Colorado Water Institute Annual Technical Report FY 2017

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, the University of Colorado, 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 CWI 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 public discussions about 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 6 104b 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. 2017CO333B Diagnosing the Role of External Forcings on Streamflow Variability, Leah Bensching (Livneh), Colorado State University, $4,999.00 (104b)

2. 2017CO334B Effects of Water Velocity on Algal-Nutrient Interactions in Streams of the Poudre Watershed, Colorado, Whitney S. Beck (Poff), Colorado State University, $5,000.00 (104b)

3. 2017CO336B Understanding Post-Flood Channel Adjustments and Reservoir Sedimentation to Inform Water Management Practices, Johanna Eidmenn (Rathburn), Colorado State University, $5,000.00 (104b)

4. 2017CO338B Effects of Snow Persistence on Soil Water Nitrogen Along the Colorado Front Range, Alyssa Nicole Anenberg (Kampf), Colorado State University, $5,000.00 (104b)

5. 2017CO339B The Effect of Wastewater Effluent on Soil and Water Chemistry Along the South Platte River, Daniel Clark (Schliemann), Colorado State University, $3,776.00 (104b)

6. 2017CO340B Estimating Agricultural Consumptive Use for Grass and Hay Pasture Fields on Colorado's Western Slope, Richard/Cabot (Richard), Colorado State University, $5,000.00 (104b)

FY17 Funded USGS Internship

1. William Farmer: National Domain Water Budgets NIWR-USGS Student Internship Program, $34,043.00

Ongoing USGS Internships

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), Michele Basile

(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 Categories:	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 U.S. Geological Survey's (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 USGS (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.”

Water Yield Sensitivity to Snow Loss in Colorado Headwater Streams

Basic Information

Title:	Water Yield Sensitivity to Snow Loss in Colorado Headwater Streams
Project Number:	2017CO332B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	CO-003
Research Category:	Climate and Hydrologic Processes
Focus Categories:	Water Quantity, Water Supply, Surface Water
Descriptors:	None
Principal Investigators:	Gigi Richard, Stephanie K Kampf

Publications

There are no publications.

Final Report for Project

Title: 2017CO332B – Water Yield Sensitivity to Snow Loss in Colorado Headwater Streams
Investigator(s): Abby Eurich, Ecosystem Science and Sustainability, Colorado State University; John Hammond, Geosciences, Colorado State University

Advisor(s): Gigi Richard, Physical and Environmental Sciences, Colorado Mesa University; Stephanie Kampf, Ecosystem Science and Sustainability, Colorado State University

Introduction

This project is part of a larger collaborative effort between faculty and students at Colorado Mesa University (CMU) and Colorado State University (CSU) and contributes to an examination of how snowpack and streamflow interact across the full elevation gradient of Colorado streams. The component of the research described here focused on streams on the west slope of the Colorado Rockies. Specifically, the grant funding was used to accomplish the following:

- Support CMU undergraduate students and faculty for data collection at three existing monitoring stations on the Grand Mesa and for the establishment of three new sites in the Uncompahgre River watershed. The data collected will be integrated into a longer-term data set that can help inform streamflow prediction, particularly in transitional elevations that are most sensitive to drought and warm temperatures.
- Replace malfunctioning equipment and add three new monitoring stations to better capture the snowmelt and runoff generation from the persistent, transitional and intermittent snow zones on the Grand Mesa, the Colorado National Monument and the San Juan mountains.

Support data organization and processing for preparation of a water year (WY) 2017 snowpack report for the Grand Mesa.

Summary of Work Accomplished

Data Collection

CMU and CSU faculty and students performed a total of 32 site visits between March 1, 2017 and February 28, 2018 (Table 1). Each site visit entailed downloading data from the stream gage, soil moisture sensors, rain gage, and snow-depth camera, conducting a snow depth and density or soil moisture transect, and a streamflow measurement. The data collection supported by these grant funds are part of a larger data collection effort that began in April 2016 with the installation of the Grand Mesa stations and will continue into the future via funds from other sources and volunteer efforts at the six west slope monitoring stations.

Data collected from the site visits have been organized on Dropbox for ease of sharing between CMU and CSU. Data from the Grand Mesa persistent and transitional sites are summarized below and will be incorporated into further analyses by Dr. Stephanie Kampf's research team at CSU. Seven CMU undergraduate students were supported by these grant funds to assist in the field data collection, data management and organization, and data processing.

Site installation and equipment updates

Three new monitoring stations were installed during the study period and one station was relocated (Figure 1). The Grand Mesa intermittent site stream had no streamflow from April 2016 through July 2017, so equipment was removed on July 30, 2017 with the intention of moving the equipment to another watershed on the Grand Mesa. Access issues, the topography of the Grand Mesa, and the abundance of diversions on the Grand Mesa made it challenging to find an unregulated intermittent catchment on the Grand Mesa. A new intermittent watershed in the Colorado National Monument was selected instead. The equipment from the Grand Mesa intermittent site was repurposed at the new Colorado National Monument site on December 1, 2017. The new site is within the National Park Service (NPS) boundaries and permitted by NPS. The stream is tributary to Ute Canyon.

Three new sites were installed in the Uncompahgre River drainage in the San Juan (SJ) mountains. The SJ persistent site, in Senator Beck Basin on Red Mountain Pass, is a collaboration with the Center for Snow and Avalanche Studies (CSAS) in Silverton, Colorado. CSAS already monitors snow depth and density, streamflow in the summer, and weather conditions throughout the year. In September 2017, we installed a second stream gage (capacitance rod), staff gage, and soil moisture sensors at three depths near the CSAS Swamp Angel Study Plot. The San Juan transitional site, installed on September 30, 2017, is located on Portland Creek on Ouray County property. The San Juan intermittent site, installed on December 28, 2017, is located on Bureau of Land Management property west of Ridgway Reservoir. The new SJ transitional and intermittent sites both include new Decagon soil moisture, air temperature, and soil temperature sensors, Decagon data loggers, Rainlog rain gages with Hobo data loggers, pressure sensors for flow depth and air pressure, snow cameras, and staff gages. The SJ transitional site is also equipped with an Arduino sensor to measure stage in Portland Creek.

Water Year 2017 Snowpack Report

Data from the Grand Mesa persistent and transitional sites were summarized for water year 2017 (Table 2). The stream at the Grand Mesa intermittent site in Shirttail Creek had no streamflow from March 2016 through July 2017 and as a result, those data are not included in the summary. Two SNOTEL stations are located on the Grand Mesa: Mesa Lakes, elevation 3,048 m and Park Reservoir, elevation 3,036 m (Figure 2) and the water year 2017 data from the SNOTEL stations have been compared to our Grand Mesa stations.

Snow accumulation at the SNOTEL sites on top of the Grand Mesa peaked on April 9 at 78 cm SWE (Park Reservoir) and April 7 at 48 cm SWE (Mesa Lakes) (Figure 3). After a few phases of melt and snow accumulation, snow melted rapidly, and the sites were snow-free by June 2 and June 13. Our persistent snow monitoring site is slightly lower in elevation than these SNOTEL sites and its peak SWE was 816 mm on March 6, comparable to the Mesa Lakes site (Figure 4). This site had several periods of mid-winter and spring melt, and it was snow-free by May 16. Further downslope at our transitional monitoring site, snow peaked in the winter at 606 mm, and there was very little accumulation through the spring (Figure 5).

Soil moisture remained relatively constant through the winter at the persistent site then began to rise with the spring melt, reaching its highest levels just after the site was snow-free. The streamflow began to rise from early snowmelt in April and flow peaked during the final stage of snowmelt. Soil moisture rose in response to summer rains but never to levels as high as those during peak snowmelt, and these rainfall responses were not evident in the streamflow hydrograph, which gradually declined for the rest of the water year (Figure 4). Greater mid-winter snowmelt at the transitional site led soil moisture to rise earlier, and this site retained high soil moisture until June, when it started to dry (Figure 5). Unfortunately, the streamflow data for the transitional site have not been reliable.

These findings contribute to a longer-term study of streamflow generation across snow zones. For the Grand Mesa sites, our measurements to date highlight how sensitive the snowpack is to small changes in temperature. Compared to the top of the mesa snowpack, which peaked in the spring, the transitional site reached peak snow accumulation in January, with very little snow added in the spring months. This led to more mid-winter infiltration into the soil, which can then change streamflow timing. The Grand Mesa sites also produce less streamflow than comparable sites on the east slope of the Rockies. This may be because the basaltic rocks on the mesa and the unconsolidated boulder fields allow high infiltration of melt water.

Figures & Tables

Title: 2017CO332B – Water Yield Sensitivity to Snow Loss in Colorado Headwater Streams
Investigator(s): Abby Eurich, Ecosystem Science and Sustainability, Colorado State University; John Hammond, Geosciences, Colorado State University

Advisor(s): Gigi Richard, Physical and Environmental Sciences, Colorado Mesa University; Stephanie Kampf, Ecosystem Science and Sustainability, Colorado State University

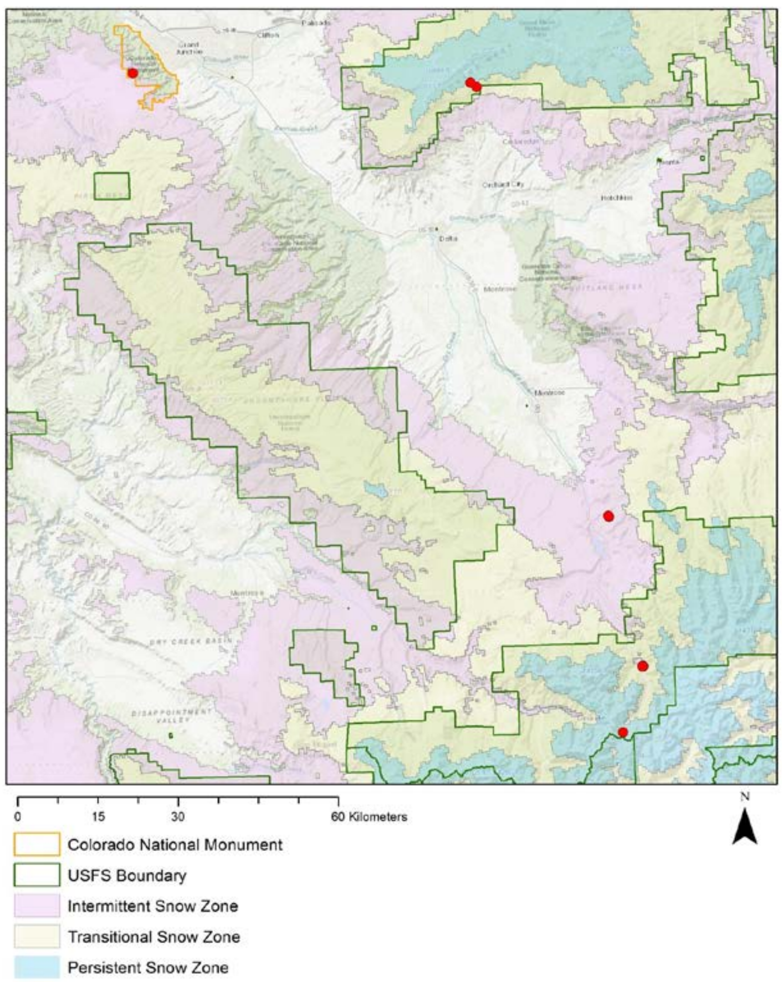

Figure 1. Locations of west slope study sites.

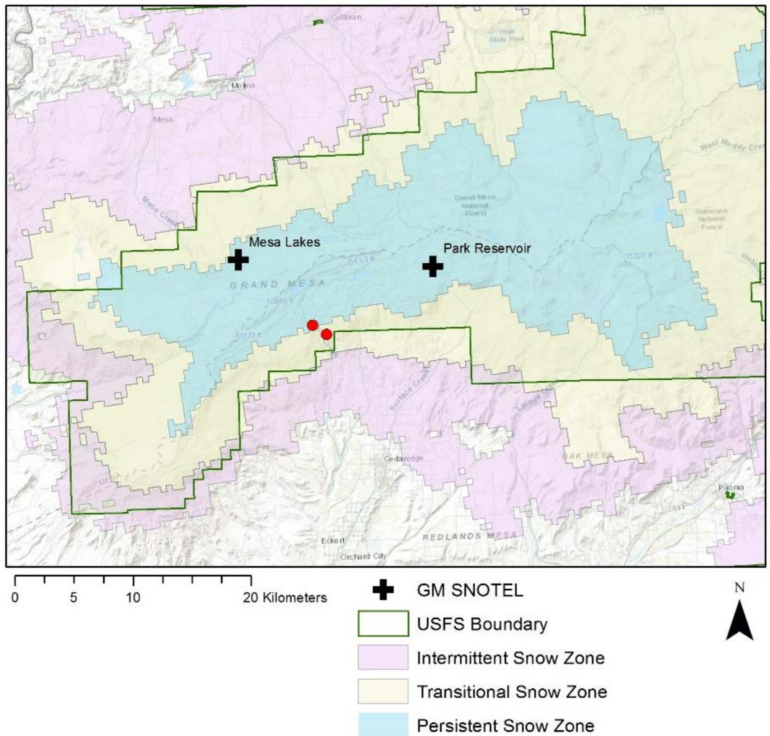

Figure 2. Locations of SNOTEL sites on the Grand Mesa.

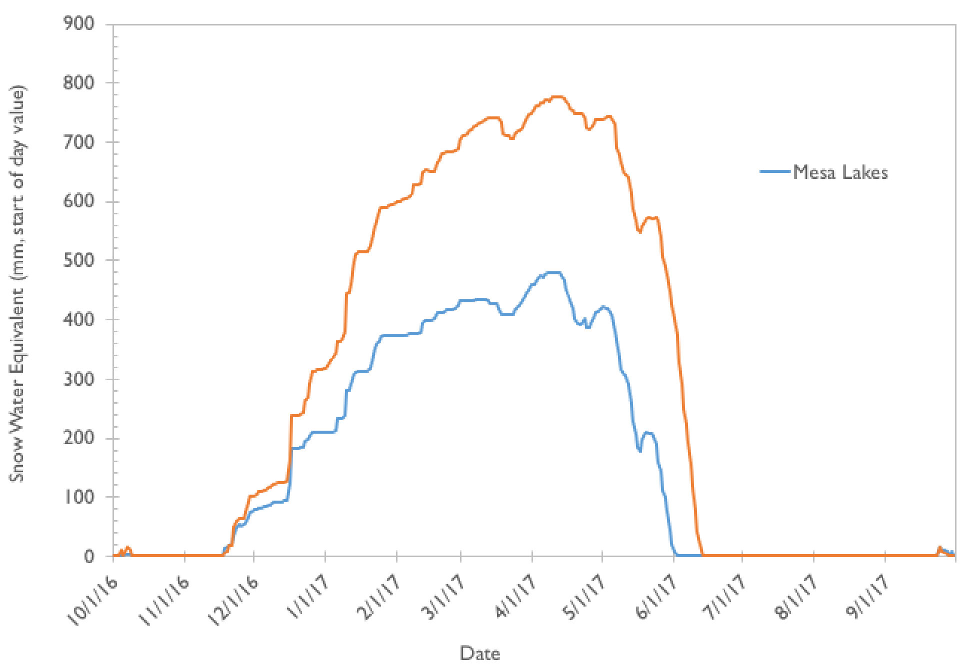

Figure 3. Snow water equivalent data from WY2017 from the two SNOTEL sites on the Grand Mesa.

