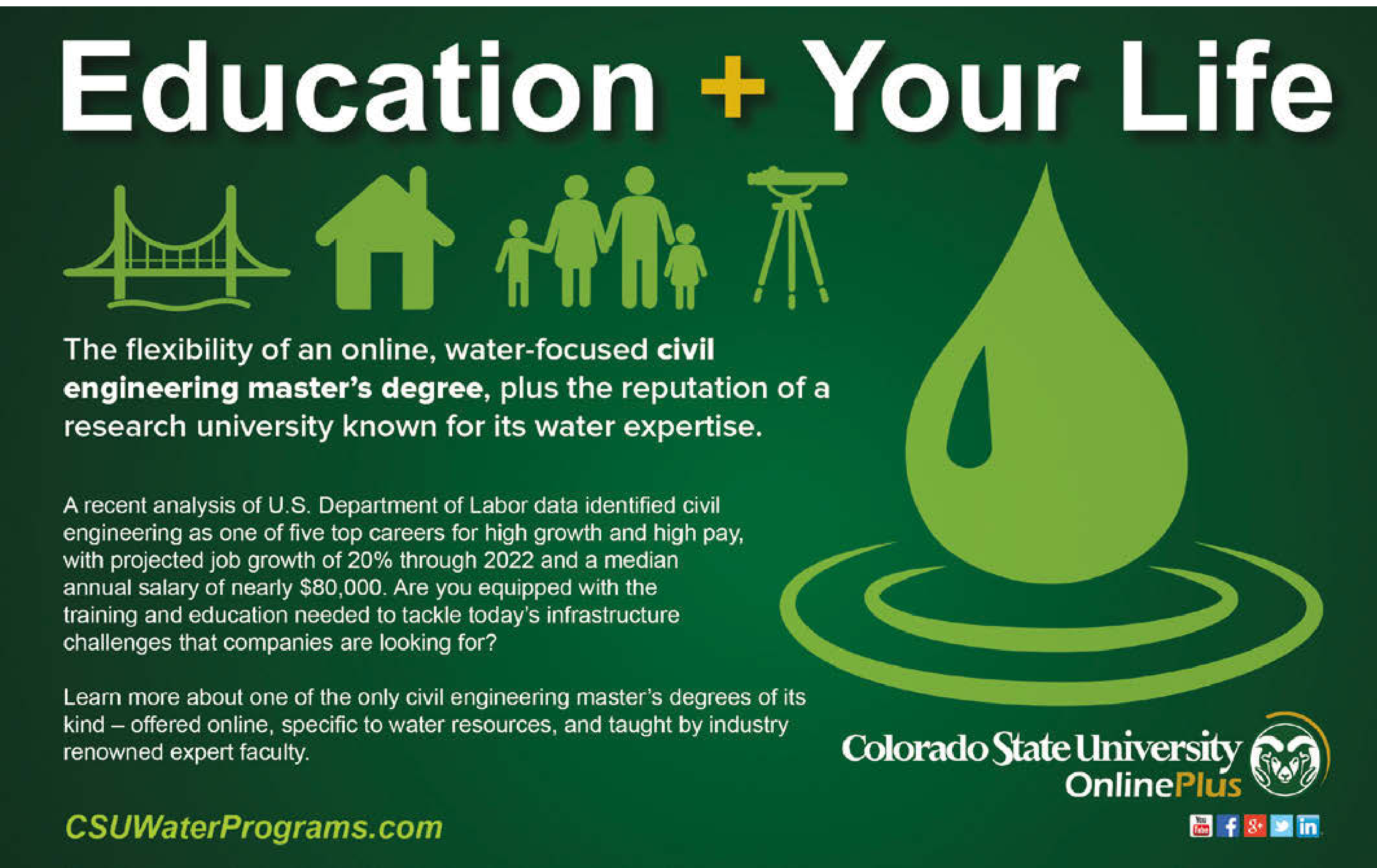
DISCUSSION

Overall, this research examined how to improve messages promoting water conservation that use social norms as leverage. We found that messages communicating social norms are even more effective when communicators include trend information stating that these social norms are becoming more popular. Doing so also makes messages stating most people are actually *not* engaging in water conservation behaviors effective in increasing water conservation in others as long as the number of those said to be engaging in water conservation behaviors is sufficiently increasing. Finally, we found that the effectiveness of these messages can be increased to an even greater degree by explicitly asking people to think about how popular water conservation will be in the future.

Though social norms are already known to be effective in communication campaigns, our research shows there may be ways to further increase the their effectiveness. Notably, these strategies for improving communication campaigns are not only effective, but also low cost or free, allowing for greater conservation of valuable water resources without having to increase funding for campaigns. Specifically, this research demonstrates strategies that can be used to encourage water conservation, but more generally, it can also be seen as helping to demonstrate the value of taking a psychological approach to promoting water conservation.

ACKNOWLEDGEMENTS

We thank the Department of the Interior–Geological Survey through the Colorado Water Institute, as well as the One World One Water Center for Urban Water Education and Stewardship for funding support.



Potential for Russian-olive Removal and Utilization at the Colorado State Forest Service Nursery

Damon Vaughan, MS Candidate, Department of Forest and Rangeland Stewardship, Colorado State University
Ryan Lockwood, Colorado State Forest Service


William Ciesla

Figure 1. Silvery, shrub-like Russian-olive trees, visible in the foreground, often outcompete native trees.

Synopsis

Russian-olive is an invasive tree that is the target of many restoration efforts across the U.S. Some research exists on Russian-olive biomass utilization, but no studies have been done on its use as a solid-sawn wood product. The CSFS Nursery in Fort Collins has hundreds of Russian-olives on its property slated for removal, which presented the opportunity to conduct an economic analysis. Utilizing the merchantable wood from Russian-olive removals could generate enough revenue to reduce total costs for the removals by 28.7 percent. This approach could help reduce the costs of removal efforts already taking place in many locations.

BACKGROUND

Russian-olive (*Elaeagnus angustifolia*) is an invasive, deciduous perennial, native to southern Europe and western/central Asia. It varies in form, from a large shrub to a small tree, and often grows in dense rows. In the U.S., Russian-olive was planted extensively for windbreaks and erosion control in the early 20th century because it is a hardy tree that establishes and grows quickly. These plantings had unforeseen consequences, and the tree quickly escaped cultivation and began to expand its range (Figure 1). The tree is now the fourth most widely distributed woody riparian species in the American West. However, a primary concern with this invasive tree is that it competes with native tree species and utilizes large quantities of water that would otherwise offer other environmental or socioeconomic benefits, prompting its removal in riparian areas to enhance water yields.

Russian-olive is now listed as a noxious weed in Colorado, New Mexico, Wyoming, and several counties in Utah and Montana. In Colorado it is classified as List B, which means that in areas where the species has established, plans must be put in place to stop its continued spread (Figure 2). Many of the agencies that once promoted its planting are now spending large amounts of money on removal projects. Between 2005 and 2007, the U.S. Bureau of Land Management expended $500,000 on Russian-olive removal in riparian areas. In 2006, Congress passed the "Saltcedar and Russian Olive Control Demonstration Act," which authorized approval and federal funding of five "demonstration projects" that involve large-scale Russian-olive and saltcedar removal for ecological restoration.

Currently, many major restoration projects are underway in areas such as the Escalante River in Utah, the Bighorn Basin in Montana, the San Juan Watershed in the Four Corners area of the southwestern U.S., and the Platte and

Figure 2. Land managers are working to remove Russian-olive around Colorado, including at Barr Lake State Park. Courtesy of CSFS

Republican rivers in Colorado. These and other large projects often involve removal of Russian-olive trees, particularly in riparian corridors and near reservoirs and irrigation ditches. These projects are very expensive and generate large amounts of woody residue in the form of tree boles and material such as branches and tops. This material is generally chipped or burned, with little product recovery other than firewood and mulch.

