Colorado Water Institute
Annual Technical Report
FY 2016

Introduction

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

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

Our charge this year included requests from the legislature and state and federal agencies. The Colorado Legislature continues to call upon the Colorado Water Institute to provide science-based approaches to water management. The Colorado Department of Public Health and Environment requested our assistance in engaging researchers and Extension in the public discussions of water quantity issues around the state. Water Roundtables in designated water basins elicited input from stakeholders with the goal in mind of creating an environment for water sharing arrangements in the state. In addition, CWI and the Colorado Department of Agriculture are co-chairing the State's agricultural drought impact task force.

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

Research Program Introduction

The Colorado Water Institute funded 8 student research projects, and 1 internship this fiscal year. The Advisory Committee on Water Research Policy selected these projects based on the relevancy of their proposed research to current issues in Colorado.

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

Active NIWR projects and investigators are listed below:

Student Research

1. 2016CO318B Investigating relationships between drought management strategies and factors contributing to their selection in analysis of adaptive capacity of South Platte River Basin water providers, Amber Childress Runyon (Ojima), Colorado State University, $4,948 (104b)
2. 2016CO319B Watershed monitoring across the snow transition zone: an east slope-west slope comparison, John Hammond (Kampf), Colorado State University, $4,770 (104b)
3. 2016CO320B Changes in water, sediment, and organic carbon storage in active and abandoned beaver meadows, DeAnna Laurel (Wohl), Colorado State University, $4912 (104b)
4. 2016CO322B Evaluating wood jam stability in rivers, Daniel Scott (Wohl), Colorado State University, $5,000 (104b)
5. 2016CO323B Channel restoration monitoring of the upper Colorado River, Rocky Mountain National Park, CO, Matthew Sparacino (Rathburn), Colorado State University, $5,000 (104b)
6. 2016CO324B Water sampling and the effects of plastic absorption on heavy metals, Haley Sir (Brazeau), Metropolitan State University of Denver, $3,200 (104b)
7. 2016CO325B Microbial community responses to metals contamination: mechanisms of metals exposure and bioaccumulation in a stream food web, Brian Wolff (Clements), Colorado State University, $5,000 (104b)
8. 2016CO326B Comparing fine scale snow depth measurements at rocky and flat surfaces using lidar and photogrammetry derived digital elevation models, Roy Gilbert (Fassnacht), $4,891 (104b)

FY16 Funded Internship

1. MOWS - Modeling of Watershed Systems NIWR-USGS Student Internship II, Roland Viger, USGS, $20,000, Melissa Valentin (Colorado School of Mines)
2. WEBB- Water, Energy, and Biogeochemical Budgets NIWR-USGS Student Internship Program, Edward Stets, USGS, $40,219, Hannah Podzorski (Colorado School of Mines)

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

Trace Organic Contaminants (TOrCs) in Urban Stormwater and Performance of Urban Bioretention Systems: a Field and Modeling Study

Basic Information

Title:	Trace Organic Contaminants (TOrCs) in Urban Stormwater and Performance of Urban Bioretention Systems: a Field and Modeling Study
Project Number:	2015CO316G
USGS Grant Number:	
Start Date:	9/1/2015
End Date:	8/31/2018
Funding Source:	104G
Congressional District:	CO07
Research Category:	Water Quality
Focus Category:	Hydrology, Water Quality, Non Point Pollution
Descriptors:	None
Principal Investigators:	Christopher Paul Higgins, Edward T Furlong, Terri Hogue, John E. McCray

Publications

There are no publications.

NIWR Research Progress Report:
Trace Organic Contaminants (TOrCs) in Urban Stormwater and Performance of Urban Bioretention Systems: a Field and Monitoring Study

Project Participants: Christopher Higgins (PI, Colorado School of Mines), Aniela Burant (Post-Doctoral Researcher, Colorado School of Mines), Edward Furlong (Co-PI, U.S. Geological Survey), William R. Selbig (Co-PI, Wisconsin Water Science Center), Terri S. Hogue (Co-PI, Colorado School of Mines), John E. McCray (Co-PI, CSM), Kathryn Lowe (Colorado School of Mines).

Introduction

Previous research on chemical contaminants in stormwater has focused on the occurrence and fate of compounds regulated under the Clean Water Act (e.g., metals, polycyclic aromatic hydrocarbons, nutrients). More recently, new research has identified new types of organic chemical contaminants in stormwater, including: biocides, rubber additives, flame retardants, and perfluorinated compounds. Most research is still focused on identifying hydrophobic contaminants, not polar organic compounds. In addition, little research has attributed organic contaminants to land use. Determining sources and relative loads of organic contaminants in stormwater will help inform policymakers in determining total maximum daily loads for certain trace organic contaminants in stormwater, and help inform engineering decisions related to treatment of stormwater. This data will inform improvements to the EPA Sustain and WinSLAMM models, which are designed to predict loadings to receiving bodies of water.

Another research objective is focused on evaluating bioretention of trace organic contaminants. Much research has focused on evaluating removal rates of hydrophobic organic compounds such as polycyclic aromatic hydrocarbons, however there is comparatively less data on trace polar organic contaminants, such as pesticides. This project aims to evaluate influent and effluent concentrations of both hydrophobic and hydrophilic compounds. This data will help inform policymakers in determining of total maximum daily loads of certain trace organic contaminants in stormwater, and help inform engineering decisions related to treatment of stormwater. This data will inform improvements to the EPA Sustain and WinSLAMM models, which are designed to predict loadings to receiving bodies of water.

Research Objectives

1. Identify sources, levels, and occurrences of TOrCs in urban environments.
2. Evaluate the removal of both hydrophobic and hydrophilic TOrCs in bioretention systems.
3. Evaluate existing stormwater models for predicting loadings to receiving bodies of water

Hypotheses

H1: There will be strong relationships between specific classes of TOrCs in stormwater associated with specific land uses types [with exceptions].
H2: Bioretention systems will effectively remove hydrophobic TOrCs (>90% removal), but will be less effective for polar TOrCs.
H3: Load sampling will help identify data model gaps.

Study Area

Two field sites have been secured related to Objective 1 for evaluation in Year one. Both are located in Madison, Wisconsin. One field site is considered a high-density residential site and the other one is a commercial strip mall site. Both have large percentages of impervious surface, and will produce significant volumes of runoff.

Methods

Samples are being collected with an ISCO auto-sampler, and flow-weight composited, which will allow for event mean concentrations of TOrCs in the stormwater to be obtained. The samples are filtered to remove particulate matter. Mass-labelled surrogates are spiked in and the organic compounds from the dissolved phase are extracted via solid phase extraction, using Oasis HLB cartridges, and the TOrCs are eluted from the cartridges using methanol. The extracts are evaporated to 0.5 mL, and reconstituted to 2 mLs using methanol. The extracts are then analyzed by using liquidchromatography coupled with tandem mass-spectrometry in both positive and negative electrospray ionization mode. Targeted TOrCs include: a variety of different pesticides and transformation products, flame retardants, and corrosion inhibitors. The extracts will also be analyzed by liquidchromatography coupled with quadrupole time-of-flight for suspect screening of organic contaminants.

Other samples are collected and are sent to the USGS' National Water Quality Lab. The method to be used targets wastewater indicator compounds, which are extracted by liquid-liquid extraction using dichloromethane. These samples are then analyzed by gas-chromatography coupled with mass spectrometry.

Preliminary Results and Achievements in the First Year

This project has been recently funded. A literature review of trace organic contaminants in stormwater is being conducted. A detailed work plan with identification of critical parameters and methodologies needed for assessment has been developed. Sampling for storm events on the high density residential site has started. Water samples from three storms, and a dry-weather flow have been collected, and processed. Samples for the first event have been analyzed, and 22 of the 26 trace organic contaminants in the LC method had detectable limits of the TOrCs. Sampling and analysis is still on-going. It is expected that sampling for the commercial strip area will begin in mid-May. Due to the early nature of the project, there are not any notable awards or achievements, journal papers, or conference presentations to report (to date – please note a planned conference presentation for this coming summer). The direct and regular communication with U.S. Geological Survey (both Selbig and Furlong) has already yielded significant benefits to both parties with respect to information transfer. At present, no graduate students have been supported on the project, but we anticipate this to change within the coming year. In addition, we are seeking opportunities to provide student training through student internship programs.

Future Conference Presentations

A poster presentation is scheduled for the end of June at the Gordon Research Conference on Environmental Science: Water, titled “Correlating organic contaminants in stormwater with land use.”

Investigating relationships between drought managment strategies and factors contributing to their selection in analysis of adaptive capacity of South Platte River Basin water providers

Basic Information

Title:	Investigating relationships between drought managment strategies and factors contributing to their selection in analysis of adaptive capacity of South Platte River Basin water providers
Project Number:	2016CO318B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	CO-004
Research Category:	Social Sciences
Focus Category:	Drought, Law, Institutions, and Policy, Management and Planning
Descriptors:	None
Principal Investigators:	Dennis Ojima, Amber Childress-Runyon

Publications

There are no publications.

Final Report for Project

Title: Investigating relationships between drought management strategies and factors contributing to their selection in analysis of adaptive capacity of South Platte River Basin water providers

Investigators: Amber Childress-Runyon, PhD Student, Ecosystem Science and Sustainability, Colorado State University

Advisors: Dr. Dennis Ojima, Ecosystem Science and Sustainability, Colorado State University, Senior Scientist, Natural Resource Ecology Laboratory

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Introduction

Droughts in the western U.S. are common and as any water user knows, the question is not if drought conditions will return, but when (Dai, 2013; Cook et al., 2015). Water management in Colorado has developed as a result of periods of water scarcity, based on lessons learned and refinements made to water policy and management strategies during and after droughts. Over time, these incremental adjustments have led to a more robust water system over time (Jones and Cech, 2009).

Water providers are organizations that often bear the responsibility of mitigating drought risk for water users, as they are the link between the environment and end users. Vulnerability created by droughts is mediated between actions taken by water providers. Most people in the U.S., particularly those residing within the western portions of the country, commonly receive their drinking water from these organizations, a percentage that is expected to grow in the coming decades (Hutson et al., 2004; Kenny et al., 2009; Engle, 2012).The primary objective is to distribute clean water to customers, which is achieved through a variety of strategies (e.g. maintaining large reserves, reservoirs, restrictions, education, pricing, etc.) that are made more difficult when conditions fluctuate far beyond normal. Engle (2012) notes that the increasing dependence of humans and ecosystems on water providers, combined with the potential impacts of climate variability and change, will make the delivery of high-quality water increasingly difficult in the future (Cromwell et al., 2007).

Climate change vulnerability reports (Statewide Water Supply Initiative, 2010; Western Water Assessment, 2011; Colorado Water Conservation Board, 2013, 2015; Gordon and Ojima, 2014) suggest that in water-scarce regions strategies historically used by water providers to manage water resources may become insufficient. This uncertainty about the future raises the need to understand how water providers have dealt with water stress in the past and to determine what strategies to utilize in the future as the environment continues to change.

Studies conducted by the State (Colorado Water Conservation Board, 2013) suggest that actions taken as a result of the 2002 drought increased the adaptive capacity of many water providers. However, because the results were aggregated by basin, the differences between providers' capacities and factors that contribute to increased adaptiveness – both important for developing actionable policy aimed at reducing vulnerability – were not investigated. Leaving the ability of these water providers to adapt to future environmental changes unknown. Therefore, the objective of this study was to evaluate the variance in the capacity of water providers in the South

Platte River Basin (SPRB) to meet their demand obligations, attributes, and institutions that affect their capacity to respond to droughts. This two part study evaluated the role that internal (organizational) and external (drought severity) factors play in affecting the capacity of water providers to meet water demands over time and strategies they use to mitigate drought effects. The first part is presented here, the second part builds off of this analysis to investigate institutional motivations or constraints for strategy selection and how that might impact capacity over time.

Methods

This study used an analogue approach, looking at past drought periods to understand what to expect in future droughts. Conveniently, there were two recent major droughts in the SPRB, in 2002 and 2012. The drought events were quite different temporally and in severity. The 2002 drought lasted longer than the 2012 drought, but the 2012 drought was more severe (Figure 1). Studying the impacts of both droughts from the perspective of water managers provides an opportunity to understand how incremental management and policy adjustments can evolve into long-term strategies on how to deal with water scarcity.

An event history calendar (EHC) was used to collect qualitative and quantitative data from managers in the SPRB. Engle (2013) proposed using EHC to gather temporal data on water management and adapted the tool which has commonly been used in anthropology to collect temporal data on individuals (Freedman et al., 1988; Axinn et al., 1999; Engle, 2012). This methodology uses a matrix of visual cues and an interactive interview process to make memory recall easier for participants. The EHC collects time-series data of water providers' management strategies and functioning through time (Figure 2).

The EHC collected two primary pieces of information from 2000-2015 including: 1.) strategies water provides used and variations in the strategies, and 2.) their relative capacity to meet water delivery requirements (referred to simply as capacity). Strategies listed in the EHC were chosen from a review of sources evaluating management in the basin and expert interviews (Kenney and Morrison, 2003; Kenney et al., 2004; Colorado Water Conservation Board, 2013). To measure capacity in the EHC, participants were asked to rank from 0 to 3 their ability to meet their water delivery requirements over the time period: where 3 represents no impairment, full ability; 2 indicating moderately impaired but still able to meet all commitments; 1 – seriously impaired with questionable ability to meet commitments, and 0 – unable to meet commitments.

Twenty-five water providers were interviewed for this study and were selected through stratified purposeful sampling. This type of sampling required dividing the 257 providers into five strata based on characteristics such as their primary water source, population, and sub-region. Senior-level water managers filled out the EHC, guided by the interviewer in a semi-structured interview. All management documents and web content for each provider were also reviewed and utilized to fill in gaps where managers were unsure of strategies used or exact timing. In addition, conservation plans were also helpful in the research analysis.

One of the many benefits of using the EHC was that it allowed for mixed methods research, requiring the collection of qualitative and quantitative data. This provided a more robust approach, resulting in an abundance of data used to analyze how providers managed their water systems, the functioning of their system over time, characteristics of their system, and motivations for changes (Engle, 2013). However, here only the variance in capacity among the water providers and an evaluation of internal characteristics that contributed to their 'adaptiveness' are presented. Future articles will contain further analysis.

Results

This study asked each water provider to provide a semiannual rank for their capacity to meet water delivery demands, which served as a proxy for their capacity to cope with conditions over time. Results from a Wilcoxon signed rank test indicated that capacity was reduced from normal levels during the 2002 drought, but not during the 2012 drought. In fact, capacity scores were higher in the second drought than the average of other non-drought periods, indicating that there was an increase in adaptive capacity. This was supported by interviews with water managers who said that lessons from the 2002 drought caused them to be more proactive during the 2012 drought, in addition to policy and structural changes made between the periods.

The severity of drought effects on water providers and the suite of drought-mitigation techniques available to them are largely determined by characteristics unique to each water provider (e.g. their source of water supply, seniority of rights, the type of community they serve, population growth rates, etc.). These internal factors shape both the motivation and ability to use management actions and their effectiveness. To evaluate how internal attributes contributed to capacity of water providers to meet their water demands over time and their choice of strategy, this study used hierarchical cluster analysis (HCA) to group the water providers based on organizational attributes. The Gower distance metric (Gower, 1971; Hennig and Liao, 2013) was used to calculate the dissimilarity between the water providers (which is appropriate for mixed-type datasets) and the providers were divided into four clusters.

Figure 3 illustrates the average number of strategies used by each of the clusters, which serves as a measure of their 'adaptiveness'. Groups 2 and 3 continued to adopt new strategies after the 2002 drought, while groups 1 and 4 saw an increase in the number of strategies used during the 2002 drought and adopted a small number of strategies in the subsequent years. However, their adoption of new strategies leveled off in the mid-2000s and did not increase again, even during the 2012 drought period. This indicates that Groups 2 and 3 are likely more adaptive and continually alter their water management strategies to be reflexive to changing conditions, while Groups 1 and 4 have more rigid responses.

Generalized estimating equations were included to evaluate strategies most likely used by different water providers during droughts of varying severity, as well as how capacity changed relative to provider groups and drought conditions. These results revealed that Groups 2 and 3 used a more diverse suite of supply-augmenting and demand-reduction strategies both during and between droughts. However Groups 1 and

4 primarily relied on supply increasing techniques between droughts and imposed mandatory restrictions during droughts.

Discussion

Looking to the past serves as a useful guide to understand how water systems will cope with future climate and population induced stresses. It is important to evaluate lessons learned and what enabled those lessons to transition into resilience. The increase of capacity for all water providers throughout the period of time presented in this study suggests that periodic droughts actually can increase the resilience of water managers, if they improve upon lessons learned. Because they were caught off guard and systems were impaired in 2002, water managers used the period after the drought to reorganize and develop new policies and/or update their systems. Then in 2012, when the signs of drought first appeared, water managers had established protocols in place. Some water providers were more adaptive to external pressures and continued to improve their management over time, while others were more rigid and only responded to abrupt changes, suggesting that the latter could be vulnerable to sudden or more severe droughts. While these results are only the first part of this study, they reveal that there is an association between internal and external factors and strategy choice and capacity. This analysis provides a better understanding of how water providers manage drought and their motivations for future adaptation. Further qualitative analysis will be conducted on this dataset to evaluate the role that institutions play as stimuli or barriers for adaptation and increasing adaptive capacity of water providers.

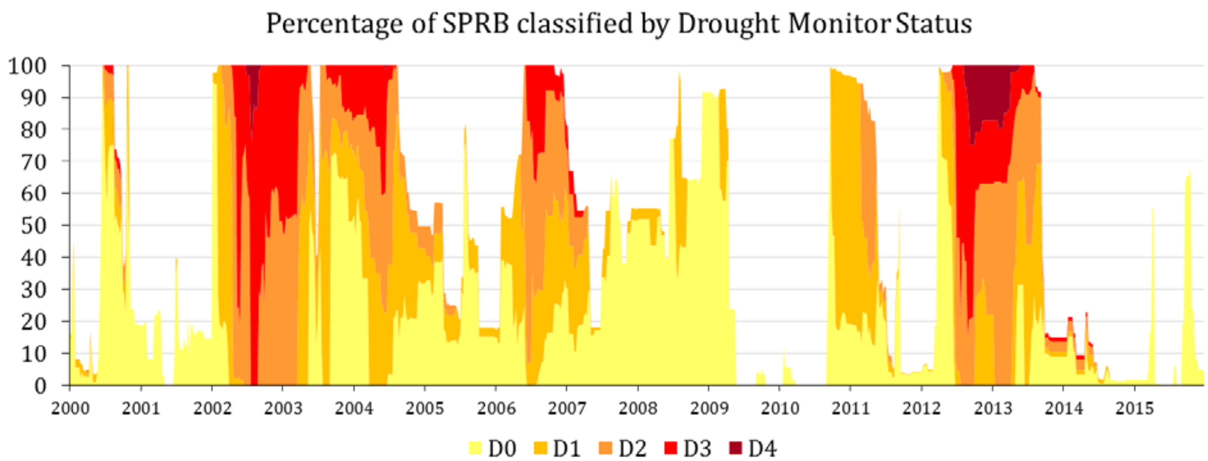

Figure 1. Drought Monitor status in the SPRB throughout the study period. http://droughtmonitor.unl.edu/

W = Winter (Oct - Mar) S = Summer (Apr - Sep)

		2000		2001		2002		2003		2004		2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015		
	Severe Drought	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W
P1	Drought Plan																																	
P2	Conservation Plan																																	
P3	Develop triggers for drought-related actions																																	
P4	Coordination between water and land-use planning efforts																																	
C1	Communicate - State																																	
C2	Communicate - Local																			P								P						C
C3	Formal education and public communication											P		W						R								R						O
R1	Declare a drought emergency											R		A						E								E						
R2	Establish water hauling programs											E	H	T						S								S						W
R3	Restrict / prohibit new taps											S	U	E						I			D					I	D					A
S1	Rehabilitate reservoirs to operate at design capacity											I	R	R						D			M					D	M					T
S2	Develop new storage facilities											D	R							E			R					E	R					E
S3	Use mechanism for storing conserved water											E	I	F						N			P					N	P					R
S4	Use of reservoir distribution techniques					S						N	C	O						T								T						
S5	Review water rights for modifications / flexibility during drought					E						T	A	R									2						2					P
S6	Dry year leasing of water rights from agriculture					P							N							O			0					O	0					L
S7	Water banks established for the sale, transfer, and exchange of water					T						B	E	2						B			1					B	1					A
S8	Interruptible water supply agreements											U		1						A			0					A	3					N
S9	Reuse					1						S		S						M								M						
S10	Wet year leasing of water rights to agriculture					1						H		T						A								A						
D1	Voluntary outdoor watering restrictions											R	K	C						E								R						
D2	Mandatory outdoor watering restrictions											E	A	E						L			U					E	U					F
D3	Enforcement of watering restrictions											-	T	N						E			P					-	P					I
D4	Implement, upgrade water metering and water loss control systems											E	R	T						C			D					E	D					N
D5	Water-efficient fixtures and appliances											L	I	U						T			A					L	A					A
D6	Low water use landscapes and efficient irrigation											E	N	R						E			T					E	T					L
D7	Rate structures to influence water use											C	A	Y						D			E					C	E					I
M1	Monitor water supply components (e.g. snow pack, stream flow, etc.)											T		A														T						Z
M2	Evaluate effectiveness post-drought and modify plans											E		C														E						E
M3	Track public perception and effectiveness of drought measures											D		T														D						D
A1	Water Delivery																																	

Management Information (P1–D6); Impacts (D7–M3)

Figure 2. Example of EHC study participants filled out with interviewer. For each time period represented in columns (semi-annual from 2000-2015), they indicated if each strategy was used, rows. They then characterized their 'capacity' to meet water delivery requirements by ranking their system from 1-3 throughout the time period.

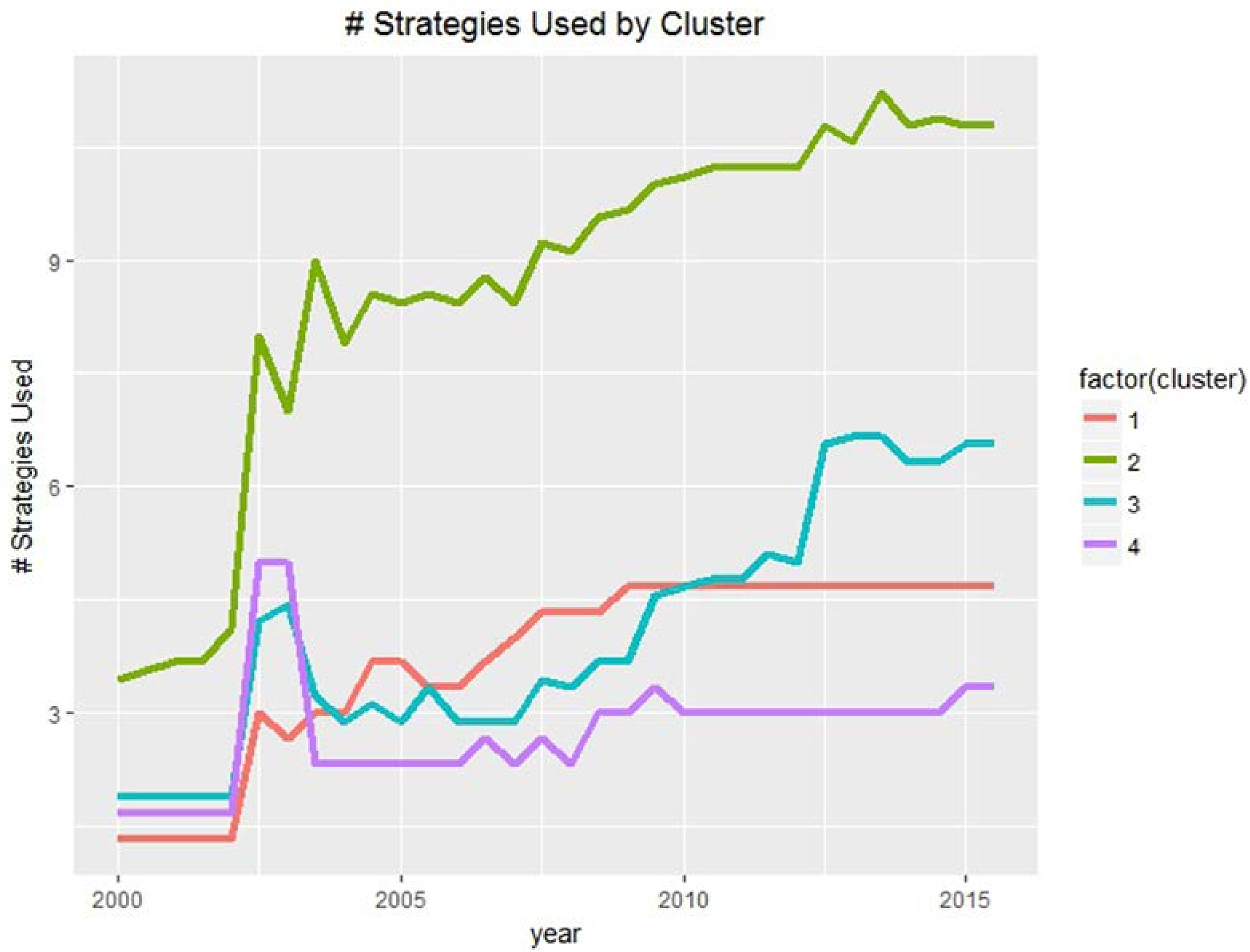

Figure 3. Number of strategies used by each provider cluster group. Groups that continued to adopt new strategies throughout the time period are more ‘adaptive’ while others are more reactive.

Watershed monitoring across the snow transition zone: an east slope-west slope comparison

Basic Information

Title:	Watershed monitoring across the snow transition zone: an east slope-west slope comparison
Project Number:	2016CO319B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	CO-003
Research Category:	Climate and Hydrologic Processes
Focus Category:	Water Quantity, Water Supply, Surface Water
Descriptors:	None
Principal Investigators:	Stephanie K Kampf, John Hammond

Publications

There are no publications.

Final Report for Project

Title: Watershed monitoring across the snow transition zone: an east slope-west slope comparison

Investigator(s): John Hammond, PhD Student, Watershed Science, Geosciences, Colorado State University; Craig Moore, BS Student, Environmental Science and Technology, Colorado Mesa University

Advisor(s): Dr. Stephanie Kampf, Ecosystem Science and Sustainability, Colorado State University; Dr. Gigi Richard, Geosciences, Director of the Water Center, Colorado Mesa University

Monitoring the Snow Transition

In mountainous regions, both snowpack trend analyses and modeling studies suggest that snowpacks are most sensitive to drought and temperature at lower elevation boundaries. In a cold region like Colorado, high elevations have persistent snow that lasts throughout the winter, whereas low elevations have intermittent snow that falls and melts several times over the winter season. Most watershed monitoring in Colorado does not include areas where the snowpack transitions between intermittent and persistent seasonal snow. Snow monitoring is concentrated at high elevations, and most streamflow monitoring is at low elevations. Expanded hydrologic monitoring that spans the gradient of snow conditions in Colorado can help improve streamflow prediction and inform land management in potentially sensitive areas near the intermittent-persistent snow transition.

This study (1) established hydrologic monitoring watersheds in intermittent, transitional, and persistent snow zones on the east and west slopes of the Rocky Mountains within Colorado, and (2) used this monitoring network to improve understanding of how snow accumulation and melt impact soil moisture and streamflow generation under different snow conditions.

The Monitoring Network

Six small watersheds (three west slope, three east slope) were monitored ranging in size from 0.8 to 3.9 square kilometers that drain intermittent, transitional, and persistent snow zones. Each of the six watersheds (Figure 1, Table 1) was equipped with the following instrumentation: one tipping bucket rain gage, three snow depth poles monitored by a time-lapse camera, one pressure transducer and/or capacitance rod to monitor stream stage, three soil moisture probes (5, 20, 50 cm) and one soil temperature probe (Figure 2). Snow depth and snow water equivalent was also measured during winter snow courses, and after the snow melted. Soil moisture along transects in each study watershed was also monitored using a handheld time-domain reflectometry (TDR) instrument.

Preliminary Findings

During the 2016 water year, the Front Range sites generally had deeper snowpack and longer snow duration than the Grand Mesa sites (Figure 3). Snow cover remained at the Front Range persistent site into June on the Front Range (Table 2), whereas much of the snow at the persistent site on the Grand Mesa had already melted by early June. Instrument failures at some of the Grand Mesa sites lead to some data loss, so here we focus on summarizing the 2016 water year at the Front Range sites.

Persistent Snow Zone

The Michigan River watershed retained snow from the onset of accumulation to the date of snow disappearance. As expected, peak snow depth and peak SWE were highest at this site (Table 2). While snow accumulated over a period of several months, snowmelt was considerably quicker (Figure 4). North-facing slopes and valley bottoms retained snow from the onset of snow in the fall to melt in the spring while south-facing slopes and ridgetops behaved more like areas in the intermittent snow zone where snow completely melted out several times throughout the fall, winter and spring months (Figure 5). Soil moisture values were elevated during and following snowmelt (Figure 4), displaying the greatest magnitude of volumetric water content (VWC) increase in response to snowmelt of all sites monitored. Snowmelt generated saturation excess overland flow in the late spring during the rise and peak of the hydrograph. The hydrograph of Michigan River is dominated by the spring snowmelt signal without substantial increases in discharge in response to summer rainfall. Peak discharge at this site lags peak SWE by 65 days, with snow completely disappearing three days following peak discharge.

Transitional Snow Zone

The Lazy D watershed, similar to Michigan River, retained snow from the onset of accumulation to the date of snow disappearance, though the total accumulation of snow depth and SWE was less than half that observed at the persistent site. Only 25 days elapsed between peak SWE and snow disappearance. Soil moisture response at this site was considerably muted as compared to the persistent site. Stream stage at Lazy D also exhibited a clear snowmelt signal (Figure 6), but with the additional input of spring rain during snowmelt. The hydrograph at this site was less flashy than at the persistent site, possibly because wetland areas adjacent to the stream dampened the hydrograph in contrast to the more confined channels in the persistent and intermittent watersheds.