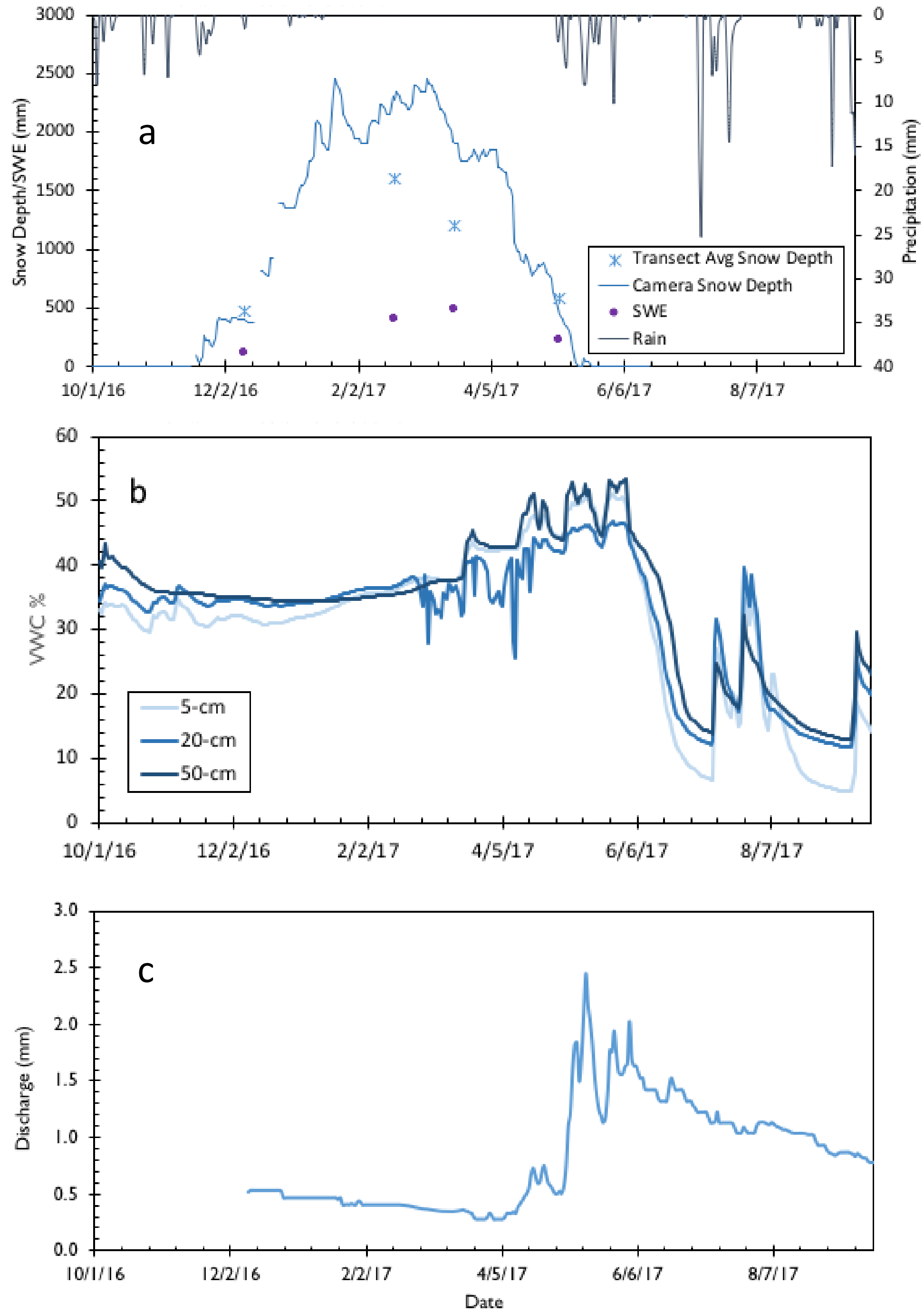

Figure 4. a) Snow depth, snow water equivalent, and precipitation; b) soil moisture; and c) discharge from Grand Mesa persistent zone monitoring site for WY 2017.

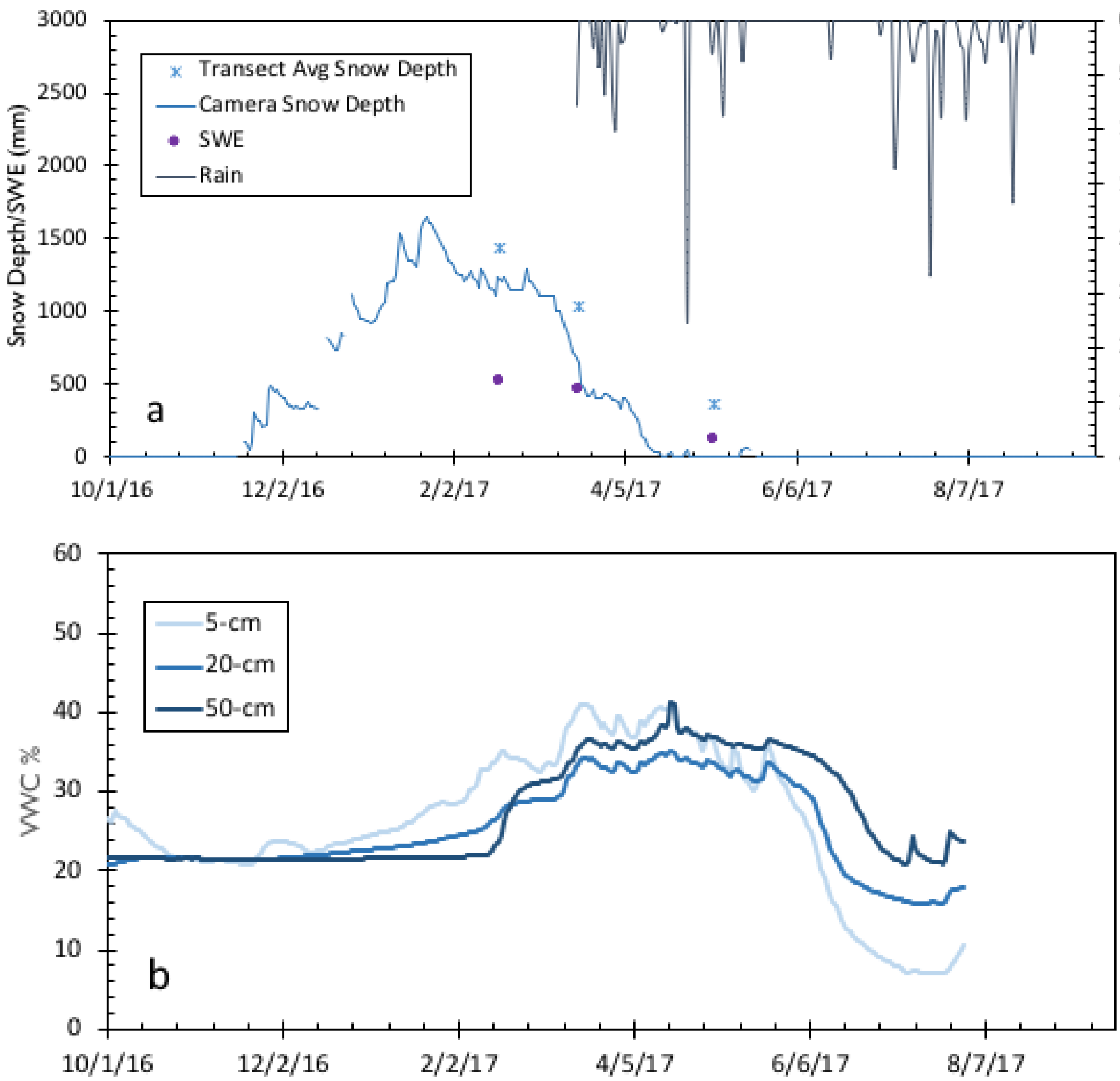

Figure 5. a) Snow depth, snow water equivalent, and precipitation and b) soil moisture from Grand Mesa transitional zone monitoring site for WY 2017.

Table 1. Site visits for the grant period between March 1, 2017 and February 28, 2018.

GM Persistent	GM Transitional	GM Intermittent	CNM Intermittent	SJ Persistent	SJ Transitional	SJ Intermittent
3/18/2017*	3/18/2017*	3/4/2017*				
		4/2/2017*				
5/6/2017*	5/6/2017*	5/12/2017				
6/18/2017*	6/18/2017*	6/18/2017*				
7/30/2017	7/30/2017	7/30/2017 (site removed)				
8/26/2017	8/26/2017					
				9/30/17 (site installation)	9/30/17 (site installation)	
				10/22/2017	10/22/2017	
11/4/2017	11/4/2017					
12/1/2017	12/1/2017		12/1/17 (site installation)			
			12/29/17 (install rain gage)			12/28/17 (site installation)
1/24/2018*	1/24/2018*		1/20/2018	1/3/2018	1/3/2018	
					1/28/2018*	

*snow or soil moisture transect performed

Table 2. WY 2017 data summary for the Grand Mesa persistent and transitional sites

Water Year 2017	**10/01/16-09/30/17**	**Grand Mesa Persistent (elevation 3019 m)**	**Grand Mesa Transitional (elevation 2939)**
PRISM	Total Precipitation	1030 mm	890 mm
	Avg. Temperature	4.7 °C	5.7 °C
Snow	Peak SWE	816 mm	606 mm
	Date of Peak SWE	03/06/17	01/23/17
Soil Moisture	Average SM 5cm	30.9%	26.1% *
	Average SM 20cm	32.1%	25.3% *
	Average SM 50cm	34.0%	27.2% *
Discharge	Total Discharge (Q)	259 mm **	
	Date of Peak Q	05/13/17	

*Missing Data: 07/31/17-09/30/17

**Missing Data: 10/01/16-12/10/16; baseflow value as streamflow used for these dates

Diagnosing the Role of External Forcings on Streamflow Variability

Basic Information

Title:	Diagnosing the Role of External Forcings on Streamflow Variability
Project Number:	2017CO333B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	CO-002
Research Category:	Climate and Hydrologic Processes
Focus Categories:	Climatological Processes, Floods, Hydrology
Descriptors:	None
Principal Investigators:	Ben Livneh

Publications

There are no publications.

Final Report for Project

Title: 2017CO333B – Diagnosing the Role of External Forcings on Streamflow Variability

Investigator(s): Leah Bensching, Civil Engineering, University of Colorado at Boulder

Advisor(s): Ben Livneh, Civil, Environmental, and Architectural Engineering, University of Colorado at Boulder

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Stress on global water resources is expected to increase in the coming decades, so our understanding of the interactions of the hydrologic cycle will be critical for mitigation and planning (Schlosser et al., 2014). For places like Colorado, this will be especially important given the over allocation of water resources. Currently, we rely on remotely sensed data and models to validate our understanding of hydrology. The assumption is that these models will transform meteorological forcing data (precipitation, evaporation, temperature, etc.) into streamflow. However, this transformation can be obscured by external forcings that may not be well documented or accounted for. External forcings are defined here as any human or natural changes in the environment that affects the hydrologic cycle. These forcings include, but are not limited to: land use change, land cover change, reservoir operations, and historically changing gaging protocols. The error due to these external forcings is often neglected and may even be erroneously attributed to model insufficiencies.

As seen in Figure 1, external forcing magnitudes vary drastically across the continental U.S. In some cases, the disturbance is regional (i.e. agriculture in the Midwest and development along the East Coast), in other cases the disturbance is scattered across the country (i.e. reservoir storage). Identifying these continually changing disturbances and their influence on the hydrology can help improve model development and the appropriate use of model forecasts.

To develop the methods for this study, a preliminary set of seven Colorado basins were selected from the USGS GAGES II database to capture variations in size, streamflow magnitude and external forcing influences. The basins are shown in Figure 2. To overcome the problem that not all disturbances are well-documented, our first hypothesis is that a broad measure of disturbance can be obtained by comparing hydrologic model simulations representative of undisturbed conditions against gaged streamflow. The undisturbed model simulations and the gaged streamflow were compared using objective functions (bias, correlation, Nash score, and standard deviation ratio) that would capture the difference between the undisturbed model and the observed monthly streamflow. The analysis was then expanded for all streamflow gages in the Missouri river basin (HUC 2 basin scale). The VIC (Variable Infiltration Capacity) model was selected here since it balances both water and energy using physically-based equations of fluxes across vegetation, soil, and snow (Liang et al.,1994). Streamflow simulations from the Livneh et al. (2015) dataset were used as a baseline for undisturbed hydrologic response. VIC

External forcings were obtained from the GAGES II database (Falcone et al., 2011). GAGES II provides characteristics of basins associated with a USGS monitored streamflow gage. Seven forcings were identified to capture common hydrologic disturbances, including: National Inventory of Dam storage, freshwater withdrawal, percent irrigated, percent developed, and percent cultivated areas, road density, and the Hydrologic Disturbance Index. The external forcings are described in table 1. Our second hypothesis was that objective functions such as bias, correlation, Nash score and standard deviation ratio would increase monotonically with the magnitude of each external forcing.

Findings

The scope of the findings are limited to a straightforward comparison between model performance and the degree of disturbance across seven basins with areas from 25 km^2 to 10,000 km^2. The Colorado basins are shown in Figure 3. In some cases (i.e. Hydrologic Disturbance Index versus Bias) there was a clear linear relationship between the external forcing and the calculated statistics. In others, (i.e. Hydrologic Disturbance Index versus Correlation), there was no clear relationship between the external forcing and the model performance statistic. Given the small sample size, our ability to assess the general pattern of disturbance response and to test our two hypotheses was limited. An ideal next step would be to increase the sample size (e.g. > 500 gaged basins) to understand disturbance impacts more broadly.