The waste generated by Russian-olive removals prompted this utilization study by the Wood Utilization and Marketing Program (CoWood) of the Colorado State Forest Service (CSFS). The opportunity for the study arose with a Russian-olive removal project at the CSFS Nursery in Fort Collins, Colorado. Originally planted as windbreaks, the trees border several of the nursery's fields in dense rows (Figure 3). Although many trees were removed by volunteers during two work days in February of 2014, the vast majority remain standing, and the nursery remains with a decision on how to proceed with the remaining removals. Many of the trees are quite large, but it was not known how many larger trees existed or what the potential value of the wood could be.

UTILIZATION POTENTIAL

The crooked form of Russian-olive makes milling the trees difficult, so mill owners avoid the high costs and low yields of processing the tree into a solid-sawn product. However, the attractive, moderately dark wood is occasionally used by woodworkers, often to produce furniture.

Utilization of urban or other trees not obtained from traditional forest tracts for wood products is a relatively new idea, but one that has gained traction. Logs from urban tree removals are often available to mills free of charge from arborists and city foresters. By donating to the mills, these entities can save on disposal costs that may be charged by landfills or wood recycling yards. Several mills in northern Colorado have successfully milled and sold wood from Russian-olives. TC Woods, in Fort Lupton, is one urban hardwood mill that has developed a market for Russian-olive wood. The mill currently sells Russian-olive lumber for five to eight dollars per board foot, depending on board size. Landowners who have Russian-olive logs they intend to dispose of thus have the option to contact local hardwood mill operators.

There are several potential product markets for Russian-olive wood. Some examples of these are rough-cut lumber, slabs, and turning stock.

ROUGH-CUT LUMBER

Rough-cut lumber is sold in varying lengths and widths, with depths in one-quarter-inch increments. Rough-cut Russian-olive lumber is marketed to woodworkers and is sold directly to consumers for specific project needs (Figure 4).

SLABS

A growing use for material from urban tree removals is for producing wood slabs. Slabs are defined as full-length log cuts of varying thickness, where unique grain patterns, burl, and shape add to the quality of the piece. End uses for slabs include tabletops, countertops, and handmade clocks. The Russian-olive growth form has traits that lend it very well to slab production (Figure 5). Many boutique shops now stock finished wood slabs, so they could potentially be sold either through a retail outlet or directly to the consumer.

TURNING STOCK

Russian-olive can also be sold in smaller sizes designed to be turned on a lathe. Various size classes are available for this, such as pen blanks (three-fourths of an inch wide and deep, six inches long),

Courtesy of CSFS (3)

Figure 3. *Prior to removal, dense Russian-olive trees at the CSFS Nursery competed with other vegetation.*

Figure 4. *This lumber was produced from Russian-olive wood.*

Figure 5. *Russian-olive wood offers an attractive grain and color, making it ideal for some furniture, including table tops.*

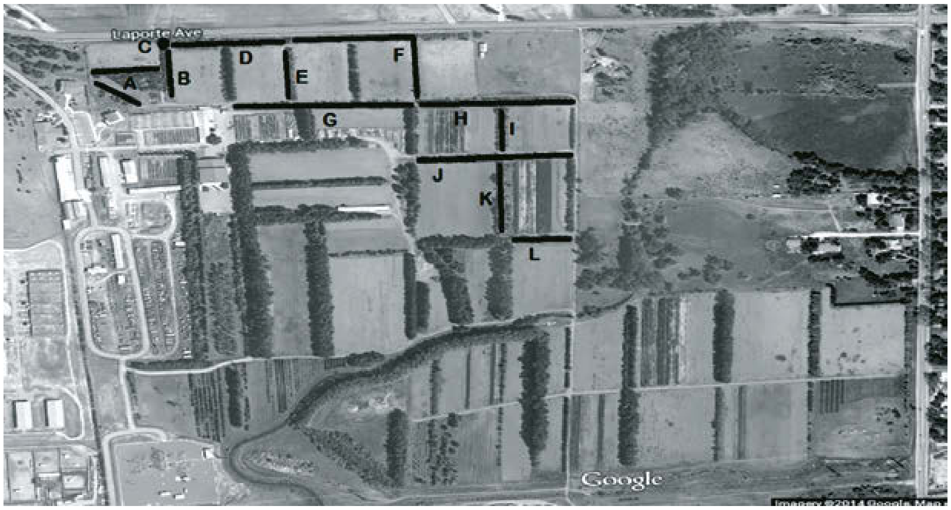


Figure 6. *A map was created of the CSFS Nursery using Google Maps with section labels for Russian-olive rows.*

turning blanks (one to two inches wide and deep, various lengths) and bowl blanks (larger, of various sizes). Russian-olive is readily available in online markets like eBay in all of these sizes.

CSFS NURSERY CASE STUDY

There were two major components to this study: an inventory of merchantable logs at the CSFS Nursery and a cost/revenue study of tree removals on the property. Below is a brief summary of the methods and important results from the study. More detailed results are pending publication and will be available in an upcoming issue of *Forest Products Journal*.

INVENTORY

To gain an idea of the number and size of Russian-olives on the property, located on Colorado State University land in northwest Fort Collins, it was necessary to first conduct a tree inventory. Data from the inventory were used to estimate the volume and value of available wood, as well as the costs for removals. The Russian-olives grow in rows surrounding fields on the northern end of the CSFS Nursery. For the purposes of this inventory, the rows were divided into 12 distinct sections, lettered A-L (Figure 6). Diameter measurements were taken of all 637 trees inventoried, and diameter and length measurements were made of all merchantable logs on the property. Logs were considered merchantable if they met minimum specifications of 4.5 feet long and eight inches diameter at the smaller end.

COST/REVENUE ANALYSIS

A pilot study was conducted that consisted of the removal and processing of all 37 trees in section B (Figure 7).

Courtesy of CSFS (2)

Figure 7. *A CSFS sawmill near the tree removal sites allowed for initial wood processing.*

Logs were then transported to a local mill, where they were further processed into two-inch-thick boards, yielding a total of 475 board feet. Finally, a selection of boards was sold to a local urban hardwood retailer for $2.50 per board foot.

An important comparison can be made here between net costs of a removal project that seeks wood utilization versus a traditional, non-utilization approach. Both approaches are net losses, but if a traditional removal project were conducted, logs would still need to be removed and disposed of without recovering any value. By projecting potential costs and revenues from this pilot study to the entire CSFS Nursery, the nursery would save an estimated 28.7 percent on the total cost of Russian-olive removals if all yields were sold for full market value.

DISCUSSION

This research shows that: 1) It is possible to harvest commercial Russian-olive sawlogs and process them into a product that consumers will pay for, and that 2) the CSFS Nursery, and potentially many other Colorado landowners and land managers, could realize a cost offset by selling Russian-olive sawlogs from tree removal projects.

When faced with high costs for invasive tree removal projects, one would have difficulty finding a reason not to seek out some profit and utilization for the resulting wood. Currently there is not a high demand for Russian-olive wood, nor are there many mills familiar with milling the logs. This study proposes that such an arrangement is economically feasible, with the hope that increased Russian-olive utilization can result in increased removal rates that are more cost-effective. Raising awareness for the value of Russian-olive wood could not only provide interesting new wood to the market, but could provide a means to an end for those wishing to remove the invasive species and restore their properties and watersheds.

Assessing Soil Moisture-Temperature Feedbacks

Will Increased Surface Heating Exacerbate Drought?

Peter Goble, MS Candidate, Atmospheric Science, Colorado State University

Advisors: **Nolan Doesken,** Colorado State Climatologist, and **Russ Schumacher,** Atmospheric Science, Colorado State University

INTRODUCTION

Root zone soil moisture is the water in the soil that is within the reach of surface vegetation. This moisture is coupled with atmospheric conditions. Energy from the sun that reaches Earth's surface is partitioned between sensible and latent heating—sensible heating raises the surface temperature, and latent heating evaporates surface water. In the case of a vegetated surface, this evaporation occurs via transpiration. Transpiration refers to residing flora converting liquid root zone soil moisture to atmospheric water vapor during the process of photosynthesis. When the root zone becomes depleted, the partitioning of latent and sensible heating shifts in favor of sensible heating and warms the surface. In other words, warmer temperatures dry out the soils more quickly, and dry soils heat up the air more quickly—a vicious cycle.