Intermittent Snow Zone

At the Mill Creek watershed snow fully melted several times mid-winter (Figure 7). In the last snow event, which happened to have the greatest observed SWE value, only four days elapsed between this peak and snow disappearance. Unlike the persistent and transitional sites, the stream responses to snow accumulation and melt was similar in magnitude to the response to summer rainfall. The effects of slope-aspect at this site were most apparent, with snow completely disappearing on south-facing slopes within hours or days after falling. Soil moisture responded rapidly to rain and snowmelt. Mid-winter snowmelt events at Mill Creek were large enough to generate streamflow, and stream stage peaked when the antecedent soil moisture was already high from snowmelt and rainfall inputs. Summer rainfall after June 15 no longer generated runoff in Mill Creek because of lower soil moisture. This was the only Front Range site to completely stop flowing (Figure 8).

Lessons Learned and the Path Ahead

Thus far we have been able to make broad assessments on differences in hydrologic response between snow zones and the West and East slopes of the Southern Rocky Mountains, with detailed comparisons of the timing and magnitude of hydrologic response to come. Our first field season taught us several lessons about monitoring watersheds ranging from snowmelt dominated systems with deep snowpacks to intermittently flowing streams where simply observing rare flow events is difficult. In general we see more mid-winter melt on the Grand Mesa as well as shorter duration of snowpack. The persistent site in the Front Range accumulates more snow, does not get much mid-winter melt, and has little to no mid-winter infiltration. In comparison, the persistent site on the Grand Mesa does have some mid-winter infiltration with soil temperatures >0. This difference in soil water input likely has consequences for streamflow response that we will continue to examine in future years. In areas with intermittent snow, the subsurface geology appears to be an important control on whether or not streams flow. Intermittent sites have similar snow intermittence and soil moisture responses in both the Front Range and Grand Mesa. However, while materials underlying Mill Creek include weathered igneous and metamorphic parent material that allows deep infiltration through fractures that supply intermittent flow, shale on the slopes of the Grand Mesa must not be allowing enough deep infiltration and/or have the fracture network to deliver flow to streams.

Conclusion

Closing the flow prediction knowledge gap is critically important as Colorado faces growing population and potential loss of snow. Water management in the state must balance water for a wide range of uses, such as irrigation, recreation, industrial, municipal, and environmental flows. Management of these water uses requires understanding water supply availability and its sensitivity to future change. With our ongoing watershed monitoring across a broad range of snow conditions in Colorado, we continue to learn about the factors that increase or decrease streamflow in the headwater streams that supply the state’s major rivers. As the monitoring continues through future water years, these findings will aid future flow prediction for Colorado’s river basins.

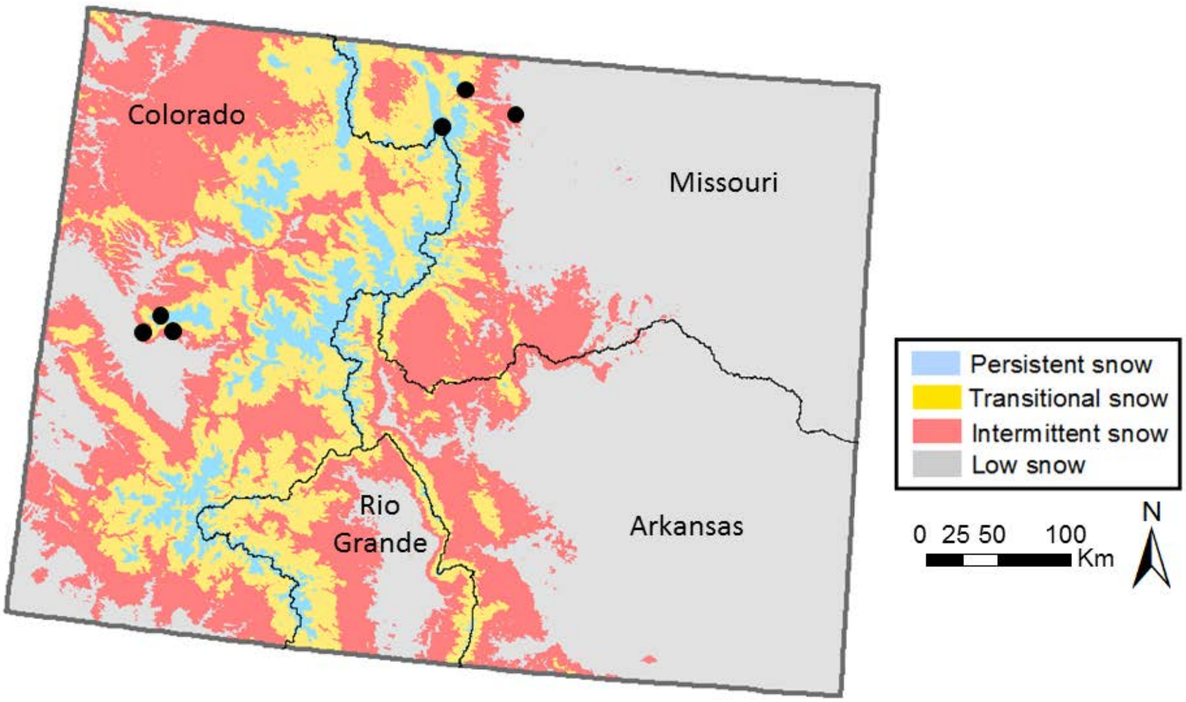

Figure 1. Study watersheds in the Front Range and Grand Mesa regions of Colorado displayed as black points on top of snow zones generated by Moore et al. (2015).

Table 1. Watershed name, snow zone, mean annual precipitation, and mean watershed elevation.

Watershed	Snow Zone	Region	Precipitation (mm)	Precipitation (in)	Mean Elevation (m)	Mean Elevation (ft)
Michigan River	Persistent	Front Range	1087	43	3437	11273
Lazy D	Transitional	Front Range	507	20	2702	8863
Mill Creek	Intermittent	Front Range	462	18	1947	6386
Ward Creek Trib 1	Persistent	Grand Mesa	1028	40	3019	9902
Ward Creek Trib 2	Transitional	Grand Mesa	877	35	2939	9640
Shirtail Creek Trib	Intermittent	Grand Mesa	415	16	2189	7180

Figure 2. Precipitation and soil moisture instrumentation at Mill Creek (left), water level instrumentation at Lazy D (center), and snow poles for time lapse camera measurements of snow depth at Mill Creek (right).

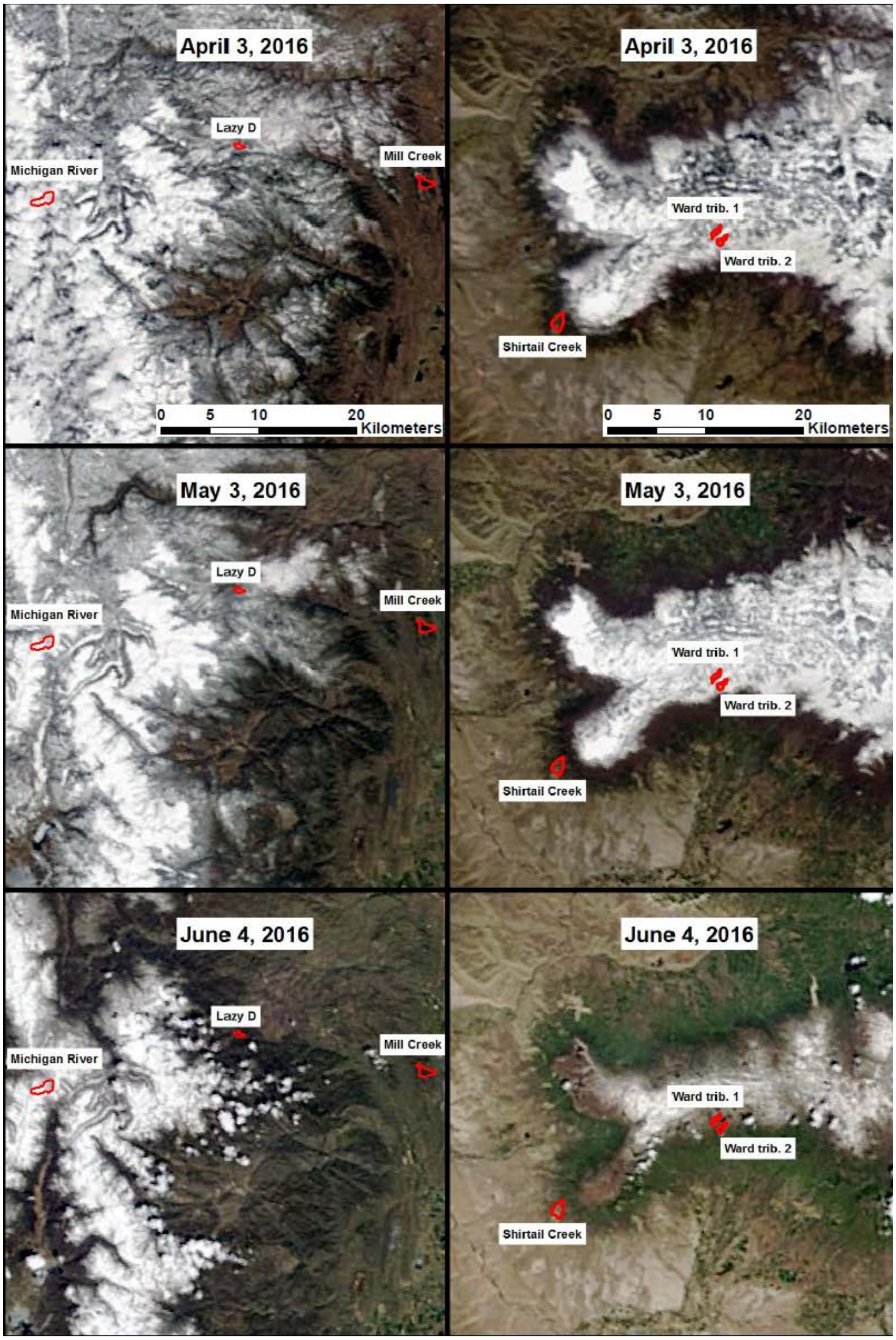

Figure 3. MODIS satellite imagery showing changes in snow at Front Range (left) and Grand Mesa (right) study watersheds from April to June 2016.

Table 2. Front Range watershed peak streamflow (Q), date of peak Q, peak snow depth (D), date of peak D, peak snow water equivalent (SWE), date of peak SWE, and date of snow disappearance.

Watershed	Q (l/s)	Date Q	D (cm)	Date D	SWE (cm)	Date SWE	Date no snow
Michigan R.	963	20-Jun	243	17-Apr	80	17-Apr	23-Jun
Lazy D	245	9-May	95	23-Mar	35	17-Apr	12-May
Mill Creek	463	3-May	43	2-Feb	6.5	24-Mar	28-Mar

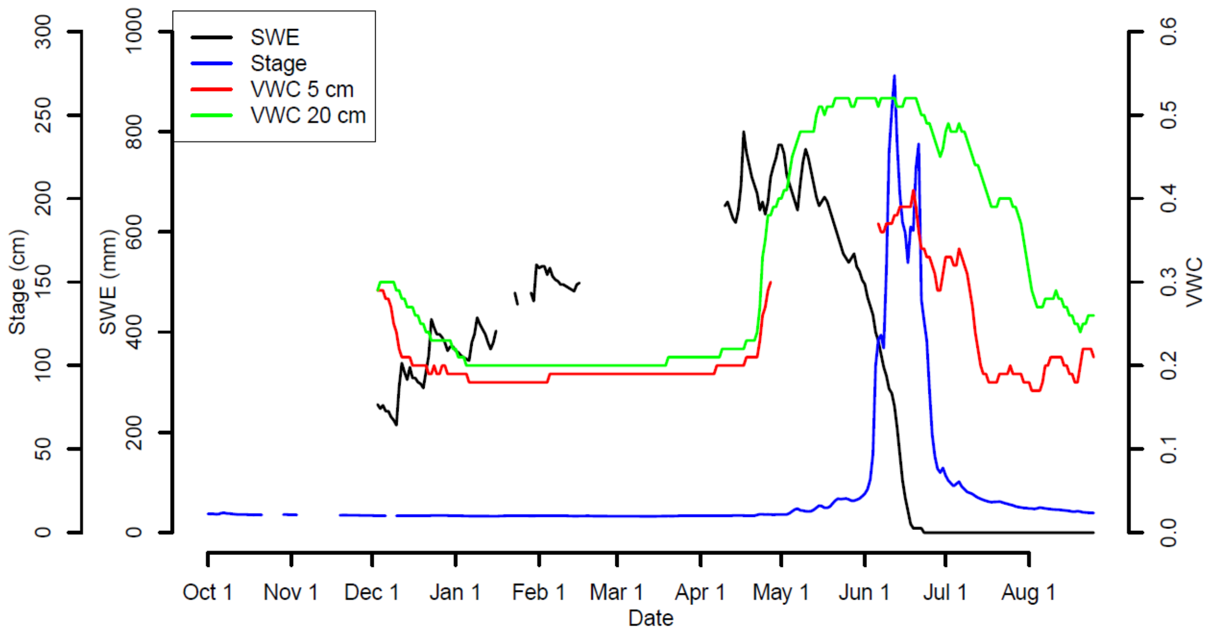

Figure 4. Snow water equivalent (SWE), stream stage, and soil volumetric water content (VWC) for the Michigan River watershed (Persistent).

Figure 5. Michigan River watershed (Persistent) near the outlet in May (left) and August (right).

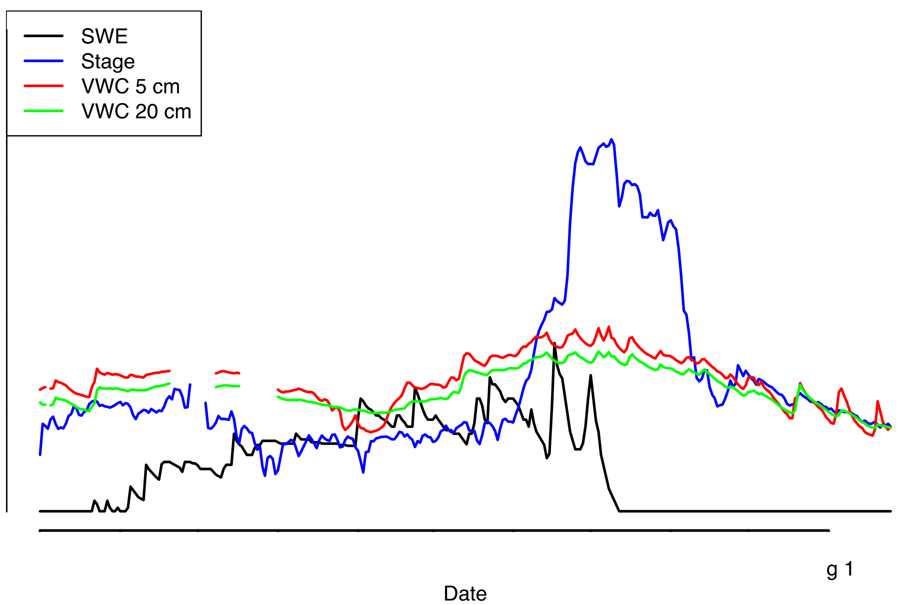

Figure 6. Snow water equivalent (SWE), stream stage, and soil volumetric water content (VWC) for the Lazy D watershed (Transitional).

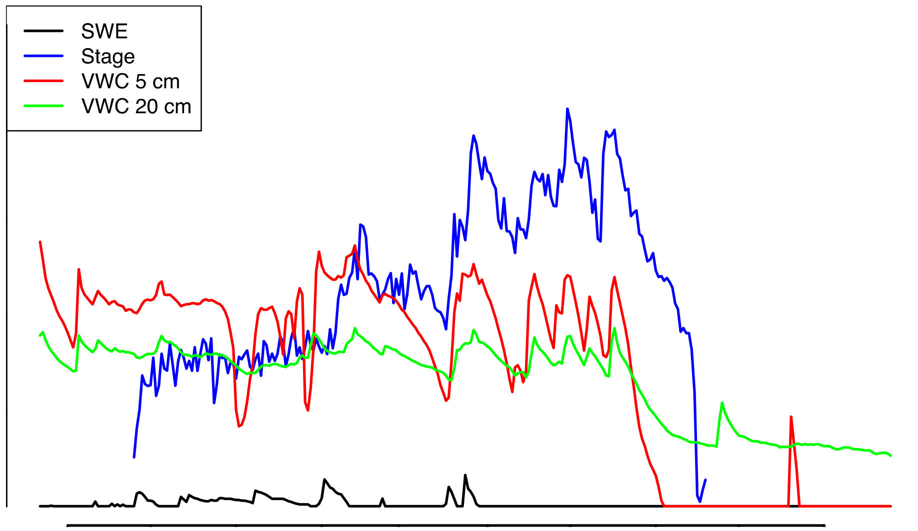

Figure 7. Snow water equivalent (SWE), stream stage, and soil volumetric water content (VWC) for the Mill Creek watershed.

Figure 8. Mill Creek watershed at the outlet in May (left) and August (right).

Changes in water, sediment and organic carbon storage in active and abandoned beaver meadows

Basic Information

Title:	Changes in water, sediment and organic carbon storage in active and abandoned beaver meadows
Project Number:	2016CO320B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	CO-002
Research Category:	Climate and Hydrologic Processes
Focus Category:	Geomorphological Processes, Groundwater, Surface Water
Descriptors:	None
Principal Investigators:	Ellen Wohl

Publications

There are no publications.

Final Report for Project

Title: Changes in Water, Sediment, and Organic Carbon Storage in Active and Abandoned Beaver Meadows

Investigator(s): DeAnna Laurel, PhD Candidate, Geosciences, Colorado State University

Advisor(s): Dr. Ellen Wohl, Geosciences, Colorado State University

Introduction

In the Colorado Mountains, stream reaches are mostly steep and narrow, confined by valley walls. The exceptions are isolated unconfined, lower gradient meadows that are like beads along the “string” of the river. Compared to the confined river segments, the unconfined meadows have relatively less efficient downstream transport and greater storage and attenuation of fluxes of water, sediment, and organic carbon. During high streamflow, water carrying sediment and particulate organic matter spills over the main channel banks into the floodplain. As streamflow decreases though the summer, the floodplain water is stored or drains back into the main channel. Beaver (*Castor canadensis*) favor the unconfined meadows where lower stream gradient results in slower velocity flows that they can dam and there is room for a large riparian corridor.

Prior to European settlement, beaver were present in North America in every suitable habitat from northern Canada to southern Mexico. Fur trapping subsequently almost eradicated beaver from their historic habitats. In the last few decades, beaver populations in Colorado have been recovering, although they still face challenges such as grazing competition with elk and conflicts with human infrastructure that have removed them from mountain stream meadows. Beaver manipulate their environments to suit their needs by building dams that alter channel and valley bottom morphology. Beaver dams encourage more streamflow to spill over onto the floodplain and into secondary stream channels resulting in complex, multi-thread wet valley meadows. In contrast, meadows where beaver have been removed tend to have single-thread channels and less complex, drier floodplains. This study aims to quantify the alteration in storage and attenuation of three fluxes: water, sediment, and organic carbon, which result from the simplification of channel and floodplain geomorphology after beavers have left a meadow. The hypothesis is that increased complexity in the meadow environments as a result of beaver activity enhances the retention of fluxes by increasing overbank flows and deposition away from the main channel. Abandoned beaver meadows that lack complexity will have relatively less attenuation of water fluxes, and less storage of organic carbon than complex active meadows. This article will focus on the hydrology and some preliminary organic carbon results. Processing of the sediment and additional organic carbon (OC) samples is still underway.

Study Area

The study takes place in central and northern Colorado within and near Rocky Mountain National Park, Colorado. The rivers in the study have snowmelt-dominated hydrology with an annual peak streamflow (discharge) occurring sometime around late May or early June. The streamflow then gradually returns to baseflow over the course of the summer, with occasional small, short increases as the result of summer storms. The active (North St. Vrain, Glacier Creek and Hollowell Park) and abandoned (Cow Creek, Hidden Valley, Upper Beaver Meadows and Moraine Park) beaver meadows on each stream are relatively wide flat-bottomed valley features in otherwise steep, narrow mountain streams, in areas that experienced glaciation. The meadows are underlain by Precambrian crystalline bedrock and have riparian vegetation in the floodplain with forested valley slopes. The forested vegetation consists of trembling aspen, fir, spruce, and pine trees. In valley bottoms, the riparian vegetation is dominated by river birch and willow in the active meadows and by grasses and sedges in the abandoned meadows. Across the study meadows there is a range of beaver activity from the North St. Vrain, Wild Basin meadow that supports multiple beaver colonies to Moraine Park and Upper Beaver Meadows that have been abandoned for at least three decades.

Methods

Geomorphic complexity of each meadow was measured by conducting surveys in multiple transects across each meadow. Complexity is characterized by the number of distinct geomorphic units present and the evenness of distribution of those units in each meadow. To measure hydrologic attenuation, instruments were placed at the inflow and outflow of each study meadow for the duration of the summer field season. The instruments recorded the water height (stage) at 15-minute intervals from before the snowmelt peak until return to baseflow in late September or early October. A geomorphic survey of the channel cross-section geometry was conducted for each instrument site, along with repeat surveys of the flow velocity. The surveys were conducted by stretching a measuring tape across the channel and recording elevation and velocity at increments across the channel using a survey auto-level and a wading rod. From the channel cross-section surveys, the velocity, and the stage data, the channel discharge could be calculated and a mathematical relationship developed for each site to convert the 15-minute stage data into 15-min flow discharge data. Attenuation of streamflow in each meadow was then quantified by comparing the timing and duration of the peak flow and flow recession at the inflow and outflow of each meadow.

Organic carbon stocks were calculated for one abandoned and one active meadow that represent end members for the range of beaver activity across the study sites. Soil samples were collected using a standard soil corer. The organic carbon concentration in each sample was measured by the Colorado State University Soil, Water, and Plant Testing Lab. Bulk density of the soil samples was calculated using the oven-dry weight and the volume of sample collected. Soil organic carbon stocks were calculated from the percent organic carbon in the sample and the bulk density.

Results and Discussion

The results of the morphologic complexity surveys, hydrologic attenuation, and organic carbon dynamics create a more complicated picture than what was hypothesized. Active beaver meadows showed greater complexity via a greater diversity of geomorphic units and a more even division between the geomorphic units present than the abandoned meadows. Active meadows had an average of 7.6 geomorphic units and a more even distribution of surface area between the units, whereas abandoned meadows had an average of 6 geomorphic units, with only 1 or 2 dominant units (Figure 1). Complexity appears to be related not only to the presence or absence of beaver, but also to the level of beaver activity and the length of time since beaver abandoned the environment. North St. Vrain Wild Basin and Upper Beaver Meadows represent the end members of the six sites examined for morphologic complexity. North St. Vrain is a highly active multithread channel meadow that supports multiple beaver colonies and has the greatest number of geomorphic units (10) and the most even division of area between those units. Upper Beaver Meadows on the other hand has been abandoned for upwards of 3 decades, has a single channel and is dominated by only two geomorphic units. The other sites, whether active or abandoned, fall somewhere in-between. Cow Creek had only been abandoned for two years at the time of the survey and displays complexity similar to Mill Creek at Hollowell Park, which has limited beaver activity.

In a related project to this study, colleagues at CSU found that the highly active beaver meadow, Wild Basin on the North St. Vrain, attenuated streamflow by acting as a sink for water during the high flow periods and a source of water during low flow periods. The results from this study support the attenuation result found for Wild Basin on the North St. Vrain. Mill Creek at Hollowell Park was a sink for water while the streamflow was increasing toward snowmelt peak in early Spring, but became a source of water at peak flow and throughout the rest of the summer as streamflow decreased. Like North St. Vrain, it shows some attenuation of flow by delaying the downstream transport of water entering the meadow. Glacier Creek did not show any attenuation of streamflow even though it has current beaver activity. For the abandoned meadows, Cow Creek and Hidden Valley both show the same attenuation pattern as North St. Vrain – becoming a sink at high streamflow and a source at low streamflows. Although these meadows are abandoned and have lower overall morphologic complexity, they retain remnant beaver dam and pond features that may still be affecting the hydrology even though the beaver have left. Further analysis of this dataset will be required to tease out the details and intricacies of hydrologic flux dynamics in Colorado mountain beaver meadows.

The organic carbon analysis only includes two meadows – North St. Vrain, a highly active meadow and Moraine Park, a meadow like Upper Beaver Meadows that has been abandoned for more than three decades. The percent organic carbon (OC) in the soil samples is not statistically different between the active and abandoned meadows, although the active meadow does have much greater variability in OC concentration. Moraine Park has an average of 55.90 Mg C/ha and Wild Basin has 36.38 Mg C/ha. Moraine Park has greater soil OC stocks than the active meadow in contrast to the hypothesis, but the difference is not statistically significant. These preliminary results indicate that beaver activity may not play a role in soil OC storage in Colorado mountain meadows, although the analysis of the data for the remainder of the meadows is necessary before any firm conclusions are made.

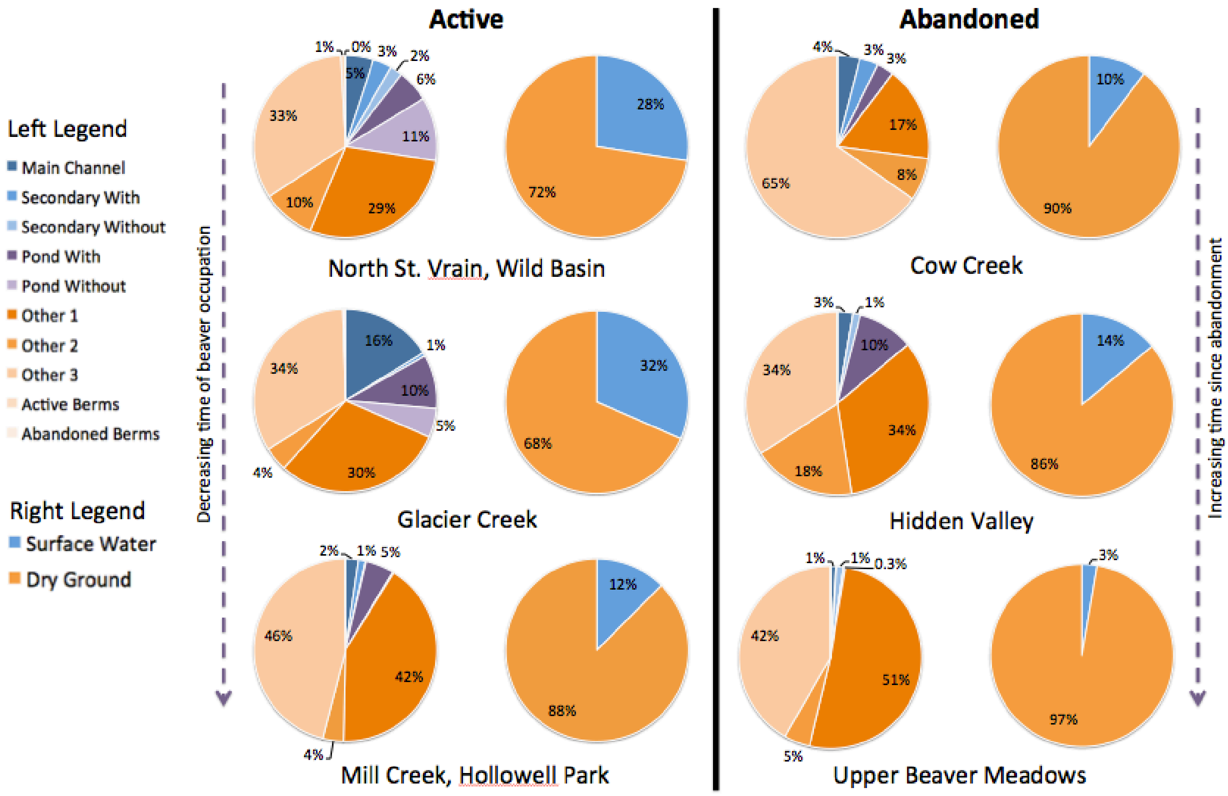

Figure 1. Geomorphic surveys to determine floodplain complexity of active and abandoned beaver meadows. Ten different geomorphic units were identified for the meadows including: the main stream channel, secondary stream channels, ponds with or without perennial surface connection to the main channel, active and abandoned beaver berms, and three categories of "other" distinguished by their elevation, wetness throughout the summer, and their vegetation. Greater complexity is indicated by a larger number of distinct geomorphic units present and increased evenness of distribution of those units in each meadow.


Figure 2. PhD Candidate DeAnna Laurel installing instrumentation to record water height (stage) on Glacier Creek in Rocky Mountain National Park. Photo Credit: Dr. Ellen Wohl.


Figure 3. Dr. Ellen Wohl conducting fieldwork on the North St. Vrain Creek in Wild Basin, Rocky Mountain National Park. Photo Credit: DeAnna Laurel.

Evaluating wood jam stability in rivers

Basic Information

Title:	Evaluating wood jam stability in rivers
Project Number:	2016CO322B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	CO-002
Research Category:	Engineering
Focus Category:	Geomorphological Processes, Management and Planning, None
Descriptors:	None
Principal Investigators:	Ellen Wohl

Publications

There are no publications.

Final Report for Project

Title: Evaluating Wood Jam Stability in Rivers

Investigator(s): Dan Scott, PhD Student, Geosciences, Colorado State University

Advisor(s): Dr. Ellen Wohl, Geosciences, Colorado State University

Background

Management of instream and floodplain wood in Colorado and across the nation has been focused on widespread wood removal, with management oriented solely toward reducing risk. The Colorado Front Range exemplifies the current state of wood management. Rivers on the Colorado Front Range are generally wood-impoverished (Wohl et al., 2015) due to human removal of wood. Despite the abundance of wood mobilized and deposited in streams in the Colorado Front Range during the September 2013 flooding, most major rivers such as the Big Thompson and St. Vrain have been subsequently stripped of wood. This trend has been the national standard for more than a century, with most wood having been removed from rivers and floodplains, especially prior to the 20th century (Wohl, 2014). This has led to a widespread misconception that wood is unnatural in rivers and a lack of understanding regarding the benefits of wood (Chin et al., 2008). Namely, wood provides essential riverine habitat and nutrients to fish and insects, stabilizes otherwise highly erosive systems, and maintains nutrient and water delivery to riparian ecosystems, all helping to maintain the general ecological health of river corridors (Gurnell et al., 2005; Wohl, 2013).