Preliminary analysis into a larger sample size was conducted by including the 924 gages in the Missouri River Basin, e.g. HUC 2 region 10. Following the same process as the seven Colorado basins, objective functions were calculated for each basin between the USGS observed streamflow and undisturbed baseline VIC model. The preliminary Missouri River Basin analysis did not reveal meaningful patterns when comparing the objective functions to the disturbance magnitude. A few examples are shown in Figure 4. These results reject the proposed hypotheses. Rejecting our hypotheses means we can learn from these results as to how to improve future analysis. Possible improvements include the following:

1) In retrospect, the Missouri River Basin was not the best choice for the large-scale disturbance analysis. Numerous hydrologic investigations have noted considerable challenges in realistically modeling the hydrology of the Missouri River Basin (e.g. Xia et al., 2012; Newman et al., 2015) due to problems with precipitation estimation, inadequate representation of surface water/groundwater interaction, and tile drainage. As such model errors could be due to factors other than the selected external forcings. A reasonable next step would be to analyze a basin such as the Sacramento, Columbia, or Ohio River Basins where model simulations are expected represent hydrologic processes with higher fidelity.
2) Most basins contained disturbances from more than one external forcing. This analysis did not distinguish between the mixed external forcings in the basins. Future studies should first identify basins with only one significant external forcing in order to isolate impacts.
3) The disturbance data from the GAGES II database provided stagnant external forcing magnitudes when many external forcings change over time. Results will be more meaningful if a time series analysis is done based off changed external forcings.

4) Models have a variety of strengths and weaknesses including the ability to capture streamflow peaks, snowmelt timing, and evaporation. Using an ensemble of hydrologic models will improve their role as an undisturbed proxy by identifying robust patterns across models and thereby decrease uncertainties.

This preliminary analysis generally rejected the proposed hypotheses about external forcings. Yet, it provided meaningful insight into the complexities of the problem at hand and leaves us with an important question: How do we consider the many changing variables in the hydrologic cycle?

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Figures & Tables

Title: 2017CO333B – Diagnosing the Role of External Forcings on Streamflow Variability

Investigator(s): Leah Bensching, Civil Engineering, University of Colorado at Boulder

Advisor(s): Ben Livneh, Civil, Environmental, and Architectural Engineering, University of Colorado at Boulder

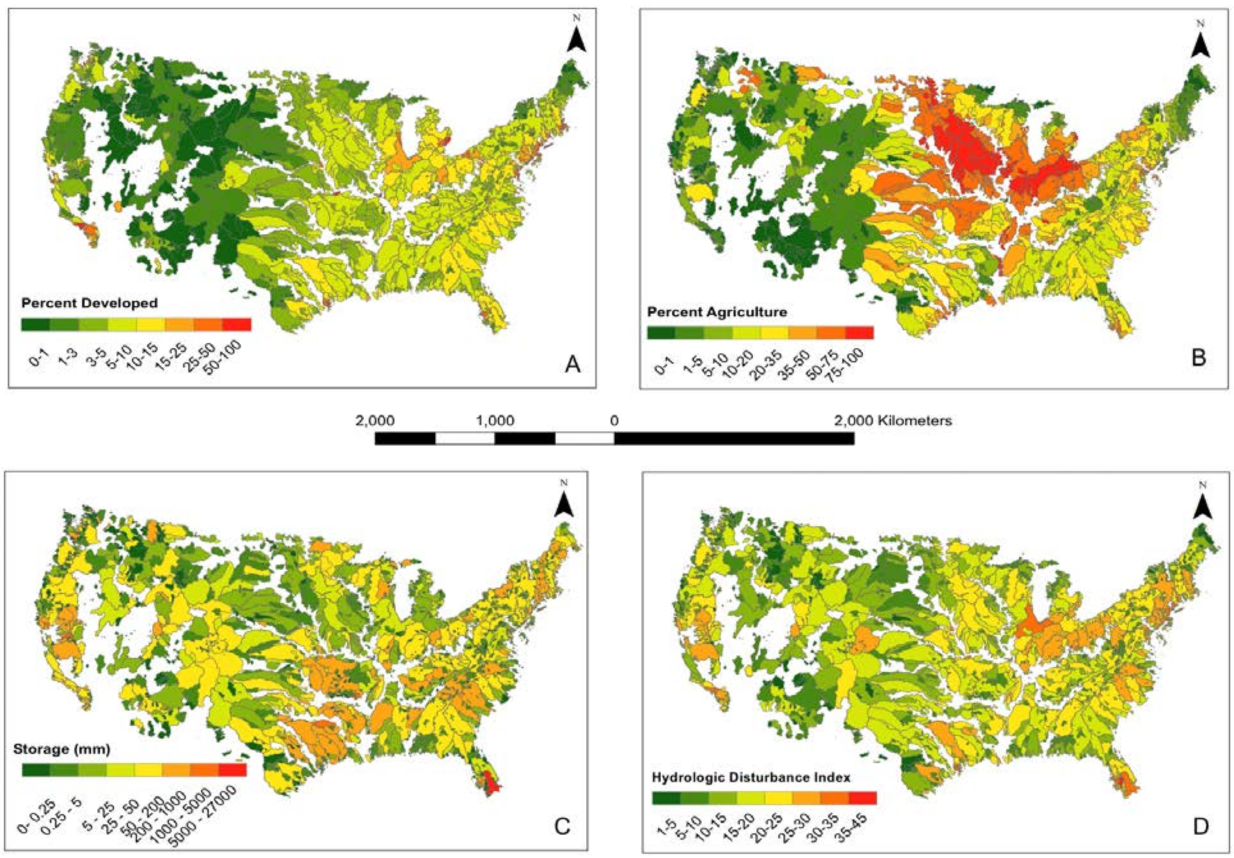

Figure 1. a) Percent developed land by area, b) Percent area planted / cultivated (agriculture), c) Dam storage in watershed from the National Inventory of Dams (mm), and d) Hydrologic Disturbance Index; all values are as of 2006.

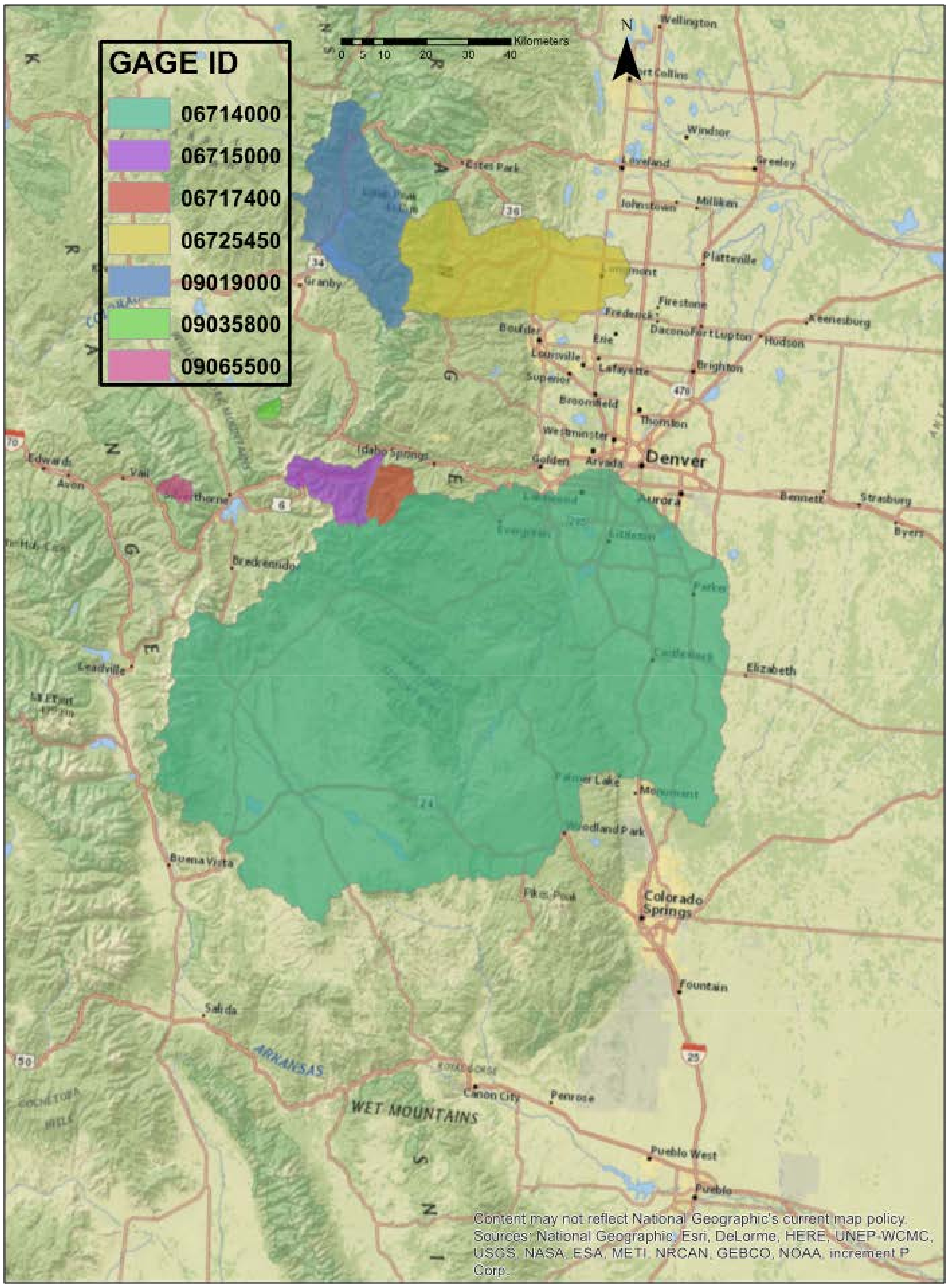

Figure 2. Basin areas corresponding to selected USGS streamflow gauges. The basin areas range from 25km^2 to 10,0000 km^2

Table 1. Explanation of GAGES II classifications used to identify disturbance metrics.

External Forcing	Description
NID Storage	Dam storage in watershed as measured by the National Inventory of Dams in 2009 (megaliters total storage / km^2)
Fresh Water Withdrawal	Average freshwater withdrawal from 1995-2000 county-level estimates. (megaliters/ year/km^2)
% Irrigated Area	Percent of watershed in irrigated agriculture from USGS 2002 250-m MODIS data
% Developed Area	Watershed percent "developed" (urban), from 2006 era
% Cultivated Area	Watershed percent "planted/cultivated" (agriculture) from 2006 era
Road Density	Road density, km of roads per watershed km^2, from Census 2000 TIGER roads
Hydrologic Disturbance Index (HDI)	HDI aims to capture the total disturbance in a basin. It is comprised of Dam density, water withdrawal, change in dam storage from 1950-2009, streams classified as canals, ditches or pipelines, proximity of gage to dam, road density, and percent developed land.

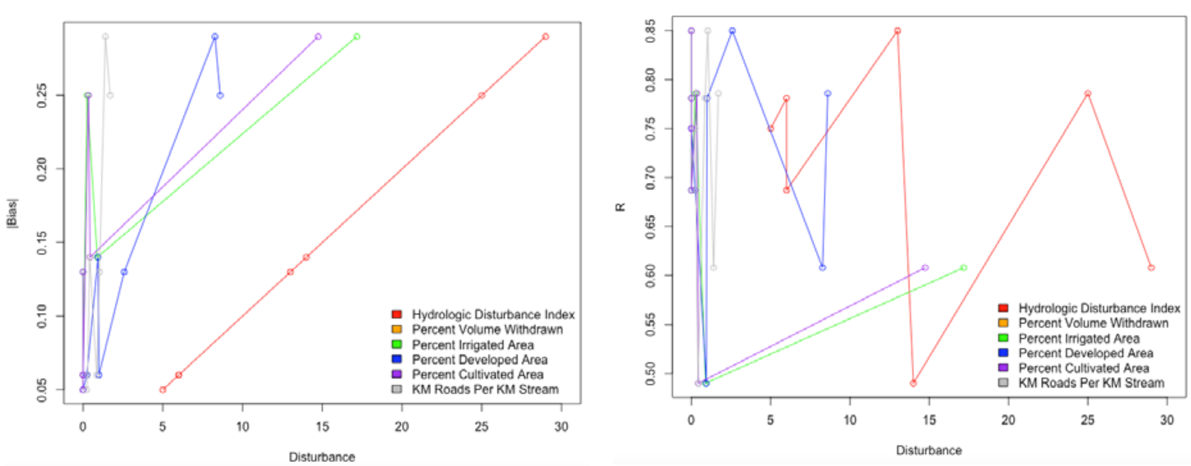

Figure 3. Absolute value of the model bias and correlation versus the magnitude of the disturbance for seven stream gauges in Colorado.

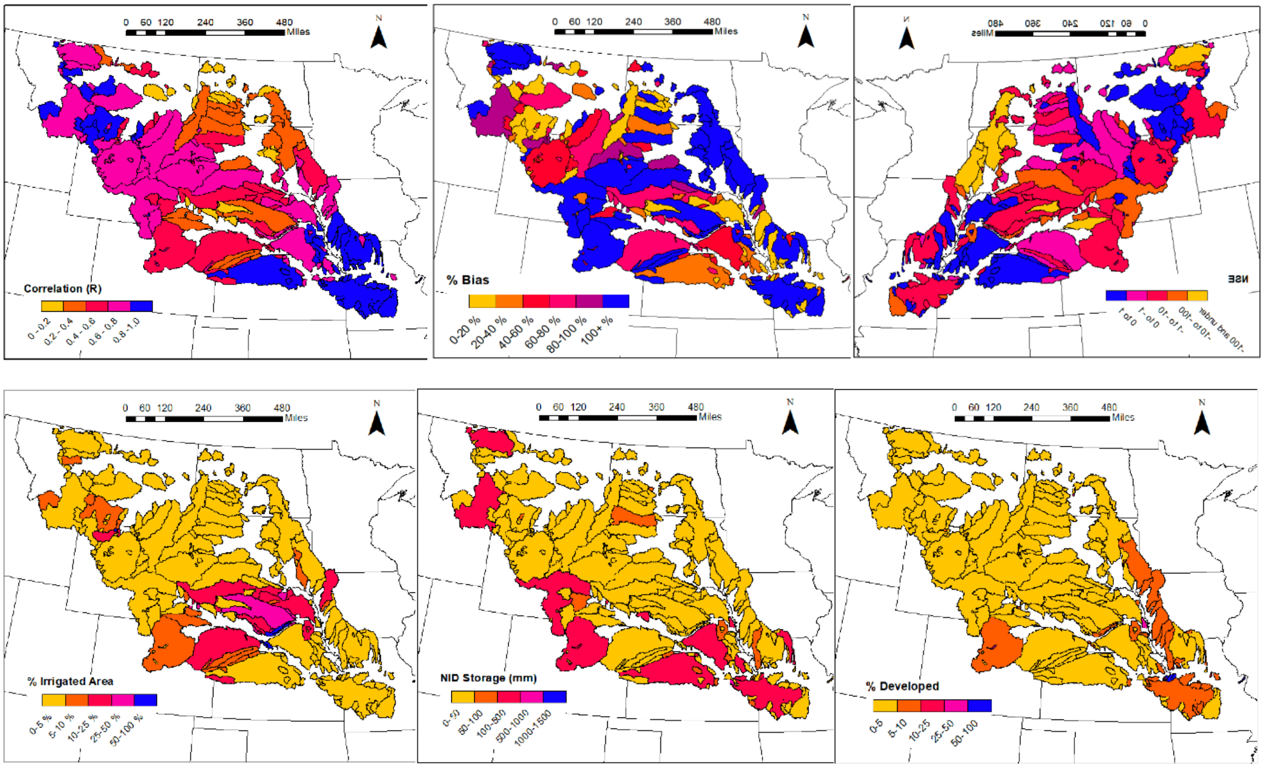

Figure 4. Spatial distribution of selected objective functions (Correlation, percent bias, and Nash score) and external forcings (percent irrigated area, NID storage, and percent developed area) for the Missouri River Basin.