This soil moisture-temperature feedback is interesting from a water resource management perspective. The U.S. Geological Survey (USGS) estimates that 86 percent of consumptive use of water is agricultural. This occurs through the process of transpiration outlined above, so the soil moisture-temperature feedback is inextricably linked to usage of water from streams and reservoirs.

RESEARCH OBJECTIVES

The goal of this case study is to quantify the root zone soil moisture-temperature feedback in the Upper Colorado River Basin, as well as the area nearby just east of the Continental Divide in eastern Colorado and southeast Wyoming. This should serve as a gateway to hopefully bolstering drought early warning capabilities in the region. If we can gain an understanding of how soil moisture can enhance or mitigate drought by location and by season, it will help in appropriately weighting soil moisture relative to other available metrics of drought.

HYPOTHESIS

The main role of the root zone soil moisture-temperature feedback will be to exacerbate drought in the summer across the Upper Colorado River Basin as well as Colorado and Wyoming east of the Continental Divide. The main reason for this hypothesis is that incoming solar radiation is increased during summer months. This has numerous consequences for land-atmosphere interactions, including increased surface heating and enhanced plant growth, implying increased demand for root zone soil moisture.

METHODS

This study utilizes 31 years of monthly North American Regional Reanalysis data coupled with an ensemble of land surface models, including the Variable Infiltration Capacity (VIC) Model, the Mosaic (MOS) Model, and the Noah model. Two meter air temperature data are used, as well as derived

Synopsis

Atmospheric Science student Peter Goble analyzed 31 years of monthly North American Regional Reanalysis data, which includes temperature, precipitation, and wind data, and utilized land surface models to determine the amount that soil moisture either enhances or mitigates drought in the Upper Colorado River Basin as well as Colorado and Wyoming east of the Continental Divide. Such work contributes to a greater understanding of drought processes and can help climatologists provide early drought warnings to this arid region. Early drought warnings might be important if summer temperatures were to increase in the region, contributing to decreased soil moisture, or if decreased soil moisture were to contribute to warmer temperatures, exacerbating drought conditions.

Figure 1. Peter Goble took soil cores from the Christman Field Weather Station near the CSU Department of Atmospheric Science. These soil cores were taken at various depths within the root zone, weighed, dried under a heat lamp, and weighed again to determine what percent of soil volume is water. The findings presented here were from computer models in which the root zone soil moisture field is mathematically derived. This is because soil core data are not available at high spatial or temporal extent. Ultimately, field observations like this must be used to ensure that data derived by land-atmosphere models, such as the ones used in this study, are accurate. Eastern Colorado (below), where the majority of the region's agriculture is located, was indicated by these data to be more resilient against the root zone soil moisture-temperature feedback than other areas.

Emmett Jordan

volumetric water content in the top meter of soil. Model resolution is ⅛ latitude by ⅛ longitude.

Model ensemble root zone soil moisture was calculated by summing the water content of the three land surface models for each model at each gridpoint, dividing by three, and then standardizing the data since soil moisture varies much more in some areas than others not as a function of atmospheric conditions, but as a function of soil type. Since the data used in this report are mathematically derived, it is important to remember that field sampling can serve to check soil moisture findings (Figure 1).

To help determine when and where root zone soil moisture has enhanced importance for the purpose of drought early warning, a correlation analysis was performed on the standardized model ensemble root zone soil moisture with the temperature of the following month for each individual grid cell using a linear fit. This one-month lag in correlation will serve to tip us off as to whether or not warm temperature anomalies are to be expected in the wake of negative soil moisture anomalies (or vice-versa).

RESULTS

Analysis did indicate that there is an appreciable feedback between temperature and the prior month's root zone soil moisture that peaks across the domain of study in the months of June and July (Figure 2). This feedback is largely dependent on location. The strength of this feedback peaks in June over western Colorado and north and central Utah with a maximum of 51 percent of variance explained (Figures 3 and 4). In July the peak is in southwest Wyoming, at 57 percent of variance explained.

Both spatial and temporal discretion should be used when asserting temperature projections for one month based on the previous month's root zone soil moisture. Correlations are low across the board through the winter months, but even in summer, the grid average percent variance only explained peaks at 15 percent in June (14 percent in July). The effect of the previous month's root zone soil moisture on the current month's temperature also scales on average as roughly an order of magnitude lower than the temperature's background standard deviation for the month.

Eastern Colorado, where the majority of the region's agriculture is located, was indicated by these data to be more resilient against the root zone soil moisture-temperature feedback than other areas, even during the summer months. These results are somewhat surprising, but non-irrigated portions of eastern Colorado are grasslands, generally receiving less than 20 inches of precipitation annually but receiving lots of incoming solar radiation under predominantly clear summer skies. It is possible that a balance favoring sensible heating is preferred climatologically. The hypothesis indicated here that the driest areas in the domain are too dry to be vulnerable to the soil moisture-temperature feedback merits further study.