Wohl et al. (2015) presents a management strategy for determining whether to remove wood in a river or on a floodplain. This strategy is designed to evaluate the benefits and risks of wood and provide a stability analysis for a single wood piece, with the end goal of improving the balance between maintaining the benefits of wood while minimizing the risks wood poses to infrastructure. However, these guidelines are limited in their applicability to entire wood jams, and lack a robust observational backing.

City, state, and national organizations have already begun to adapt the guidelines proposed by Wohl et al. (2015). However, many of these organizations have contacted Dr. Wohl about applying the guidelines to wood jams, which motivated the proposed research. These organizations include, but are not limited to the City of Fort Collins, USDA Forest Service Stream Systems Technology Center, Boulder County, Friends of the Poudre, and The Nature Conservancy. Dr. Wohl's communication with these organizations has demonstrated the immediate need for an expanded set of guidelines that will address all forms of wood in riverine environments.

Our broad goal for this project is to develop an understanding of the hydrologic, morphologic, and biotic conditions that impact the stability of wood jams in rivers. Our specific objectives for this project are to: 1) create a dataset of wood jam characteristics and conditions under which wood jams are significantly changed or mobilized that will enable us to develop a model to predict wood jam stability across a wide range of river environments, 2) develop a model sufficiently robust as to enable its use by managers, technicians, consultants, and researchers to predict wood jam stability and make informed management conditions that balance ecological integrity and human uses of rivers, and 3) structure the model and associated tools to evolve using new, user-submitted data on a regular basis to reflect evolving understanding of wood jam dynamics.

Methods

Our general approach involved surveying individual wood jams across the Colorado Front Range as well as in the Cascade Range of Washington State to capture a wide variety of channel geometry, hydrologic regime, and tree species. We measured wood jam geometry, channel geometry, bed material size, and wood jam characteristics (e.g., whether the jam was anchored on a relatively immobile object, included rootwads or live wood, obstructed flow, etc.) across a sample of 38 jams (Figure 1). We placed time lapse cameras near a subset of 18 jams to observe them at 1-hour intervals throughout the high flow season. We then returned to each jam after high flow season (spring in the Colorado Front Range and autumn in the Cascades) to record whether the jam significantly changed (gained or lost substantial amounts of wood), remained substantially unchanged, or was transported downstream.

We plan to model wood jam stability using the variables we measure before peak flow. We will use a statistical decision tree model to predict whether a jam experienced significant change or transport due to high flow conditions. This model will maximize the amount of interpretation users can glean from its results, meaning that any probability assigned to a modeled jam will have a clear explanation for the reasoning behind that probability and an estimate of the uncertainty associated with it. For example, a jam may be predicted to be unstable due to its close proximity to the deepest portion of the channel and lack of anchoring material. However, if a user is attempting to model a jam that includes, for example, tree species that are very different from the dataset used in the model, the model will flag its prediction as being potentially unreliable due to the lack of data for that particular species. This allows for context-dependent predictions to inform management decisions regarding wood jams in rivers.

Our wood jam stability model will be hosted on a Colorado State University website and will be freely accessible to the public. Because of the complexity inherent in wood jam dynamics, we will regularly update this model with new data from our own field work as well as from those who use the model. Users of the model can provide us with new data simply by recording whether the model correctly or incorrectly predicted the stability of jams they are monitoring. In this way, we hope to develop an evolving model that can bring to bear as much of our understanding regarding wood jam stability as possible to every management scenario.

Current Findings

Only three of our currently surveyed jams experienced significant change, probably due to relatively mild high flow seasons in both study regions. This has limited our ability to develop our statistical model at the present. However, we have gleaned important observations from our timelapse camera data. Diurnal flow fluctuations in snowmelt systems cause a repeated dilation and contraction of wood jams during peak flow, which we hypothesize has a cumulative effect in destabilizing jams over time, sometimes resulting in total breakup and transport of the wood jam. We have also noticed that the angle of key structural logs (i.e., those that support the bulk of the wood in the jam) relative to the horizontal controls the effect that an incremental rise in stage will have on the destabilization of the jam. A horizontal log will be buoyed and potentially floated downstream by only a small increase in stage, whereas a nearly vertical log requires a much larger stage increase to cause floating and transport, resulting in a more stable jam. We are currently integrating these findings into revising our field measurements.

Future Directions

We plan to expand our dataset to over 100 wood jams by the beginning of spring snowmelt in the Colorado Front Range. We will also deploy another 12 timelapse cameras. We are currently revising our field methods to minimize variability between different people taking measurements. This will allow for more reliable, widespread use of our field methods to increase the rate at which we collect data. Over the next two years, we plan to expand our field sites to include small ephemeral streams in the desert southwest, a larger multi-thread river in the Pacific Northwest (Hoh River, Washington), and a low gradient plains river (Laramie River, Wyoming). We hope to achieve a dataset of at least 200 jams through at least one peak flow season before making the model available to the public and soliciting data from model users. Thus, we hope to have the model fully operational in late 2018 or early 2019. Coupled with the model, we will be hosting a publicly accessible dataset of wood jam characteristics, including the persistence and location of surveyed wood jams. These web resources will be accompanied by a Forest Service General Technical Report, to be published in late 2017, that will place our wood jam stability analysis tools in a holistic context of wood management in rivers. We hope these resources will assist others in understanding, managing, and researching wood jams in the future.

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Figure 1. Ellen Daugherty helping with a wood jam survey on the South Fork of the Poudre River

Figure 2. Ellen Wohl surveying wood jams on Little Beaver Creek

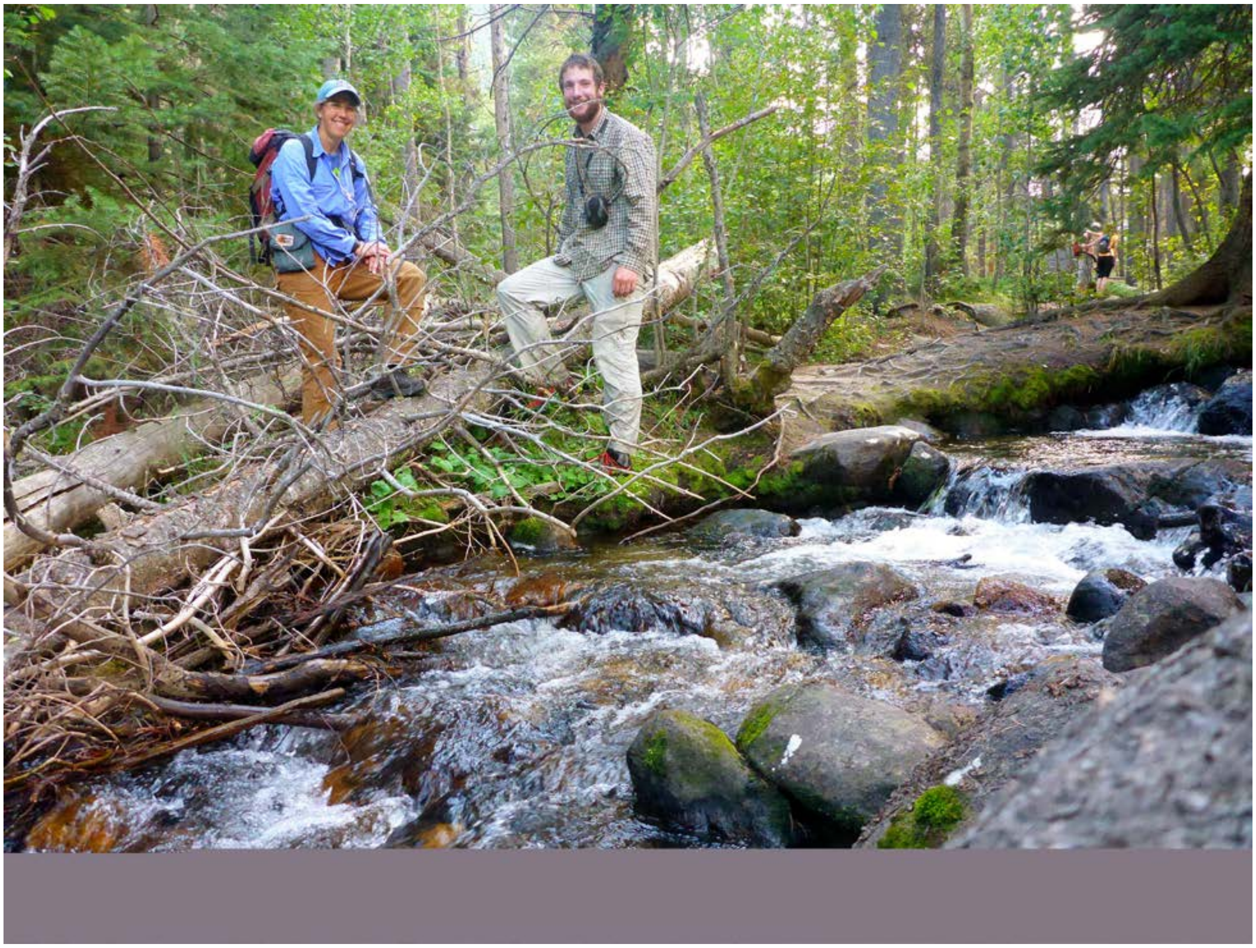

Figure 3. Dan Scott and Ellen Wohl performing fieldwork on North St. Vrain creek, Colorado.

Figure 4. Wood Jam near the Big South Trail on the Cache La Poudre River, backpack for scale.


Figure 5. Wood jam on Cache La Poudre River with backpack for scale

Channel restoration monitoring of the Upper Colorado River, Rocky Mountain National Park, CO

Basic Information

Title:	Channel restoration monitoring of the Upper Colorado River, Rocky Mountain National Park, CO
Project Number:	2016CO323B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	CO-002
Research Category:	Climate and Hydrologic Processes
Focus Category:	Geomorphological Processes, None, None
Descriptors:	None
Principal Investigators:	Sara Rathburn

Publications

There are no publications.

Final Report for Project

Title: Channel restoration monitoring of the Upper Colorado River, Rocky Mountain National Park, CO

Investigator(s): Matt Sparacino, MS Student, Geosciences, Colorado State University

Advisor(s): Dr. Sara Rathburn, Geosciences, Colorado State University

Introduction

Wetlands provide valuable ecosystem services by facilitating processes like water filtration, oxygen cycling, fine sediment storage, flood peak attenuation, and nutrient cycling, and they support diverse ecological communities. These processes occur when water is temporarily stored within the floodplain, delivered through either overbank flooding or subsurface flow paths. During the past 200 years, increased human activity and land use changes have reduced total wetland area in the continental United States by more than half. High elevation wetlands, which are delicately sustained by during short growing seasons, are especially vulnerable to degradation. In response, river and wetland restoration has become increasingly popular in the United States.

In Rocky Mountain National Park (RMNP), a 2003 debris flow eroded 36,000 m^3 of sediment from the hillslope below Grand Ditch, an earthen water diversion structure. The debris flow scoured channels, deposited up to a meter of sediment at the head of Lulu City wetland ~2 km downstream and altered the course of the Colorado River through a west channel. In 2015, RMNP completed restoration work to divert and realign a portion of the Colorado River as it flows into Lulu City wetland (Realigned Reach; Figure 1). The primary goal of the restoration was to restore the wilderness character and natural self-sustaining functioning of the affected system. The main goal of the research was to assess the effects of the channel restoration on a variety of channel and wetland hydrogeomorphic functions, focusing on two objectives including: 1) the surface flow redistribution and 2) surface water-groundwater exchange within Lulu City wetland.

Methods

A series of replicate measurements were collected throughout Lulu City wetland under similar environmental conditions in 2015 (pre-restoration) and 2016 (post-restoration) to assess the effects of the channel realignment. To address objective (1), hydrographs (flow discharge through time) were used to characterize changes in flow redistribution throughout Lulu City wetland. To address objective (2), a salt tracer injection test was paired with continuous surface conductivity measurements to quantify changes in surface water-groundwater interactions.

Hydrographs were calculated from discharge measurements collected weekly at six monitoring sites throughout the wetland (Figure 1). Average daily flow rates for the upstream and downstream (Lower Sentinel; Figure 1) sites were extracted from hydrographs and normalized by drainage area to produce comparable values. A daily discharge flux was calculated by subtracting the upstream daily flow rate from the downstream daily flow rate. This discharge flux provided an indication of how evapotranspiration and storage within the wetland changed as a result of the river restoration.

A salt solution, injected at the upstream site was used to elevate the conductivity of surface water above background concentrations, which allowed us to track the movement of water through the wetland. Continuous measurements of surface water conductivity at all downstream sites were used to calculate how much mass was stored within Lulu City wetland (Figure 1). Mass recovery through time, as represented by breakthrough curves, was used to evaluate the exchange behavior between surface water and groundwater.

Results and Discussion

Prior to channel restoration, two thirds of surface flow through Lulu City wetland was routed through a western channel underlain by permeable debris flow deposits (Figure 1). The remainder of flow was routed through a longer and more sinuous historic channel through the center of the wetland, underlain by less-permeable, fine-grained deposits. The channel restoration effectively rerouted all but the highest flows through the center channel, resulting in a 48% decrease in flow through the west channel. The restoration also decreased the combined wetland flow paths by 650 m, which decreased the channel wetted perimeter (area in contact with flow) and open channel surface area by half.

The change in surface flow dynamics as a result of the restoration affected how and where water is retained within Lulu City wetland. Under the pre-restoration condition, the cumulative discharge flux indicated 58 mm of water was retained in storage or lost to evapotranspiration. Conversely, the discharge flux calculated over the same post-restoration time period indicated a gain of 11 mm water (Figure 2). Together these results indicate that less water was retained in the wetland through storage or lost to evapotranspiration as a result of channel restoration. Less storage means water was routed through the wetland more quickly, thereby limiting the beneficial ecosystem processes that require stored water.

The change in discharge flux through Lulu City wetland between 2015 and 2016 can be explained by channel changes that effectively routed all surface flow through one channel instead of two. Decreases in wetted channel perimeter and exposed water surface area lowered the total potential storage and evapotranspiration by 50%. The channel realignment also altered channel complexity through the wetland. Despite a longer flow path, the center channel facilitates less exchange between surface water and groundwater because of a comparatively fine-grained, impermeable bed. Prior to restoration, the coarse bed and steep slope of the then-active west channel facilitated stream water movement into longer subsurface flow paths, which may explain the water retention in Lulu City wetland in 2015.

Breakthrough curves from the wetland outlet indicate that along with a negative discharge flux (more water storage in the wetland), there was more surface water-groundwater exchange in 2015 than 2016 (Lower Sentinel; Figure 3). Inflections on both the rising and falling limbs of the 2015 wetland outlet breakthrough curve are distinctly absent from the same curve in 2016 - an omission that indicates differences in surface water-groundwater exchange dynamics between the two years. The rising limb inflection can be explained by the fact that in 2015 the west channel was the fastest flow path between the wetland inlet and outlet. The falling limb inflection indicates that a portion of tracer water was slowed during its travel to the downstream site prior to restoration, but not after. This can again be explained by the subsurface pathways that were accessed through the west channel and not the center channel.

Management Implications

The goal of the channel restoration in RMNP was to restore the wilderness character and hydrologic function of the affected Colorado River-Lulu City wetland system. The construction of a shorter, straighter, and less geomorphically-complex flow path that consolidated flow into the historic center channel with lower substrate permeability resulted in less surface water retained within the wetland. This loss of surface water-groundwater exchange pathways between the river and adjacent wetland is an important, and unintended, side-effect of a project that prioritized the restoration of form over function.

In this system, restoration guided by the belief that human-induced disturbance must always be reversed has limited the potential gains in wetland biodiversity supported by the hyporheic exchange pathways in the western channel. After one year, this restoration project was effective at drying the west side of Lulu City wetland, as indicated by a 120% decrease in discharge flux calculations. If this drying continues, the lowering of water tables will facilitate the encroachment of upland vegetation on the west side of the wetland and inhibit the growth of desired wetland vegetation. More intensive restoration is planned for Lulu City wetland to further enhance the hydrologic functioning of the wetland; however, constructed wetlands often do not provide the same level of ecosystem services as natural ones because of unintended disruption of key processes. Given the unique location of Lulu City wetland within a national park, this system may be an ideal setting in which to observe the natural river restoration process.

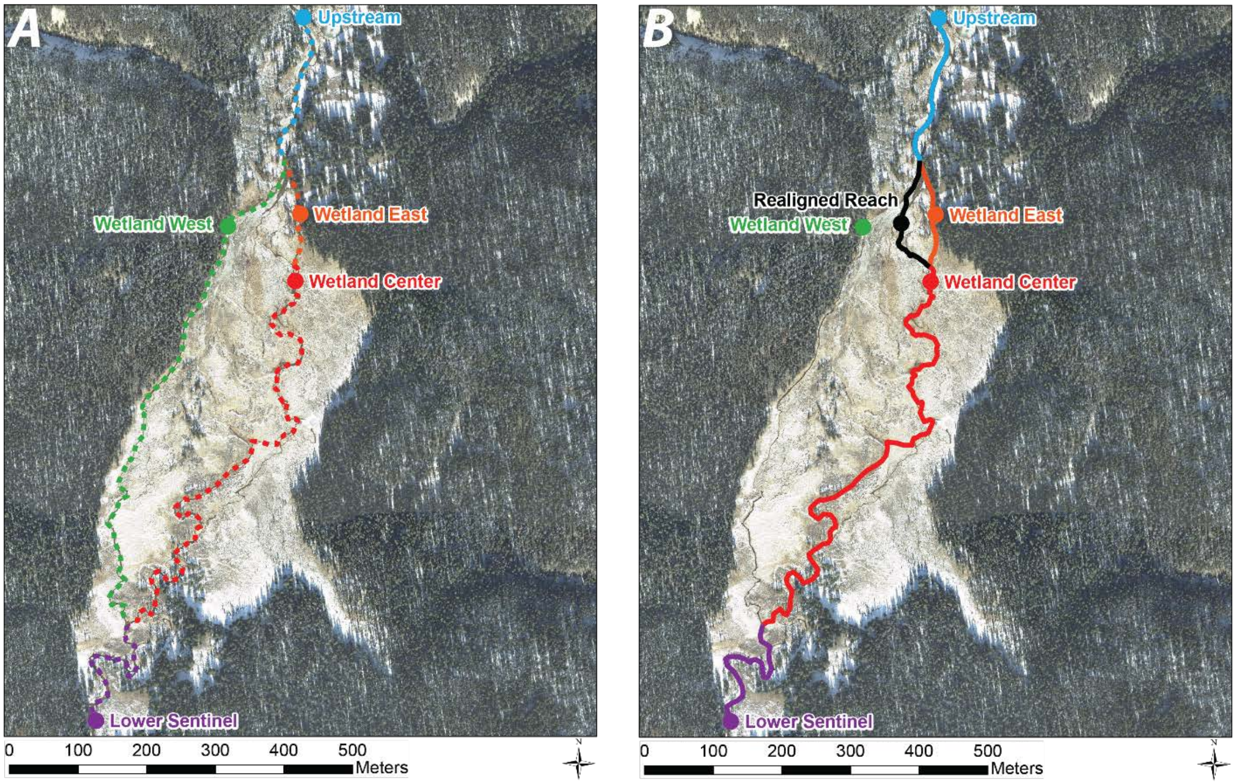

Figure 1: Measurement site locations and major stream flow paths through Lulu City wetland, Rocky Mountain National Park. Colored circles indicate discharge and surface conductivity measurement locations. Colored streamlines indicate major flow paths through Lulu City wetland. Panel A: Pre-realignment (2015) flow paths. Panel B: post-realignment (2016) flow paths. Note the straight, western flow path (green dashed line) compared to the sinuous center flow path (red solid line)."

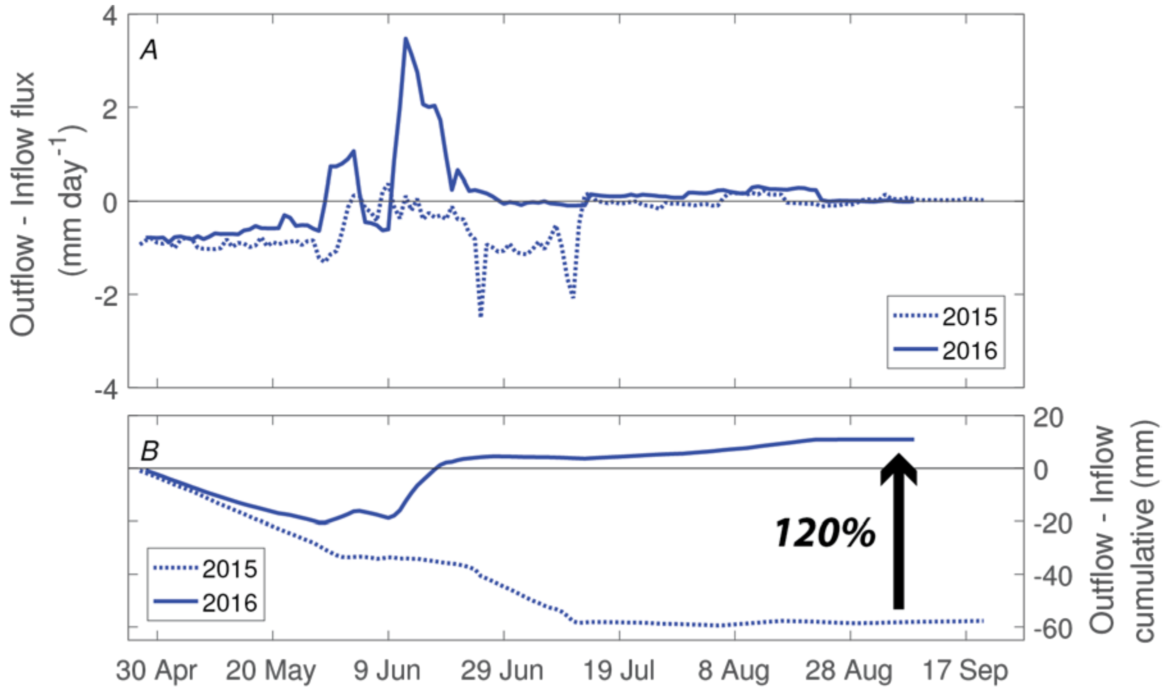

Figure 2: Discharge flux through Lulu City wetland. Panel A: The daily discharge flux through the wetland was calculated for 2015 prior to restoration, and 2016 post restoration. The discharge flux provides an indication of wetland storage and evapotranspiration: negative values = more; positive values = less. Panel B: Cumulative discharge flux through the wetland increased by 120% between 2015 and 2016.

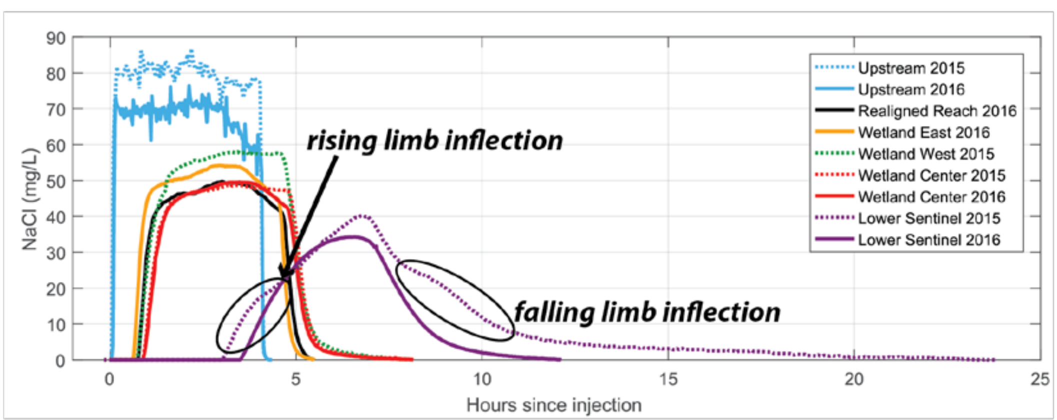

Figure 3: Surface conductivity breakthrough curves from salt tracer injection. Breakthrough curves from all study sites are listed in order of distance from the upstream site. Note Lower Sentinel rising and falling limb inflections present in 2015, but not 2016.

Credit: Rick Aster
Caption: Matt Sparacino and Sara Rathburn measure discharge during 2015 high flow on the Upper Colorado River, Rocky Mountain National Park.

Credit: Dave Dust

Caption: Matt Sparacino and Sara Rathburn mix salt water in preparation for the 2016 tracer test near the Upstream measurement site on the Upper Colorado River.

Water sampling and the effects of plastic absorption on heavy metals

Basic Information

Title:	Water sampling and the effects of plastic absorption on heavy metals
Project Number:	2016CO324B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	CO-003
Research Category:	Water Quality
Focus Category:	Methods, Surface Water, Toxic Substances
Descriptors:	None
Principal Investigators:	Randi Brazeau

Publications

There are no publications.

Final Report for Project

Title: Water sampling and the effects of plastic absorption on heavy metals

Investigator(s): Haley Sir, BS Student, Environmental Science: Water Quality and Hydrologic Science

Advisor(s): Dr. Randi Brazeau, Earth and Atmospheric Science, Metropolitan State University of Denver; Dr. Sarah Schliemann, Earth and Atmospheric Science, Metropolitan State University of Denver

Background

In environmental research, sampling techniques can strongly influence the results of a study. Therefore, it is in the researcher's best interest to reduce variability to provide the scientific community, as well as the public, with the most accurate data possible. This study specifically investigated the concentrations of aqueous heavy metals in sampling containers spiked with lead and cadmium. The study aimed to mimic water samples that would have been collected along the Las Animas River in August of 2015 after the Gold King Mine Spill in Silverton, Colorado.

In Colorado's history, mining has often been one of the main sources of income and economy for small towns throughout the Rocky Mountains. However, many mines in the state have long since been abandoned and have become possible sources of environmental damage due to acid mine drainage. The Gold King Mine in Silverton, Colorado has been out of commission since 1923, but like other historic mines, it has posed an environmental threat due to tailings that release heavy metals into soil, sediment, and surrounding surface waters. Past studies have shown that dissolved metals in aqueous samples may not be as stable as we once thought (Sekaly et al., 1999). The effects of these types of heavy metals that may be released into waterways are varied and sources for these types of inorganic chemicals should be closely monitored. The Environmental Protection Agency (EPA) has set very strict standards on these types of contaminants for drinking water that are legally enforceable and apply to all public water systems in the United States. The metals of concern in this study (cadmium and lead) are on this regulated list at extremely low levels (Environmental Protection Agency, 2016). The Las Animas Spill in 2015 dumped concentrations of lead, arsenic, and cadmium far exceeding these levels into the waterway causing panic and possible harm to drinking water treatment facilities downstream for many miles (Environmental Protection Agency, 2015).

In cases like these, countless samples are taken, assessed, and often times stored for possible use in the future. Storage containers for environmental water samples range in size and shape, although most are made of plastic or glass. High-density polyethylene (HDPE) is one of the most commonly used materials. Past research has concluded that during the collection, transport and storage of water samples, various constituents may be removed from the aqueous solution as they become adsorbed to the bottle (Spangenberg, 2012). Polymer used to make many synthetic materials such as plastics, has proven to be an excellent adsorbent and has been used in the past to remove heavy metals from wastewater by combining a recycled polymer substance with natural clay (Alsewailem & Aljlil, 2013). These studies support the hypothesis that plastics may play a role in metal adsorption and could very well be a significant factor in inaccurate data for water samples. As plastics become more widely used throughout the world, more caution is being brought to their chemical properties and their economic, social, and environmental impacts. Adsorption of aqueous metals by glass has been less studied than plastics, but its use also raises some concern. By limiting sampling conditions and focusing on a few particular variables, this study aimed to investigate the effect that sampling techniques may have on aqueous metal adsorption.

Methods

In this study, a total of twelve samples were observed including four controls. Water samples were taken from the Arkansas River upstream from the town of Buena Vista (Figure 1) and spiked with standards of cadmium and lead. Spiked concentrations were far below those reported in the Las Animas River spill due to detection limits of the equipment used. The uniform spiked sample was then divided into eight closed-lid sampling bottles of approximately the same shape and size, half glass and half plastic. From each plastic and glass sample group, half were stored at a refrigerated temperature of 35 degrees C and half were stored at room temperature. The four control samples included the two different sampling bottles (plastic and glass); two containing natural river water (one at 35 degrees C and one at room temperature) and two with distilled water spiked with the metal standards of concern (one at 35 degrees C and one at room temperature). Concentrations of cadmium and lead were measured every hour for four hours on the first day. On the second day, they were measured first thing in the morning (approximately 20 hours after the initial sample) and then a little later on (about 22 hours after the initial sampling) using an inductively coupled plasma mass spectrometer (ICP-MS) (Figure 2). Concentrations were then compared with initial readings to determine the change in cadmium and lead concentrations.

Results

A consistant downward trend in concentration can be seen in all of the samples (Figures 3-6). There did not seem to be an overwhleming difference between the glass and plastic sampling containers. Nor was there a significant difference in samples kept at the refrigerated temperature and those kept at room temperature. For all four samples, lead decreased slightly faster than cadmium. Lead had an average decrease of 21% while cadmium only decreased by an average of 13% for all four samples.