Effects of Water Velocity on Algal-Nutrient Interactions in Streams of the Poudre Watershed, Colorado

Basic Information

Title:	Effects of Water Velocity on Algal-Nutrient Interactions in Streams of the Poudre Watershed, Colorado
Project Number:	2017CO334B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	CO-002
Research Category:	Water Quality
Focus Categories:	Ecology, Hydrology, Nutrients
Descriptors:	None
Principal Investigators:	N. Leroy Poff

Publications

There are no publications.

Final Report for Project

Title: 2017CO334B – Effects of Water Velocity on Algal-Nutrient Interactions in Streams of the Poudre Watershed, Colorado

Investigator(s): Whitney Beck, Biology, Colorado State University

Advisor(s): Leroy Poff, Biology, Colorado State University

Introduction and Background

The Poudre River provides an important source of freshwater to Colorado's Front Range, supporting recreational activities and fisheries. Headwater mountain streams that flow into the Poudre River serve important ecological functions, producing streambed algae and transporting organic matter that can feed insects and fish. Headwater streams also serve as refugia for cold water fish, which are being threatened by warming water temperatures across the state (Colorado Climate Plan, 2015). Finally, these smaller streams provide recreational opportunities for floating and fishing, and many of them lie adjacent to hiking trails. Clearly, these waters are of great value ecologically and for human use.

Headwater streams are being threatened by nutrient enrichment, which occurs when human-derived nitrogen and phosphorus enter the streams. Nutrients can come from grazing livestock, atmospheric deposition, or deforested lands in the mountains (Carpenter et al., 1998). Adding nutrients often increases algal biomass, and algae serve an important function of removing those nutrients from the water column so they are not transported downstream to larger rivers like the Poudre. However, under certain conditions large algal blooms can form, and these produce detrimental effects on fish and insects by blocking sunlight, producing toxins, and lowering stream dissolved oxygen (Carpenter et al., 1998).

There is evidence that algal biomass in Poudre watershed streams is responsive to increases in nutrients, particularly nitrogen. A study of 74 Colorado Front Range Streams showed that algal biomass was positively correlated with in-stream nitrogen levels (Lewis et al., 2010). If human activities continue to increase nitrogen, we are likely to see substantial increases in algal biomass. High elevation streams in the Poudre Watershed are particularly vulnerable because my research shows that they currently have high nitrogen levels and algal accumulation rates. This is surprising because high elevation sites have low summer temperatures (e.g., 4-6° Celsius) which would be expected to slow algal growth (Stevenson et al., 1996).

A little-explored research area is how stream water velocity can regulate the development of algae. Stream water velocity changes throughout the Poudre Watershed's snowmelt seasonal cycles, and also varies spatially in the riffle-pool sequences. Water velocity has been shown to a) influence algal uptake of nutrients (Stevenson et al., 1996), b) scour algae from rocks and other surfaces, and c) regulate insect grazing activity (Opsahl et al., 2003). In summer 2017, we completed field experiments in mountain streams of the Poudre Watershed to investigate how water velocity interacts with nutrient additions and aquatic insects to control algal biomass growth and accumulation. The five focal streams spanned an elevation gradient of 2,000 meters to 2,800 meters (Table 1). These small streams vary widely in temperature and have relatively low nutrient concentrations, making them ideal for answering questions about nutrient enrichment impacts.

Project Methods

Experiment 1: How does stream velocity influence algal responses to nutrient additions?

In August 2017, we deployed nutrient diffusing substrate experiments in fast (>40 cm $second^{-1}$) and slow (<15 cm $second^{-1}$) sections of five different streams. Nutrient diffusing vials were filled with just agar (control), agar + nitrate (N treatment), agar + phosphate (P treatment), and agar + nitrate + phosphate (NP treatment). Agar is a thick, gelatin-like substance from which nutrients are slowly released during the experimental period. The agar-filled vials were capped with porous glass discs, which served as a growth surface for algae in streams for a period of three weeks. Upon collection, the vials were analyzed for algal biomass (measured as the photosynthetic pigment chlorophyll a). ANOVA statistical tests were used to determine the effect of nutrients and velocity on algae.

Experiment 2: How does current velocity influence aquatic insect consumption of algae?

To answer this question, we completed experiments at the Colorado State University (CSU) Mountain Campus in August and September 2017. We built an underwater electric fence to exclude aquatic insect grazers and allowed algae to grow on the nutrient diffusing substrates within and outside the fence. Upon collection, the vials were analyzed for algal biomass and organic matter, and ANOVAs were used to determine the effect of nutrient, velocity, and aquatic insects on these response variables.

How do stream background conditions vary during these experiments?

During each experiment, we completed in-stream surveys of physical, chemical, and biological parameters. These included in-stream nutrients (total nitrogen, nitrate, and phosphate), conductivity, pH, riparian canopy cover, discharge, plot-level velocity (measured at a fine, 1-cm scale), and aquatic insect densities.

Results & Discussion

In experiment 1, we found that algal growth in the Poudre watershed streams was generally limited by the availability of nitrogen, which was evident from the strong response of algae to nitrogen additions (Figure 1). Algae also responded strongly to the nitrogen + phosphorus treatment. This is consistent with previous experiments we completed in summer 2015-2016, but is troublesome because we know nitrogen levels are increasing in nearby areas like Rocky Mountain National Park from atmospheric deposition. Indeed, we see an unexpected increase in stream nitrogen with elevation in the Poudre watershed.

A novel conclusion from this study was that nutrient limitation changed depending on the velocity tested. For instance, at the South Fork Poudre River, we found nitrogen limitation in slow velocities (i.e., algae increased significantly with nitrogen additions) but phosphorus limitation in fast velocities (i.e., algae increased significantly with phosphorus additions). In Seven Mile Creek, we found no nutrient limitation in slow velocities (i.e., algae on nutrient treatments was similar to algae on controls), but nitrogen limitation in fast velocities. We recommend that researchers and managers consider the influence of current velocity when thinking about how to manage algae. Completing experiments in a single location will not help us understand the vulnerability of a stream to nutrient additions, and whole stream nutrient uptake experiments are likely more informative.

We also found that algal growth was higher in faster velocities (Figure1). This may be counter-intuitive because in many streams, algal blooms form in slow pools. However, we hypothesize that faster current velocities support higher nutrient delivery rates in these low resource streams, allowing algae to thrive. Fast velocities may also decrease the mobility of aquatic insect grazers that consume algae.

In experiment 2, we found that aquatic insects depleted organic matter but not algal biomass (Figure 2). Organic matter consists of live and dead carbon, including algae, bacteria, fungi, and detritus. This finding reflects the high abundance of Diptera (flies) and Coleoptera (beetles) present in the stream, which primarily consume and dislodge organic matter. Furthermore, there was no relationship between current velocity and insect consumption. This was likely because we tested a narrow range of velocities (2-30 cm $second^{-1}$) that the insects were already adapted to.

Conclusions and Future Directions

Taken together, these experiments have considered factors that increase algal biomass (in-stream nutrients and nutrient additions), factors that deplete algal biomass (aquatic insect consumers), and how they are mediated by current velocity. In general, nitrogen additions are likely to increase algal biomass in Poudre watershed streams, and aquatic insects may not be able to consume algae quickly enough to compensate (especially in fast velocities).

These small-scale experiments are informing the design of a larger modeling study that will inform water quality policy and stream management programs. We plan to use Environmental Protection Agency (EPA) and United States Geological Survey (USGS) government datasets to model how algae respond to nutrients and insect grazers on a national scale, and whether those relationships changed based on streamflow disturbance metrics like flood frequency. These models will help inform when and where streamflow management could be used to control algal biomass in rivers and streams that experience harmful blooms.

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Figures, Tables, and Images

Title: 2017CO334B – Effects of Water Velocity on Algal-Nutrient Interactions in Streams of the Poudre Watershed, Colorado

Investigator(s): Whitney Beck, Biology, Colorado State University

Advisor(s): Leroy Poff, Biology, Colorado State University

Nutrient diffusing vials deployed in streams to determine whether more algae grows on nutrient-enriched treatments as compared to controls (left). The vials were filled with gelatin-like agar and nutrients, and capped with porous glass discs serving as an algal growth service. Aquatic insect larvae (Diptera, flies) colonized some of the vials and discs (right). Photo credit: Whitney Beck.

Table 1. Study sites for experiments in the Poudre Watershed.

Site Name	Elevation (meters)
Elkhorn	1992
Seven Mile	2212
Little Beaver	2443
South Fork Poudre	2740
Killpecker	2798

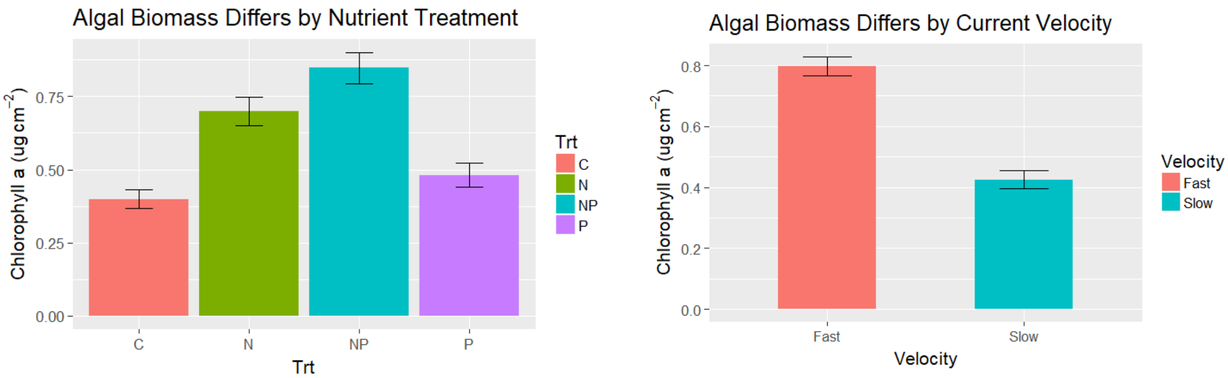

Figure 1. In Summer 2017, we deployed nutrient diffusing substrate experiments in two different velocities, within five streams of the Poudre Watershed. We found significantly higher algal biomass on the nitrogen and nitrogen + phosphorus treatments as compared to controls (left), and we found significantly higher algal biomass in fast velocities as compared to slow velocities (right).

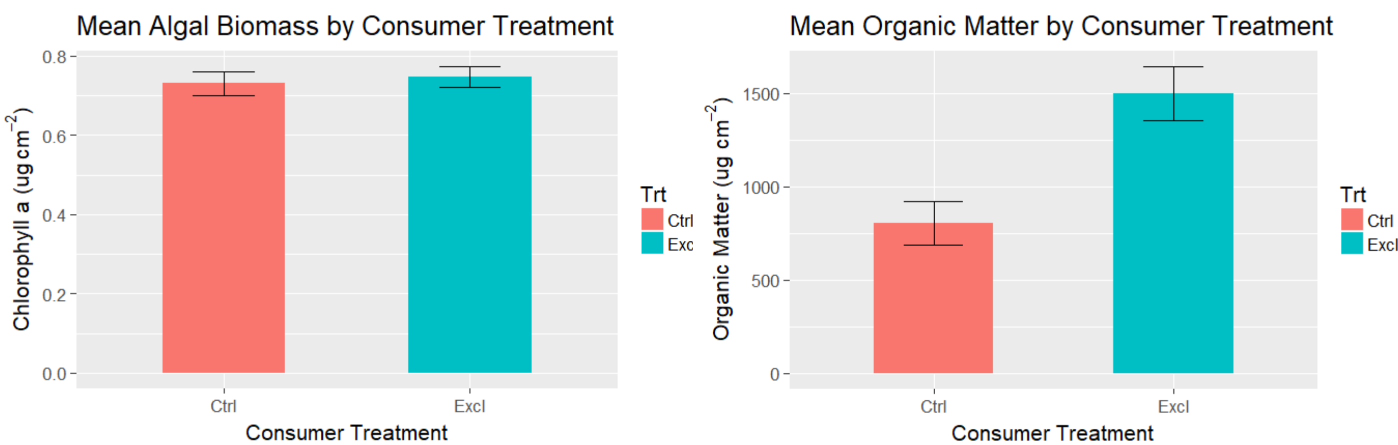

Figure 2. In Summer 2017, we built an underwater electric fence to exclude aquatic insects from algal growth plots. We found no difference in algal biomass between exclusion treatments and controls (left), but we did find a significant difference in organic matter (right). There was no interaction between current velocity and the influence of aquatic insects (data not shown).

Understanding Post-Flood Channel Adjustments and Reservoir Sedimentation to Inform Water Management Practices

Basic Information

Title:	Understanding Post-Flood Channel Adjustments and Reservoir Sedimentation to Inform Water Management Practices
Project Number:	2017CO336B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	CO-002
Research Category:	Climate and Hydrologic Processes
Focus Categories:	Floods, Geomorphological Processes, Water Supply
Descriptors:	None
Principal Investigators:	Sara Rathburn

Publications

There are no publications.