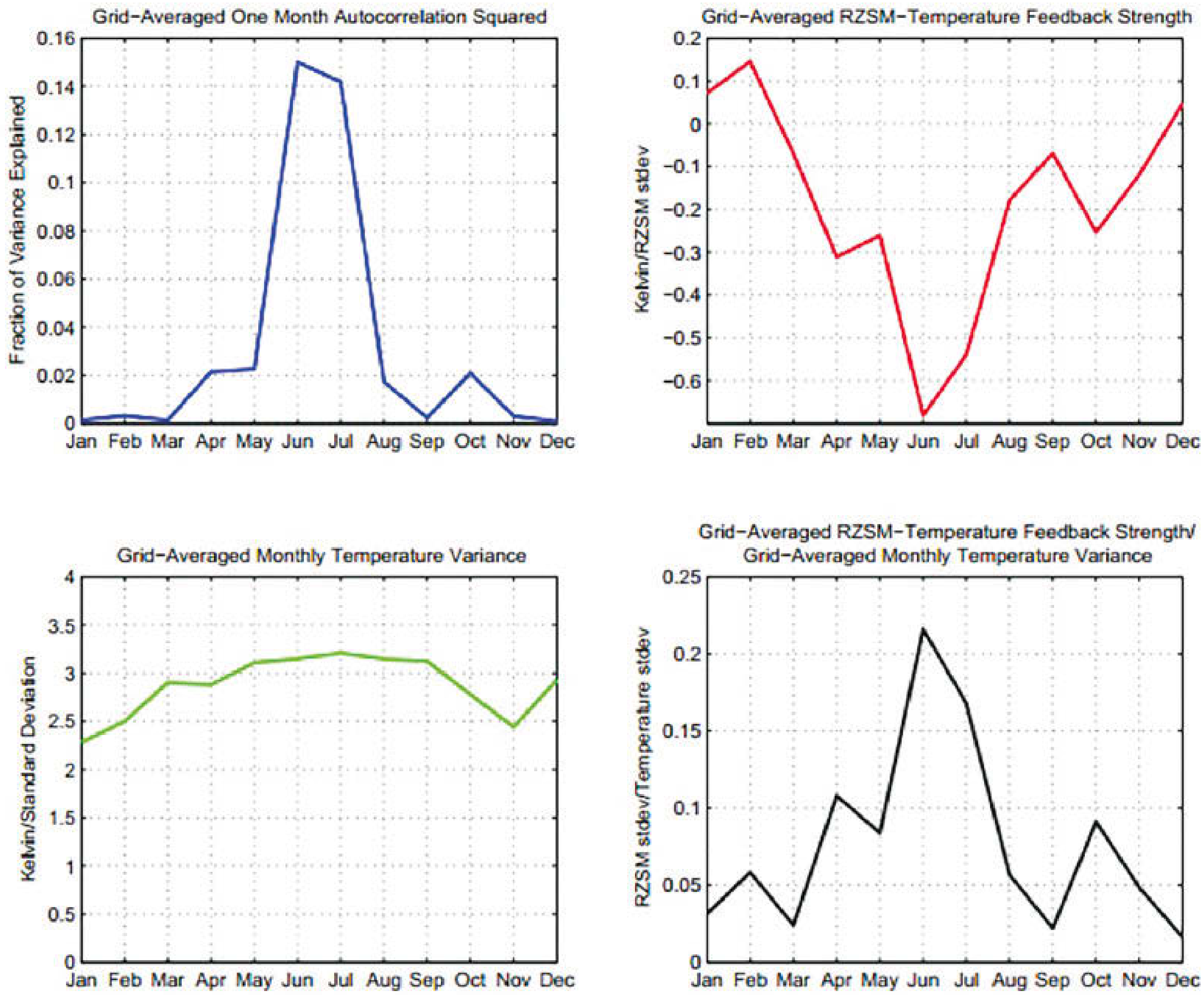
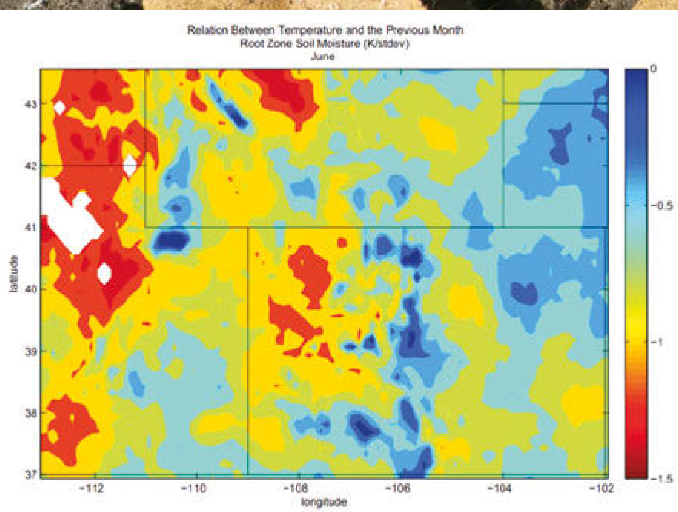
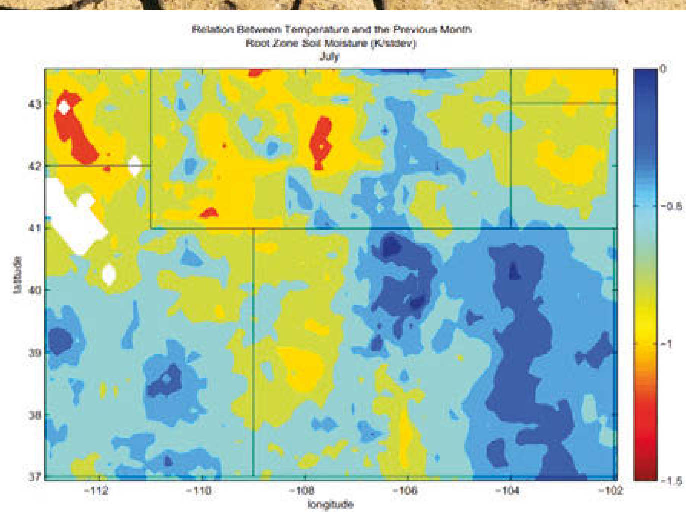


Figure 2. Upper Left: *This figure shows the area-averaged* R^2 *across all 4,860 gridspaces in the domain using a linear fit approximation. There is a distinct peak in the months of June and July driven by a negative correlation between temperature anomalies and root zone soil moisture (RZSM) anomalies from the previous month.* ***Upper Right:*** *Domain-averaged slope of the least-squares line for scatterplots of temperature anomaly vs. root zone soil moisture anomalies from the previous month. The most robust result is that a minus one standard deviation RZSM anomaly in May on average leads to a warming of 0.7 Kelvin in the month of June.* ***Lower Left:*** *To give an idea of expected variance in temperature, this plot shows the domain-averaged monthly temperature standard deviation in units of Kelvin.* ***Lower Right:*** *Scale analysis of the amount of warming or cooling that can be expected from the previous month's soil moisture anomalies with respect to the background amount of temperature variance anticipated. This yields a similar result to the plot of percent variance explained.*





Figures 3 and 4. *These contour plots show the amount of cooling (or warming) anticipated from given how high (or low) root zone soil moisture is in the prior month for the two months where the feedback signal was the strongest. According to this analysis, the areas most susceptible to the root zone soil moisture-temperature feedback are central and northern Utah and western Colorado. The signal was weakest east of the Continental Divide and in high mountain valleys.*

On the west side of the divide, sensitivity to the feedback decreases dramatically in August. It is possible that this is because root zone soil moisture reserves left over from snowpack are low by that point in a normal year, whereas in previous months, the amount of soil moisture reserves from winter snowpack are controlling the latent and sensible heating budget to a degree. The sizable decrease in incoming solar radiation over this time likely plays an important role as well.

CONCLUSIONS

The root zone soil moisture-temperature feedback is primarily a June and July phenomenon for the Upper Colorado River Basin and the eastern Colorado and Wyoming region. It is strongest in the Wasatch Mountain Range in Utah and along the northwestern slopes of the Rocky Mountains in Colorado. Relatively, the feedback appears to be weakest in areas that are climatologically dry such as high mountain valleys, the plains east of the divide, and the low elevations in eastern Utah between the Wasatch and Rocky Mountain Ranges. There is a large weakening in the domain-averaged root zone soil moisture-temperature feedback from July to August. This may be related to the drop off in solar radiation and/or the depletion of soil moisture from snowpack.

FUTURE WORK

This study indicates that the root zone soil moisture-temperature feedback is important during the summer in northern and central Utah as well as southern and western Colorado, but this may be more evident because climatologically, soil dryness is expected to reach certain thresholds, allowing this feedback to come into play. Areas where correlations were lower could still come into play in years of extreme drought. It is possible that this feedback is still important in other areas in cases of extreme drought onset, but the signal is buried under years of data where extreme drought onset does not occur. More investigation is needed in cases of extreme drought across the region, such as 2002 and 2012 using atmospheric reanalysis data coupled with land surface models.

ACKNOWLEDGEMENTS

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U.S. Highway 34 and the 1976 Big Thompson Flood

A Road to Unnatural Disaster?

Will Wright, MA Student, History, Colorado State University
Advisor: **Mark Fiege,** History, Colorado State University

Synopsis

History student Will Wright examined the history of several natural disasters, with the case study provided here of the construction of mountain highways in Colorado. Many of the techniques employed by engineers and workers to create the Big Thompson Canyon road made the canyon much more accessible to tourism and traffic, but arguably, these methods also reduced the health of the river, contributing to the magnitude of flooding events. Wright argues that in some cases, the term "natural disasters" underrepresents human contributions to the state of natural systems.

INTRODUCTION

As we approach the 40th anniversary of the 1976 Big Thompson Flood, and in light of the recent 2013 northern Colorado floods, it is time for all of us to rethink the term "natural disaster." By viewing floods, wildfires, and other extreme events as such, we often conceal the very human decisions and actions that actually make these environmental catastrophes highly "unnatural." My M.A. thesis project, using insights from environmental history, tries to uncover the "unnaturalness" at work on the Big Thompson River Flood of 1976. In the selected portion below, 1930s highway engineers and road-building crews—despite worthy intentions—erected automobile infrastructure that ultimately increased human vulnerability during the 1976 deluge.