Discussion and Conclusions

A steady decrease of both elements was observed throughout the twenty-four hour period suggesting possible adsorption of these aqueous heavy metals to the sampling containers. However, there did not appear to be a significant difference due to bottle type (plastic vs glass) or temperature. In both the plastic samples, there was a small uptick in the lead concentration near the end of the sampling period. This may be due to desorption of the metals within the plastic containers after a period of time, however further research would need to be done to verify this. The results from this research suggest that there should be some consideration taken when analyzing water samples for heavy metal contamination. In particular, water samples should be analyzed as soon as possible after sampling to minimize adsorption. Samples stored for long periods of time, even in cold temperatures may produce erroneously low readings. We suggest that studies analyzing heavy metal concentrations in water should report the time elapsed between collection and analysis to account for possible adsorption.

The results of this study also suggest that heavy metals may adsorb to plastics in other locations, in particular, plastic pipes in the premise plumbing of homes. Future research is needed to determine if this adsorption is occurring and, if it is, what measures should be taken. For example, adsorption and desorption of heavy metals may affect recommended flushing protocol in times of contamination. These types of recommendations are not fully understood and often vary between events and types of contaminants. Further understanding of how heavy metals interact with various materials may help to develop an understanding of how we may better address these types of situations that are often time-sensitive for the residents in an affected area.

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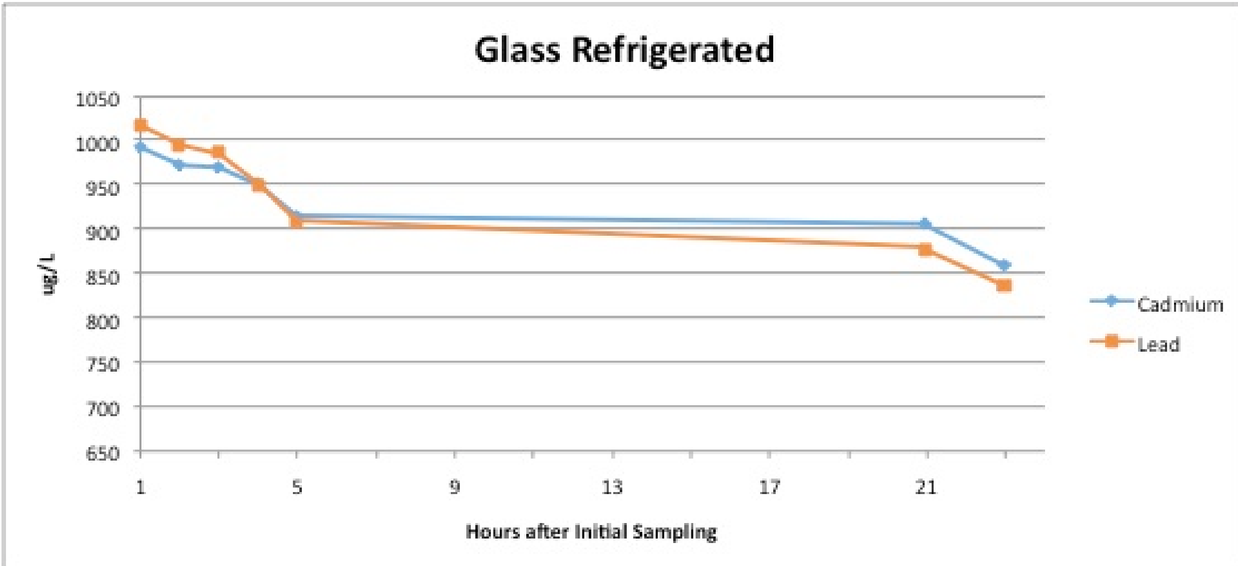
Figure 1. Randi Brazeau and Haley Sir at the ACE Conference in Chicago discussing their current research. (Photographer: Randi Brazeau)

Figure 2. Location of alpine river sampling for this study (The Arkansas River north of Buena Vista, Colorado). (Photographer: Haley Sir)

Figure 3. Student Haley Sir running samples on the ICP-MS for analysis at Metropolitan State University of Denver. (Photographer: Sarah Schliemann)



Figures 4. Cadmium and lead concentrations for each type of sampling container over a 24 hour period. (Created by Haley Sir)

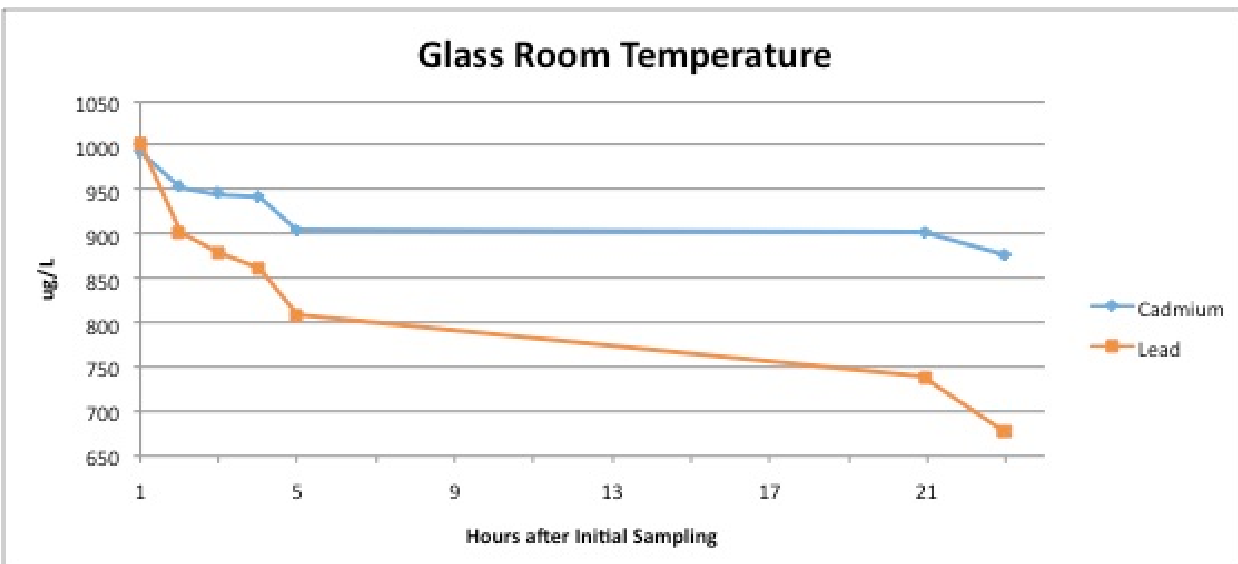


Figure 5. Cadmium and lead concentrations for each type of sampling container over a 24 hour period. (Created by Haley Sir)

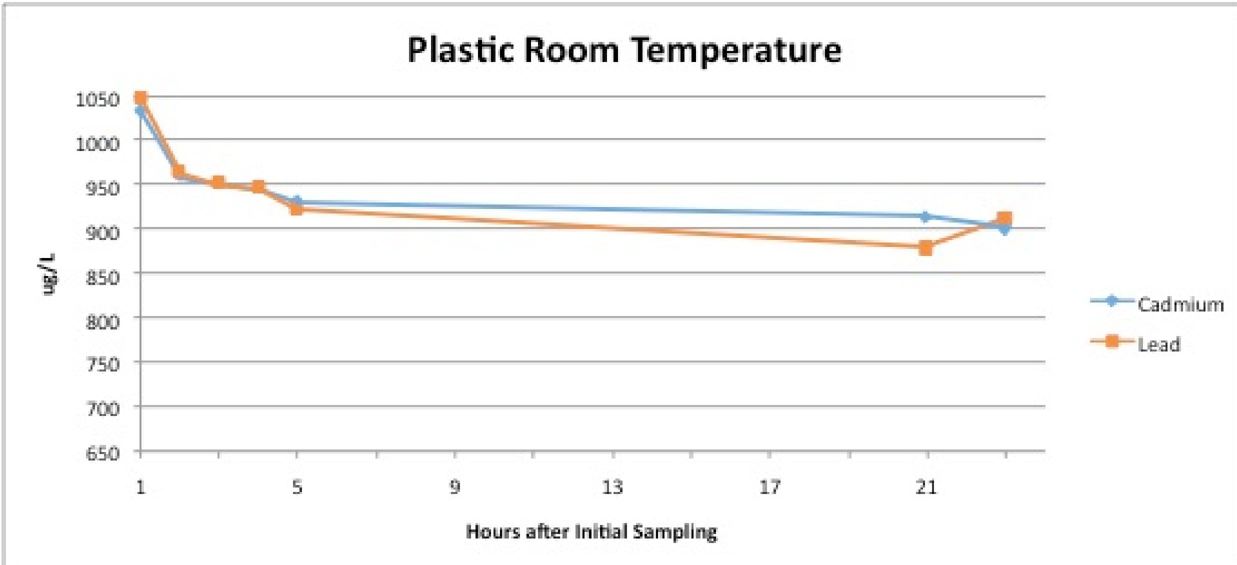


Figure 6. Cadmium and lead concentrations for each type of sampling container over a 24 hour period. (Created by Haley Sir)

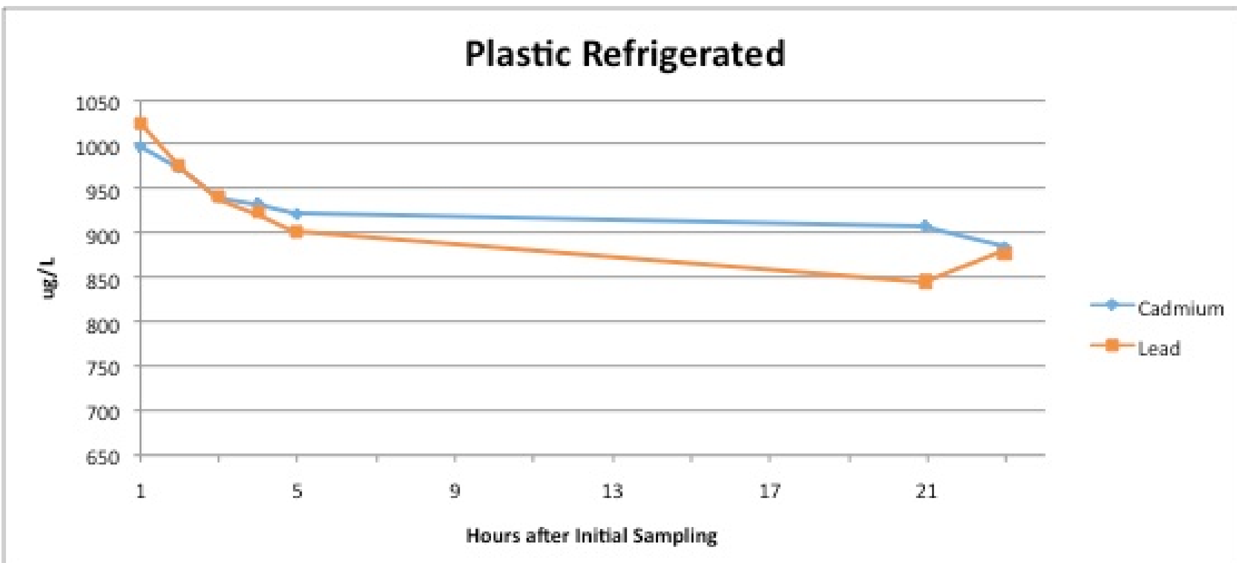


Figure 7. Cadmium and lead concentrations for each type of sampling container over a 24 hour period. (Created by Haley Sir)

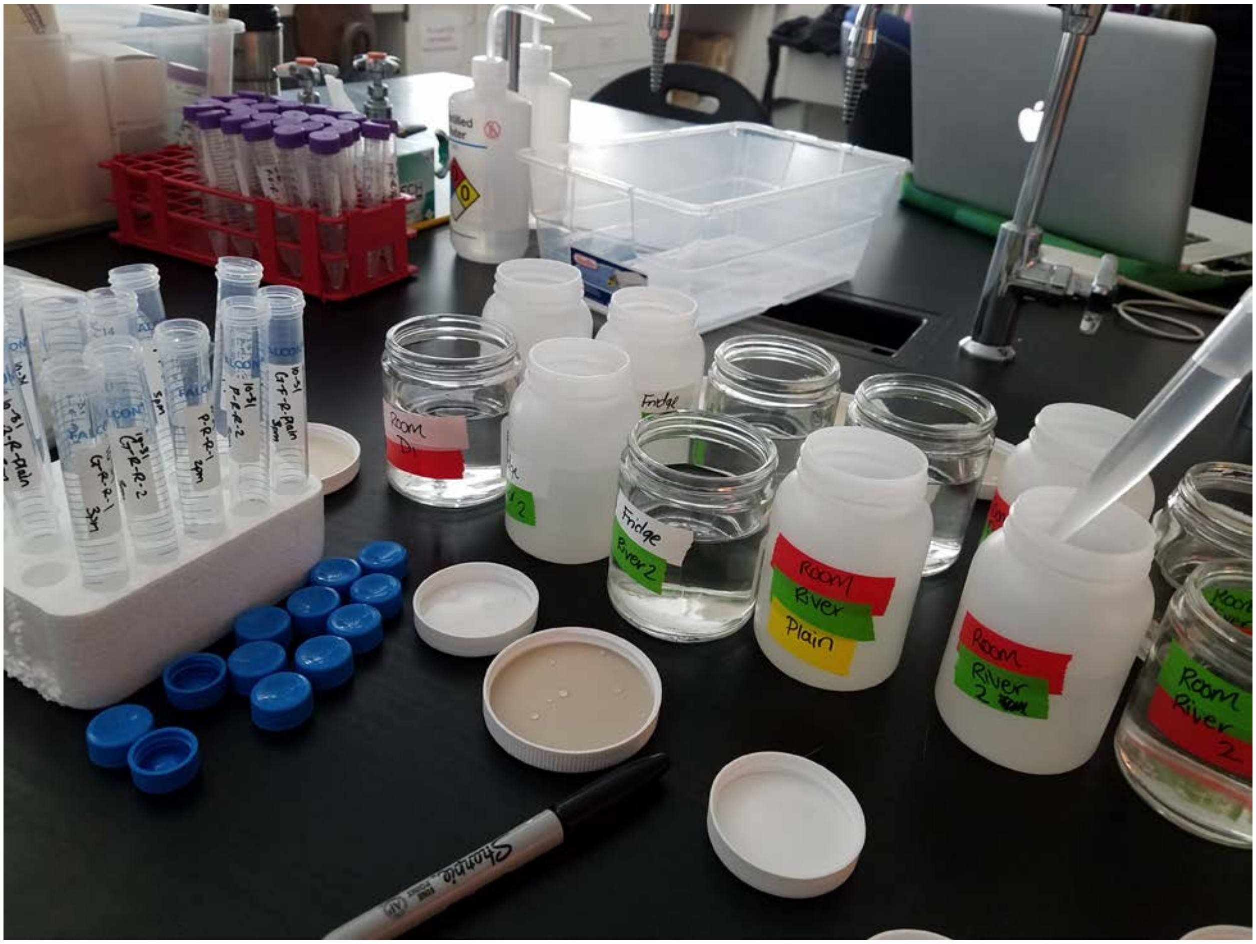


Figure 8. Labeling and first sampling of containers into ICP tubes. (Photographer: Haley Sir). Taken at Metropolitan State University of Denver.

Microbial community responses to metals contamination: mechanisms of metals exposure and bioaccumulation in a stream food web.

Basic Information

Title:	Microbial community responses to metals contamination: mechanisms of metals exposure and bioaccumulation in a stream food web.
Project Number:	2016CO325B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	CO-005
Research Category:	Water Quality
Focus Category:	Toxic Substances, None, None
Descriptors:	None
Principal Investigators:	Will Clements, Brian Wolff

Publications

There are no publications.

Final Report for Project

Title: Microbial Community Responses to Metals Contamination: Mechanisms of Metals Exposure and Bioaccumulation in a Stream Food Web

Investigator(s): Brian Wolff, PhD Student, Ecology, Colorado State University

Advisor(s): Dr. William Clements, Fish, Wildlife, and Conservation Biology, Colorado State University; Dr. Ed Hall, Ecosystem Science and Sustainability, Colorado State University

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Introduction:

Mining practices have generated an estimated 45 billion metric tons of waste that have impaired approximately 8,000 km of streams in the U.S. These effects are widespread in Colorado, where a recent survey suggested that about 25% of mountain streams showed some level of degradation due to metal exposure. With the recent accidental release of metals from historical mining into the Animas River in 2015, it is clear that impacts from historical mining will continue to be an important issue to the public.

Our research is focused on the upper Arkansas River (near Leadville, Colorado) that has been historically impacted from mining activity. The Arkansas River itself is the 6th longest in the United States and represents a major tributary to the Mississippi River. It also provides an important water source to many communities such as Pueblo, Colorado . Thus, researching the impacts of mining activity on this river system may have broad-level implications for other impaired streams of Colorado, and to downstream users in other States.

In 1983, the U.S. Environmental Protection Agency (EPA) added California Gulch, the main source of metals (e.g. Cd, Cu, and Zn) into the upper Arkansas River, to the National Priorities ('Superfund') List. Traditional monitoring of this area was performed using aquatic insect communities as 'bioindicators' of stream health. This form of bioassessment is founded on the principle that certain aquatic insect taxa are more sensitive to contaminants than others. Thus, the relative abundances of these different groups may be used as indication of stream health. Indeed, it was found that metals contamination caused a shift in stream benthic insect community composition, with more 'sensitive' taxa at upstream reference sites (no metals contamination) and more 'tolerant' taxa at contaminated sites downstream of California Gulch.

Much of the upper Arkansas River has since been remediated to remove most of metals sources (completed by 1999). However, despite significant improvements in water quality, the relative abundance of 'sensitive' taxa remain low at sites downstream of California Gulch (Figure 1).

The traditional approach for setting stream water quality guidelines has relied upon laboratory experiments and assumed direct aqueous exposure (e.g. exposure to external gills) to aquatic insects. However, dietary exposure is increasingly becoming recognized as an important route of toxicity in stream insects. Interestingly, the most sensitive stream insects are also commonly consumers of benthic microbial biofilms (a complex matrix of bacteria, algae, archaea, and fungi attached to substrate). In contrast, other groups such filter-feeders of stream seston (material suspended in the water columns) are typically more abundant in metals contaminated streams. The difference in dietary preference between sensitive and tolerant stream insects is consistent with the hypothesis that dietary metals exposure is important; however, the exact mechanism through which this affects the fitness of stream organisms has yet to be evaluated. Therefore, we sought to better understand how metal pollution affects stream resources to understand the exact mechanism for how metals enter the aquatic food web.

Research Questions

Specifically, we addressed the following research questions: (1) are metals concentrations greater within benthic biofilms than in seston at downstream ('impacted') sites?; (2) are there differences in upstream and downstream resource composition and dietary quality (i.e. nutrient content)?; and (3) what are the effects of exposure to metal-contaminated biofilm and seston on aquatic insect consumers?

We had two competing hypotheses through which differences in metals at the base of the food web may affect stream insect communities. Our first hypothesis was that insects consuming biofilms likely bioaccumulate relatively more metals through dietary exposure (i.e., greater direct exposure) than consumers of seston. Our second hypothesis was that aqueous metals concentrations may be low enough at downstream sites that are not directly toxic to the consumer, but high enough to alter biofilm community structure and resource quality (i.e., greater indirect effect in biofilms). We tested these hypotheses by examining biofilm community composition, metals concentrations, and resource dietary quality (e.g. nutrients content) from biofilm and seston at sites upstream and downstream of California Gulch.

Methods

(1) Are metals concentrations greater within benthic biofilms than in seston at downstream ('impacted') sites?

To determine if metals are the key determinants of microbial communities it was important to explicitly test if metals concentrations are higher at downstream locations (Figure 2) and test if metals are higher in benthic biofilms than seston. To address this question, ceramic tiles were deployed at one site upstream (reference) of the metals contamination source (California Gulch) and one site downstream (impacted). Tiles were retrieved approximately 5 weeks later following pronounced microbial biofilm colonization.

Biofilm on tiles were scraped with a sterile ceramic knife and placed immediately into cryogenic vials and flash frozen in liquid nitrogen. Seston was collected by suspending an 80 µm plankton net in the water column for 5 minutes. Each seston sample was transferred from the net into a cryogenic vial and flash frozen in liquid nitrogen. Upon return to the laboratory, all samples were immediately transferred in a -80°C cryofreezer. Samples were then freeze dried and analyzed for metals (Cd, Cu, and Zn) concentrations using Atomic Absorption Spectrometry.

(2) Are there differences in upstream and downstream resource composition and dietary quality (i.e. nutrient content)?

We sought to determine if metals exposures altered biofilm community structure. Removal of certain taxa could fundamentally change dietary quality available to aquatic insects. To determine biofilm community composition, we used an in situ handheld fluorometer (BenthoTorch®) on natural rock substrate at sites upstream (reference) and downstream of California Gulch ('impacted'). This instrument works by exciting cell pigments with varying wavelengths that ultimately is used to estimate abundance of green algae, diatoms, and cyanobacteria from a single measurement.

To address the effects of metals on nutrient content of microbial communities we measured C:N from natural rock substrate at sites upstream (reference) and downstream of California Gulch ('impacted'). Samples were freeze dried and submitted to the Cornell University Stable Isotope Laboratory (COIL) for C:N analysis.

(3) What are the effects of exposure to metal-contaminated biofilm and seston on aquatic insect consumers?

Finally, we measured metal concentrations and C:N of upstream and downstream aquatic insects representing two different feeding guilds: (1) benthic biofilm grazing mayflies, and (2) seston filter-feeding caddisflies. Directly measuring metals and C:N from insects provided a direct measure how differences in dietary exposure affect higher trophic levels.

Results:

Our analysis suggests that seston and biofilms downstream of California Gulch have much higher metals concentrations than at upstream reference sites (Figure 3). Additionally, we found that metals concentrations in biofilms were greater than in our seston samples. Metals analysis of a seston-feeding caddisflies revealed that concentrations remained unchanged between upstream and downstream sites (Figure 3). We found that mayflies at upstream reference sites had higher metals concentrations that found in the caddisflies. However, we did not have enough dried mayfly biomass at the downstream ‘impacted’ site for metals analysis. Thus, we were unable to determine if mayflies are also able to regulate metals bioaccumulation at downstream sites.

Despite higher metals concentrations in downstream biofilms, we found higher chlorophyll-a, suggesting that metals do not have a negative effect of algal biomass (Figure 4). However, the community composition was different between reference and impacted sites. The reference sites had greater abundance of diatoms and green algae, but the impacted site had greater abundance of cyanobacteria, with no green algae present (Figure 4).

Results from our C:N ratios suggest that metals may influence resource quality. Biofilm C:N ratios were lower in the reference sites, implying greater nitrogen or less carbon availability; however, seston C:N ratios were not different between sites (Figure 5). Interestingly, mayfly C:N ratios remained relatively unchanged between reference and impacted sites despite the observed changes in C:N ratios of their diet.

Discussion

Overall, our results show that the effects of metals on stream ecosystems are highly complex. The fact that metals accumulation in caddisflies did not change between reference and impacted sites suggests that these insects may have the capacity to regulate metals. Without currently having metals concentrations of mayflies downstream of California Gulch, it remains unclear whether those types of insects are also able to maintain consistent metals concentrations at impacted sites as well.

Metals also likely created a shift in algal biomass at impacted sites and it appears that theses shifts resulted in changes in resource quality. However, resource quality only changed between reference and impacted site biofilms, but not seston C:N. Therefore, metals, in combination with a shift in resource quality, may be more stressful to insect scrapers than filterers.

There is a limited amount of previous research on how stream resources change in relation to mining activity. However, our approach has expanded upon this work by determining how such changes in microbial resources affect higher levels of organization through examining putative pathways for bioaccumulation of metals and resulting shifts in dietary quality. Our research will contribute to water quality and stream assessments by filling a muchneeded knowledge gap of how stream resources facilitate or mitigate metals exposures.

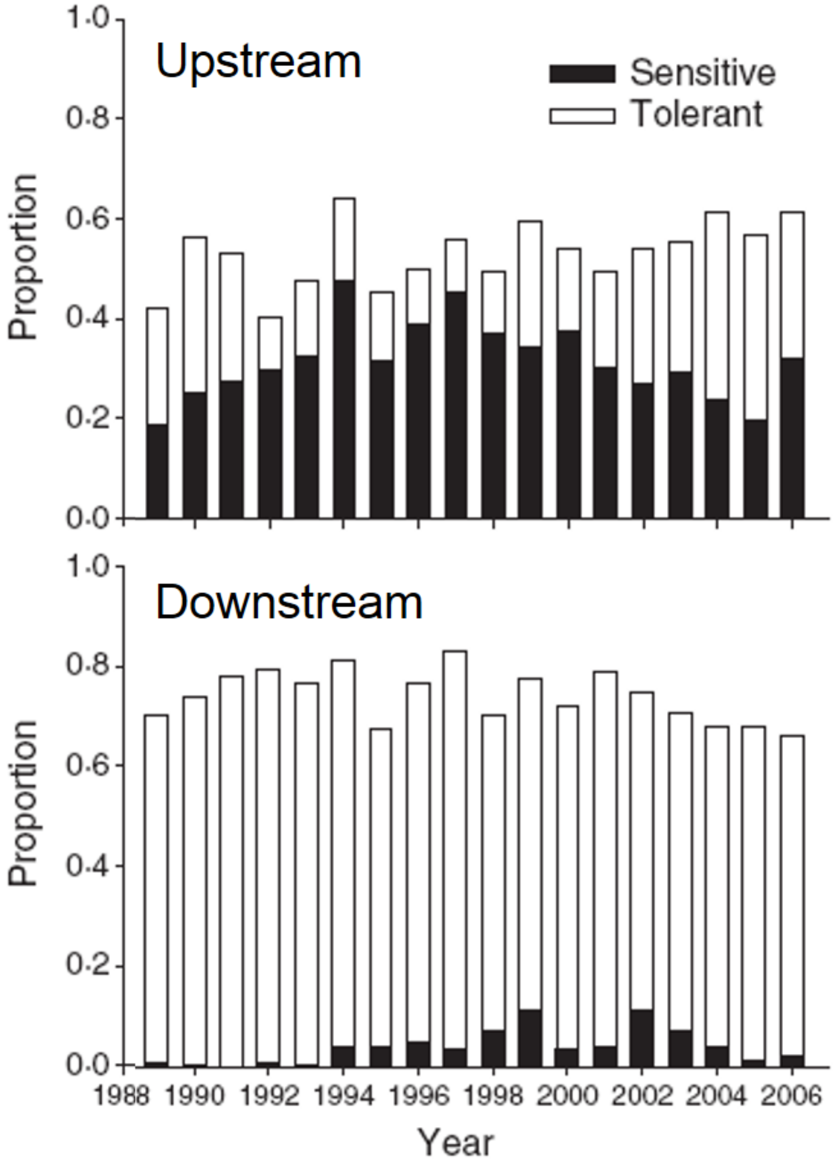


Figure 1. Relative proportions of 'sensitive' and 'tolerant' aquatic insects from the upper Arkansas River, 1998 – 2006.

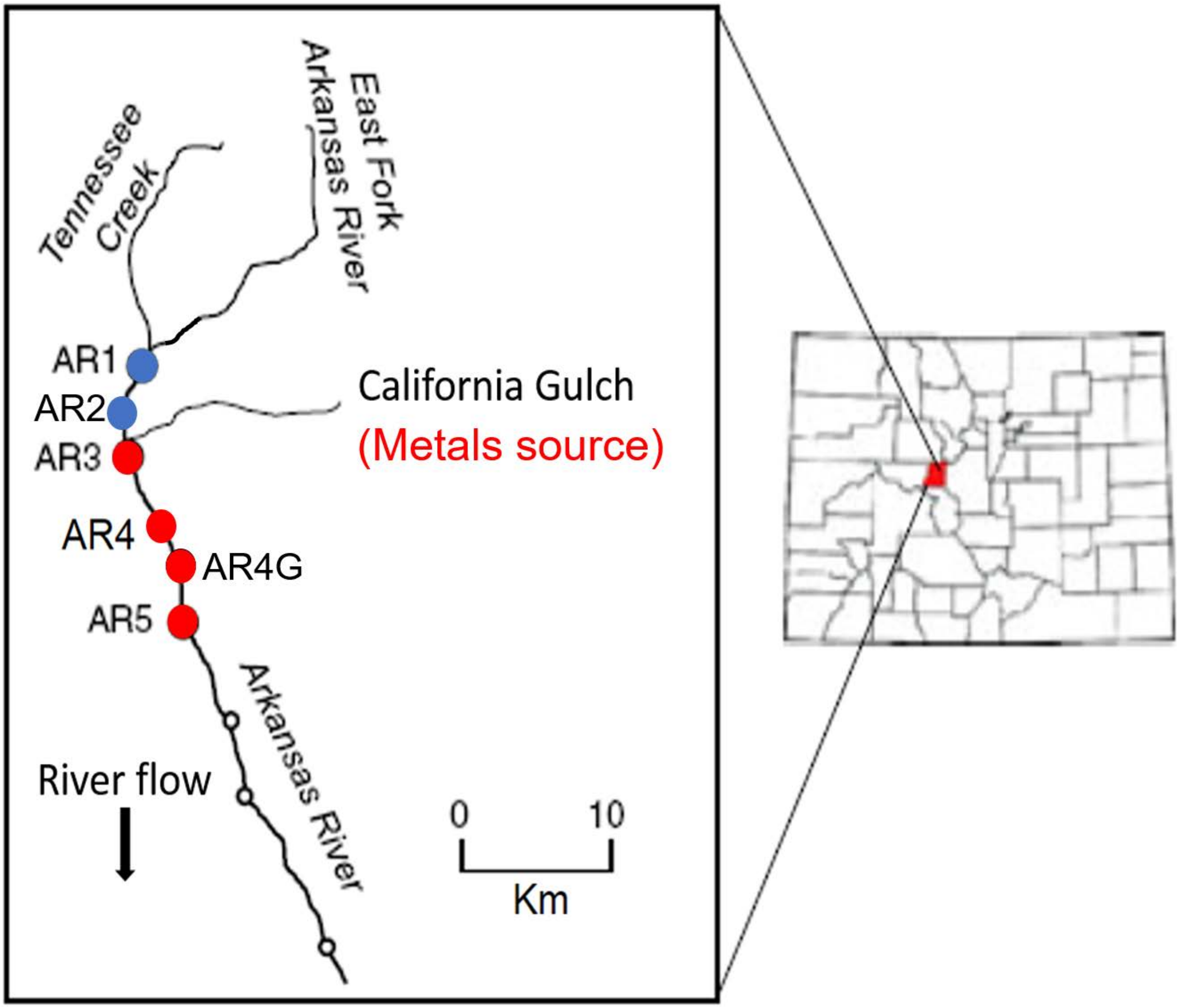


Figure 2. Map of study sites on the upper Arkansas River, Leadville, Colorado. All sites in blue represent upstream 'reference' sites, and those in red represent downstream 'impacted' sites.