Final Report for Project

Title: 2017CO336B – Understanding Post-Flood Channel Adjustments and Reservoir Sedimentation to Inform Water Management Practices

Investigator(s): Johanna Eidmann, Geosciences, Colorado State University

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

Introduction

From September 9-15, 2013, a tropical storm swept across the Colorado Front Range, producing a >200-year flood (Yochum, 2015) that resulted in major damage to numerous Front Range communities. In its wake, 8 lives were lost (Gochis et al., 2015), and homes, roads, bridges, buildings, as well as water supply and treatment facilities were damaged. Within the North St. Vrain (NSV) Watershed, the storm produced between 200 and 450 mm of precipitation (Gochis et al., 2015) and triggered over 100 landslides. North St. Vrain Creek, which flows into Ralph Price Reservoir near Lyons, Colorado (Figure 1), experienced extensive flooding and channel change[1]. Over 10 m of aggradation occurred along an 800-m length of the channel, transforming the inlet into an approach channel (Figures 1B and 1C). In addition, over 300,000 m^3 of sediment was deposited in the reservoir, causing a 2-4% loss in reservoir storage capacity (Rathburn et al., 2017). The 2014 snowmelt runoff remobilized and deposited a volume of sediment to the reservoir that was comparable to the flood-derived deposition (Rathburn et al., 2017).

As the aggraded channel adjusts towards a state of equilibrium, sediment continues to be remobilized and transported into the reservoir. This research focuses on quantifying the ongoing channel change and sediment movement along NSV Creek into the reservoir, as well as the rate of the delta progradation caused by the remobilization of sediment. This research is a collaborative effort with the City of Longmont, which enables research results to inform future water management decisions.

Research Objectives

The primary goal of this research is to better understand and track continued sediment fluxes from the NSV into the Ralph Price Reservoir. For purposes of this paper, we focus on two objectives including: 1) quantifying the rate of delta progradation at the reservoir inlet between 2013 and 2017 and 2) quantifying the volume and spatial distribution of sediment that continues to be remobilized into the reservoir over time.

During our research, the reservoir was unexpectedly lowered to accommodate downstream post-flood bridge reconstruction. As a result, we took the opportunity to assess the impacts of this reservoir base level drop on channel erosion and associated deposition. An additional research objective is therefore 3) quantifying how post-flood (2014) rates of sedimentation and erosion compared to rates observed following a drop in reservoir base level (2016-2017).

Methods

To quantify the volume of sediment aggradation at the inlet and track delta progradation, we collected bathymetric surveys following the September 2013 storm. The sonar surveys were conducted at the reservoir inlet prior to snowmelt in April 2014, April 2016, and May 2017. Due to the low reservoir level in May 2017, an additional and more detailed bathymetric survey was also conducted in August 2017. Spatial statistical analyses were applied to create DEMs from the sonar tracks, and the DEMs were then differenced for volumetric change over time.

Eight sediment cores were collected from the reservoir inlet in April 2017 using a Livingstone surface corer (Figure 2A). To evaluate the spatial continuity of various sediment layers, six cores were collected near the center of the inlet along the long axis of the reservoir, and two cores were placed across the inlet (Figure 1B). Analyses on the collected cores include grain size analysis, bulk density, magnetic susceptibility, XRF analysis, and loss on ignition (LOI; for total organic carbon).

Results and Discussion

Four years after the flood, impacts to the reservoir are still being measured. Repeat bathymetry of the inlet reveals that the delta front has prograded over 170 m since the September 2013 flood (Figure 3). The rate of delta progradation (50 m/yr) has remained constant between April 2014 and April 2016 (post-flood), and between April 2016-May 2017 (the period associated with a 10 m drop in base level, Figure 4). However, the sub-annual rate of progradation between May 2017 and August 2017 (encompassing 2017 snowmelt) suggests a decrease in the progradation rate. An additional bathymetric survey in April 2018 will confirm this finding.

Volumetric differencing of bathymetric data indicates that, between 2014 and 2017, over 57,000 m^3 of sediment was deposited in the reservoir delta (Table 1). Net deposition occurred in the area of common bathymetry between 2014-2016, with up to 11 m of vertical aggradation (Figure 5). Net sediment erosion occurred between 2016-2017, associated with the drop in reservoir stage (base level), when up to 4 vertical meters of sediment was eroded from the inlet and transported into the deeper portion of the reservoir, possibly following the former NSV channel (Figure 5).

Since the 2013 flood, 10 cores were collected at the reservoir inlet in the prodelta sediment, in front of the mapped delta front (Figure 3). The cores represent additional, not yet quantified deposition because they were collected in an area outside the common bathymetric surveys. As a result, our volumetric differencing represents a minimum amount of sediment remobilization and deposition into the reservoir inlet.

Cores collected at the reservoir inlet not only showed visually distinct sediment layers associated with pre- and post-flood sedimentation, but also depicted a post-flood (2014-2017) sediment accumulation of 20 cm to over 70 cm in thickness. Magnetic susceptibility, LOI, and grain size were further used to correlate the post-flood sediment layers between the cores (Figure 6). Cores showed that post-flood (Fall 2013 - Spring 2014) sediments include a laminated sand layer overlain by silty mud and organic layers present in almost all of the cores; sedimentation that is most likely associated with the initial flood event. A mud layer stratigraphically younger than the organic layer suggests the settling of fines during Winter 2014. Its occurrence as the top stratigraphic layer of a core collected in April 2014 further supports this conclusion. Remobilized sediment of coarser lenses of sand overlain by mud with organics is found at the top of a core collected in 2016, and is therefore most likely associated with the snowmelt runoff in 2015 and 2016. Unique to cores collected closest the approach channel in 2017 was a fine, silty layer, suggesting its recent deposition in winter or early spring of 2017. The pinching out of these layers with the progression to the more distal parts of the inlet (Cores 5-7) corroborate that the top layers in the core are associated with lower-magnitude discharges than the flood.

A comparison between Cores 5a, 5b, and 5c shows a thicker lens of sand in Core 5a--the core closest to the inner bend of the former channel at the inlet. This suggests that coarser materials are preferentially deposited along the bend, whereas the outer bend is characterized by layers with a smaller median grain size.

Conclusions

Our research indicates that the effects of extreme floods on rivers are ongoing. On the NSV, post-flood snowmelt hydrographs influence the erosion, deposition, channel change, and resulting delta deposition. In 2014, an above average runoff hydrograph transported an additional volume of sediment comparable to the flood (Rathburn et al., 2017). Between 2014 and 2017, over 57,000 m^3 of sediment was remobilized and deposited in the delta, causing over 170 m of delta progradation. This represents a volume equivalent to 20% of the initial flood-derived sediment introduced into the reservoir in the four years following the flood. Core analysis of sediments collected at the prodelta further indicate widespread sedimentation associated with the flood and continued remobilization of flood sediments in the following years.

Quantifying the sediment influx into Ralph Price Reservoir provides water managers with useful information pertaining to the lasting impact of the 2013 storm and consequences of lowering the base level on reservoir storage capacity. Our findings are relevant to communities in Colorado and elsewhere that face challenges in providing water in a region where water demand often exceeds supply[4] and in planning for increased disturbances under a changing climate.

Future Research

Additional research will analyze recorded changes in the channel geometry of the approach channel, grain size, discharge, and sediment transport, to better predict future sediment influxes under various discharge scenarios. We specifically seek to understand: 1) whether the drop in base level (2016-2017) had a larger impact on channel morphology and recovery than other triggers such as high post-flood discharges, 2) whether the magnitude of overall channel response after the flood decreases with time, and, 3) whether erosion and deposition causing changes in channel geometry at the approach channel equate to sediment volume calculations in the delta to close our sediment budget.

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Figures, Tables, and Images

Title: 2017CO336B – Understanding Post-Flood Channel Adjustments and Reservoir Sedimentation to Inform Water Management Practices

Investigator(s): Johanna Eidmann, Geosciences, Colorado State University

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

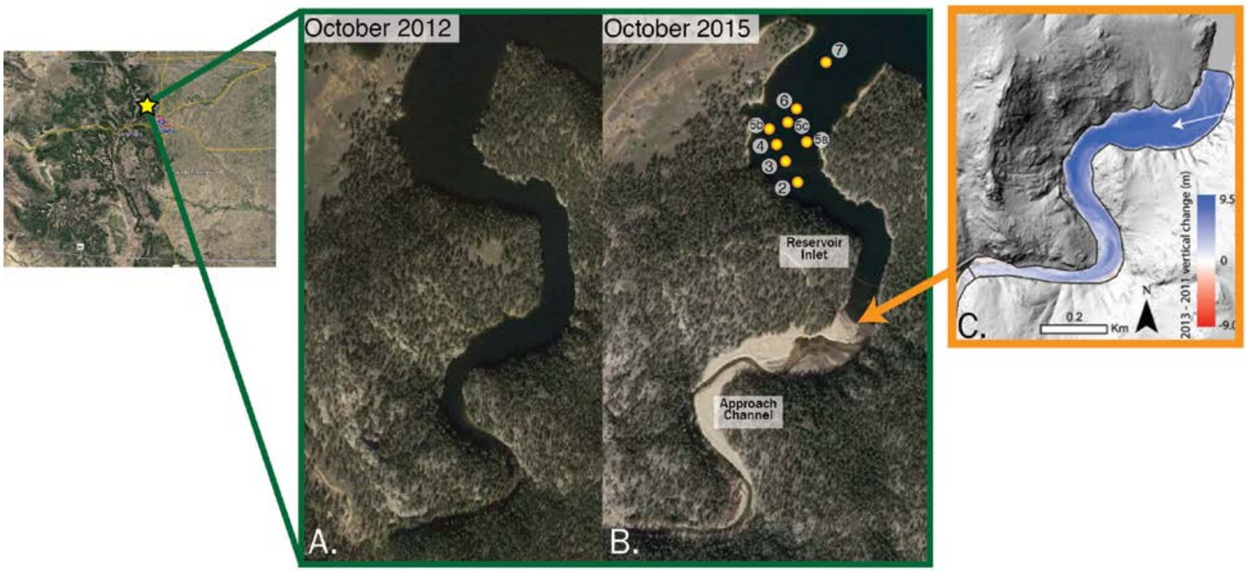

Figure 1. Google Earth images and DEM differencing showing significant sediment accumulation at the approach channel due to the flood. Figure 1B. shows the sediment core locations along the inlet.

Figure 2. Fieldwork photos of A) a core being collected on the reservoir, and B) a group photo of fieldwork participants during a photogrammetry survey.

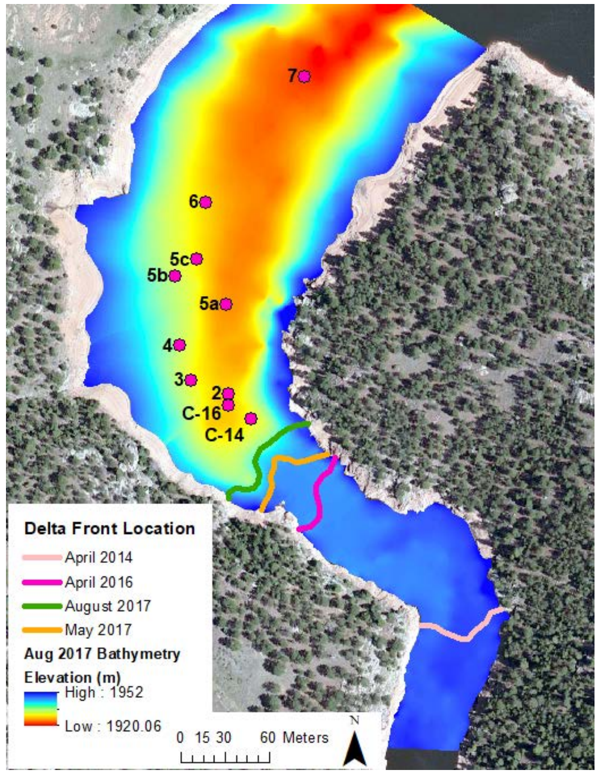

Figure 3. The August 2017 bathymetry of the reservoir inlet. Colored lines indicate the position of the delta front with time, and points indicate coring locations.

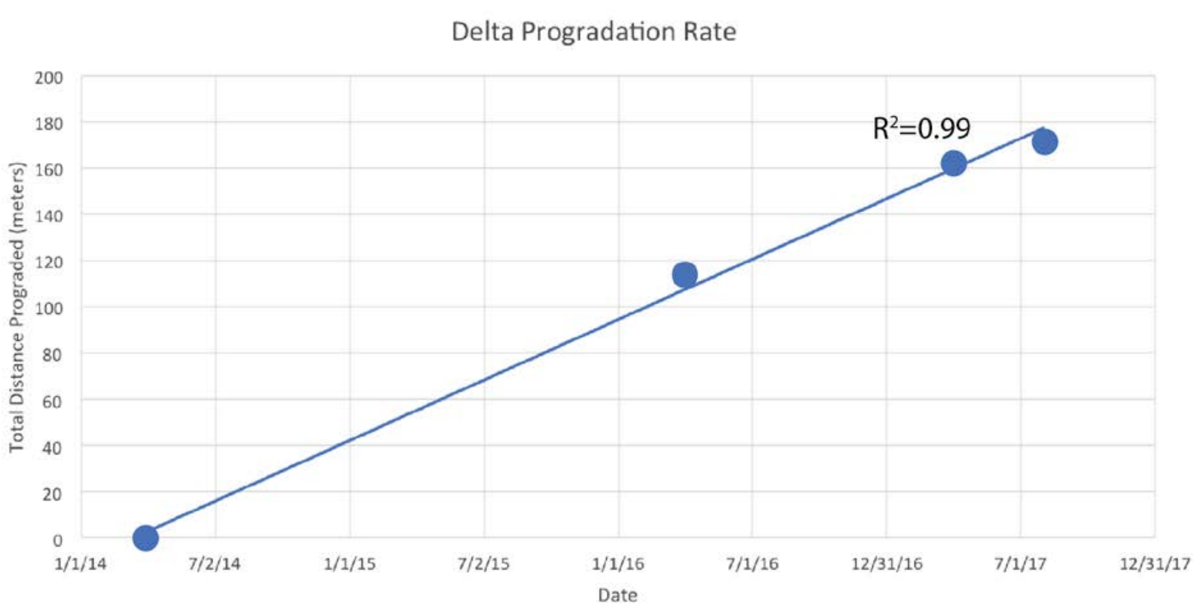

Figure 4. The distance of delta progradation relative to the location of the delta front in April 2014 with time.

Table 1. The calculated volume of sediment eroded and deposited within the analyzed portion of the inlet between 2014 and 2017.