ENGINEERS AND ROAD-BUILDING IN THE BIG THOMPSON CANYON

In the early morning hours of November 6, 1936, highway-construction laborer Earl Gainsforth wielded a jackhammer to drill into the solid rock of the Big Thompson Canyon. Gainsforth's duty, along with his fellow comrades, was to grade a smooth path into the daunting Colorado mountainscape for a future asphalt expressway. Once finished, the paved road would extend from the low-lying town of Loveland to the high-country retreats of Estes Park and Rocky Mountain National Park. At 7:10 a.m., Gainsforth directed his pulverizing jackhammer, driven by a diesel-powered air compressor, toward an area that, unbeknownst to him, contained "a charge of dynamite which had evidently failed to discharge in [a] previous blast." When his mechanical tool struck the envelope of nitroglycerin, it exploded, projecting enormous amounts of rubble onto the ground and into the Big Thompson River. When the dust and debris settled, Gainsforth suffered terribly. A supervisor observed, "The shot hit him in the face and destroyed one eye and injured the other eye. He was also hurt in one ankle."

The construction incident reveals the enormous measures engineers and road-building crews undertook to erect a modern highway for auto tourism. Highway planners conceived of this New Deal project both to employ downtrodden Americans during the Great Depression and, once completed, to encourage sightseeing with the convenience of accessible motorist travel. In modifying rock, gravel, and dirt, road-building crews not only erected a substantial thoroughfare between the canyon walls, but they also altered the form and function of the canyon stream in significant ways. By doing so, the human-built infrastructure within the gorge amplified the hydraulic force of the Big Thompson River and its potential for destructive flooding.

In the midst of the Great Depression of the 1930s, the U.S. government looked for ways to put Americans like Gainsforth back to work. In 1933 when recently-elected President Franklin D. Roosevelt stepped into office, one-quarter of the entire American workforce, some thirteen million laborers, were jobless. Roosevelt, in concert with U.S. Congress, sought to provide assistance to struggling citizens through a series of federal programs called the New Deal. This legislation partly comprised massive bureaucratic schemes—like big dams and extensive road systems—meant to rearrange the natural world in order to restore the capitalistic ethos. While providing economic assistance in the short term, and expanding state power in the long term, public works projects of the New Deal embodied an overall rehabilitation of American industrial society.

As part of the New Deal, Congress passed the National Industrial Recovery Act (NIRA) on June 16, 1933. NIRA included provisions that apportioned "not less than four-hundred million dollars, to be expended" toward the "[c]onstruction, repair, and improvement of public highways and park ways." The law allotted federal monies to work in conjunction with the Federal-Aid Highway Act of 1921, which stipulated that the national legislature would match state governments, through gasoline and vehicle taxes, at a fifty-fifty percent rate for highway construction. With this new act, the viability of engineering new highways during the Great Depression materialized for numerous states.

Within Colorado, state highway engineer Charles "Chas." D. Vail wanted to put federal dollars to work for road building. Governor William H. Adams found Vail, a graduate of the University of Illinois and long-time railroad civil engineer, well-suited for the job and appointed him to the position in November 1930. Vail, an ambitious and hard-headed director, would be later characterized by an associate as "blunt, undiplomatic, tough as leather, never dodged a fight or an issue." He was also a classic technocrat who believed that technical expertise and the rational application of engineering could overcome any natural obstacle. Vail used his domineering personality to his advantage and convinced the Colorado state legislature to raise matching funds for the construction of new highways. By the time Vail would be finished, he grabbed a considerable share of federal dollars through NIRA—$6,874,530 to be exact—for Colorado to be matched, adding up to nearly $14 million for road construction.

Using these newly-acquired funds, Vail and the Colorado State Highway Department developed a highway plan to construct six major expressways leading into the Rocky Mountains. It included one proposal to revamp a dilapidated, gravel road within the Big Thompson Canyon. Back in the early 1900s, local business interests financed the construction of a single-lane motorway from Loveland to Estes Park. State officials upgraded the road in the following decades—mainly by widening and reinforcing—to expedite travel to the newly-established nature reserve, founded in 1915, called Rocky Mountain National Park. Yet traveling along the route still took considerable time as motorists navigated difficult geophysical features. Piloting bumpy roads, steering through hairpin corners, and honking automobile horns at sharp curves to prevent oncoming vehicular accidents made the passage uneasy for drivers and passengers alike. A new motorway, the state engineers argued, would transform the canyon landscape and serve as the main link for recreationalists to the national park from the Colorado plains and beyond.

The Colorado State Highway Department commenced "Federal Aid Project No. 9-R" in the early 1930s by announcing the invitation for construction bids from private contracting firms. Vail and other state engineers would oversee the project as hired companies built the newly-integrated portion of U.S. Highway 34 in smaller sections, usually in one- to three-mile segments, from Loveland to Estes Park. After weighing the submitted options, Vail chose five construction businesses to complete respective sections of highway into the canyon: Hamilton & Gleason, Sacra & Watts, Lowdermilk Brothers, and Gordon Construction, all from Denver, as well as W.A. Colt & Sons of Lyons, Colorado. The preliminary estimated costs to craft the modern highway within the mountain gorge was a sizeable $700,000.

Before these construction firms could complete any serious work, state highway engineers surveyed the proposed route and acquired rights of way. Vail and his assistants, while conforming to some topographical features, nonetheless chose the straightest possible lines within the canyon—eliminating sharp curves and difficult grades—to aid future motorists' speed and comfort. Their motivations likely matched those of a 1934 civil engineering textbook: "The economist demands the straightest road that can possibly be secured…." These technocrats largely disregarded, though, where the road transected homes and river, imposing modifications to both human property and stream hydrology. In regard to the first category, the biggest challenge for the Colorado State Highway Department lay in obtaining parcels owned by private citizens—mostly a scattered collection of plots inhabited by motels, cabins, and vacation houses. For example, Walter Lawson, a permanent resident of Drake, became upset when he discovered that highway plans would destroy a ditch he built to irrigate a small acreage of pastureland for his cows. When Lawson wrote a letter to Vail about his concern, the unsympathetic highway engineer bluntly responded, "We are not interested in the cattle industry of the State; we are interested in building highways. That is our one and only business."

Once highway engineers surveyed the area and secured easements, the next task involved "Clearing and Grubbing" the upcoming transportation corridor to prepare it for grading. Sweat dripped down the brows of construction workers as they removed all debris that would inhibit a smooth motorway, getting rid of old fences and taking away large boulders that stood within the right-of-way. As crews labored, they also cleared away "Scattered Pine, Cedar, and Cottonwood Trees and Small Brush" alongside the