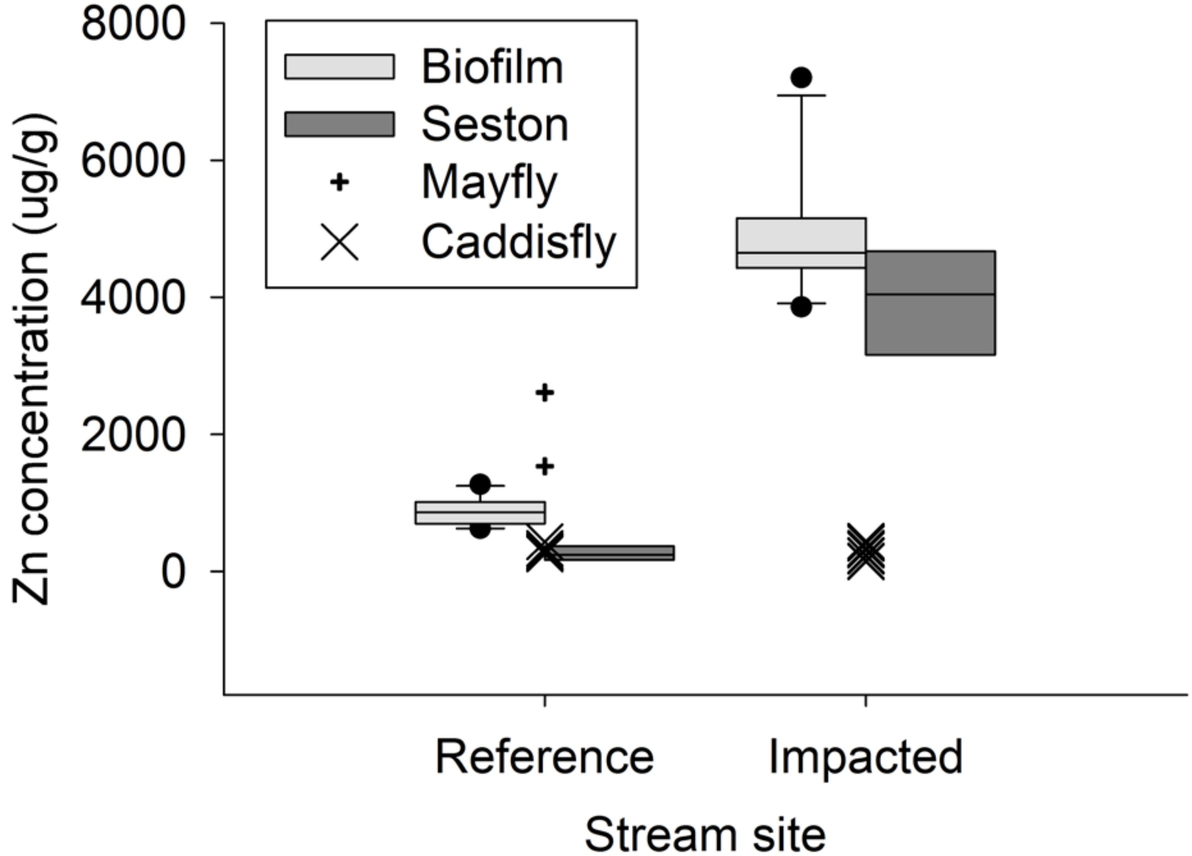


Figure 3. Metals concentrations from samples collected at sites upstream ('Reference') and downstream ('Impacted') of California Gulch on the upper Arkansas River.

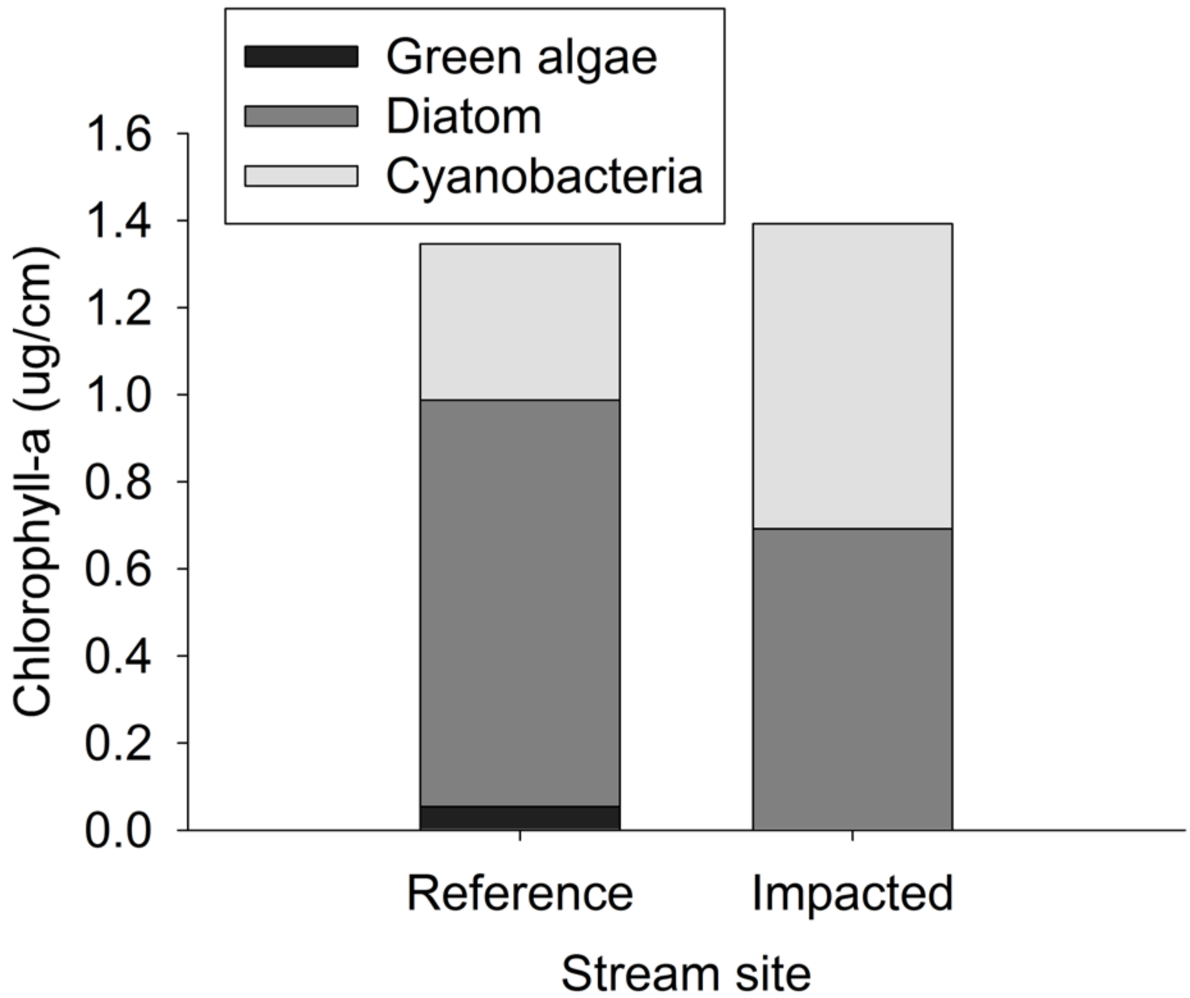


Figure 4. Biofilm chlorophyll-a from BenthoTorch measurements at sites upstream (‘Reference’) and downstream (‘Impacted’) of California Gulch on the upper Arkansas River.

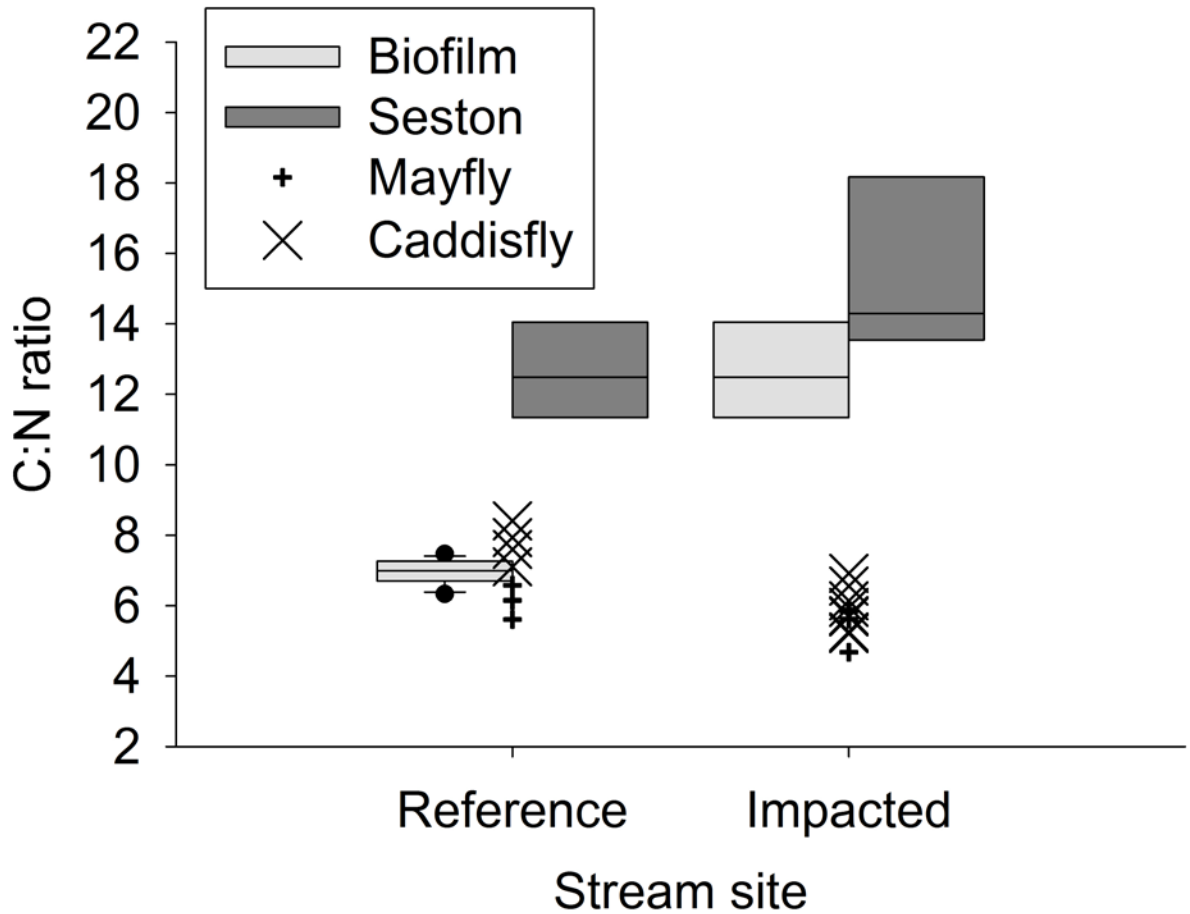
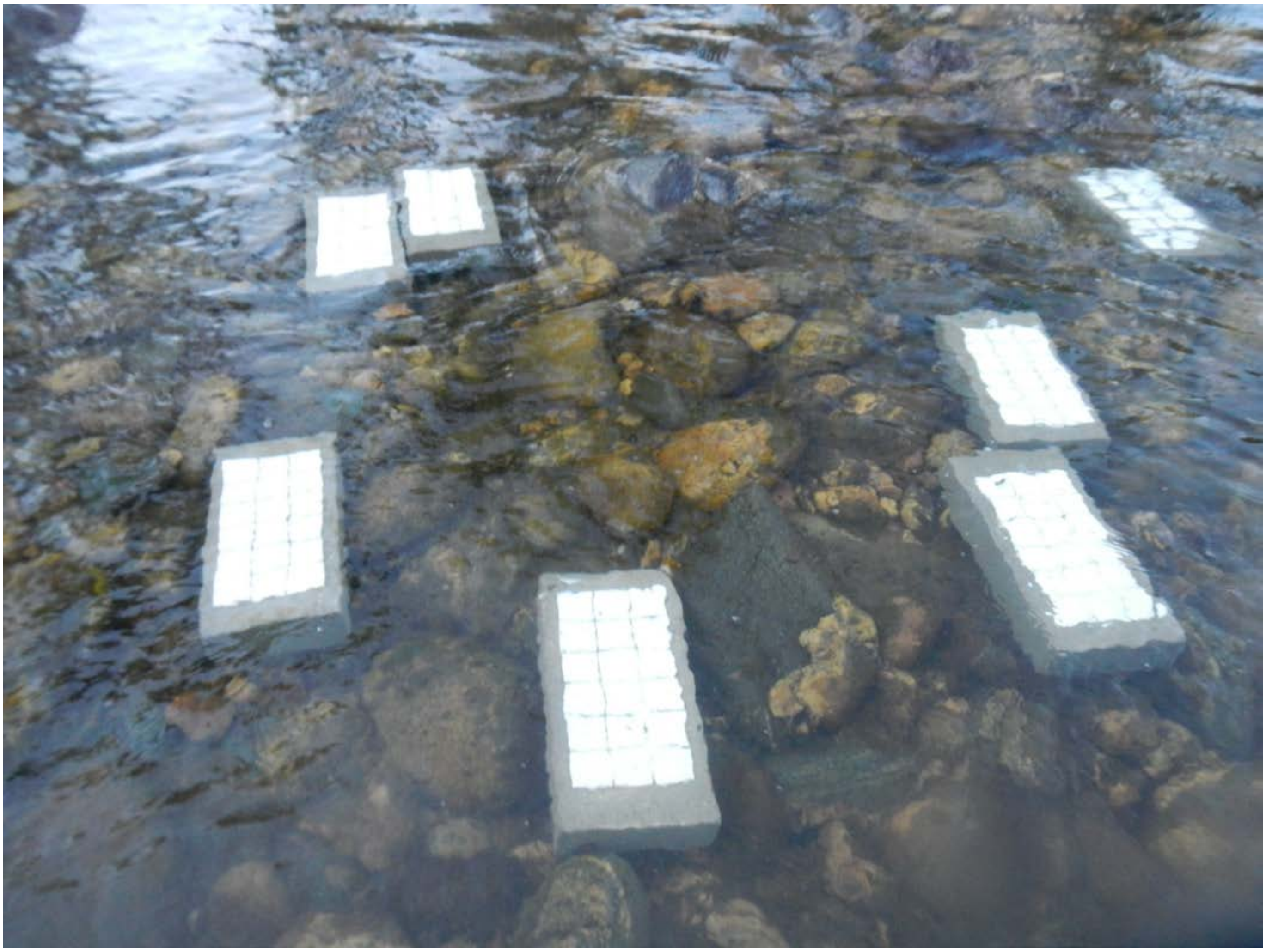


Figure 5. Percent carbon to nitrogen (C:N) ratios from samples collected at sites upstream (‘Reference’) and downstream (‘Impacted’) of California Gulch on the upper Arkansas River.



Tiles deployed in river for benthic biofilm colonization. Photo credit: Sam Duggan

Stream flow measurements at the upper Arkansas River. Photo credit: Sam Duggan

Collecting biofilm samples at the upper Arkansas River. Photo credit: Sam Duggan

Comparing fine scale snow depth measurements at rocky and flat surfaces using lidar and photogrammetry derived digital elevation models

Basic Information

Title:	Comparing fine scale snow depth measurements at rocky and flat surfaces using lidar and photogrammetry derived digital elevation models
Project Number:	2016CO326B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	CO-002
Research Category:	Climate and Hydrologic Processes
Focus Category:	Methods, Water Supply, None
Descriptors:	None
Principal Investigators:	Steven Fassnacht

Publications

There are no publications.

Final Report for Project

Title: Comparing fine scale snow depth measurements at rocky and flat surfaces using Lidar and photogrammetry derived digital elevation models

Investigator(s): R. Allen Gilbert Jr., MS Student, Watershed Science, Colorado State University

Advisor(s): Dr. Steven R. Fassnacht, Ecosystem Science and Sustainability, Colorado State University

Introduction

Snow is important to a number of interests in Colorado, and techniques to measure its extent, depth, and density are technologically limited. Until the late 1970s, snow measurements were accomplished regularly through periodic manual point measurements of snow depth and snow water equivalent, and the data are used to estimate runoff volumes. The intermountain west is now populated by the automated snow telemetry (SNOTEL) network of remote stations to provide daily snowpack measurements, but the network is still at a coarse resolution. Finer resolution direct data collection is often done manually, but requires much effort, and are typically only collected over short distances.

Light detection and ranging (LiDAR) is a proven technology that provides accurate sub-meter snow depth data at landscape scales. Current aerial and terrestrial LiDAR products require equipment and practices that are expensive and may not be used with enough frequency to justify their purchase. Recent efforts to measure snow depth on low relief areas at landscape scales using aerial photogrammetry in Alaska have shown promise in providing results similar to those produced using LiDAR but at reduced cost. Although aerial platforms can provide data across a much larger extent, it is possible to use these technologies terrestrially with great success. This study endeavors to quantify vertical differences between photogrammetric methods and terrestrial LiDAR scanned surfaces using commercial off-the-shelf photographic equipment and processing software. The overall effect of this study is to describe techniques for use at the operational level that may refine products used to estimate snow coverage across large spatial domains. Our ultimate determination is that both technologies are viable when properly scoped and produce better products than current spatial interpolation techniques allow.

Research Design

Two sites were selected to provide variety in terrain and data collection variables. A nearly 3,000 m^2 site was selected at the CSU Agricultural Research Development and Education Center’s southern area (ARDEC-South). It is located along Interstate 25, is mostly flat with plowed rows, and is relatively devoid of vegetative cover. A 900 m^2 plot near the Joe Wright SNOTEL (# 551) station was chosen to represent montane conditions (Figure 1a). This plot is in a sloped clearing dominated by woody shrubs and surrounded by trees at various stages of growth.

Data collection for this study occurred during the 2016 – 2017 snow season. Each site was scanned using a FARO Focus3D LiDAR, and a series of approximately evenly spaced camera stills using a Nikon D810 digital single lens reflex (DSLR) camera with a Nikkor 24 mm fixed focal-length lens were taken along each of the plot's edges. Snow on images were captured as bracketed sets adjusting time settings so that one image was properly exposed, a second was one stop overexposed, and a third image was two stops overexposed. Although when previewed, overexposed image highlight areas appeared not to contain usable data. This study found that post-processed overexposed images produced the best photogrammetric results by equalizing their histograms.

Spherical reference points made of 6 in (15 cm) Styrofoam spheres were set at each corner (Figure 1), approximately 1 m above the surface, and were used to align point clouds within a survey and between survey sessions. LiDAR scans were processed using CloudCompare open sourced software. Images were processed using the commercially available Agisoft Photoscan software to produce dense point clouds (Figure 2a), which were then imported into CloudCompare and aligned to LiDAR point clouds (Figure 2b). Digital surface models (DSM) for each cloud were created at 1-m and 10-cm resolutions. A lens calibration was created for the DSLR using a feature present in the Photoscan software.

Comparison

This study considered LiDAR surfaces as the actual snow surface. Photogrammetrically derived surfaces were subtracted from the LiDAR surface and the absolute value was computed to provide an overall magnitude of vertical difference between surfaces (Figure 3 at a 1-m horizontal resolution). No obvious spatial patterns, except the vertical lines present at ARDEC-South (Figure 3a), were observed in the surface differences. It should be noted that aligning surfaces proved more difficult than originally anticipated and likely exacerbates our observed difference. Further alignment of surfaces may reduce the overall error, but the potential time dedicated to those refinements may only prove marginally beneficial.

Average overall vertical difference was within 10 cm between surfaces. Table 1 summarizes the vertical difference of the photogrammetric surface from the LiDAR surface for each site by record date. Photogrammetric surfaces recorded at the Joe Wright study site (Figure 3b) agreed with their corresponding LiDAR surfaces more often than those at ARDEC-South (Figure 3a). The obvious differences between these sites is the variation in topography and different lighting conditions common during collection events. The results in Figure 3 may suggest, not surprisingly, that lighting is the dominant factor to successfully record snow using photogrammetry. All images were taken at about solar noon. The final day at ARDEC-South (January 5th) was brighter than the others and all the days at Joe Wright were clear and bright. Those recorded differences have the smallest difference magnitudes and appear more evenly distributed throughout the entire surface.

Discussion and Recommendations

Photogrammetry can substantially reduce the cost of equipment and data acquisition without substantial reduction in data quality. The collection process described in this study used a professional DSLR, but the technique is able to use almost any photographic image, making its incorporation into other data acquisition or management activities a viable solution for agencies interested in three-dimensional imaging at increased frequency. This study recommends three metrics be used when comparing these methods:

1) Measurement accuracy and precision - LiDAR will almost always result in better vertical accuracy and finer resolved precision, but geographic accuracy is more reliant on the quality of ground control and influences both techniques. Imaging equipment should be considered part of the entire package which, combined with a survey grade GPS, can create highly accurate products.
2) Time and monetary costs - Photographic equipment is much more affordable than LiDAR equipment. It may be able to maintain that price gap in the future even though LiDAR is becoming smaller to meet other commercial demands. An element that was not shown in this study, but is worth mention, is that digital imaging equipment can include spectrum beyond the visible and could be used to enhance already high resolution photogrammetric products with multispectral output. Data collection time for each technique is substantially different, wherein LiDAR required approximately an hour to record a moderate resolution point cloud but photographic images were recorded in about fifteen minutes. Processing times varied, but all data were processed on a higher end four-year-old home desktop computer, suggesting viability for both at the small office operational level.
3) Integration into existing workflows - Each method has its learning curve and both may be automated to some degree. Photogrammetry's ability to use most images allows an agencies existing infrastructure to be included as potential data collection assets. The determining factor is performing the steps to develop a lens calibration.

It is becoming more common to find versions of both technologies that are small enough to fit on unmanned aerial systems (UAS) or that could be fitted to mobile terrestrial platforms. Some commercial survey firms are already using such technologies and techniques to produce centimeter resolution surfaces over extents covering hectares.

This study described a means of implementing photogrammetric snow measurement into existing operational workflows. Camera equipment and photogrammetric software were the most expensive investments; both are consistently being improved. It is recommended to use a camera with the ability to manually control exposure settings, but this research team has had some success with cell phone and GoPro cameras shooting subjects other than snow. The recent increased interest in photogrammetry may also result in open source or other freely available software. VisualSFM, for example, is freely available and a promising alternative. Ultimately, the core elements of this study comparing LiDAR and photogrammetric techniques and outputs should remain relevant beyond technological advances.

Figure 1. Data Collection

Figure 1a. Allen (right) and Allis (left) Gilbert establishing ground control at Joe Wright during the initial data collection event on November 13, 2016.

Figure 1b. Allen Gilbert using the FARO LiDAR unit to collect data on January 29, 2017.

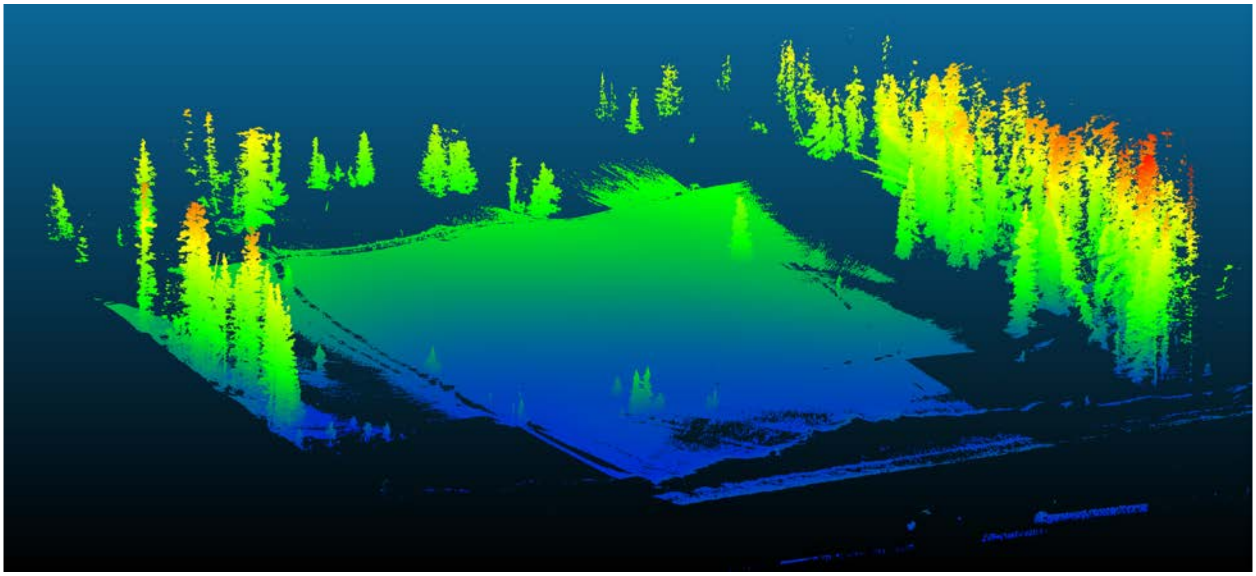


Figure 2a. LiDAR point cloud displayed as a height color ramp.

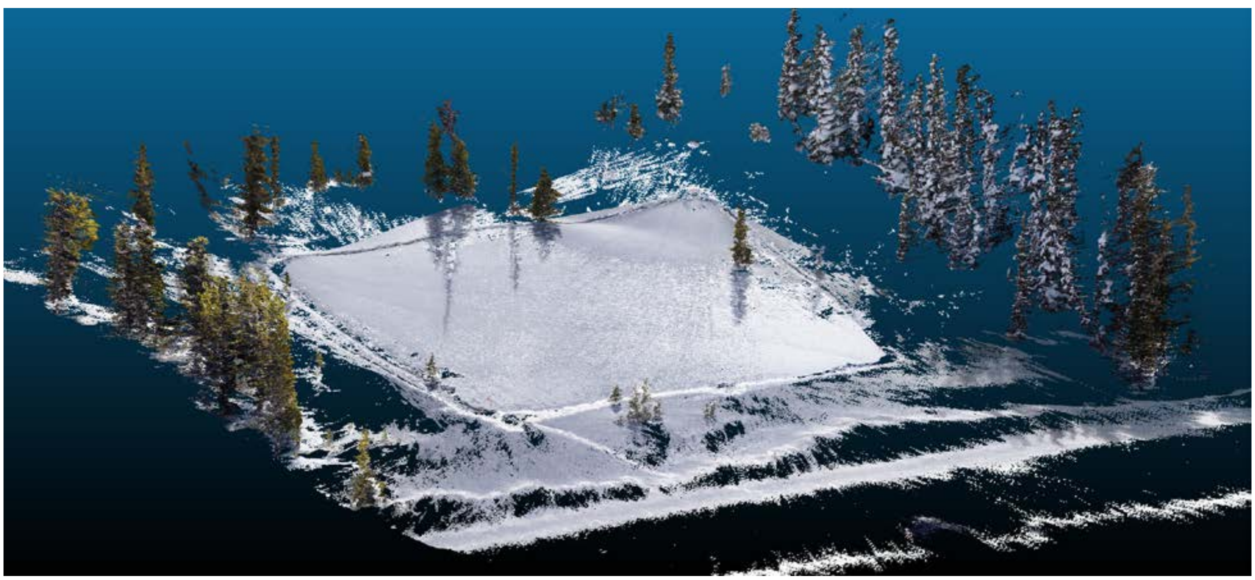


Figure 2b. Photogrammetric point cloud displayed as real color captured in photographic images. These data are from the Joe Wright study site recorded on January 29, 2017. Although these images are from an aerial perspective, the underlying data to create their point clouds was taken at ground level.

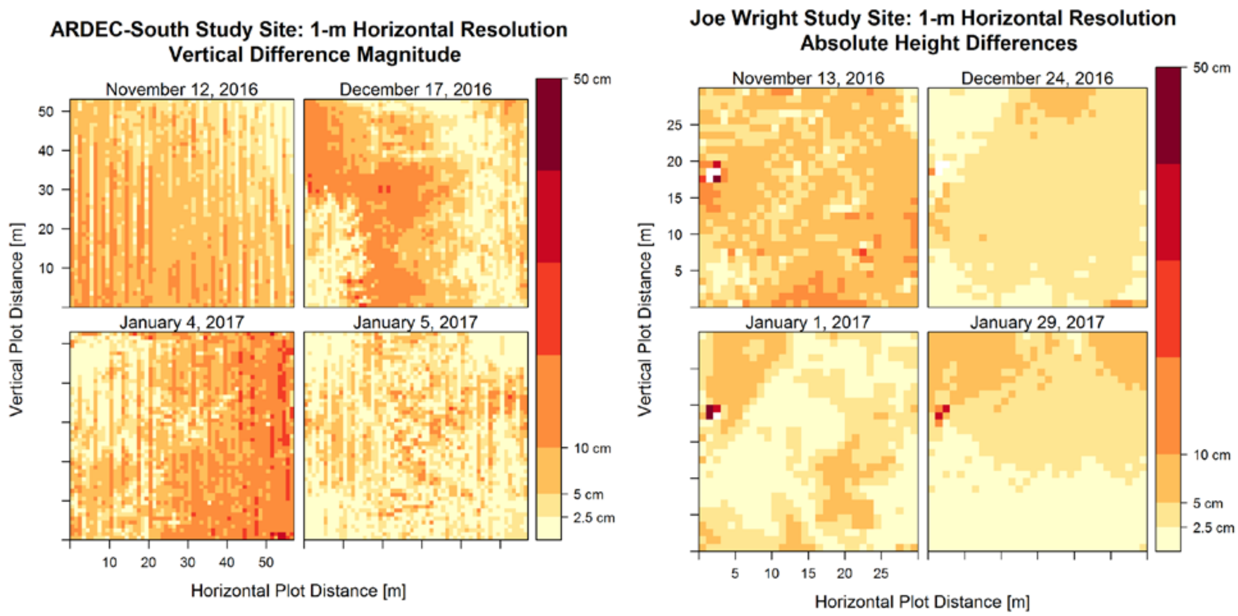


Figure 3. : Vertical Difference Surfaces
These plots visualize the magnitude of error between photogrammetrically derived surfaces when compared to LiDAR derived surfaces by record date.