Time Interval	Volume Eroded (m^3)	Volume Deposited (m^3)	Net Volume Moved (m^3)	Total Volume (m^3)
April 2014 to April 2016	1,150	68,230	67,080	69,380
April 2016 to August 2017	15,660	5,550	-10,110	21,210
April 2014 to August 2017	65	57,040	56,970	57,100

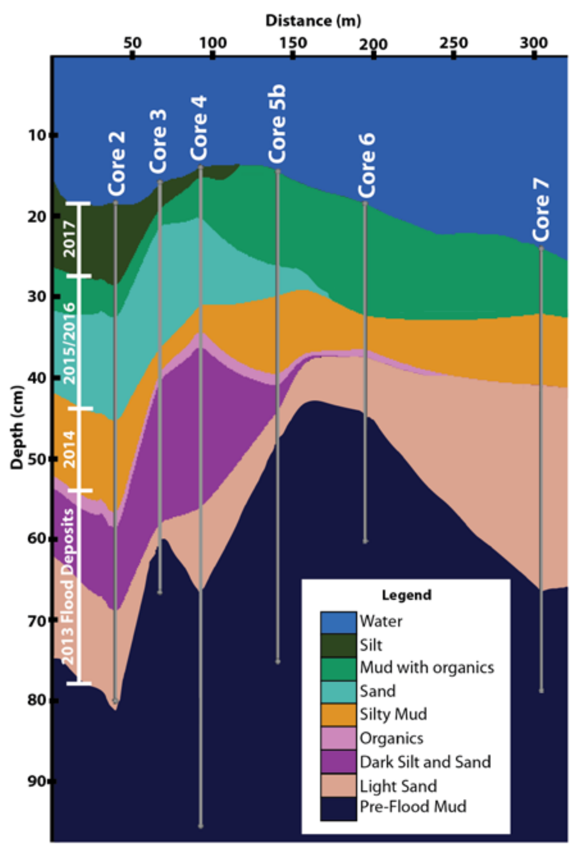

Figure 6. A cross section of core stratigraphy progressing from least distal (left) to most distal (right) parts of the inlet. Note that the surface topography is vertically exaggerated 5x, whereas the stratigraphic layers are exaggerated 50x.

Effects of Snow Persistence on Soil Water Nitrogen Along the Colorado Front Range

Basic Information

Title:	Effects of Snow Persistence on Soil Water Nitrogen Along the Colorado Front Range
Project Number:	2017CO338B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	CO-002
Research Category:	Climate and Hydrologic Processes
Focus Categories:	Geochemical Processes, Hydrogeochemistry, Hydrology
Descriptors:	None
Principal Investigators:	Stephanie K Kampf

Publications

There are no publications.

Final Report for Project

Title: 2017CO338B – Effects of Snow Persistence on Soil Water Nitrogen Along the Colorado Front Range

Investigator(s): Alyssa Anenberg, Ecosystem Science and Sustainability, Colorado State University

Advisor(s): Stephanie Kampf, Ecosystem Science and Sustainability, Colorado State University; Jill Baron, Natural Resource Ecology Laboratory, Colorado State University

Introduction

Nitrogen is an essential nutrient for all life on Earth. It forms the building blocks of DNA and chlorophyll and is often the most limiting nutrient in crop and forest production. In most ecosystems little soil water nitrogen is available for plant growth, constraining growth rates and primary productivity. Conversely, too much soil water nitrogen, while increasing growth rates and productivity, can cause adverse effects on the environment by changing biodiversity and leaching nitrogen from soils to streams. In the western U.S. mountains, the timing and magnitude of snowmelt is an important control on soil water and nutrient availability for plants. The broad goal of this study is to understand how the timing of snow accumulation and melt change soil moisture and soil water nitrogen concentrations. The specific objectives are to (1) manipulate snow depths at catchments in persistent, transitional, and intermittent snow zones along Colorado's Front Range, and (2) use the results to understand how snow accumulation and melt affect soil moisture and soil water nitrogen. This research is integrated into longer-term hydrologic monitoring examining how snow persistence affects soil moisture and streamflow generation from high to low elevations of Colorado mountains.

We hypothesize that higher elevations will accumulate deeper snowpack, causing increased spring snowmelt and elevated soil water nitrogen, whereas lower elevations will exhibit lower snow depths, snow moisture, and soil water nitrogen. Where winter snowpacks are deep and sustained throughout the winter, soils remain insulated from cold winter temperatures. If soil temperatures stay above freezing, this can allow winter microbial activity and retention of soil nitrogen. Concentrated melt of these deep snowpacks in the spring and early summer leads to elevated soil moisture and release of nitrogen in the soils. In contrast, low snow depths that are not sustained throughout the winter can cause soil water to freeze. This may trigger lysis of microbial cells, reduce nitrogen immobilization, and result in higher winter nitrogen export. Without the concentrated spring/summer snowmelt, low snowpack can lead to lower soil moisture to sustain plants through the growing season and a lower export of nitrogen in the spring.

Experimental Design

We monitor snow, soil moisture, and soil water nitrogen at three elevations in the Colorado Front Range. The highest elevation site, Michigan River, is located in the persistent snow zone at 3,197 m elevation. It has sandy loam soils that support vibrant wildflowers and dense fir trees throughout the summer growing season but is covered by a deep snowpack throughout the winter and a majority of the year. The middle elevation site, Dry Creek, is located in the Poudre Canyon, in the transitional snow zone. Snow persists throughout the winter, but at lower depths than Michigan River. This site sits at 2,340 m elevation and also has sandy loam soils. The low elevation site, Mill Creek, is located in Lory State Park, in the intermittent snow zone. The study site is in a small valley bottom at 1,784 m elevation, with sandy loam soils that support tall grasses and cacti.

To assess the effects of variable snow depth on soil moisture and soil water nitrogen, we constructed three plots at each study site, each 1.5 m x 1.5 m. One plot was a control, with no changes to snow; the other two were designed to increase and decrease snow depth. These latter two were constructed with PVC frames wrapped in either black or white canvas on three sides. The fourth side had a clear plastic side with visible depth increments facing a time-lapse camera used to document snow depth within the chamber. We hypothesized that the black canvas would decrease plot albedo and expedite snow melt while the white canvas would increase plot albedo and delay snow melt. Beneath each plot we installed two soil moisture probes (5 and 20 cm depth) and one soil temperature probe. To monitor soil water nitrogen, ion exchange resin probes (referred to as PRS™ probes / Plant Root Simulators) manufactured by Western Ag Innovations were installed in each plot. The resins attract nitrogen molecules that can be measured in the laboratory. Four sets of probes were inserted vertically into the soil for month-long burial periods between April and August. Once a probe was removed, a new probe was reinserted into the same location. Probes were cleaned with deionized water to prevent further ion exchange and refrigerated until shipped to the lab for analysis.

Preliminary Findings

During the 2017 water year, the high elevation Michigan River study site accumulated snow over several months, reaching peak snow depth (245 cm) in early May 2017. Soil moisture was relatively constant throughout the accumulation period and reached a maximum of 41% in June 2017 in response to spring snowmelt. Soil moisture gradually declined during the summer to a minimum of 15%. The middle elevation Dry Creek and low elevation Mill Creek study sites accumulated significantly less snow (75 and 35 cm, respectively) and experienced earlier mid-winter snowmelt, displaying the greatest magnitude of soil moisture following a late May storm event. Soil moisture at Dry Creek reached 49% while Mill Creek reached 43%. The snow accumulated and fully melted following each storm event, sending pulses of snow melt into the soil throughout the winter and spring. Soil moisture declined throughout the summer to a minimum of 8% at Dry Creek and 1% at Mill Creek.

Resin probes produce a nutrient supply rate based on the amount of nitrogen accumulated over the burial period. The highest nitrogen supply rates observed during the 2017 water year were at the high elevation site, Michigan River, during snowmelt, when soil moisture was high. These rates declined from June to August. Nitrogen supply rates at Dry Creek and Mill Creek were noticeably lower, with peak rates approximately one-third the magnitude observed at Michigan River. Rates were initially highest during snowmelt, declined in May, then increased again in July.

Results supported our original hypothesis that higher elevations would exhibit deeper snowpack and higher soil moisture. This high flux of water through the soil led to mobilization of nitrogen. Since the PRS™ probes simulate plant roots, they readily adsorb this available nitrogen following melt events. Traditionally higher elevation sites support a deep snow pack that would insulate the soils and reduce soil water nitrogen export, however during this water year, snow melted during October and increased soil moisture, which then froze during November snow events and the winter season. Results for the lower elevation sites were consistent with our original hypothesis that lower snow depths would result in lower soil moisture and soil water nitrogen. These sites experienced freeze-thaw events that may have released nitrogen but not at the quantities observed for the deep snowpack site.

Future Directions

This first field season indicated that the snow manipulation approach within each study did not produce large differences in snow, and variability in soil water between plots was high. Therefore, for the second season, we are conducting more intensive monitoring on the low elevation site to better understand the effects of pulse-melt events and to increase the plot sample size. For 2018, we have (1) increased the number of plots to enhance statistical strength, (2) installed lysimeters to supplement seasonal data with more quantitative event data, and (3) increased snow manipulation by shoveling snow from black plots into white plots to amplify snow depth variability.

Conclusion

The timing and magnitude of snowmelt change soil moisture and nutrient dynamics. Understanding nutrient dynamics in this region is important for managing the health of ecosystems and water resources. This research provides preliminary data on the elevational response of soil moisture and nitrogen supply to changes in snow cover. Higher elevations with deep snowpacks resulted in a surge of early summer snowmelt that caused high soil moisture and flushing of soil water nitrogen. Lower elevations with smaller snowpacks experienced freeze-thaw events that released pulses of snowmelt throughout the winter and spring, and generated lower soil water nitrogen supply. As monitoring continues, we hope to gain a more detailed understanding of how these factors affect the supply of soil water nitrogen in these mountain regions.

Figure, Tables, and Images

Title: 2017CO338B – Effects of Snow Persistence on Soil Water Nitrogen Along the Colorado Front Range

Investigator(s): Alyssa Anenberg, Ecosystem Science and Sustainability, Colorado State University

Advisor(s): Stephanie Kampf, Ecosystem Science and Sustainability, Colorado State University; Jill Baron, Natural Resource Ecology Laboratory, Colorado State University

Table 1. Study site name, snow zone, and elevation.

Study Site	Snow Zone	Elevation (m)	Elevation (ft)
Michigan River	Persistent	3,197	10,489
Dry Creek	Transitional	2,340	7,678
Mill Creek	Intermittent	1,784	5,854

Table 2. Mean snowpack and soil moisture properties

Study Site	Snow Onset Date	Snow Duration (days)	Peak Snow		Maximum Soil Moisture		Minimum Soil Moisture	
			Date	Depth (cm)	Date	%	Date	%
Michigan River	10/7/16	262	5/1/17	245	6/9/17	41	7/23/17	15
Dry Creek	11/17/16	188	5/19/17	75	5/27/17	49	7/4/17	8
Mill Creek	11/17/16	186	1/5/17	35	5/21/17	43	9/15/17	1

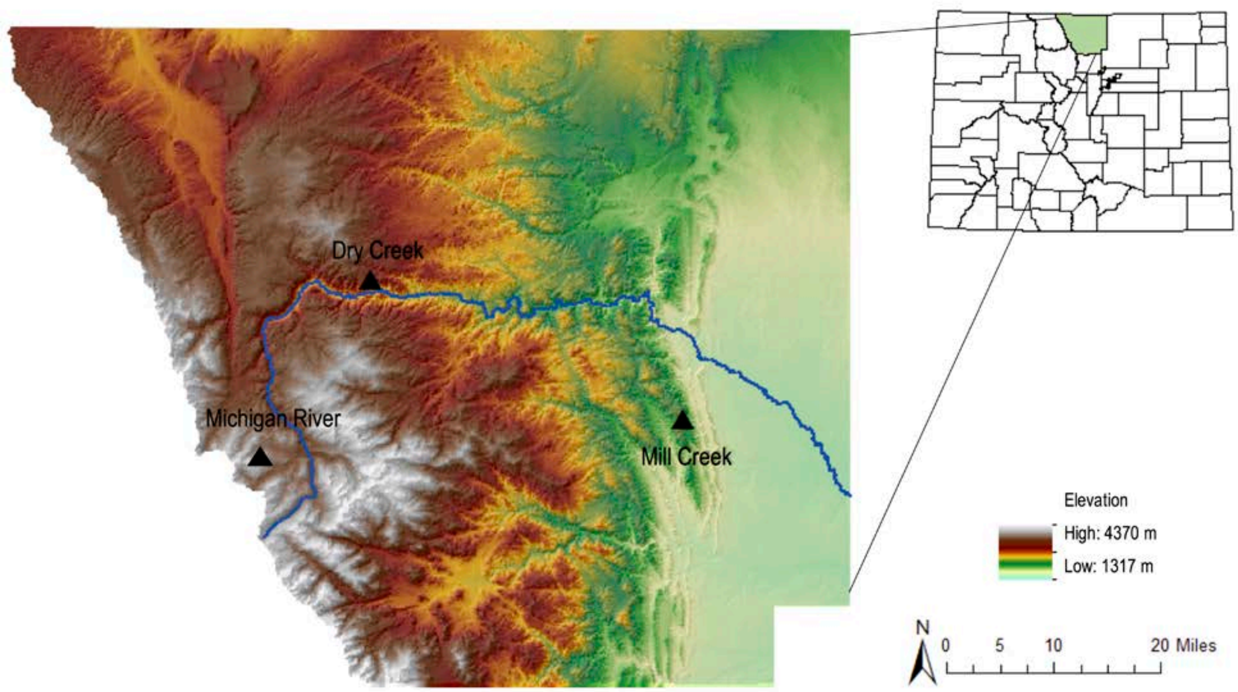

Figure 1. Research site locations along the Colorado Front Range.

Figure 2. Alyssa Anenberg retrieving PRS™ probes during a May 2017 field visit to the Michigan River study site.

Figure 3. John Hammond, Alyssa Anenberg, Stephanie Kampf, and Chenchen Ma at Michigan River during site installation in October 2016.

Figure 4. A December 2016 snow event at Dry Creek (above) followed by a rapid snowmelt response (below). Photo credit: Alyssa Anenberg

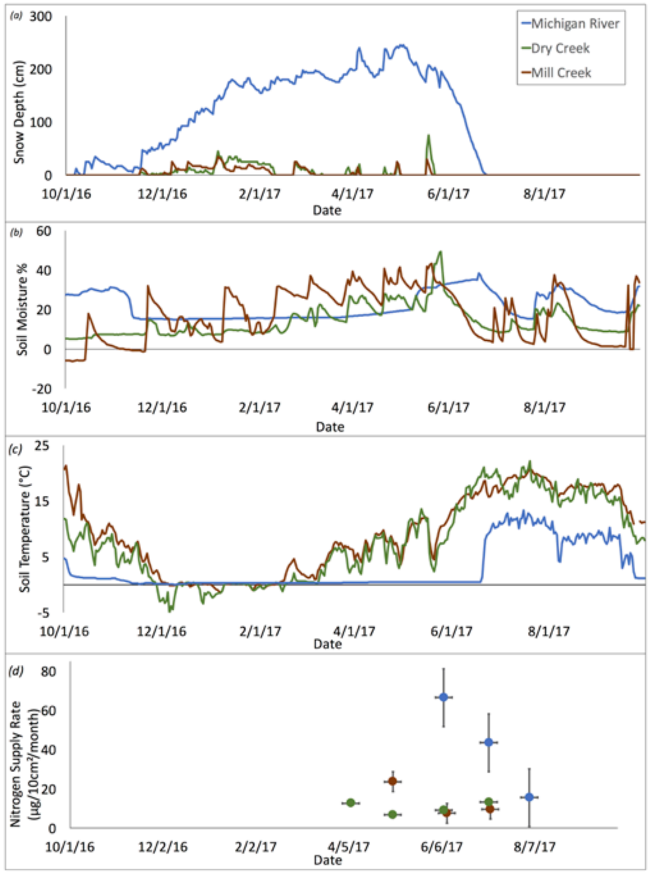

Figure 5. (a) snow depth, (b) soil moisture, (c) soil temperature, and (d) nitrogen supply rates for all sites during the 2017 water year.