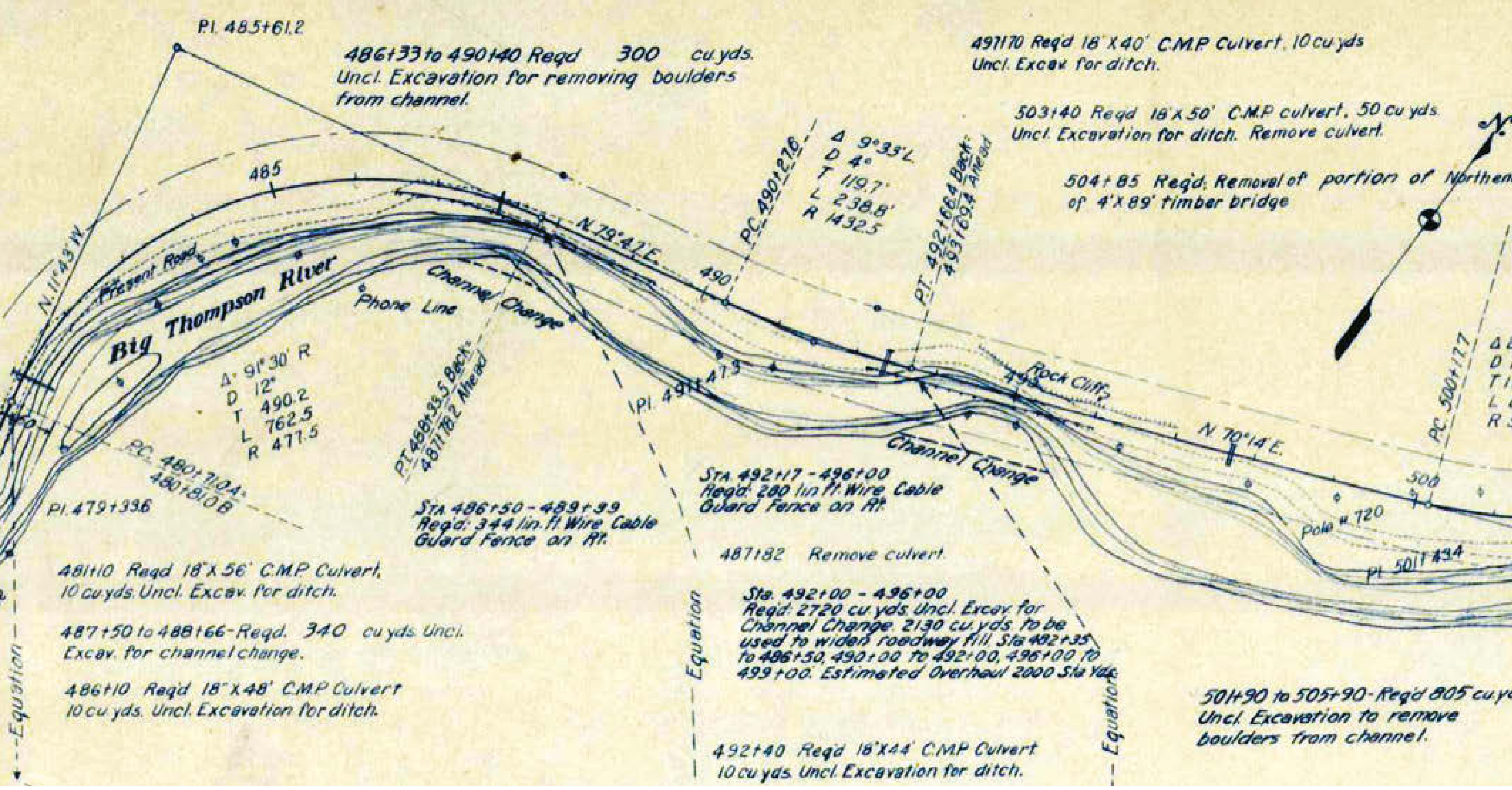

Figure 1. *1930s construction plans for U.S. Highway 34 between Estes Park and Drake. Note the "channel change" to Big Thompson River, twice. Courtesy of Colorado Department of Transportation*

Big Thompson River. The indiscriminate removal of streamside vegetation, however, resulted in several detrimental features for this canyon watercourse: first, the elimination of riverfront plants contributes to increased stream flows because less water is absorbed by foliage; second, riparian flora serve as a buffer zone to check flood height and velocity, decelerating river currents; and third, streamside vegetation anchors the soils, providing channel stability and preventing erosion. Clearing and grubbing, overall, meant positive steps toward the future highway at the expense of the future river.

After the natural obstructions were removed, the construction companies transitioned to the next task of grading the landscape to provide a solid foundation for the paved highway. The initial phase involved "Drilling and Shooting," or blasting away at the rock and leveling impeding geophysical features. Laborers drilled holes into key intervals on the mountainside and placed dynamite in these tunneled spaces. When workers ignited the nitroglycerin charges, debris flew everywhere with little control. Some jetted toward the ground. Some soared into vacationers' housing. Some smashed into workers' bodies, like what happened to Gainsforth. Some cascaded down into the Big Thompson River. D.S. Moore, a resident engineer on the project, reported: "During the necessary shooting, some of the material has dropped over the shoulder and into the river. …I have had the contractor clean up the channel [but] …it is very difficult to get the shovel into the river." Although Moore maintained that "the flow of water will not be in any way impaired by this condition," the highway engineer ignored the fact that construction rubble next to the river, especially when accumulated, concentrated stream flow.

In the secondary "Excavation" phase, construction teams with mechanized bulldozers, shovelers, rollers, and dump trucks moved into the thoroughfare to create a level, firm substructure surface before paving. Unloading gravel and moving dirt with the petroleum-fueled machinery, workers built large "embankments" to shield the road from the river and enlarged a route two to three times wider than the original path. While the road design facilitated more lanes for more vehicles, the groundwork altered the form of the river by constricting it in numerous sections. In several cases, the topographical realties within the canyon forced engineers to make "channel changes" to the Big Thompson River. What technocrats like Vail and regional engineer A.B. Collins labeled as "channel improvements" often entailed straightening out the natural bends in the stream. Instead of the twisting and turning meant to slow river currents, construction workers aligned the river course in some twenty-seven junctures throughout the canyon (Figure 1). By modifying river form—constricting and straightening—highway engineers thus altered river function, increasing its hydraulic power and velocity.

The nearer construction crews inched toward completion, the more frantically they labored to meet engineers' deadlines: installing culverts, pouring concrete, reinforcing with steel rods, erecting eleven bridges, and steamrolling the ground. All these steps were meant to prepare the firm roadbed for the final stage—"oil surfacing." Highway workers

Figure 2. *The 1938 dedication ceremony for the Big Thompson Canyon highway. Note Governor Teller Ammons (second from right with key) and engineer Charles Vail (far right). Fort Collins Express-Courier, 29 May 1938. Courtesy of Fort Collins Museum of Discovery*

operated large, gasoline-fueled trucks to apply a sticky "oil" substance, manufactured as a byproduct during fuel refining, known as asphalt. When construction workers sprayed the petroleum derivative onto the road surface, it mixed with dirt and gravel, hardening over hours. Oil surfacing delivered a more durable highway for motorist travel, but it also provided a more impermeable surface to water infiltration. Instead of rainfall penetrating down into the soil, water now collected on the pavement, contributing to overland flow and strengthening the movement of the Big Thompson River. In sum, asphalt paving, while facilitating convenient and dust-free auto tourism, expedited fluvial accumulation and speed.

After nearly seven years, from 1932 to 1938, road builders finished the modern Big Thompson Canyon route. Despite the fact that Vail and the Colorado State Highway Department overshot their initial budget by a million for a final cost of $1.8 million, local Coloradoans celebrated this engineering accomplishment. On May 28, 1938, Governor Teller Ammons led a formal dedication ceremony for U.S. Highway 34 at the mouth of the canyon near Loveland (Figure 2). Ammons offered an opening address, "applied a three-foot key to an equally oversized padlock" to "unlock" the route, and ordered an eighteen-gun salute by the National Guard. The next day, around 20,000 people gathered in Estes Park for a parade and opening festivities. Within the string of floats that passed by, Rocky Mountain National Park provided one that depicted the evolution of the tourist, praising the benefits of new automotive travel for the park.

Figure 3. *U.S. Highway 34 and the Big Thompson River in the aftermath of the 1976 flood. Note the eroded road where the structure had constricted the canyon watercourse. Courtesy of Maurice L. Albertson Papers, Water Resources Archive, Colorado State University Libraries*

CONCLUSION

In hindsight, the canyon bottom—occupied by both highway and stream—offered mixed results. In a positive sense, it became more accessible, more convenient, and more "legible" to travelers. However, in a negative regard, it also became more simplified, more channelized, and more vulnerable to a catastrophic flood (Figure 3). Instead of building a road that would complement the topographical and natural realities within the Big Thompson Canyon, highway engineers believed in a malleable nature that would conform to human-built infrastructure. In large part, the hydrocarbon energy derived from petroleum—providing the mechanical power for dump trucks, bulldozers, and jackhammers—allowed engineers to do so. These technocrats constructed an automobile highway that they thought would both provide smooth transportation for tourists and withstand the forces of nature. When July 31, 1976 came and the Big Thompson River roared, they would be right on one count.

For references and citations, including the author's notes, please contact the editor at cwi@colostate.edu.