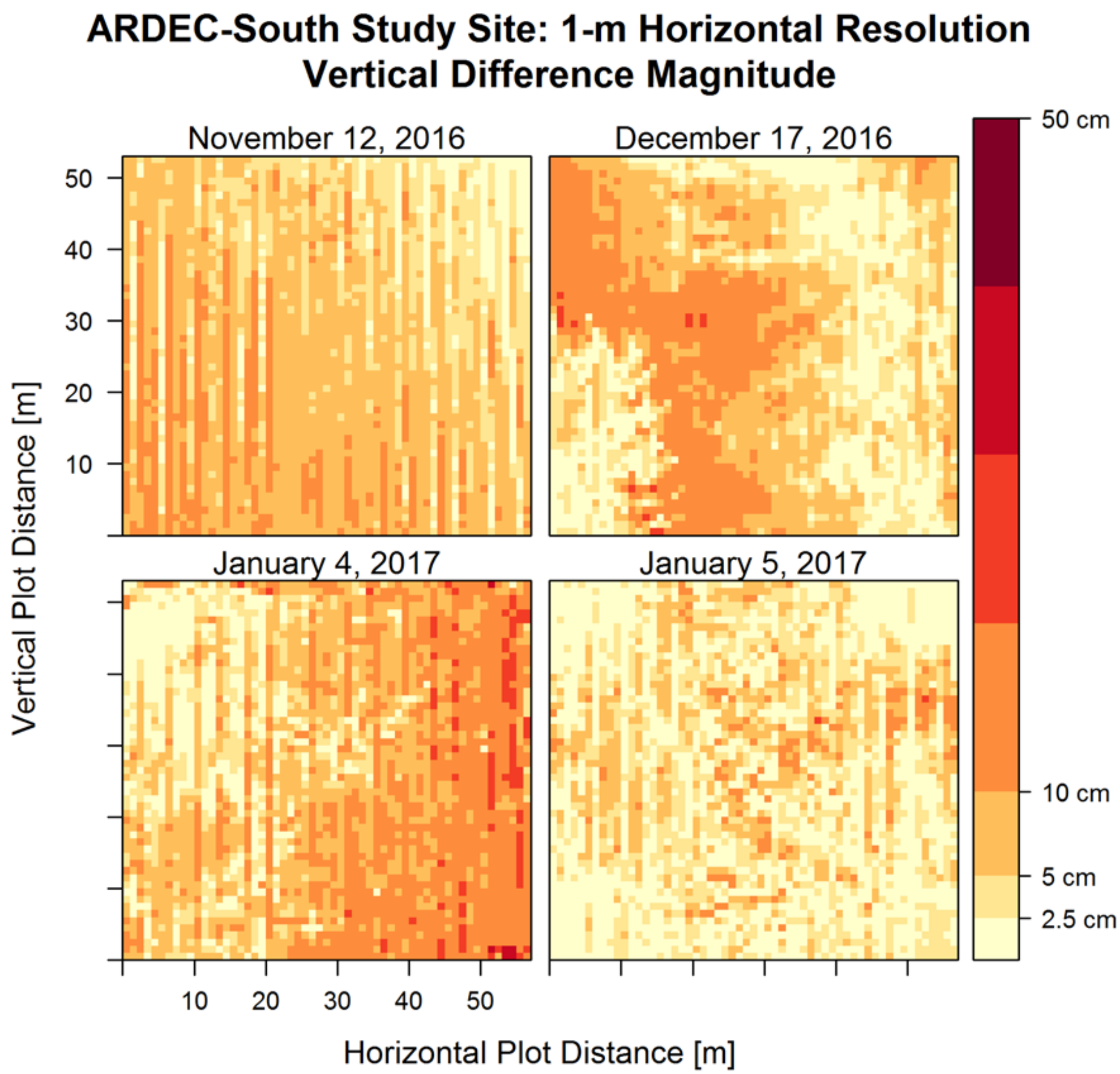


Figure 3a. ARDEC-South generally experienced more error and a mottling artifact best observed on Dec. 17th, 2016 suggesting the photogrammetric software had difficulty identifying similar objects between images.

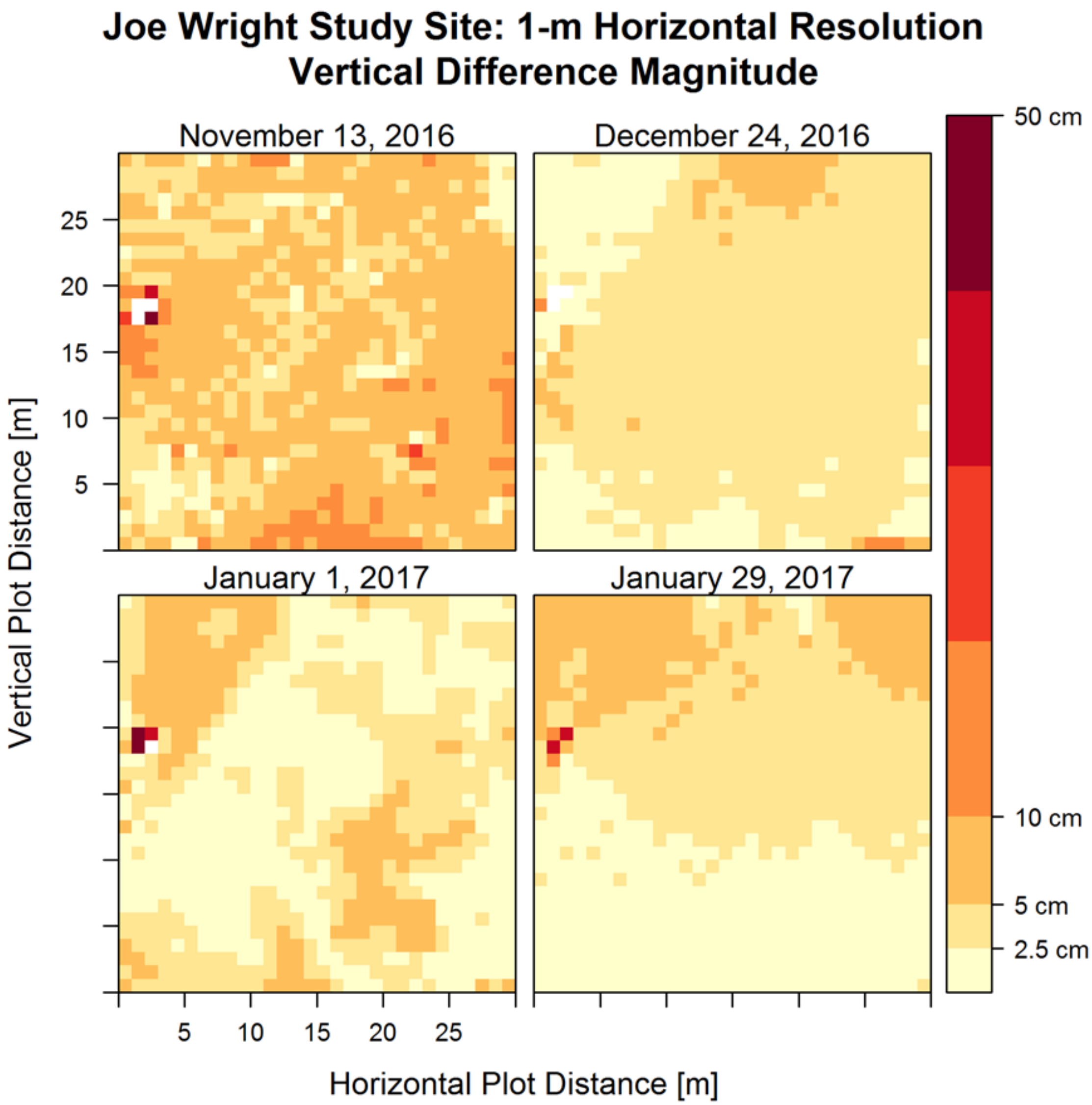


Figure 3b. Joe Wright differences are more evenly distributed throughout the surface allowing for a more direct comparison between surface types.

Table 1: Summary Statistics

Assessment statistics, recorded in centimeters, of the vertical difference between LiDAR and photogrammetric 1-m surfaces.

Date	Site	Min Difference	Mean Difference	Max Differences	Standard Deviation
20161112	ARDEC-South	-4.9	6.6	18.9	3.5
20161217	ARDEC-South	-23.7	-4.7	14.7	6.6
20170104	ARDEC-South	-25.1	8.2	39.6	6.3
20170105	ARDEC-South	-24.6	-2.1	14.6	4.2
20161113	Joe Wright	-7.5	6.6	159.4	7.3
20161224	Joe Wright	-61.9	-3.1	109.1	5.7
20170101	Joe Wright	-9.9	-1.5	87.6	5.0
20170129	Joe Wright	-38.5	3.2	30.7	2.4

Allen Gilbert at Joe Wright site

Information Transfer Program Introduction

Requests from the Colorado legislature and key water agencies to facilitate and inform basin-level discussions of water resources and the state water plan emphasized the role Colorado Water Institute plays in providing a nexus of information. Some major technology transfer efforts this year include:

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

Technology Transfer and Information Dissemination

Basic Information

Title:	Technology Transfer and Information Dissemination
Project Number:	2016CO317B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	CO-002
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Reagan M. Waskom

Publications

1. Colorado Water Newsletter, Volume 33 – Issue 1 (March/April 2016), Colorado Water Institute, Colorado State University, Fort Collins Colorado, 40 pages.
2. Colorado Water Newsletter, Volume 33 – Issue 2 (May/June 2016), Colorado Water Institute, Colorado State University, Fort Collins Colorado, 36 pages.
3. Colorado Water Newsletter, Volume 33 – Issue 3 (July/August 2016), Colorado Water Institute, Colorado State University, Fort Collins Colorado, 40 pages.
4. Colorado Water Newsletter, Volume 33 – Issue 4 (September/October 2016), Colorado Water Institute, Colorado State University, Fort Collins Colorado, 36 pages.
5. Colorado Water Newsletter, Volume 33 – Issue 5 (November/December 2016), Colorado Water Institute, Colorado State University, Fort Collins Colorado, 40 pages.
6. Colorado Water Newsletter, Volume 34 – Issue 1 (January/February 2017), Colorado Water Institute, Colorado State University, Fort Collins Colorado, 32 pages.
7. Akhbari, Masih, Smith, MaryLou. June 17, 2016. Case Studies Outlining Challenges and Opportunities for Agricultural Water Conservation in the Colorado River Basin. Colorado Water Institute, Colorado State University, Fort Collins, CO. 60 pages. http://cwi.colostate.edu/publications/SR/27.pdf
8. Hill, Rebecca, Pritchett, James. August 8, 2016. Economic Impact Analysis and Regional Activity Tool for Alternative Irrigated Cropping in the San Luis Valley. Colorado Water Institute, Colorado State University, Fort Collins, CO. 58 pages. http://cwi.colostate.edu/publications/SR/28.pdf
9. Norton, Andrew Katz, Gabrielle Eldeiry, Ahmed Waskom, Reagan Holtzer, Tom. December 21, 2016. SB14-195 Report to the Colorado Legislature South Platte Phreatophyte Study. Colorado Water Institute, Colorado State University, Fort Collins, CO. 108 pages. http://www.cwi.colostate.edu/publications/SR/30.pdf
10. Cabot, Perry Olson, Christopher Waskom, Reagan Rein, Kevin, 2016, Rainwater Collection in Colorado, CSU Extension, Colorado State University, Fort Collins Colorado, 4 pages

Colorado Water Institute Activities

- Topics in Western Water Law, GRAD592, Fall 2016
- *Colorado Water*, Colorado Water Institute, March 2016 – February 2017
- CSU Water Experts, cwi.colostate.edu/CSUWaterExperts/default.aspx
- CSU Hydrology Days, March 21 – 23, 2016
- Colorado State University Focus on Climate Smart Agriculture, May 5, 2016
- United States Secretary of Agriculture Tom Vilsack Visits CSU, May 20, 2016
- Fort Collins Poudre RiverFest, June 4, 2016
- Water Archives Western Water Symposium, July 25, 2016
- Extension Water Tour, July 28-30, 2016
- South Platte Forum, October 26-27, 2016
- Strengthening Collaborative Capacity for Better Water Decisions, November 9-11, 2016
- 4th Annual Poudre River Forum, February 5, 2016
- Water Tables 2017, January 26, 2016

Interdisciplinary Water Resources Seminar GRAD592

Mondays 4:00 – 5:00 PM,
BSB Room 103

Fall 2016 Theme: *Topics in Western Water Law*

The purpose of the 2016 Interdisciplinary Water Resources Seminar (GRAD592) is to expose students to the various topics of western water law.

Specifically, the seminar will:

1. Discuss topics including: history and evolution of western water law, state compacts and federal water law, hybrid water law systems, water quality law, groundwater law, and environmental law
2. Provide in-depth discussion about water-related court cases
3. Provide students with the opportunity to interact with prominent water professionals

Students interested in taking the one-credit seminar should sign up for GRAD592, Water Resources Seminar, CRN 74006. The seminar will be held at 4:00pm Monday afternoons in **BSB Room 103.** (Students who have enrolled in GRAD592 in the past may also enroll for this offering.)

Seminar Organizers: Ryan Bailey, Troy Bauder, Pete Taylor, and Reagan Waskom.

Aug 22	Introductions and course overview
Aug 29	Justice Gregory Hobbs, *History and evolution of western water law*
Sept 5	No Class, *Labor Day*
Sept 12	Doug Sinor, *How water law is made today: statutes, case law, rule making, and the constitution*
Sept 19	Justice Gregory Hobbs, *Key Colorado court cases and statutes*
Sept 26	David Robbins, *Compacts and federal law*
Oct 3	Anne Castle, *Law of the River*
Oct 10	Andy Jones, *Groundwater law*
Oct 17	Trisha Oeth, *Water quality law*
Oct 24	Linda Bassi, *Instream flow law*
Oct 31	Dan Brown, *Water courts and the court process*
Nov 7	Larry MacDonnell, *Hybrid water law systems and evolving models of surface and ground water administration*
Nov 14	Amy Beatie, *Water transactions*
Nov 21	No Class, *Fall Break*
Nov 28	Dick Wolfe, *Water law administration and management*
Dec 5	Class discussion, semester assignment due (attendance required)

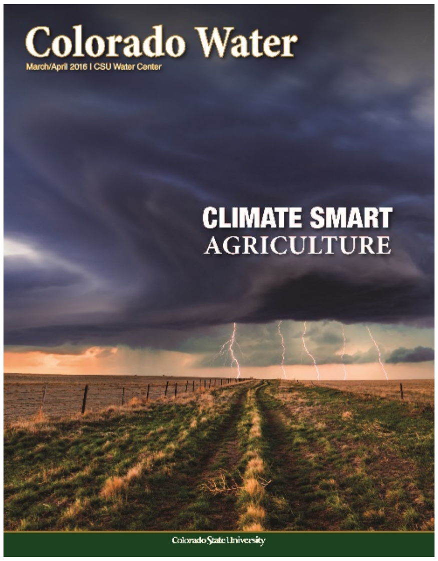
All interested faculty, students, and off-campus guests are encouraged to attend.

For more information, contact Reagan Waskom at reagan.waskom@colostate.edu or visit watercenter.colostate.edu

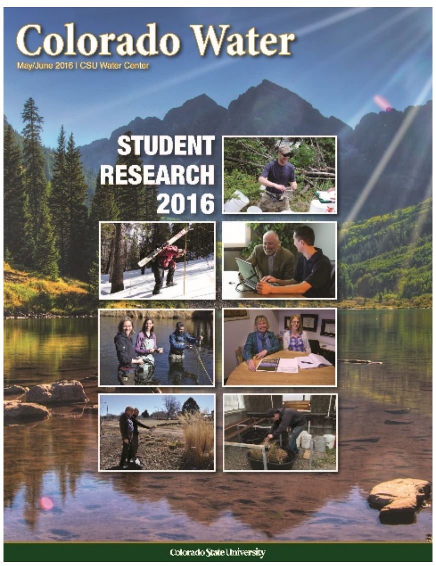
Colorado Water Institute

Colorado State University

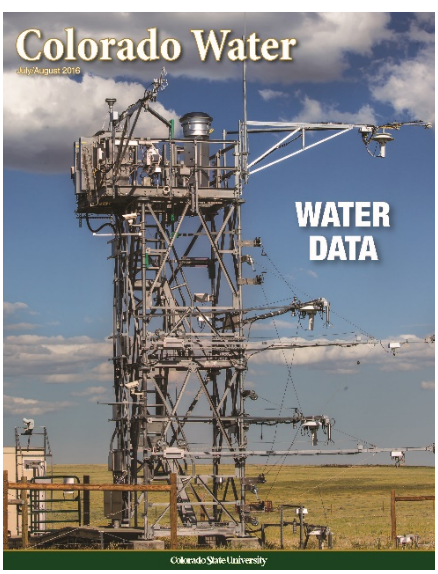
CSU WATER CENTER



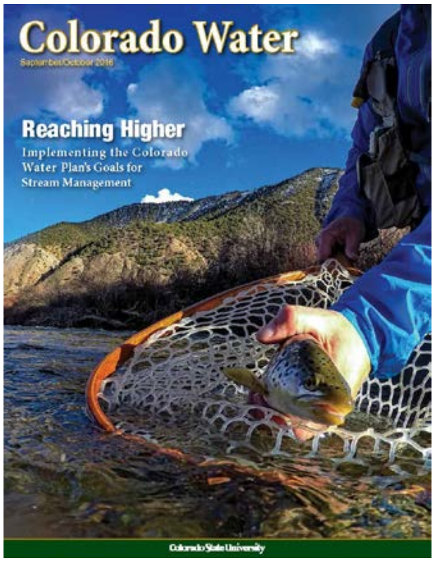
Colorado Water
Volume 33, Issue 1
Climate Smart Agriculture



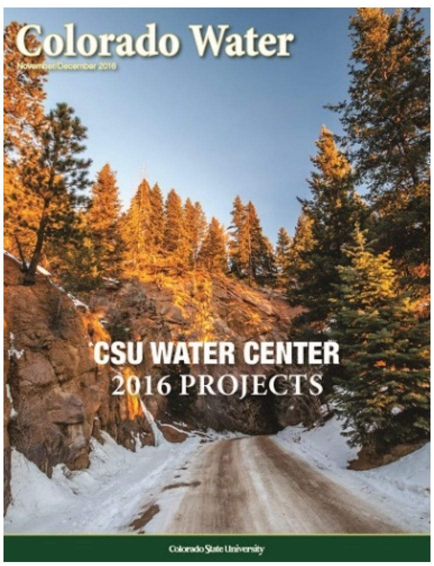
Colorado Water
Volume 33, Issue 2
Student Research 2016



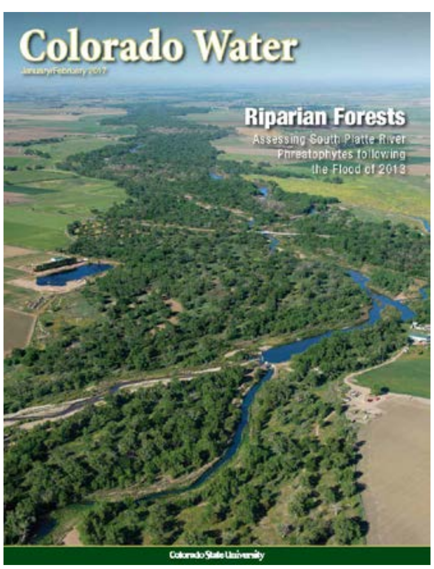
Colorado Water
Volume 33, Issue 3
Water Data



Colorado Water
Volume 33, Issue 4
Reaching Higher, Implementing the Colorado Water Plan's Goals for Stream Management



Colorado Water
Volume 33, Issue 5
CSU Water Center, 2016 Projects



Colorado Water
Volume 34, Issue 1
Riparian Forests, Assessing South Platte River Phreatophytes following the Flood of 2013

This newsletter is directly related to the Colorado Water Institute's Special Report #30 which can be found on: http://cwi.colostate.edu/publications/SR/30.pdf

CSU WATER EXPERTS

CSU WATER CENTER

Colorado State University

By Name A B C D E F G H I J K L M N O P Q R S T U V W X Y Z (View all)

By Department

(select a department)

By Expertise

- (View all)
- Agriculture
- Anthropology, History, and Sociology
- Aquatic, Wildlife, and Forest Ecology
- Business
- Chemistry
- Climate Science
- Ecosystem Dynamics
- Education and Outreach
- Energy
- Environmental Engineering
- Fisheries Biology
- Fluvial Geomorphology and Sediment Transport
- Geosciences
- Groundwater
- Horticulture and Landscape
- Hydraulics
- Hydrology
- Irrigation and Drainage
- Library Materials
- Limnology
- Management and Planning
- Models, GIS, and Data
- Recreational Resources
- Remote Sensing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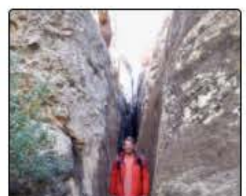
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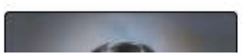
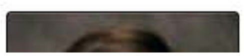
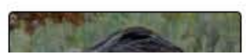
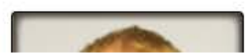
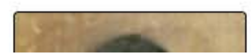






Colorado State University

Focus on Climate Smart Agriculture

May 5, 2016

Lory Student Center Ballroom A
Colorado State University
Fort Collins, CO

Welcome to the 2016 Focus on Climate Smart Agriculture, hosted by Colorado State University. As outlined in the recent Colorado Climate Report, climate change will have a wide range of impacts on Colorado agriculture. Colorado State University – its leadership, faculty, researchers and students – is well-positioned to create new partnerships and lead on this pressing issue.

We welcome your participation in this in-depth conversation about climate impacts, Climate Smart Agriculture and how Colorado agriculture can set a nationwide gold standard on the topic.

Agenda

8:00 AM **Coffee and Registration**

Morning Moderator: Reagan Waskom, Colorado Water Institute

8:30 AM **Welcome Remarks**
- Introduction by Alan Rudolph, Vice President for Research, Colorado State University
- Tony Frank, President, Colorado State University

8:45 AM **Opening Keynote - What is Climate Smart Agriculture and How Will It Help Feed the Future?**
- Jerry Hatfield, Laboratory Director and Supervisory Plant Physiologist, Iowa State University and USDA-ARS

9:15 AM **Panel: Current Climate Trends and Future Projections**
Moderated by Brad Udall, Colorado Water Institute, Colorado State University
- Nolan Doesken, Atmospheric Science, Colorado State University
- Scott Denning, Atmospheric Science, Colorado State University
- Taryn Finnessey, Climate Change Risk Management Specialist, Colorado Department of Natural Resources

10:15 AM **Morning Break**

This Forum is sponsored by Colorado State University Vice President for Research; Office of Engagement, Colorado State University; Colorado Climate Center; Colorado Water Institute

Agenda Continued

10:40 AM **USDA Perspective on Climate Smart Agriculture**
Alexis Taylor, Deputy Under Secretary for Farm and Foreign Agricultural Services, USDA

10:45 AM **Climate Adaptation and Mitigation - Applying Climate Smart Agriculture to Feed 9 Billion**
Moderated by Jerry Hatfield
- Raj Khosla, Soil and Crop Sciences, Colorado State University
- Dennis Ojima, Ecosystem Science and Sustainability, Colorado State University
- Peter Backlund, School of Global Environmental Sustainability, Colorado State University
- Justin Derner, Research Leader, USDA-ARS

12:00 PM **Lunch**

12:00 PM **Colorado Governor John Hickenlooper Video Message**
Introduced by Don Brown, Colorado Commissioner of Agriculture

Afternoon Session Moderator: Meagan Schipanski, Soil and Crop Sciences, Colorado State University

1:30 PM **Engaging with Ag Producers and the Private Sector**
Moderated by James Pritchett, College of Agricultural Sciences, Colorado State University
- Jon Slutsky, La Luna Dairy
- Trevor Amen, CoBank
- Kate Greenberg, National Young Farmers Coalition
- Steve Ela, Ela Family Farms

2:30 PM **Where Do We Go From Here? Putting Theory Into Practice**
Moderated by Gene Kelly, Soil and Crop Sciences, Colorado State University
- Research - Keith Paustian, Soil and Crop Sciences, Colorado State University
- Education - Amber Childress, Ecosystem Science and Sustainability, Colorado State University
- Extension - Lou Swanson, Office of Engagement, Colorado State University
- Private Sector Engagement - John Stulp, Office of Governor Hickenlooper

3:30 PM **Audience Discussion and Wrap-Up**
- Brad Udall, Colorado Water Institute, Colorado State University

4:00 PM **Reception: Looking Ahead to the Future**
Hosted by the College of Agricultural Sciences
- Brief Remarks by Dean Ajay Menon, College of Agricultural Sciences, Colorado State University
- Opportunity to visit with CSU lead researchers and Governor's Climate Team

U.S. Secretary of Agriculture Tom Vilsack Visits CSU

Lou Swanson, Vice President for Engagement and Director of Extension, Colorado State University

With Climate Smart Agriculture (CSA) practices, farmers and ranchers constantly adjust to weather variability to assure their economic and ecological resilience.

CSA is a major U.S. Department of Agriculture initiative, and U.S. Secretary of Agriculture Tom Vilsack visited the CSU campus on May 20, 2016 to discuss CSA initiatives at CSU, a follow-up to a daylong forum held on campus May 5, 2016.

Vilsack shared his assessment of global climate change and the challenges confronting global food production and distribution. He applauded CSU's engagement with Colorado producers as well as U.S. Department of Agriculture's (USDA) Northern Great Plains Climate Hub, located at the Agricultural Research Service in Fort Collins, Colorado. CSU is a partner in the Climate Hub with land-grant universities located in Montana, Wyoming, North and South Dakota, and Nebraska.

In addition to recognizing the efforts of the Climate Hub and CSU research, teaching and engagement climate programs, Vilsack answered a broad array of questions from Colorado's agricultural leaders who had also attended the May 5th forum.

CSA initiatives

CSU leaders emphasized that its CSA initiatives enhance partnerships with Colorado producers, where ideally farmers and ranchers will take the lead in working with their neighbors. CSU Extension, the Colorado Water Institute (CWI) and the College of Agricultural Sciences are actively seeking collaborations with farmers and ranchers and their respective organizations.

"These initiatives are focused on improving Colorado's food systems and food value chains as they adapt to variable weather and climate," said Lou Swanson, Vice President for CSU's Office of Engagement. "The College of Agricultural Sciences and our Office of Community and Economic Development have programs focused on agriculture and food systems innovations that are equally impactful in rural and urban areas of Colorado."

Faculty from a variety of colleges and departments, along with CWI and CSU Extension are providing the primary engagement and outreach programming for these CSA initiatives. A principle program goal, in collaboration with Colorado's farmers and ranchers and their organizations, is to improve their economic and ecological adaptability and resilience as weather patterns change. A guiding engagement principle is emphasis on co-creating programs and developing applied research with Colorado's farming and ranching communities.

Both the USDA and CSU are founding and active members of the United Nations Food and Agriculture Organization's Global Alliance for Climate Smart Agriculture.

More information on CSA and CSU's initiatives, including identifying faculty and staff working in this area is available at http://engagement.colostate.edu/climate-smart-agriculture/.

The spring 2016 issue of *Colorado Water* is dedicated to Climate Smart Agriculture. This magazine is available online at http://www.coopext.colostate.edu/comptrain/docs/ColoradoWater.pdf.

(Above Photo) Provost Rick Miranda (left), Secretary Tom Vilsack (middle) and Vice President Lou Swanson (right). Photo by Joe A. Mendoza

SAVE THE DATE

"The Politics of Water"

Monday, July 25, 2016

lib.colostate.edu/wwsb2016

Benefitting the
Water Resources Archive at Morgan Library

WATER RESOURCES
ARCHIVE

Colorado State University
Morgan Library

WATER RESOURCES ARCHIVE



"The Politics of Water"
Monday, July 25, 2016
9 a.m. - 6 p.m.
Morgan Library
Colorado State University

Morning Session • Barbecue Lunch • Afternoon Session • Reception

Register

Politics — front and center this presidential election year — are always at or near the surface with Western water issues. Whether you are a concerned citizen, political figure, or water professional, attend the 2016 Western Water Symposium and Barbecue to up your political game!

The day of learning, debate, and discussion focused on the politics of water features dynamic speakers from diverse backgrounds. They will each explore ways water politics have shaped our present and could affect our future. From dams to designations, from local water planning to entire basin perspectives, topics are sure to engage, excite, and entertain!

Brad Udall
Senior Water and Climate Research Scientist/Scholar at Colorado State University's Colorado Water Institute

Symposium emcee and moderator

Hank Brown
Former Republican U.S. Representative and U.S. Senator from Colorado, C.P.A., and attorney

"Water: The Key to Improving Colorado's Environment"

D.C. Jackson
Cornelia F. Hugel Professor of History at Lafayette College

"Engineering Politics in the American West: The St. Francis Dam Disaster and San Francisco's Hetch Hetchy Dam"

Jim Lochhead
CEO/Manager, Denver Water

"Can Western Water Politics Avoid a Zero-Sum Game?"