Figure 6. Soil moisture sensors installed at 5 cm and 20 cm depth.

The Effect of Wastewater Effluent on Soil and Water Chemistry Along the South Platte River

Basic Information

Title:	The Effect of Wastewater Effluent on Soil and Water Chemistry Along the South Platte River
Project Number:	2017CO339B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	CO-001
Research Category:	Water Quality
Focus Categories:	Surface Water, Wastewater, Water Quality
Descriptors:	None
Principal Investigators:	Sarah Schliemann

Publications

There are no publications.

Final Report for Project

Title: 2017CO339B – The Effect of Wastewater Effluent on Soil and Water Chemistry Along the South Platte River

Investigator(s): Daniel Clark, Geospatial Science, Metropolitan State University of Denver

Advisor(s): Sarah Schliemann, Earth and Atmospheric Sciences, Metropolitan State University of Denver

Introduction

The Denver metro area is fully contained within the South Platte Watershed. Thus, the South Platte River can truly be classified as an urban waterway as it flows through the Denver Metro Area, highly impacted by urban runoff and stream modification. Elevated nutrient concentrations, pesticide residue, heavy metals, and halogens have been observed in the river (USGS, 1998; Health, 2014). This diminished water quality impacts the ecosystems along the river through the Denver Metro area including riparian wetlands that tend to have high proportions of non-native plants (Smith, 2015). The fish community of the South Platte River is also affected by the urban environment. The community changes dramatically from Denver, where Tate and Martin (1995) found low species richness (8 observed species, 3 non-native), to North Platte, Nebraska where the authors found higher species richness (15 species, 3 non-native). The authors theorize that the differences in the fish communities could be due to differences in water quality. Many urban factors can contribute to low species richness including the pollutants described above as well as sediment loading and thermal pollution. Colorado's Water Plan (2015) has acknowledged the degraded water quality throughout the South Platte River in the metro area and has "identified recovery of key species of trout and native plains fish as important."

Chlorine is widely used as a disinfectant in water treatment because it is a strong oxidizer and will kill microbes as it reacts with cellular material. In the Denver metro area, two forms of chlorine are primarily used. Metro Wastewater uses sodium hypochlorite at the Robert W. Hite Treatment Facility as a final treatment before wastewater is discharged into the South Platte River. Sodium hypochlorite quickly reacts with organic material in the presence of oxygen and forms sodium or calcium chloride, rendering it less toxic. In contrast, chloramine is far more stable and will remain in water for long periods. Because of this persistence, it is often the preferred form of chlorine for drinking water disinfection, since the water will remain safe as it travels from the water treatment facility to the consumer (EPA, 1999). Denver Water currently uses chloramines in its disinfection process. While treated drinking water is not discharged directly into the South Platte River, some of this water does end up in the river when it flows through the hundreds of stormwater drains that deposit water originating from residential and commercial irrigated landscaping.

Chloramines have been shown to causes adverse impacts on aquatic systems; causing mortality in invertebrates and vertebrates alike. The EPA has set the limit for chronic free chlorine expose to 0.011 mg/L. Above this level, biological organisms in the water body may be adversely affected (EPA, 1986). Chloramines can also react with organic matter to form disinfectant byproducts (DBPs) that can themselves be toxic. DBPs can be difficult to quantify due to the large number of chemicals that can form, however some of the more common DBPs include trihalomethanes, trihaloacetic acids, and dihaloacetonitriles (Du et al., 2017).

Because chloramines are not found in natural systems, they can also be used to gauge the total amount of municipal treated water that is found in a water body. The goal of this project was to investigate chloramine levels in the South Platte River and two of its main tributaries: Clear Creek and Sand Creek.

Methods

In the Fall of 2017, 12 sample sites were identified in the northern part of the Denver metro area including: 10 along the South Platte River; 1 along Sand Creek, upstream of the confluence with the South Platte River; and 1 along Clear Creek, upstream of the confluence with the South Platte River (Figure 1). Samples were collected from the bank every two weeks from October 2017-February 2018 (Figures 2-4). In the lab, samples were prepared in accordance with Standard Methods for the Examination of Water and Wastewater and were pH buffered with sodium hydroxide and treated for hard water prior to analysis. Chloramine concentrations were subsequently measured using an indophenol colorimetric method on a Hach DR 900 colorimeter.

Results

Chloramine was present in 98% of the samples, with samples collected at sites along the South Platte River showing the highest concentrations (Figure 5). Over the course of the investigation, the measured concentrations ranged from a minimum of 0 mg/L to a maximum of 1.09 mg/L. There was a large amount of variability from one sampling period to the next and there were no temporal trends.

Conclusions

All the sites in this study had average chloramine concentrations that far exceeded the chronic exposure limit of 0.011 mg/L set by the EPA. At these levels, it is likely that invertebrate and vertebrate species are negatively impacted. Juveniles are often the most susceptible to elevated chlorine levels and so, there may be issues with recruitment of key fish, amphibian, and invertebrate species in these areas (Pasternak et al., 2003).

The high levels of chloramines found in this investigation are especially interesting given that the samples were collected during the winter. Presumably, a significant amount of municipal water runs from residential yards and ends up in the river during the summer. It is possible that, with every snowmelt, a flush of chloramines are moved from the soil or groundwater into the river, but that idea is impossible to confirm with the present data.

This project has initiated several new investigations that will begin this summer. We will widen our sampling area to include areas along the South Platte River upstream and downstream of the present sampling locations. In particular, we will include locations upstream of the city to measure the concentration before the water begins to accumulate inputs from storm drains. In our current area, we will also collect samples from storm drains to attempt to identify the sources of the chloramines. Moreover, we will expand our research to isolate other species of chlorine including chloride, chlorate, chlorite, free chlorine, and total chlorine. Using this information, we will attempt to identify sources of chlorine pollution in the South Platte River and its tributaries.

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Figures, Maps, and Images

Title: 2017CO339B – The Effect of Wastewater Effluent on Soil and Water Chemistry Along the South Platte River

Investigator(s): Daniel Clark, Geospatial Science, Metropolitan State University of Denver

Advisor(s): Sarah Schliemann, Earth and Atmospheric Sciences, Metropolitan State University of Denver

Figure 1. Map of sampling locations. Map created by Daniel Clark.

Figure 2. Sarah Schliemann and Daniel Clark collecting water samples from the South Platte River. Photo credit: Sara Jackson.

Figure 3. Deja Knox with water samples collected from the South Platte River. Photo credit: Daniel Clark.

Figure 4. Dominic Baca collecting water samples from the South Platte River. Photo credit: Daniel Clark.

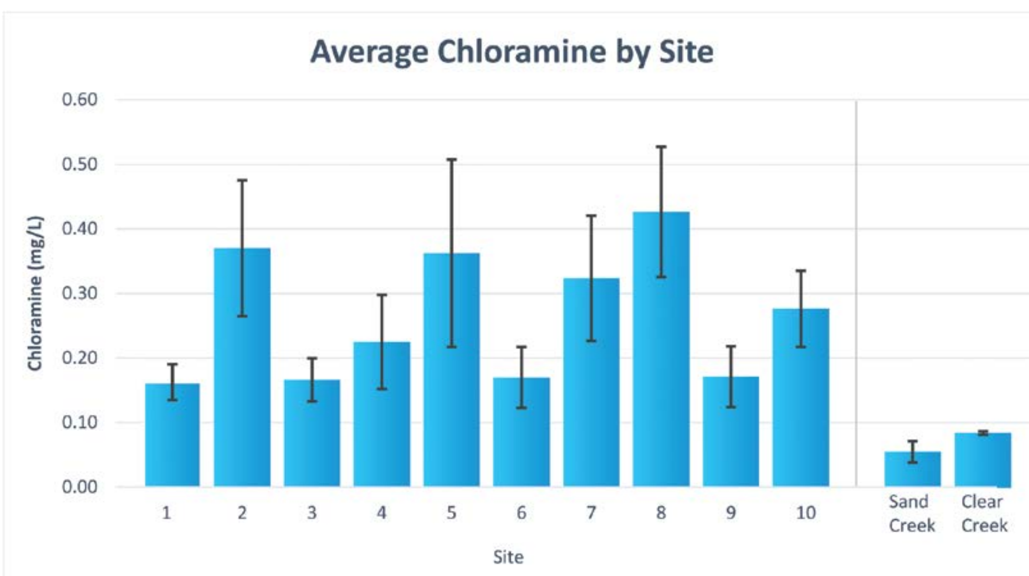


Figure 5. Mean chloramine concentrations at sample plots. Numbered plots are along the South Platte River. Error bars illustrate standard error. Figure created by Daniel Clark.

Estimating Agricultural Consumptive Use for Grass and Hay Pasture Fields on Colorado

Basic Information

Title:	Estimating Agricultural Consumptive Use for Grass and Hay Pasture Fields on Colorado
Project Number:	2017CO340B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	CO-003
Research Category:	Climate and Hydrologic Processes
Focus Categories:	Agriculture, Climatological Processes, Hydrology
Descriptors:	None
Principal Investigators:	Gigi Richard, Perry E Cabot

Publications

There are no publications.

Final Report for Project

Title: 2017CO340B – Estimating Agricultural Consumptive Use for Grass and Hay Pasture Fields on Colorado

Investigators: Christopher Pack, BS student, Environmental Science and Technology, Colorado Mesa University; Christopher Louie, former BS student, Environmental Science and Technology, Colorado Mesa University

Advisors: Gigi Richard, Geosciences, Colorado Mesa University and Perry E. Cabot, Colorado Water Institute.

Introduction

More sophisticated evaluation of agricultural consumptive use (CU) on the western slope of Colorado is needed for evaluating the delivery requirements for improved infrastructure, contending with recurrent drought and water shortages, as well as assessing the amount of water potentially available for water sharing arrangements. Given that only the CU fraction of a Colorado direct diversion rights can be transferred or leased to other uses, a method for accurate estimation of the amount of CU occurring on agricultural parcels will ensure that water sharing programs are executed fairly. Measures of actual consumptive use (ACU) or actual evapotranspiration (ET_a) on parcels that are and are not enrolled in water sharing programs will also help to account for the conserved consumptive use (CCU) that resides elsewhere in the delivery system when diversions are foregone in order to conserve consumptive uses.

Grass and hay pasturing for animal feeding is by far the largest agricultural endeavor on the western slope of Colorado, on the basis of acreage. The Colorado Water Bank Workgroup estimates a potential 1,069,759 acre-feet of CU occurring in this land use sector. These estimates were derived from generalized empirical approaches for predicting CU, but more advanced methods are available for these same assessments. In particular, remote-sensing approaches using energy-balances or reflectance-based models will help improve estimates of ACU on a more accurate spatio-temporal basis. Satellite imagery and multi-spectral observations are available free of cost through Landsat on an 8-day basis. These observations may occasionally suffer from interference from cloud coverage, so the measurements needed to make regular CU estimates can be improved using ground-based multispectral remote sensing surface reflectance data.

This project was conducted to: 1) estimate CU from ground-based multispectral remote sensing surface reflectance data; 2) create spatially-averaged GIS maps of CU at these locations; and 3) compare ground-based CU estimates performed using reflectance data in order to determine the utility of ground-based methods to fill in data gaps resulting from the infrequent Landsat passes. The project tested the hypothesis that a vegetation index derived from ground-based multispectral remote sensing surface reflectance data can be related to grass pastures in the western slope of Colorado.

Methods

Measurements of surface reflectance were taken on separate visits using an MSR5 multispectral radiometer at two grass hay/pasture locations in Hotchkiss, Colorado. The data used for this project was obtained in 2016 and collected under a project done for the Colorado River District. This device is housed in an 80 x 80 x 100 mm casing, made from anodized aluminum, consisting of an upward and a downward facing sensor to measure both incoming solar radiation and reflected radiation from the canopy surface. As indicated by the name of the device, the MSR5 measures 5 bandwidths corresponding to blue (450–520 nm), green (520–600 nm), red (630–690 nm), near infrared (760–900 nm) and short-wave infrared (1550–1750 nm). The field of view of the sensor is 28 degrees, and measurement is taken on the field diameter equal to half the height at which the radiometer is held from the ground. The data collected are stored in a data logger in millivolt format, which is later processed using the CropScan software to obtain the percent reflectance data. Because the MSR5 is a handheld device, the instrument is easier to use, and data processing is simple as opposed to the other satellite based methods which are more time consuming and complex to process the satellite images. In addition to that, useful readings can be obtained even during the cloudy conditions (Cropscan, 2011).

A small subset of soil moisture measurements was taken in 2017 using Watermark^{TM} sensors manufactured by Irrometer® (Riverside, California). Chávez et al. (2011) reported accuracies of ±11% for soils of Eastern Colorado using Watermark^{TM}

sensors to measure soil moisture. Rather than measuring soil moisture directly, the Watermark™ sensor effectively measures the soil matric potential (ψm) or soil tension by monitoring water movement through the porous granular matrix when in good contact with the soil. Therefore, soil tension must be related to volumetric water content using a soil water characteristic curve, which was developed for the project site using standard methods (Saxton and Rawls, 2006) and existing soils data. Data was collected from the sensors every 30 minutes using an industry-supplied data logger for comparison with ET_a rates

The Normalized Difference Vegetation Index (NDVI) was calculated from the surface reflectance data. The NDVI is the mathematical combination or transformation of surface reflectance in different spectral bands. They are derived using reflectance properties of the vegetation. Usually, the visible to near-infrared bands are used to calculate vegetation indices. The differences in reflectance values at different bandwidth from typical multispectral signatures help to determine current or actual canopy properties. There are several vegetation indices developed till date, ranging from very simple to very complex band combinations, but the NDVI is the most widely used vegetation index to study the plant biophysical properties (Jiang et al., 2006). NDVI uses the surface reflectance readings of near-infrared (NIR) and Red bandwidths of the electromagnetic spectrum and is calculated by the following equation, where the units of NIR and Red are nanometers:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}}$$

The NDVI can range from -1.0 to 1.0, but generally, for sparse vegetation, values range from 0.2 to 0.5 while denser vegetation ranges from 0.6 to 0.9.