Kelly Jones will be working on a project analyzing costs of fire mitigation techniques, which can include prescribed burns. Courtesy of USFWS

Profile: Kelly Jones

by *Lindsey Middleton,* Editor, Colorado Water Institute

Kelly Jones was hired as a Colorado State University (CSU) faculty member in 2014. She joined the Human Dimensions of Natural Resources (HDNR) department as an assistant professor of ecological economics. Before coming to CSU, Jones was an assistant professor at the University of Idaho. Her teaching and research focus on topics like payments for ecosystem services and drivers of land cover change.

Jones earned a B.S. in Biology from Meredith College in North Carolina, an M.S. in Forestry and Environmental Resources from North Carolina State University, an M.A. in Agricultural and Applied Economics from the University of Wisconsin-Madison, and a Ph.D. in Forest and Wildlife Ecology from the University of Wisconsin-Madison. She participated in the Master's International Program at North Carolina State University and spent two years working for the Peace Corps in Togo, West Africa, on natural resources management projects. Working in Togo, says Jones, she became interested in tradeoffs between conservation management and rural livelihoods.

Jones has focused a large portion of her research work, both as a student and as faculty, on international topics, which was part of the draw for Jones to move to CSU. "CSU has a reputation for both international and U.S. research, and I'm interested in both," she says.

Jones is working on projects in the Pacific Northwest, Mexico, Ecuador, and three countries in Mesoamerica. She hopes to begin local projects in Colorado and recently received funding for an interdisciplinary project that would look into the economic benefit to water utilities of investing in upstream wildfire mitigation. The research team, made up of three departments—Ecosystem Sciences and Sustainability, Forest and Rangeland Stewardship, and HDNR, will look into whether fire mitigation treatments reduce the costs that utilities pay to provide clean water after fires, when water quality is impaired. The study will first have to determine the effectiveness of fire mitigation treatments, then evaluate the costs avoided by utilities that pay for mitigation rather than taking on after-fire costs.

Another current project is taking place in Veracruz, Mexico. The project, part of the National Science Foundation's Dynamics of Coupled Natural and Human Systems program, includes a "truly diverse team," says Jones—hydrologists, civil engineers, soil scientists, rural sociologists, and economists are working within two watersheds to evaluate the environmental, social, and economic outcomes from payments for ecosystem services programs and tradeoffs across these outcomes. The team has deployed water monitoring and soil monitoring devices and begun conducting interviews with both participants and non-participants in the area, and they will be conducting household surveys next year. Jones says that while there are a lot of payments for ecosystem services programs, they are not often evaluated, and many programs are drawing criticism as a result. Are payments for ecosystem services effective? Jones and the project team hope to have feedback to offer to the local government as well as insights for the scientific community on the subject.

Jones is currently teaching both graduate and undergraduate level courses at CSU in Ecosystem Services and Human Wellbeing. In the fall of 2015, she plans to teach a graduate course on Evidence-Based Conservation, highlighting the need for more rigorous evaluative approaches to conservation management. Jones is also working on developing a one-credit seminar with departments from five other universities to introduce students to the topic of payments for ecosystem services.

Jones is still working with four graduate students from her previous post at the University of Idaho, including one student who is evaluating what factors influence voluntary participation in instream flow programs in Oregon. Jones is also taking on one CSU graduate student, who will be working on the Veracruz project.

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Water Research Awards

Colorado State University (January 16, 2015 to March 15, 2015)

Arabi, Mazdak, Civil & Environmental Engineering, North Carolina State University, Analysis of Conservation Practice Effectiveness and Producer Adoption Behavior in Lake Jordan Watershed, NC, $15,000

Arabi, Mazdak, Civil & Environmental Engineering, Texas A & M, Application of the SWAT Model to Determine the Environmental Sustainability of Feedstock Product of Biofuels In Hawaii, $20,000

Barbarick, Kenneth A, Soil & Crop Sciences, City of Littleton, Land Application of Sewage Biosolids - 2015, $109,594

Bestgen, Kevin R, Fish, Wildlife & Conservation Biology, DOI-Bureau of Reclamation, Evaluating Effects of Non-Native Predator Removal on Native Fish in the Yampa River, Colorado, $90,105

Bestgen, Kevin R, Fish, Wildlife & Conservation Biology, DOI-Bureau of Reclamation, Identification and Curation of Larval and Juvenile Fish by Colorado State University Larval Fish Laboratory, $240,119

Bestgen, Kevin R, Fish, Wildlife & Conservation Biology, DOI-Bureau of Reclamation, Monitoring Effects of Flaming Gorge Dam Releases on the Lodore/Whirlpool Fish Community, $67,320

Bledsoe, Brian, Civil & Environmental Engineering, DOI-NPS, Answering Ecological Management Questions for Aquatic Resources in National Parks Using GIS and Remote Sensing Tools, $93,837

Caldwell, Elizabeth D, CEMML, DOD-ARMY-Corps of Engineers, Safe Drinking Water Compliance Study US Army Garrison, Hawaii, $63,000

Doesken, Nolan J, Atmospheric Science, YLACES, CoCoRaHS and Rural Schools in Eastern Colorado: Students Engaged in Citizen Science and Research, $10,000

Gruby, Rebecca L, Human Dimensions of Natural Resources, Oak Foundation, Human Dimensions of Large Marine Protected Areas, $449,953

Holfelder, Kirstin Anne, Colorado Natural Heritage Program, DOI-Bureau of Reclamation, BOR Endangered Fishes Database, $123,492

Kampf, Stephanie K, Ecosystem Science & Sustainability, NSF-GEO, Threshold Hydrologic Change across the Intermittent-Persistent Snow Transition, $85,981

Lemly, Joanna, Colorado Natural Heritage Program, EPA, Lower Arkansas River Basin Probabilistic Wetland Condition Assessment, $102,909

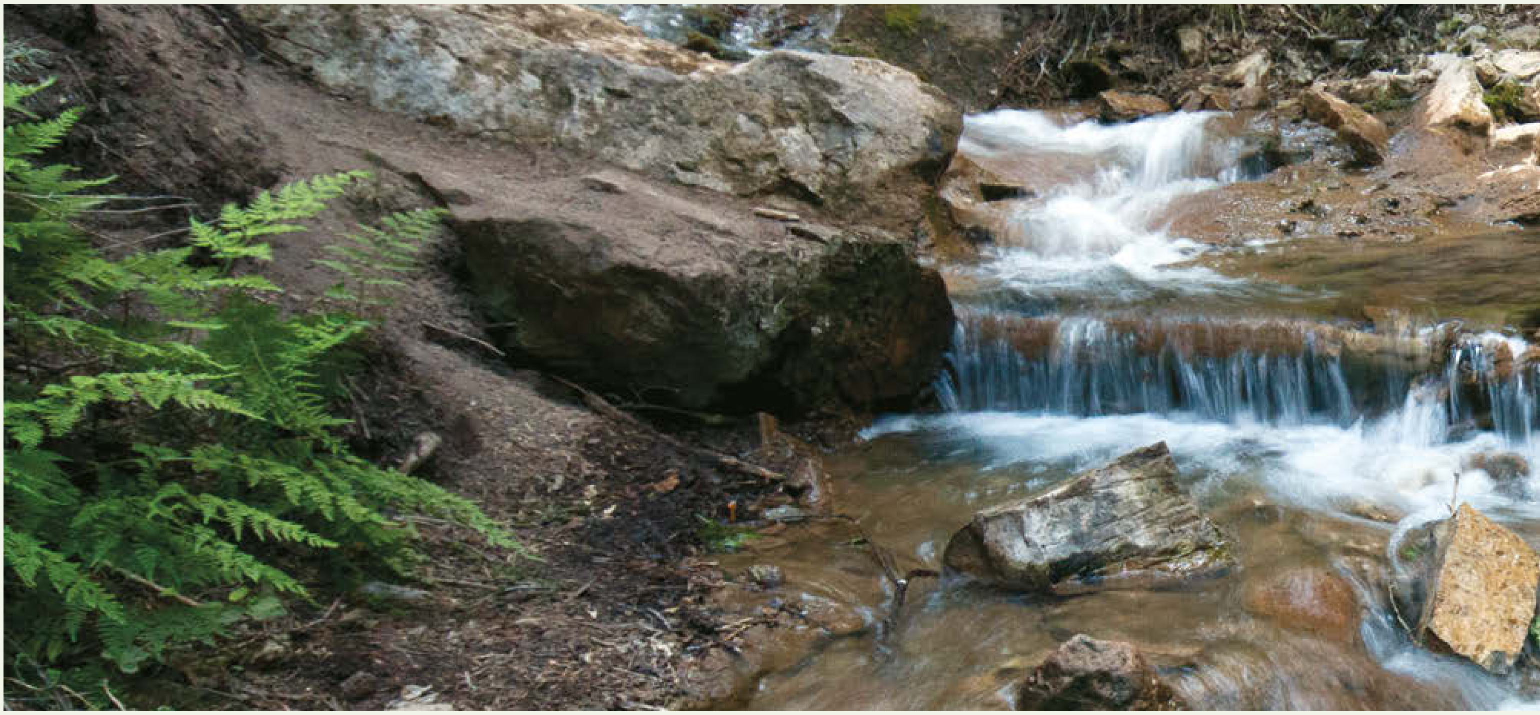
Wardle, Erik M, Soil & Crop Sciences, Western Sugar Cooperative, Refining an Online Irrigation Scheduling Tool for Use in Sugarbeet Production in Northern Colorado and Other Western Sugar Cooperative States, $8,720