Pat Mulroy
Senior Fellow, William S. Boyd School of Law, UNLV; Climate Adaptation and Environmental Policy, Brookings Institution

"The Politics of the California Bay Delta: Shaping the Future of the Colorado River"

Colorado Water Institute

CDR ASSOCIATES
COLLABORATIVE DECISION RESOURCES

Strengthening Collaborative Capacity for Better Water Decisions

Sylvan Dale Ranch, Loveland Colorado
November 9-11, 2016

Collaborative decision-making on complex water issues requires acknowledging diverse values and competing interests. It requires thoughtful, inclusive, well-defined processes that build relationships and long-term capacity for problem-solving. The need for collaborative processes and practices to address water challenges in the West is more critical than ever. This is certainly true for Coloradans facing the challenge of crafting definitive actions to address issues laid out in the Colorado Water Plan. Leaders and participants in the water community can benefit immensely from learning best practices to design, facilitate and participate in meaningful collaboration and consensus-building.

What:

A 16-hour, highly interactive, hands-on training to help water professionals, leaders, and stakeholders deepen and strengthen their skills, tools and capacity for collaboration and consensus around complex water challenges.

Who Should Attend:

Water professionals, leaders, and stakeholders from Colorado's public, private and non-profit sectors.

Workshop Framework:

This interactive training workshop will employ basic and advanced principles and best practices and their application through skills-building exercises, case studies, and discussions that explore challenging situations faced by participants. Highlights include:

- Principles, best practices, and skills in collaborative problem-solving
- Interest-based negotiation skills and practice
- Design and facilitation of effective collaborative processes

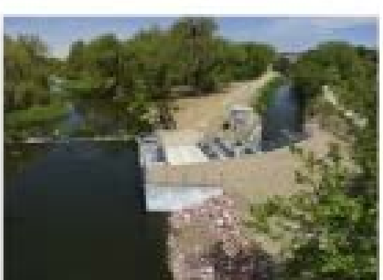
When and Where:

- Begins **Wednesday, November 9 at 3pm** and ends **Friday, November 11 at 3pm**
- Sylvan Dale Ranch, Loveland CO – http://www.sylvandale.com
- This is the second in a series of workshops held at locations throughout Colorado.

Information and Registration:

- To register, visit http://cdrassociates.org/training-courses
- For more information, email MaryLou Smith at MaryLou.Smith@colostate.edu or Ryan Golten at rgolten@mediate.org.

POUDRE
River Forum
The Poudre Runs Through It



Cultivating Connections for a Healthy, Working River

Third Annual Poudre River Forum

Friday, February 5, 2016

9am - 4pm | The Ranch, Loveland

Featuring

"Nexus of Agriculture and the Poudre River: Current Realities and Plans for the Future"

Representing a variety of agricultural operations and expertise, panelists discuss their reliance on Poudre River water, their planning for the future with a growing demand for this limited resource, and how the dynamics of this vital economic sector affect their relationship with the River.

Moderator: Luke Runyon, KUNC and Harvest Media

"An Inspiring Story of Agricultural/Environmental Cooperation on Wyoming's Little Snake River"

Keynote remarks from Pat O'Toole, Family Farm Alliance

"Challenges of Pursuing Water Projects and Initiatives: Key Ingredients and Lessons for Success"

Panelists explore getting to "yes" on large, complex and controversial projects. Examples include the Platte River Recovery Implementation Program, the Colorado River Cooperative Agreement, the Upper Colorado River Endangered Fish Recovery Program, and the Windy Gap Firming Project.

Moderator: Kevin Duggan, Coloradoan

Plus

Videos on the *Animated History of the Poudre* and *Year in the Life of Ditch Company*, two dozen educational displays, and a closing celebration with music from Blue Grama, Odell brews and other refreshments, and door prizes

$50

Scholarships and reduced rate are available.
Registration includes lunch and social hour.

Register online before JANUARY 25

http://cwi.colostate.edu/ThePoudreRunsThroughIt/forum_2016.shtml

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WATER RESOURCES
ARCHIVE






Water Tables 2017

Refilling the Leadership Reservoir

Welcome to Water Tables 2017! We are excited to be working again in conjunction with the Annual Convention of the Colorado Water Congress to host our annual fundraising dinner in Denver on **Thursday, January 26, at the Hyatt Regency Denver Tech Center**.

A fundraising dinner for the Water Resources Archive, Water Tables features hosted tables for an evening of conversation on specified topics. Guests have their choice of host on a first-come, first-served basis.

Topic: Refilling the Leadership Reservoir

Western water issues have long benefitted from bold leaders taking great risks, bringing forth innovative solutions, and committing to creative collaborations. Ongoing political, environmental, and educational challenges require a steady flow of able individuals to keep the leadership reservoir topped off. Join the CSU Morgan Library Water Resources Archive for an evening of stimulating dinner conversation led by established and emerging water professionals widely recognized for their excellent leadership qualities. Engage with Aspinall Award recipients, Water Leaders Program alumni, and other luminaries in once-in-a-lifetime discussions of leadership lessons, inspirations, and advice.

Event Questions?

Please contact David Ramsay, (970) 492-4019, `David.Ramsay@colostate.edu`

Also, for group reservations of six or more, please contact David Ramsay as well.

About the Water Resources Archive

The **Water Resources Archive** preserves materials critical for documenting the state's water history. It is Colorado's only archive dedicated to water issues. The ever-growing contents of the Archive serve as a living repository for the history of public policy, engineering, law, ecology, economics, and the cultural aspects of water use. Funds raised from Water Tables support the Archive's efforts to preserve and make available over 100 collections important to the water heritage of Colorado and the West, including outreach activities, digitization projects, and several student assistants.

Other Colorado Water Institute Research and Activity Reports

- Developing a Refined Groundwater Flow Model for the LaSalle/Gilcrest Area, Ryan Bailey, CWCB
- Quantifying Pumping-Induced Streamflow Depletion in the South Platte River Corridor, Ryan Bailey, CWCB
- Data Collection and Analysis in Support of Improved Water management in the Arkansas River Basin, Phase 3, Timothy Gates, CWCB
- Aquifer Storage and Recovery – Fountain Formation in Northern Colorado, Tom Sale, CWCB
- Colorado Irrigation Center Design and Concept Development, Jose Chavez, CWCB
- Enhanced Open Data for Colorado's Water Resources, Steve Malers, CWCB
- Agronomic Responses to Partial and Full Season Fallowing of Alfalfa and Grass Hayfields, Perry Cabot, CWCB
- Determination of Consumptive Water Use of Winter Wheat in the Arkansas Valley (Year 2), Allan Andales, CWCB

Developing a Refined Groundwater Flow Model for the LaSalle/Gilcrest Area

Dr. Ryan Bailey, Assistant Professor, rtbailey@engr.colostate.edu
Department of Civil and Environmental Engineering, Colorado State University

Location of the Work. LaSalle/Gilcrest Area, Colorado

Background. The surface watershed of the South Platte River Basin (SPRB) lies on alluvial deposits that form an unconfined aquifer system connected with the surface water, with a thickness that reaches 200 ft in the lower SPRB. The aquifer, which sustains the base flow in the river, is recharged by infiltrations from precipitation and irrigation canals, as well as seepage from surface water bodies and streams. Conjunctive use of surface and groundwater resources in the SPRB is regulated accordingly with the 1969 Groundwater Administration Act (Senate Bill 81), which requires all non-exempt groundwater rights to come into priority. Following legislative changes that occurred in 2003-2004, water resources have been administered following strict priority rules since 2006, with all non-exempt wells required to have a decreed augmentation plan that replaces 100% of their estimated stream depletion. About 4,000 wells have been totally or partially curtailed from pumping during the last 6 years (Nettles, 2011), potentially resulting in reduced aquifer drainage and rising water table levels in several areas of the SPRB, including the LaSalle/Gilcrest area.

Project Objectives. The objectives of this project are to use a refined groundwater flow for the LaSalle/Gilcrest area to:

(1) Investigate reasons for high water table elevation in the area; and
(2) Explore the effect of best-management practices (BMPs) on water table elevation.

The model is being developed in a current project through funding from the Colorado Water Conservation Board (project ends June 30 2016), and will be further refined, calibrated, and tested in the proposed project. Potential refinements include implementing unsaturated-zone flow into the model and using the USG (UnStructured Grid) version of MODFLOW (Panday et al., 2013). The model will be run for the time period 1990-2012, thereby assessing groundwater flow dynamics and water table fluctuation patterns before and after well curtailment.

Methods. The project objectives will be accomplished by the following 3 tasks:

Task 1: Model Refinement
The model being developed in the current CWCB project is based on the SPDSS groundwater flow model, with spatial discretization (horizontal cell size, vertical layering) refined to depict spatial variations in water table elevation more accurately for the LaSalle/Gilcrest area. For the proposed project, groundwater flow in the unsaturated zone will be simulated using the Unsaturated Zone Flow (UZF) package of MODFLOW, which has been used successfully in similar agricultural regions of Colorado (e.g. Arkansas River Valley). Including the UZF package is important due to the dependence of shallow groundwater on near-surface processes

such as infiltration, evaporation, and plant transpiration. Main inputs to the UZF package are infiltration from rainfall, applied irrigation water, canal seepage, and recharge pond water. A potential refinement could be the conversion of the model to the USG version of MODFLOW, to enable locally refined grid cells near pumping wells, canals, and hydro-stratigraphic units. This conversion will take place if time allows.

Task 2: Model Calibration and Testing

Model results for the years 1990-2012 will be tested against measured water table elevation from observation wells in the region. Model parameters (hydraulic conductivity) will be modified within acceptable ranges to minimize residuals between simulated and observed values. Newly acquired pumping test data within the Gilcrest area will be used to constrain aquifer parameters.

Task 3: Assess Causes of High Water Tables and Effect of BMPs

The tested model will be used to assess the cause of water table fluctuation during the 1990-2012 time period and, most importantly, the cause of rising water table elevation during the post-2006 time period. This will be accomplished using sensitivity analysis, with each system stress (e.g. irrigation water, canal seepage, recharge pond infiltration, pumping) analyzed for its impact on water table elevation and overall groundwater storage. Results of the model simulations will yield a ranking of stress influence and also identify the source/sink that could have the largest effect on decreasing water table elevation. Using these results, a final set of simulations will be run to determine the effect of implementing single and multiple BMPs, including scenarios of increased groundwater pumping and decreased surface water delivery for irrigation. For each scenario simulation, the volume of streamflow depletion from the South Platte River will be estimated and compared with results from analytical models (e.g. Glover, Hunt solutions).

Deliverables. At the end of year (June 30, 2017), a final technical report describing project activities, analysis results, and findings will be submitted to the CWCB. In addition, the PI will meet with CWCB representatives at least twice during the project duration, either at the CSU campus or at CWCB offices to best coordinate projects activities and discuss project progress and future direction.

Completion Date. This project will be completed by June 30, 2017. All deliverables will be provided to the CWCB on or before that date.

Budget and Budget Justification. The following table summarizes the proposed budget.

0.75 Month Faculty Salary[1]	$9,656
12 Month PhD half-time Salary[2]	$27,694
1 semester tuition and fees	$5,462
Indirect Cost (15% rate)	$6,422
Total	**$49,234**

One PhD student will be hired as a Graduate Research Assistant and supported financially in this study. PhD student salary includes $1700/month during each semester and $3,500/month during the summer.

[1]Includes 25% fringe [2]Inclues 5.5% fringe

Quantifying Pumping-Induced Streamflow Depletion in the South Platte River Corridor

Dr. Ryan Bailey, Assistant Professor, rtbailey@engr.colostate.edu
Department of Civil and Environmental Engineering, Colorado State University

Location of the work. Centennial Well Field / South Platte River system (downstream of Chatfield Reservoir, south Denver)

Purpose. Stream-aquifer interaction has been studied intensively in Colorado during the last 50 years due to the important role it plays in water rights management in alluvial aquifer systems. Of prime importance is the impact of groundwater pumping on nearby streams, as streamflow is reduced due to pumping-induced infiltration of stream water into the aquifer. Typically, one-dimensional analytical models (e.g. Glover-Balmer, 1954; Hunt , 1999; Hunt, 2003) are used to determine streamflow depletion. However, these models rarely are tested against field data, in particular the actual volumes of stream water depleted from the stream channel. Furthermore, these models assume a large degree of hydraulic connection between the aquifer and the stream, which may not be the case in certain settings. For example, field work performed during a recent visit to the Centennial Well Field adjacent to the South Platte River downstream of Chatfield Reservoir indicated that indeed a strong hydraulic connection between the aquifer and the river is not present, despite an extended pumping period. As water conservation efforts continue throughout the state, a better understanding of these processes is needed.

The hypothesis motivating this project is that *available analytical and numerical groundwater models do not adequately represent pumping-induced groundwater-surface water interactions*. Using a combination of field data collection and modeling applications, the following research questions will be used to address this hypothesis: (1) What is the overall impact of high-capacity pumping on a reach of a nearby river? Specifically, what volume of river water is depleted due to the pumping? (2) What is the degree of hydraulic connection between the river and the aquifer during both long-term and short-term pumping periods? Does the hydraulic connection depend on time of pumping? Do the pumps' drawdown cones extend to the other side of the stream? (3) Can available models (analytical; numerical) account for the physical processes observed in the study region? If not, what modifications can be implemented to provide accurate processes in the models? This project provides training for a graduate student and an undergraduate student within the area of groundwater hydrology and water resources engineering.

Objective and Methods. The overall objective of this project is to determine the impact of high-capacity pumping on streamflow of a section of a major river. This will be accomplished using a combination of field data collection (streamflow, water table elevation, pumping flow rates) and model application for a reach (~300 m) of the South Platte River just downstream of Chatfield Reservoir in the south Denver area. The Centennial Well Field consists of 4 high-capacity pumping wells, with each well located within 200-400 ft of the river. Furthermore, pumping rates can be a significant fraction of streamflow during winter months, thereby allowing the effects of pumping on streamflow to be quantifiable. This project will be supplemented by Water

& Environmental Systems Technology, Inc. to install observation wells, and by Centennial Water District for site access. The objective will be accomplished by the following 4 tasks:

Task 1: <u>*Field Site Instrumentation.*</u> The monitoring system will consist of 6 observation wells on the side of the river where the pumps are located, and 1-2 observation wells on the opposite side of the river. Two observation wells will be located within 10 ft of the river, with the others located closer to the pumping wells. Stream depletion along the 300-m control volume of the South Platte River will be quantified by assessing streamflow at the upstream and downstream sections of the control volume using weirs and data loggers. Data loggers will be installed in the wells and at the gaging sites. [*Timeline*: Months 1-3; *Deliverables*: Monitoring Network]

Task 2: <u>*Data Collection and Analysis*</u>. Water level data will be downloaded from the data loggers frequently for quantifying spatial and temporal patterns of groundwater drawdown. Water level data will be used at the upstream and downstream sections of the river control volume to quantify inflows and outflows, with the difference assumed equal to stream depletion. Drawdown data in the wells immediately adjacent to the river, and also drawdown data in the wells on the opposite side of the river, will provide information regarding hydraulic connection between the aquifer and the river. [*Timeline*: Months 1-10*; Deliverables*: Data sets]

Task 3: <u>*Modeling Testing*</u>. Analytical stream depletion models will be tested against the drawdown data and estimated streamflow depletion to determine their applicability to the study site. Groundwater-surface water exchange processes in numerical models (e.g. MODFLOW) also will be assessed to determine their adequacy in representing physical processes of the study site [*Timeline*: Months 4-11*; Deliverables*: Model input files for a number of scenarios; Model results]

Task 4: <u>*Report Results*</u>: The final report will describe the methods, results of the research, and recommendations for expanding the work to larger scales. A CWI newsletter article will be written, and the results presented regionally. Peer-reviewed publication of this work will be pursued. [*Timeline*: Months 7-12*; Deliverables*: Final report, CWI newsletter article]

Budget and Budget Justification. The following table summarizes the proposed budget. Fieldwork and equipment costs include water level data loggers (Hobo Onset) for the monitoring wells and for stream gaging sites, and also travel costs for frequent trips to the study site (~180 mi roundtrip). Additional field equipment costs (observation well materials and installation, stream gaging equipment) and site access will be covered through partnership with Water & Environmental Systems Technology, Inc. and Centennial Water District.

Faculty Salary, 0.5 months	$5,200
Graduate Research Assistant, 12 months	$21,600
Tuition for GRA (1 semester)	$5,500
Undergraduate Research Assistant, 200 hours	$2,700
Fieldwork & Equipment	$4,400
Facilities and Administrative @ 15%	$5,910
Total	**$45,310**

Pre-Proposal to Colorado Water Institute FY2016 Water Research Program

Title: Data Collection and Analysis in Support of Improved Water Management in the Arkansas River Basin, Phase 3

Principal Investigator: T. K. Gates, Prof. (tkg@engr.colostate.edu), **Co-Principal Investigator**: Jeffrey D. Niemann, Assoc. Prof.; *Civil and Environ. Engrg. Dept., CSU*

Location: Arkansas River Basin, Colorado

Purpose of the Research: The Arkansas River, drawing from Colorado's largest watershed (more than 28,000 mi^2), serves as a vital part of the State's water resource system. In the years to come, important decisions, including long-term investments in infrastructure and amended management practices, will need to be made in Colorado's Arkansas River Basin to enhance overall beneficial water use, redress serious problems of water quality degradation (e.g., salinity, selenium, uranium, and nutrients), conserve water, and find innovative ways (e.g., the Super Ditch) to address mounting pressures for increased diversions out of the Basin.

A reliable database is needed to allow characterization of the Basin's stream-aquifer system and to undergird both existing and future modeling tools, including the proposed Arkansas Basin Decision Support System (Ark DSS). Data on both surface and subsurface waters are needed in both the mountainous Upper Arkansas River Basin (UARB), above Pueblo Reservoir, and in the agriculturally-intensive Lower Arkansas River Basin (LARB). For over 16 years in the LARB and 4.5 years in the UARB, Colorado State University (CSU) has conducted extensive field monitoring to build such a database. *The project proposed herein constitutes the third phase of project that began in FY2014 (Phase 1). The purpose is to collect and analyze key field data in representative regions of the Arkansas River Basin needed to maintain and enhance a database in support of improved water management. Thereby, this project will prevent interruption of long-term data collection efforts.*

Objectives: The data-focused objectives of this one-year project are:

(1) Gather data on water table levels and water quality in existing groundwater monitoring wells distributed over representative study regions in the UARB and LARB, for characterization of the aquifer system and to support flow and solute transport models developed by CSU, the Lease-Fallowing Water Accounting Tool, and the proposed Ark DSS to be developed over the coming years by the Colorado Water Conservation Board;

(2) Gather data on water quality, water levels, and flows at selected sites along canals, tributaries, and the main stem of the Arkansas River in the UARB and LARB to characterize the stream system and to support current and future models;

(3) Conduct quality-control tests of the gathered data and enter them into the SQL database for the Arkansas River Basin developed and maintained by CSU; and

(4) Conduct a preliminary analysis of the data gathered under this project and summarize in a final report for use in system characterization and model support.

Methods: About 150 landowners provide access to water sampling sites in the UARB and LARB. *Site availability provides valuable in-kind matching support for this proposed project.* Data on groundwater and surface water quantity and quality were gathered during 4 sampling events at numerous locations in Phase 1 in the UARB between July 2014 and April 2015 and during 6 sampling events in the LARB in between May 2014 and June 2015. In Phase 2, similar field data have been gathered so far during events in July and August 2015 in the UARB and in August 2015 in the LARB. Field data on water table depth and in-situ water quality parameters (electrical conductivity, temperature, pH, dissolved oxygen, and oxidation reduction potential) will continue to be gathered at about 18 existing groundwater monitoring wells in a study region in Chaffee County in the UARB and about 60 to 70 groundwater monitoring wells in two study regions within Otero, Bent, and Prowers Counties in the LARB. Three to four sampling events will be conducted in each of the three study regions. During one sampling event in both regions of the LARB, water samples will be extracted from 30 to 40 wells and analyzed for major dissolved ions, nutrients, selenium, and uranium. Similar water samples will be taken from UARB wells during one sampling event. Water quality samples will be analyzed by EPA-approved laboratories. In-situ water quality parameters will be measured during the sampling events at about 22 surface-water sites in the UARB and at about 30 to 50 sites in the LARB. Flow rates will be measured at about 8 of the surface-water sampling sites in the UARB. If available funds permit, pressure transducers will be installed in stilling wells to monitor water level changes (hourly intervals) near flow-measurement locations within two or three key tributaries that are not equipped with permanent stream gauges.

Standard procedures and protocols will be followed in maintaining equipment for field measurements and sample collection. Field data will be checked to ensure that values are physically reasonable and will be subjected to statistical outlier tests in comparison with previously collected data.

Data will be added to CSU's SQL database (compatible with Colorado Division of Water Resources HYDROBASE). Preliminary data analysis will describe spatiotemporal variability of measured values and basic statistical characteristics in relation to previous data gathered in the study regions. Field measurement methods, along with procedures and results of preliminary analysis, will be documented in a final project report.

Timeline, & Completion Date: Data collection under Phase 3 is planned to commence in July 2016. Two irrigation season sampling trips and one to two off-season trips are planned for each study region in the UARB and LARB. Data will be checked and entered into the database over the course of the one-year project. Final data analysis will commence on about 1 March 2017 and a final report will be prepared. The project is scheduled for completion on 30 June 2017.

Budget: An estimated budget is summarized in Table 1.

Table 1. Estimated Project Budget ($) (July 2016 – June 2017)

Salaries	18215
Travel	9338
Materials and Supplies	2375
Laboratory Analysis	13550
Indirect Costs (15%)	6522
TOTAL	50000

Budget Justification: Included are about 750 person-hours of undergraduate student effort and 0.5 person-months of faculty effort; mileage, per diem, and accommodations; parts/maintenance for multi-probes, pressure transducers, sampling pumps, acoustic Doppler velocimeters; water sample filters; sample bottles and preservatives; calibration solution; field books; and other miscellaneous supplies. Costs of laboratory analysis are based upon recent quotes from respective laboratories.

Dept. Head Cont. Info.: Chuck Shackelford, 491-5049, shackel@engr.colostate.edu.

Colorado Water Institute

FY 2016 Request for Pre-Proposals

1. **Title. Aquifer Storage and Recovery – Fountain Formation in Northern Colorado**
2. **Principal investigator name(s) and university.**

Dr. Tom Sale
Associate Professor
Civil and Environmental Engineering, Colorado State University
970-491-8413 TSale@engr.colostate .edu

Dr. Mike Ronayne
Associate Professor
Geosciences, Colorado State University
Michael.Ronayne@colostate.edu

Dr. Sally Sutton
Associate Professor
Geosciences, Colorado State University
Sally.Sutton@colostate.edu

3. **Location** - Colorado State University and Northern Colorado
4. **Purpose of the research –**

Aquifer storage and recovery (ASR) is emerging as promising strategy for water storage in Colorado. Potential attributes of coupling ASR to existing infrastructure include reduced losses to evaporation and seepage, lower costs, and greater reliance including drought storage.

Recent research at CSU has led to the realization that the Fountain Formation in Northern Colorado could be a remarkable resource for ASR. The Fountain Formation:

- Lies immediately above the crystalline rock of the Front Range.
- Is composed of approx. 800 feet of interbedded sandstones and siltstone.
- Extends along the Front Range in northern Colorado, is largely undeveloped, and appears to be largely isolated by surrounding aquitards and structural features.
- Dips to the east providing the potential for large yields due to the potential to apply large drawdown or mounding.
- Lies in close proximity to key complementary infrastructure associated with the Colorado Big Thomson project and the cities of Northern Colorado.

The purpose of this project will be to synthesize and apply available data to assess the feasibility of incorporating ASR in the Fountain Formation into Northern Colorado's water supply infrastructure.

5. **Objectives, methods, timeline and completion date.**

The overarching objective for this study is to investigate the feasibility of ASR in the Fountain Formation in Northern Colorado. Critical elements of the study will include:

- **Develop a conceptual hydrogeologic model** for the Fountain Formation in Northern Colorado. Synthesize available data to describe the geologic framework (stratigraphy, major geologic structures) and estimate aquifer properties. Data sources will include the USGS, State Engineers Office (Aqua Maps), and Colorado Geologic Survey.
- **Apply CSU's well field superposition model** to evaluate the hydraulic performance of the two or more portions of the Fountain Formation using hydraulic stresses that are representative of current proposed water storage projects in northern Colorado (10s thousands of acre-feet).
- **Apply CSU's subsurface water storage assessment model** to evaluate the performance and cost of at least two Fountain Formation ASR projects.

All work will be completed in a one-year time frame. Result from all of the work will be documented in a comprehensive report

6. **Budget. - $50,000**

7. **Budget justification.** Fund will be split between a full time master student and faculty including Drs. Sale, Ronayne, and Sutton. Complementary support will come from currently supported students including Azia Alqahtani / Civil and Environmental Engineering and Cat Cannan / Geosciences.

8. **Department Head Contact Information.**

Chuck Shackelford / Civil nd Environmental Engineering / 970-491-5051 / shackel@engr.colostate.edu

Rick Aster / Geosciences / 970-491-7606 / Rick.Aster@colostate.edu

9. **Department Accountant Contact Information for Pre and Post Award.**

Cathy Smith / 970-491-5914 / cathy.smith@colostate.edu
Heather Ihde / 970-491-3521 / Heather.Ihde@colostate.edu

9. **Office of Sponsored Programs Team Leader Contact Information.**

Jennifer Strange / 970-491-2083 / jennifer.strange@colostate.edu
Kristine Miller / 970-491-1552 / Kris.Miller@colostate.edu

PROJECT TITLE: Colorado Irrigation Center Design and Concept Development

PRINCIPAL INVESTIGATORS (CO-PIs): Dr. José Chávez, Associate Professor, Civil and Environmental Engineering, Colorado State University; 970-491-6095; Jose.Chavez@colostate.edu

Dr. Reagan Waskom, Director, Colorado Water Institute and Chair of Colorado Water Center; Colorado State University; 970-491-6308; Reagan.Waskom @colostate.edu

Dr. Stephen W. Smith, Owner, Buena Vida Farm and Wade Water LLC, 970-222-9680, swsmith@buenavidafarm.com

LOCATION WHERE THE WORK IS TO BE CONDUCTED: This project will be conducted at the Colorado State University (CSU) – **Agricultural Research, Development and Education Center** (ARDEC), north of Fort Collins, Colorado.

PURPOSE OF THE RESEARCH

Current pressures on available water supplies in the western U.S. are creating unprecedented political, sociological, engineering, and management issues for practitioners in the irrigation sector. This includes both the agricultural irrigation and landscape irrigation sectors of the irrigation industry. Climate change, extended drought periods, and population forecasts portend significant future water shortages due to the combination of increased demand and probable long term reductions in water supplies. The western U.S. has experienced severe, and even exceptional-rated, drought for much of the past decade. Competition has increased for a limited water resource from agriculture, growing municipalities and the environment. Over 70% of water diverted from western rivers goes to irrigation demands, thus the irrigation industry is the primary target for change and improvement as water becomes increasingly scarce. Technology, large data, management and information systems currently exist that can significantly upgrade irrigation system efficiency, but they have not yet been widely implemented in most of the world, including the western U.S. Additionally, several state and federal water related agencies such as the US Geological Survey and USDA Agricultural Research Service / Water Management Unit have science staff located in close proximity to Colorado State University, uniquely positioning this area to be a global center of activity with respect to irrigation and water management. What is missing is a not-for-profit, non-advocacy, non-proprietary training organization that can serve as a connector and nucleus for this economic cluster. There are also strong potential synergies between Colorado State University, Colorado Water Innovation Cluster, Irrigation Association, Irrigation Foundation, and numerous irrigation equipment manufacturers with opportunities for joint collaborations in demonstrations, technology transfer, tailored workshops, certifications, and student training. In particular, CO Division of Water Resources has raised the need of an irrigation center in CO. Thus, this project will develop a 5-year business plan for the design and operation of a Colorado Irrigation Training and Demonstration Center (CITDC).

OBJECTIVES and METHODS

The main objective of this project is to develop a business plan to create and operate a Colorado Irrigation Training and Demonstration Center (CITDC) within Colorado State

University (ARDEC). A partnership is proposed between private business and the public sector to create a new Center of excellence in irrigation automation, SCADA, modernization, evaluation, management, training to enhance the economic and environmental opportunities for water sharing arrangements in CO, the U.S. and across the globe.

The CITDC concept development will revolve around the envisioned goals of the center which are listed below:

- Develop a state of the art instrumented location to showcase current irrigation technologies (hardware, software and management systems)
- Provide hands on training in the use of new irrigation technologies to diverse clientele – field days, short courses, distance education and semester long graduate and undergraduate courses
- Provide on-site evaluation of irrigation systems and technology
- Provide a clearinghouse of irrigation information for Extension, NRCS, consultants and industry personnel
- Provide training and outreach to irrigated crop producers
- Develop certification training and continuing education for professional irrigation practitioners
- Use instrumented hydraulics lab to certify and test gates and sensors, and as a training site for industry personnel, students and international visitors
- Help train the next generation of irrigation engineers and water managers

In that regard, the sub-objectives of this proposal are to: 1) establish a consortium of interested parties that will help develop a business plan for the CITDC, 2) design the center physical plans (e.g., buildings, equipment), 3) identify entities and obtain commitments (pledges) to support the creation of the CITDC (e.g., instruments, equipment).

In order to achieve the established goals the following steps will be followed:

a) (Sub-objective 1): Contact potential collaborators (listed at the end of the proposal) and hold face to face (at least 6) meetings and phone (as well as Skype) conference calls (as needed). Visit two established irrigation centers (i.e., Center for Irrigation Technology at Fresno State, and the Irrigation Training and Research Center at Cal Poly) in CA to learn about their business model and structure.
b) (Sub-objective 2): Work with an hourly student and a member of the Irrigation Association (to be contracted) based on outcomes from the previous objective.
c) (Sub-objective 3): Contact and visit federal, state and local agencies as well as the irrigation industry to obtain pledges for acquiring (or develop) irrigation equipment, instruments, sensors, teaching/training/testing material, and other needed support for the center.

Project timeline: July 1st 2016 through June 30th 2017.

Progress reports will be made available quarterly (i.e., every three months).

BUDGET AND JUSTIFICATION

This agreement is for a maximum of $49,876 budgeted as follows.

Salary (one month, co-PI Chávez; $11,344)	$11,344
Fringe benefits (@ 25.4%)	$ 2,881
Hourly student salary and fringe (1260 hrs)	$15,845
Sub-contract with Irrigation Association	$ 5,000
Travel to irrigation centers in CA (four tickets)	$ 6,000
Mileage for trips to meetings in CO	$ 1,100
Group meetings, venues, refreshments	$ 1,200
Subtotal	$43,370
Indirect cost (@ 15%)	$ 6,506
Total	$49,876

These funds will pay for 1 month salary of co-PI Chávez, hourly student 1260 hours (part time during regular semesters and full time during summer months), Irrigation Association consulting costs, trips within the state and to CA, and group meetings.

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Department Accountant Contact: Pre-award Valorie M. LeFebre, 970-491-6628, valorie.lefebre@colostate.edu; Post-award Rebecca (Becky) A. Burke, 970-491-3943, rebecca.burke@colostate.edu

OSP Team Leader Contact: Jennifer E. Strange, 970-491-2083, jennifer.strange@colostate.edu

Potential Collaborators: Chris Thornton (CSU, ERC), Zach Thode (Rubicon), Colorado DWR, CSU Civil & Environmental Engineering and Soil and Crop Sciences Departments (among others) irrigation related faculty, CSU ARDEC administration, CO Ag Experiment Station , CSU Extension, USDA ARS and NRCS, Aqua Engineering, Irrigation Association (IA), USCID, etc.

Enhanced Open Data for Colorado's Water Resources

Principal Investigators:
Reagan Waskom, Colorado Water Institute (CSU), 970-491-6308, reagan.waskom@colostate.edu
Steve Malers, Open Water Foundation (OWF), 970-286-7462, steve.malers@openwaterfoundation.org

Location of the work and project team: The work will be performed in Fort Collins utilizing a CSU student intern in collaboration with the Open Water Foundation (OWF), a Fort Collins nonprofit that focuses on open source software and open data for water resources. OWF works with CSU on various projects and employs CSU interns on an ongoing basis.

Purpose of the Research: The proposal is being submitted under priority research topic "Developing and disseminating open source data systems for Colorado". The purpose of the project is to increase public access to State of Colorado water resources data and information, consistent with the State's desire to promote open data initiatives. There is a need to provide open data access both to increase the amount of data that are accessible, and also to increase the effectiveness and efficiency of using such data. Improved access to data will allow integration of datasets to address larger and more difficult issues such as those addressed in the Colorado Water Plan (CWP). Currently, the following barriers exist to accessing data:

- Lack of open data policies and governance
- Lack of standard data formats, and data formats that are difficult to use
- Lack of metadata and documentation explaining the data and how a dataset can be used
- Lack of software that can be used by the public to access open data

A number of State efforts, such as CWP, Statewide Water Supply Initiative (SWSI), and Basin Implementation Plans (BIPs), could benefit from improved implementation of open data protocols. Although the State has made progress (such as use of data.colorado.gov) available data are not being used in an integrated way to publish and support important efforts such as the CWP. This project will focus on developing working examples of open data for important efforts such as the CWP, SWSI, and BIPs that will demonstrate protocols for publishing data using open data standards. This will allow the public and organizations to use the data in a variety of analyses and leverage existing work as much as possible.

Objectives:

1. Determine standards and implement working examples of data sets formatted for open data (for example data products mentioned in the CWP and SWSI). The goal is to increase publishing CWP and SWSI data in open data formats and enable increased use of such datasets.
2. Expand the use of water data available on data.colorado.gov by providing documentation and working examples of how to use the data in common tools such as Microsoft Excel, Google Maps, Google Earth, and other technologies.

3. Enhance software in Colorado's Decision Support Systems (CDSS), such as TSTool, to interface with the Socrata software web services provided on the data.colorado.gov website, for example to automate reading datasets such as population, water resources, and economics data.
4. Facilitate State of Colorado staff in publishing additional datasets on data.colorado.gov, to facilitate increased use of open datasets.

Method (Approach): If awarded, one or more CSU students will be identified to work with OWF technical leadership. The following broad tasks are envisioned:

1. Review Colorado Water Plan, SWSI, and Basin Implementation Plans to identify important datasets that can benefit from an open data approach. Coordinate with CWCB staff to select datasets.
2. Determine how best to format the datasets for download from the CWCB website and/or data.colorado.gov. Develop working examples and documentation for creating and using the datasets, for example in Microsoft Excel, Google Maps, and Google Earth. These examples can serve as templates for CWCB staff and consultants who develop datasets for studies.
3. Enhance CDSS software to read data from the Socrata web services provided by data.colorado.gov using Socrata Open Data API (SODA). This capability will allow CDSS tools to automate access to open data available on data.colorado.gov, which will facilitate integrated water resources planning.
4. Present the results of the project to CWCB staff, Basin Roundtables including education subcommittees, webinars, university seminars, etc., as appropriate.

Timeline and Completion Date: The scope is expected to be substantially completed within the first eight months after signing the contract, with follow up based on feedback.

Deliverables: Deliverables will include open data documentation guidelines, and open datasets from the Colorado Water Plan, SWSI, and/or BIPs, suitable as examples for CWCB staff and consultants that may publish open data. CDSS software will also be updated. OWF recommends that deliverables be managed in open source cloud repositories such as GitHub that allow easy access by various stakeholders and users of products.

Budget: $50,000 is being requested for this project, with distribution estimated as follows (final distribution will be based on available student intern resources):

- $15,000 to $20,000 – CSU student intern for one year
- $30,000 to $35,000 – OWF technical team

Budget Justification: Budget will be used to pay for software developers and technical leadership at OWF, and CSU student(s) to perform tasks to improve open data access. The resulting work can be leveraged by State staff and consultants on efforts such as SWSI, as well as by university researchers.

Department Head Contact Information: Reagan Waskom
Department Accountant Contact Information for Pre and Post Award: Nancy Grice
Office of Sponsored Programs Team Leader Contact Information: TBD

Memorandum

To: Tim Feehan (Colorado Water Conservation Board), Dr. Reagan Waskom (Colorado Water Institute

From: Dr. Perry Cabot

Date: 6/7/2016

Re: Additional funding to support continuation of CWI Project entitled “Agronomic Responses to Partial and Full Season Fallowing of Alfalfa and Grass Hayfields

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This memo supplies information regarding the request for an additional $5,000 to support an additional season of data collection for research under the CWI Project entitled “*Agronomic Responses to Partial and Full Season Fallowing of Alfalfa and Grass Hayfields*.” This project is embedded within the larger goals of the project partially-funded by the CWCB, entitled “*Colorado River Water Bank Feasibility Study Phase 2B*” that is administered through the Colorado River District.

The bulk of this research was conducted by Prof. Joe Brummer and his graduate student Lyndsay Jones. Ms. Jones recently received her Master’s Degree from the Department of Soil and Crop Sciences for her thesis entitled “*Agronomic Responses of Grass and Alfalfa Hayfields to No and Partial Season Irrigation as Part of a Western Slope Water Bank*.” Ms. Jones degree schedule did not allow time for her to finish evaluating the recovery behavior of the crops in 2015. We are pleased to say that Ms. Jones has gone on to secure employment as a Lead Feed Technician at Aurora Organic Dairy. Since the completion of her thesis, Dr. Perry Cabot has taken on a supervisory role in the project, and has utilized a graduate student (Sumit Gautam) and AES personnel to continue evaluating the recovery behavior of the stressed crops.

The first phase of project results indicates that reduced irrigation may improve forage quality slightly, but will significantly reduce yields during the stress year. When irrigation is returned after one year of partial irrigation, forages may have increased quality due to reduced fiber content, but grass yields will likely not fully recover while alfalfa yields may recover depending on length and severity of reduced irrigation. Due to its ability to recover, using partial season irrigation similar to that of the SA2 treatment on alfalfa hayfields may be the most practical approach to make water available to a Western Slope water bank.

The diminishment of yield would be offset by a compensatory structure, paying the farmer for impacts to their farming operations in return for forgone diversions of their irrigation water. Continual dialogue with farmers will be necessary in order to determine the best compensatory structure to support agricultural sustainability and profitability, while still providing a pathway for agriculture to play a role in offsetting basin-wide water shortages.

- ***Summary of Field Sites.*** Grass and alfalfa (Medicago sativa L.) hayfields may be ideal for inclusion in a Colorado Water Bank as they are the primary users of agricultural water in this region and may have a greater ability to withstand water stress in comparison to other crops. This study was conducted to determine effects of withholding irrigation for a full season from high elevation grass hayfields and implementing partial season irrigation on lower elevation alfalfa hayfields on forage yield, nutritional quality, and associated recovery period to confirm if this approach is worth pursuing.

  In 2013, grass hayfield sites at 4 locations were established and subsequently resampled in 2014 to determine crop recovery after a two year period of split-season irrigation. High-elevation, grass hayfields were selected that typically irrigated using “wild” flood irrigation and most produce 1 cutting annually. Sites were located in Kremmling, Hayden, Gunnison and Steamboat Lake. The grass hayfields were split into side-by-side plots, one of which was irrigated normally as the control while the other was subjected to total cessation of irrigation. Both plots were fully irrigated in the second year of the study (2014). Three established alfalfa fields were subjected to irrigation treatments including normal irrigation (control), irrigation stopped after the 1st cutting (SA1), and irrigation stopped after the 2nd cutting (SA2) for 2 consecutive years. These plots were returned to full irrigation in 2015.

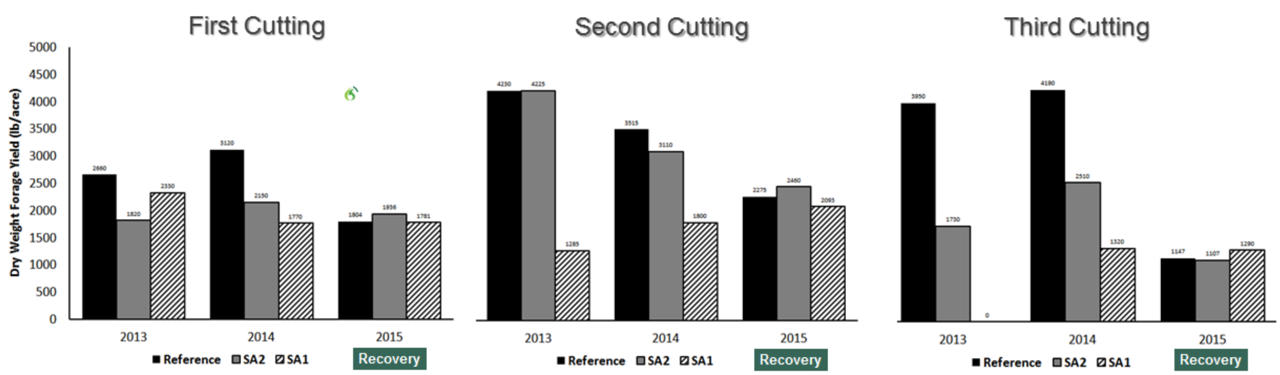
- ***Summary of Yield Data.*** In Year 1 (2013), average dry matter yields in non-irrigated grass plots were reduced to 39% (2497 kg ha-1) of the control (6377 kg ha-1). Yields of non-irrigated grass plots did not fully recover when returned to irrigation in Year 2 (2014) producing 49% (3623 kg ha-1) of the control (7442 kg ha-1). One of the grass sites that was able to be sampled after returning to full irrigation for 2 years, yields had fully recovered.

  Averaged over both years, SA2 alfalfa plots maintained production similar to the control in the 1st and 2nd cutting while SA1 alfalfa plots were reduced to 61% (2089 kg ha-1) of the control (3430 kg ha-1) by the 2nd cutting. By the 3rd cutting, SA2 and SA1 alfalfa yields decreased to 53% (1804 kg ha-1) and 30% (1013 kg ha-1) of the control, respectively. On a total season basis, both alfalfa plots receiving partial season irrigation were reduced with SA2 plots producing 72% (7880 kg ha-1) and SA1 plots producing 33% (3650 kg ha-1) of the control (11040 kg ha-1).

- ***Summary of Forage Quality Data.*** Neutral detergent fiber (aNDF) concentration - *a measure of forage quality* - in non-irrigated grass plots was 5% lower while crude protein (CP) content was 30% greater than the control. In-vitro true digestibility (IVTD) was unaffected by irrigation treatment. When returned to irrigation, aNDF concentrations were still reduced by 8% and CP contents were similar to that of the control.

  The aNDF concentrations were greatest in the control at 34.6% and lowest in SA1 alfalfa plots at 28.2%. By the 2nd cutting, SA1 plots had the highest IVTD (80%), and by the 3rd cutting, S2 and S1 plots were equally greater (80%) than the control (75%). Effects on CP content were inconsistent.

- ***Additional Research Expenses.*** Results from one of the research sites are depicted below for in Eckert, CO.



This project has been favorably received by the Colorado Water Institute Advisory Board and the partner members of the Colorado Water Bank Workgroup. Of particular interest to the CWI Board was the recovery of the forage crops during the 2015 season. In the figure above, for instance, the second cutting of alfalfa in 2015 displayed consistent yields among all field sites. The "fully irrigated" reference plot diminished in yield, whereas the most stressed field (SA1 - "stop irrigation after first cutting") gained yield each year eventually becoming consistent with the reference plots in 2015. These findings suggest value in continuing to examine the recovery of these plots through 2016. A modest research budget will enable this research to continue, as summarized below:

Description	***Cost***
o Student Hourly (8 months @ 4.33 wk/month @ 10 hr/wk @ $12/hr)	$ 4,156.80
o Travel Budget (60 mi @ 2 trips/mo @ 6 month @ $0.51/mile	$ 367.20
o Laboratory Feed Analysis	$ 470.00

Project No.

Andales: Lysimeter

PROJECT TITLE: Determination of Consumptive Water Use of Winter Wheat in the Arkansas Valley (Year 2)

PRINCIPAL INVESTIGATORS:

Dr. Allan A. Andales, Associate Professor of Irrigation and Water Science; Department of Soil and Crop Sciences, Colorado State University; Tel. (970) 491-6516; Email: Allan.Andales@colostate.edu
Dr. Michael E. Bartolo, Research Scientist; CSU-Arkansas Valley Research Center, Rocky Ford, CO; Tel. (719) 254-6312; Email: Michael.Bartolo@colostate.edu
Mr. Lane Simmons, Research Associate; CSU-Arkansas Valley Research Center; Rocky Ford, CO; Tel. (719) 254-6312; Email: Lane.Simmons@colostate.edu

LOCATION WHERE THE WORK IS TO BE CONDUCTED: This project will be conducted at the Colorado State University (CSU) – Arkansas Valley Research Center (AVRC), Rocky Ford, CO.

PURPOSE OF THE RESEARCH

This proposal addresses the priority issue of "Data collection and analysis in support of improved water management in the Arkansas River Basin". One of the recommendations that came out of the Kansas v. Colorado Arkansas River Compact litigation is for Colorado to use the American Society of Civil Engineers (ASCE) Standardized Penman-Monteith equation (PME) to estimate crop evapotranspiration (ET) in the Arkansas River Basin. This equation requires accurate measurements of hourly weather data (solar radiation, air temperature, humidity, and wind speed) to calculate a reference crop ET (ET_r), which is a measure of local atmospheric demand for water. Crop ET (ET_c) is then calculated by multiplying ET_r by a crop coefficient (K_c) that varies with crop growth and development. After alfalfa hay and corn, winter wheat is the next dominant irrigated crop in the basin (21,661 irrigated acres in lower basin; 39,891 total acres including dryland wheat in 2014) and a localized K_c curve for it has not been developed. This project will augment the first season of winter wheat ET data being collected in 2015-2016. The project will collect a second full growing season (2016-2017) of winter wheat ET_c data using two weighing lysimeters that will lead to a more robust winter wheat K_c curve that accounts for variable weather conditions. The more accurate calculations of ET_c will ultimately improve the estimates of river flow that are used to determine compliance with the Arkansas River Compact. Related to this, accurate hourly weather data from 12 automatic weather stations in the basin are continuously needed to calculate ET_r and ET_c for the entire basin. These weather stations are part of the Colorado Agricultural Meteorological Network (CoAgMet). The winter wheat K_c curve will also be incorporated in the Water Irrigation Scheduler for Efficient Application (WISE) online tool that was developed for Colorado (http://wise.colostate.edu/). Inclusion of a locally-developed K_c curve for winter wheat in WISE will enable farmers in the Arkansas River Basin to schedule winter wheat irrigations based on better estimates of their field-specific soil water deficits (daily irrigation requirements).

OBJECTIVES and METHODS

1. Develop a seasonal crop coefficient curve for winter wheat that accounts for local environmental conditions for a second growing season in the Arkansas basin.
2. Assess the impact of a second season of local weather and soil conditions on the ET_c of winter wheat at various growth phases of the crop.

The objectives will be achieved in close collaboration with engineers in the Colorado Division of Water Resources (CDWR). Winter wheat was planted on the small (1.5 m x 1.5 m) lysimeter in Fall 2015. This crop is currently being used to develop the first season of winter wheat ET_c and K_c data. This proposed project will plant a second crop of winter wheat in the small lysimeter, and additionally in the large (3 m x 3 m) lysimeter in Fall 2016. From both lysimeters, winter wheat ET_c will be calculated by mass balance (from automated weighing scale readings) and aggregated to 5-minute, 15-minute, and hourly totals. Lane Simmons (Research Associate) will manage the daily operations, crop management, maintenance, and data quality control of the 2 lysimeters. The following will be the major deliverables of the project: (1) Seasonal crop coefficient curve that characterizes winter wheat ET_c (2016-2017 growing season) at different developmental phases; and is appropriate for local conditions in the Arkansas Basin; (2) Observed seasonal consumptive water use (ET_c) of winter wheat (2016-2017); (3) Accurate hourly weather data from 12 CoAgMet stations in the basin, made available through the CoAgMet online database; (4) One technical report published by the Colorado Water Institute detailing the methods and findings of the CSU research team. A draft of the report shall be provided to CDWR and CWCB by October 15, 2017. This project will be conducted from July 1, 2016 to June 30, 2017.

BUDGET AND JUSTIFICATION

This agreement is for a maximum of $50,178 budgeted as follows.

Salary (one research associate; $5784/mo x 6 mo)	$34,704
Fringe benefits (@ 25.73%)	$ 8,929
Subtotal	$43,633
Indirect cost (@ 15%)	$ 6,545
Total	$50,178

These funds will pay for 6 months of work by one full-time research associate (Lane Simmons), who will manage the day-to-day operation of the lysimeters, take all measurements, and process the data.

Department Head Contact: Dr. Mark Brick (acting Head), (970) 491-6551, Mark.Brick@ColoState.edu

Department Accountant Contact: Pre-award – Cliff Schulenberg, (970) 491-0926, Cliff.Schulenberg@colostate.edu; Post-award – Jennifer Scheffing, (970) 491-1757, Jennifer.Scheffing@colostate.edu

OSP Team Leader Contact: Marilyn Morrissey, (970) 491-2375, Marilyn.Morrissey@ColoState.EDU

USGS Summer Intern Program

Basic Information

Start Date:	3/1/2016
End Date:	2/28/2017
Sponsor:	DOI-USGS-Geological Survey
Mentors:	Edward Stets
Students:	Hannah Podzorski

Internship Evaluation

Question	Score
Utilization of your knowledge and experience	Acceptable
Technical interaction with USGS scientists	Acceptable
Treatment by USGS as member of a team	Acceptable
Exposure and access to scientific equipment	Acceptable
Learning Experience	Acceptable
Travel	About Right
Field Experience Provided	About Right
Overall Rating	A+

Additional Remarks

Basic Information

Start Date:	3/1/2016
End Date:	2/28/2017
Sponsor:	DOI-USGS-Geological Survey
Mentors:	Roland Viger
Students:	Melissa Valentin

Internship Evaluation

Question	Score
Utilization of your knowledge and experience	Very Good
Technical interaction with USGS scientists	Very Good
Treatment by USGS as member of a team	Very Good
Exposure and access to scientific equipment	Very Good
Learning Experience	Very Good
Travel	About Right
Field Experience Provided	About Right
Overall Rating	A

Additional Remarks

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	14	0	0	0	14
Masters	2	0	1	0	3
Ph.D.	4	0	1	1	6
Post-Doc.	0	0	0	0	0
Total	20	0	2	1	23

Notable Awards and Achievements

Upper Yampa Water Conservancy District Scholarships Announced

The Upper Yampa Water Conservancy District John Fetcher Scholarship provides financial assistance to a committed and talented student who is pursuing a water-related career in any major at a public university within the state of Colorado. Congratulations to this year's recipient, Carter Stoudt. Carter is currently studying Environmental and Natural Resource Economics with a minor in the sustainable water interdisciplinary program.

Four States Irrigation Council Scholarship

The Four States Irrigation Council is a collaborative forum for the discussion of interstate-related issues and problems and the exploration of these. The Four States Irrigation Council awarded a $2,000 scholarship for the 2016-2017 academic year to one recipient interested in a career in irrigation or water-related fields and enrolled at a university or college in Colorado, Kansas, Nebraska, and Wyoming. The recipient, Ross Niehues, is a student at Kansas State University's Department of Agricultural Technology Management and will graduate in May 2017.

2012CO257B - Assessing the Benefits and Drawbacks of Different Institutional Arrangements to Enhancing Forest and Water Ecosystem Services and Ecosystem Services Markets in Colorado

Heidi Huber-Stearns, National Social-Environmental Synthesis Center (SESYNC) Fellowship.

2015CO312B - Groundwater Recharge Within the South Platte Basin

Presented research at 2 conferences.

Evaluated the use of GRACE at the aquifer-scale for aiding in the understanding of groundwater resources.

Advanced the knowledge and understanding of groundwater resources within the South Platte Basin.

2015CO314B - Nutrient Retention and Productivity in Rocky Mountain Streams Under Alternative Stable States

Best Student Oral Presentation, 41st Annual meeting of the Western Division of the American Fisheries Society.

Herdrich, A.T., D.L. Winkelman, and D. Walters. Effects of large wood and log jams on eastern slope Rocky Mountain trout populations. 41st Annual meeting of the Western Division of the American Fisheries Society. April 23, 2016. Reno, NV. Best Sudent Paper, 1st Place.

2016CO319B - Watershed monitoring across the snow transition zone: an east slope-west slope comparison

Obtained a Colorado Mountain Club Fellowship in support of this work

2016CO323B - Channel restoration monitoring of the Upper Colorado River, Rocky Mountain National Park, CO

2017 Rich Herbert Memorial Scholarship, AWRA-CO section

Publications from Prior Years

1. 2012CO257B ("Assessing the Benefits and Drawbacks of Different Institutional Arrangements to Enhancing Forest and Water Ecosystem Services and Ecosystem Services Markest in Colorado") - Articles in Refereed Scientific Journals - Huber-Stearns, Bennett, Posner, et al., (2017). Social-Ecological Enabling Conditions for Payments for Ecosystem Services: A Review of Current Dialogues in Environmental Policy. Ecology & Society.
2. 2012CO257B ("Assessing the Benefits and Drawbacks of Different Institutional Arrangements to Enhancing Forest and Water Ecosystem Services and Ecosystem Services Markest in Colorado") - Articles in Refereed Scientific Journals - Ozment, Gartner, Huber-Stearns, et al. "Protecting Drinking Water at the Source: Lessons from Watershed Investment Programs." World Resources Institute report, October 2016.
3. 2012CO265B ("Thermal preference of age-0 stonecats (Noturus flavus): Are thermal water quality standards protective for this species?") - Articles in Refereed Scientific Journals - Herdrich, A. T., and C. A. Myrick. Critical thermal maximum of 20C-acclimated adult stonecats Noturus flavus. The Prairie Naturalist 46: 101-103.
4. 2012CO267B ("Using Water Chemistry to Characterize the Connection between Alluvial Groundwater and Streamflow Water Under Augmentation at the Tamarack Ranch State Wildlife Area, Colorado") - Articles in Refereed Scientific Journals - Ronayne, M., J. A. Roudebush, and J.D. Stednick. 2017. Analysis of managed aquifer recharge for retiming streamflow in an alluvial river. J. of Hydrology 544(2017)373-382.
5. 2014CO297B ("WOOD: Windows Of Opportunity for Debris Retention in Response to 2013 Front Range Flooding") - Articles in Refereed Scientific Journals - Wohl, Ellen, Brian P. Bledsoe, Kurt D. Fausch, Natalie Kramer, Kevin R. Bestgen, and Michale N. Gooseff, 2016. Management of Large Wood in Streams: An Overview and Proposed Framework for Hazard Evaluation. Journal of the American Water Resources Association (JAWRA) 52(2): 315-335. DOI: 10.1111/1752-1688.12388
6. 2014CO298B ("The Effect of Normative Trends on Water Conservation") - Articles in Refereed Scientific Journals - Mortensen, Chad, Trending Norms: A Lever for Encouraging Behaviors Performed by the Minority, Social Psychological and Personality Science "in preparation".
7. 2014CO302B ("Exploration of Morphometric Approaches for Estimating Snow Surface Roughness") - Conference Proceedings - Fassnacht, S.R., I. Oprea, G. Borleske, and D. Kamin, 2014. Comparing Snowpack Surface Roughness Metrics with a Geometric-based Roughness Length. Proceedings of the 34th Annual American Geophysical Union Hydrology Days Conference, (ed., J.A. Ramirez) Fort Collins, Colorado, p44-52.
8. 2014CO302B ("Exploration of Morphometric Approaches for Estimating Snow Surface Roughness") - Conference Proceedings - Fassnacht, S.R., I. Oprea, P. Shipman, J. Kirkpatrick, G. Borleske, F. Motta, and D. Kamin, 2015. Geometric Methods in the Study of the Snow Surface Roughness. Proceedings of the 35th Annual American Geophysical Union Hydrology Days Conference, (ed., J.A. Ramirez) Fort Collins, Colorado, p41-50.
9. 2015CO308B ("Combined Influences of Hydrologic Connectivity and Nutrient Uptake on System-scale Retention") - Articles in Refereed Scientific Journals - Wegener, P., T. Covino, E. Wohl., 2017, Beaver-mediated lateral hydrologic connectivity, fluvial carbon nutrient flux, and aquatic ecosystem metabolism, Water Resources Research "in preparation".
10. 2015CO308B ("Combined Influences of Hydrologic Connectivity and Nutrient Uptake on System-scale Retention") - Dissertations - Wegener, P., 2016, The influence of lateral hydrologic connectivity on fluvial nutrient flux and ecosystem metabolism in a river-floodplain system, "MS Thesis," Ecosystem Science and Sustainability, Warner College of Natural Resources, Colorado State University
11. 2015CO310B ("Impact of Limited Irrigation on Health and Growth of Three Ornamental Grass Species") - Dissertations - Hagopian, Sam, 2016, Irrigation Effects on Growth, Stress, Visual Quality

and Evapotranspiration of Ornamental Grasses, “MS Thesis,” Horticulture and Landscape Architecture, College of Agricultural Sciences, Colorado State University.

12. 2015CO310B ("Impact of Limited Irrigation on Health and Growth of Three Ornamental Grass Species") - Articles in Refereed Scientific Journals - Hagopian, Sam and James E. Klett, 2016. “Water Research with Ornamental Grasses”. CNGA Looseleaf 34 (2) 16-17.
13. 2014CO302B ("Exploration of Morphometric Approaches for Estimating Snow Surface Roughness") - Other Publications - Kamin, D., and S.R. Fassnacht, 2015a. New Approaches for Estimating Snow Surface Roughness. Poster presentation at the 35th Annual AGU Hydrology Days Conference, Fort Collins, Colorado, March 23-25, 2015.
14. 2014CO302B ("Exploration of Morphometric Approaches for Estimating Snow Surface Roughness") - Other Publications - Fassnacht, S.R., I. Oprea, P. Shipman, J. Kirkpatrick, G. Borleske, F. Motta, and D. Kamin, 2015. Geometry Methods to Evaluate Snow Surface Roughness. Poster presentation at the 35th Annual AGU Hydrology Days Conference, Fort Collins, Colorado, March 23-25, 2015.
15. 2014CO302B ("Exploration of Morphometric Approaches for Estimating Snow Surface Roughness") - Other Publications - Fassnacht, S.R., I. Oprea, P. Shipman, J. Kirkpatrick, G. Borleske, F. Motta, and D. Kamin, 2015. Geometry Methods to Evaluate Snow Surface Roughness. Poster presentation at the 35th Annual AGU Hydrology Days Conference, Fort Collins, Colorado, March 23-25, 2015.
16. 2014CO302B ("Exploration of Morphometric Approaches for Estimating Snow Surface Roughness") - Other Publications - Oprea, I., S.R. Fassnacht, G. Boreske, and D. Kamin, 2014. Comparing Roughness Metrics with Geometric-based Roughness Lengths for a Snowpack Surface. Poster presentation at the Annual AGU Hydrology Days Conference, Fort Collins, CO, March 24-26, 2014.
17. 2015CO309B ("Temporal Consistency of Spatial Snowpack Properties") - Other Publications - Von Thaden, B.C., and S.R. Fassnacht, 2015a. Spatial Accumulation Patterns of Snow Water Equivalent. Poster presentation at the Eastern Snow Conference, Sherbrooke, QB, June 9-10, 2015.
18. 2015CO309B ("Temporal Consistency of Spatial Snowpack Properties") - Other Publications - Von Thaden, B.C., and S.R. Fassnacht, 2015b. Relative snow accumulation patterns and inconsistencies across the Southern Rockies, U.S.A. Poster presentation at the American Geophysical Union Fall Meeting, San Francisco CA, December 14-18, 2015 (C33C-0837).
19. 2015CO312B ("Spatiotemporal Assessment of Groundwater Resources in the South Platte Basin, Colorado") - Other Publications - Ruybal, C.J., Hogue, T.S., and McCray, J.E. Using the GRACE Satellites and Ground-Based Data to Assess Groundwater Storage Changes in the South Platte Basin, Colorado. Poster Presentation. Geological Society of America 2016 Annual Meeting, Denver, CO.