Waskom, Reagan M, Colorado Water Institute, DOI-USGS, ICIWaRM Research Workshops and Advisory Committee, $73,753

Waskom, Reagan M, Colorado Water Institute, DOI-USGS, USGS Sedimentary Transport Internship, $12,376

Winkelman, Dana, Cooperative Fish & Wildlife Research, Colorado Division of Parks & Wildlife, Stonecat Ecology in St Vrain Creek, $39,632

Chris Canipe



Student researchers Natalie Kramer Anderson and Adam Herdrich contributed in the last year to longer-term projects looking into the effects of instream woody debris.

Calendar

August

19-21 **Colorado Water Congress Summer Conference**
Vail, CO
This high-energy conference is packed with great topical content. It's a don't-miss event for those who wish to stay informed about water issues in Colorado while engaging in numerous professional development activities.
www.cowatercongress.org

September

10 **Colorado River District Annual Seminar**
Grand Junction, CO
Every Autumn, the Colorado River District hosts a seminar on current and sometimes historical Colorado River Basin issues.
www.coloradoriverdistrict.org/district-business/annual-seminar/

13-16 **2015 RMSAWWA/RMWEA Joint Annual Conference**
Loveland, CO
Joint annual conference of the Rocky Mountain Section of the American Water Works Association and the Rocky Mountain Water Enviornment Association.
http://bit.ly/1I9lVh2

13-16 **30th Annual WateReuse Symposium**
Seattle, WA
Water professionals attend to learn about the latest innovations in water reuse, to network with colleagues, and to find solutions to critical water supply issues.
www.watereuse.org/symposium

October

6-8 **2015 Sustaining Colorado Watersheds Conference**
In it for the Long Haul
Avon, CO
www.coloradowater.org/Conferences

27-28 **2015 Natural Gas Symposium**
Fort Collins, CO
The Energy Institute at Colorado State University is hosting the fifth annual Natural Gas Symposium at the Lory Student Center. The symposium is open to everyone.
www.naturalgas.colostate.edu/

28-29 **2015 Upper Colorado River Basin Water Forum**
Managing for Extremes
Grand Junction, CO
www.coloradomesa.edu/watercenter/UpperColoradoRiverBasinWaterForum.html

28-29 **26th Annual South Platte Forum**
Loveland, CO
Growing Forward in the South Platte Basin
www.southplatteforum.org/

November

4-6 **NWRA Annual Conference**
Denver, CO
www.nwra.org/upcoming-conferences-workshops.html

16-19 **AWRA 2015 Annual Water Resources Conference**
Denver, CO
www.awra.org/

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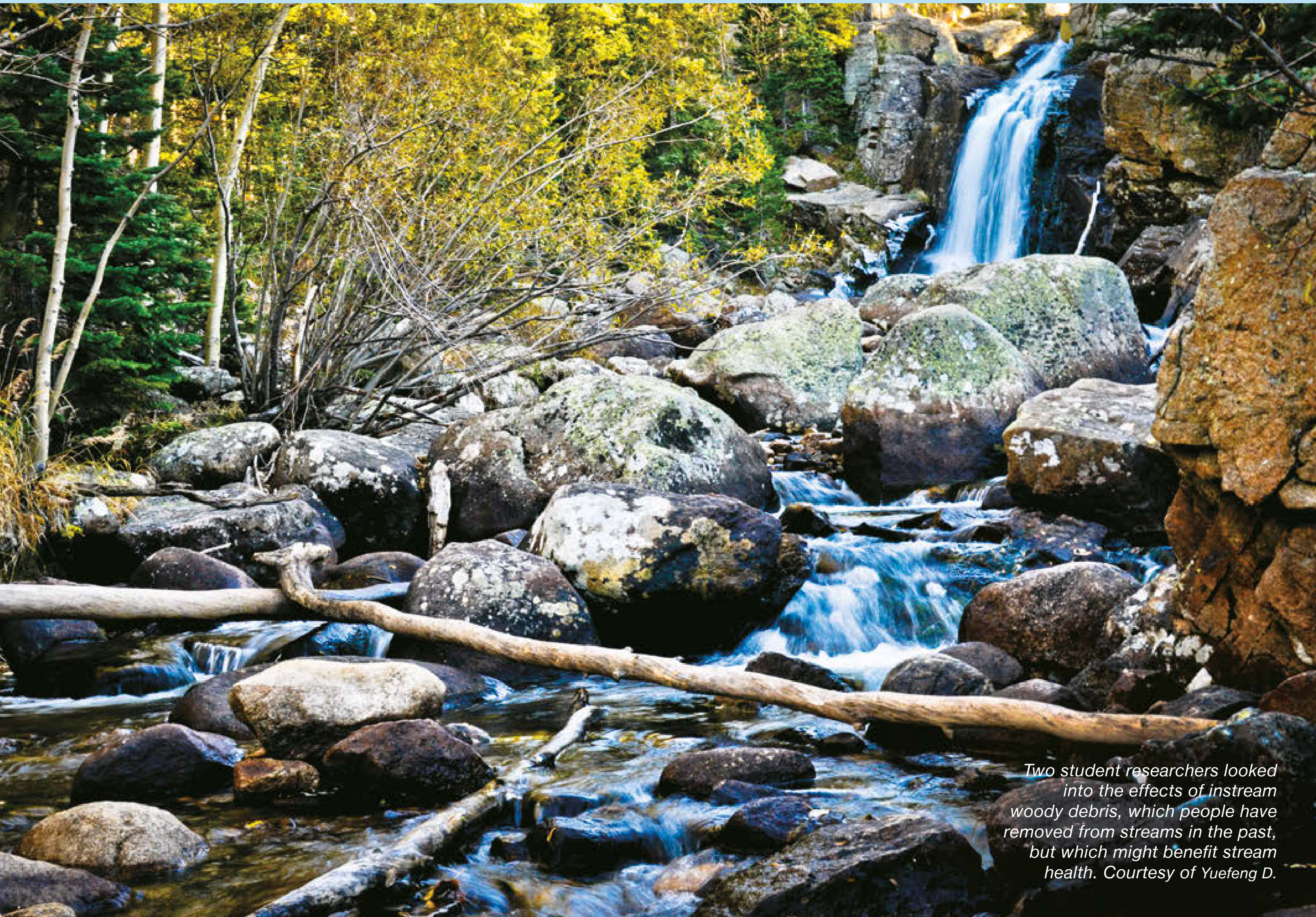

Two student researchers looked into the effects of instream woody debris, which people have removed from streams in the past, but which might benefit stream health. Courtesy of Yuefeng D.