Using an empirical regression model (Kca = [1.12 × NDVI]- 0.08) developed by Gautam (2018), the NDVI was related to a quasi- crop coefficient (K_{ca}) to estimate the actual crop evapotranspiration (ETa) rate.

$$\mathrm{ET_a} = K_{ca} \times \mathrm{ET_{ref,alfalfa}}$$

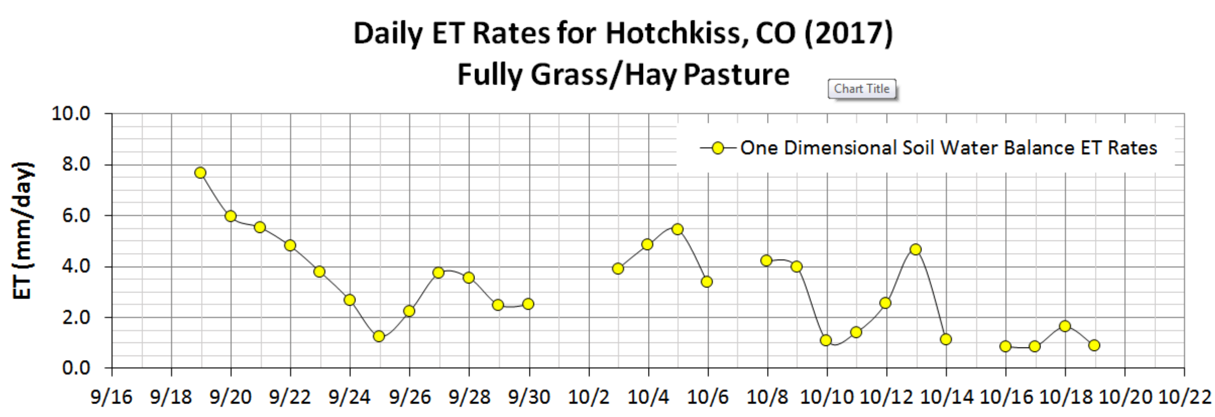
Where ET_a = actual ET estimate (assumed as a proxy for CU) and $ET_{ref,\ alfalfa}$ = a reference ET calculated from the ASCE Standardized Equation using data measured at the nearby CoAgMet Station located on Rogers Mesa Agricultural Experiment Station.

The quasi- crop coefficient estimated here is a single crop coefficient, which is the sum of basal crop coefficient (K_{cb}) and soil evaporation rate (K_e).

Results

The surface reflectance data taken with the MSR5 was applied to the empirical regression model to derive K_{ca} and applied to $ET_{ref,\ alfalfa}$ for the given day of each visit. The maps of ET_a are shown in Figure 1 and Figure 2 for each of the two evaluated sites. The calculated values of ET_a for these locations correspond reasonably well to published values for grasses (Romero and Dukes, 2016).

A one-dimensional soil water balance (assuming a root zone of 36 inches) was performed using the 2017 soil moisture data to compare estimates of ET_a at one of the grass pasture locations. While these data do not overlap with the ET_a estimates taken in 2016, they provide a comparative set of measurements that are useful for general comparison against the 2016 ET_a estimates taken with the surface reflectance data. The need to use two different years of data arose in this project due to several changes in the student participants during the 2017 year of the study. The most reliable subset of soil moisture data obtained from the one-dimensional soil water balance is shown in Figure 3.



Discussion

Surface reflectance readings from a hand-held multispectral radiometer were processed and related to a quasit-crop coefficient to develop from calculated NDVI. An NDVI based model has high potential to be used to estimate locally calibrated quasicrop coefficient and grass evapotranspiration rates at near-real-time as well as on the seasonal scale. The results from this evaluation indicate that further investment of time for research would be beneficial to continue evaluating this inexpensive and faster method to estimate evapotranspiration rates for grass hay/pastures of western Colorado. While this research has shown positive results, further evaluations should be performed with more sophisticated and lengthy soil water balances at greater depth, using instruments like neutron probe or a weighing lysimeter. The results from this evaluation do suggest, however, that further effort with remote sensing models should be applied to the western slope of Colorado used as an inexpensive and faster method to estimate evapotranspiration and consumptive use rate under a variety of irrigated conditions.

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Figures

Title: 2017CO340B – Estimating Agricultural Consumptive Use for Grass and Hay Pasture Fields on Colorado

Investigators: Christopher Pack, BS student, Environmental Science and Technology, Colorado Mesa University; Christopher Louie, former BS student, Environmental Science and Technology, Colorado Mesa University

Advisors: Gigi Richard, Geosciences, Colorado Mesa University and Perry E. Cabot, Colorado Water Institute.

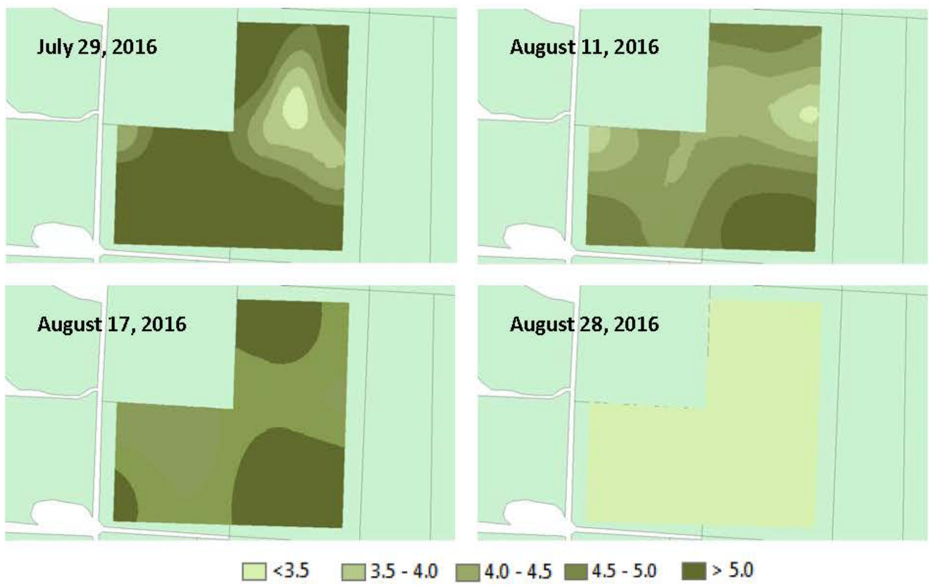

Figure 1. Evapotranspiration estimates (mm/day) for a grass pasture field in Hotchkiss, CO during the 2016 growing season. Estimates made using methods developed by Gautam (2018).

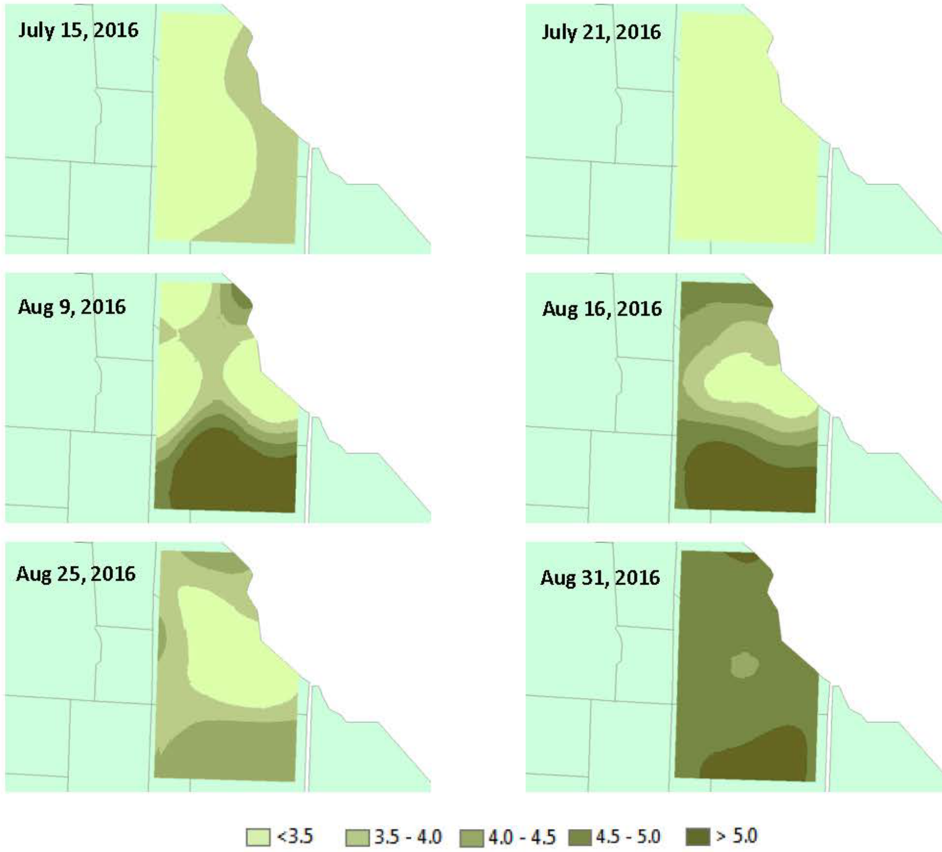

Figure 2. Evapotranspiration estimates (mm/day) for a grass pasture field in Hotchkiss, CO during the 2016 growing season. Estimates made using methods developed by Gautam (2018).

Hydrodynamic-Enhancement of Nitrate Attenuation by Integrating Reactive Biobarriers into Shallow, Open Water Treatment Wetlands

Basic Information

Title:	Hydrodynamic-Enhancement of Nitrate Attenuation by Integrating Reactive Biobarriers into Shallow, Open Water Treatment Wetlands
Project Number:	2017CO350G
USGS Grant Number:	G17AP00133
Start Date:	9/8/2017
End Date:	9/7/2020
Funding Source:	104G
Congressional District:	None
Research Category:	None
Focus Categories:	
Descriptors:	None
Principal Investigators:	

Publications

There are no publications.

Research Progress Report: Sept 2017-Feb 2018 (Year 1)
NIWR/USGS #G-62991-01

Hydrodynamic-Enhancement of Nitrate Attenuation by Integrating Reactive Biobarriers into Shallow, Open Water Treatment Wetlands

Principal Investigators:
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John McCray, Professor and CEE Department Head, Colorado School of Mines

Co-Principal Investigators:
Richard Smith, Research Hydrologist, National Research Program USGS
Scott Nygren, Director of Field Operations, Orange County Water District
Megan Plumlee, Director of Research and Development, Orange County Water District

Project Overview: As we envision water treatment in the 21st century and beyond, there is growing interest in the integration of natural water treatment infrastructure that has the ability for both water storage and the improvement of water quality while simultaneously providing recreational, aesthetic, and wildlife habitat benefits. Engineered wetlands have immense promise in these and other areas; however, broad adoption has been limited due to concerns about the impact of seasonality, preferential flow paths, and other variables on performance and reliability as well as the large surface area needed for effective treatment. *Our project goal is to decrease the footprint while increasing the reliability and resiliency of an engineered wetland design by enhancing biological contaminant transformation capacity. This will be approached through passive hydrologic manipulation that utilizes microbially active treatment barriers that increase water exchange within a vertically stratified biomat while also facilitating complementary biological attenuation processes.*

To this end, the project focuses on the design, construction and study of a novel wetland flow-through experimental system designed to investigate and quantify the efficacy of coupling a self-colonizing diatomaceous benthic biomat to denitrifying biobarriers that facilitate favorable hydrodynamic processes while providing complementary biological treatment processes. The photosynthetic biomat that resides within this type of shallow, open water treatment wetland has been demonstrated in prior research by our team to be capable of higher surface area normalized rates of nitrate attenuation (via denitrification and anammox) than more traditional vegetated systems. Lignocellulose-based denitrifying bioreactors have similarly shown promise for the passive treatment of impaired waters, and we envision a novel coupling of the biomat, whose capacity for treatment is limited by vertical mixing, to biobarriers that directly facilitate nitrate attenuation while also providing a hydrologic manipulation strategy that increases water exchange within this stratum.

Our multidisciplinary and hypothesis-driven approach, which pools academic and USGS researcher talent with municipal water provider knowhow and resources, merges themes of hydrology and microbiology to explore a potential adaptation and integration of novel water treatment processes applicable in both agricultural and urban settings. Our proposed work will develop and evaluate innovative approaches to water treatment and infrastructure that will enable informed design, management, and maintenance as society addresses the replacement of our aging water treatment infrastructure. The graduate and undergraduate students trained in association with this project will be exposed to these research themes as well as a broader network of researchers and practitioners who are part of an NSF funded engineering research center that focuses on future urban water infrastructure and facilitating information transfer and adoption of novel technologies. Project findings and our collaborative demonstration-scale system will enable water providers and stakeholders to learn from our findings and utilize engineered treatment wetlands for a variety of impaired waters (*i.e.* agricultural runoff, storm water, secondary wastewater effluent) where removal of nutrients is desired to enable beneficial capture and reuse. Importantly, this can be achieved with less energy and infrastructure demand than more traditional engineered water treatment systems while ensuring system reliability.

System Design and Construction: Field-scale implementation began shortly after the award was announced with design and construction efforts providing the focus of this reporting period. In fall 2017, this focused on refining our proposed design through close collaboration with OCWD. The experimental units were then constructed at the Prado Engineered Wetland in California in the winter of this reporting period (winter 2018). The Orange County Water District provided in-kind support for the construction process and this has been chronicled in budgeting updates. The initial phase of construction of these cells was completed late in this reporting period and biological colonization is now underway.

The final design consisted of seven parallel wetland flow-through experimental systems (orange cells in **Fig 1A**). The design was optimized to investigate and quantify the efficacy of coupling a self-colonizing diatomaceous benthic biomat to denitrifying biobarriers that facilitate favorable hydrodynamic processes while providing complementary biological treatment processes (**Fig 1B**). To this end, those seven cells contain experimental variables including 1) the presence or absence of a liner where the biomat can colonize, 2) the presence or absence of hydrodynamic barriers for increased mixing, and 3) deployment variables of both spacing and the type of barrier (permeable woodchips or horizontal boards to disrupt the flow). After this flowpath, we further constructed a deeper, serpentine wetland system containing a series of three lignocellulose-based biowalls designed for robust denitrification. This was done to more carefully study and quantify attenuation rates and mechanisms while minimizing hydraulic short-circuiting potential (**Figs 1A** in blue with a picture of a biowall in **Fig 1C**).

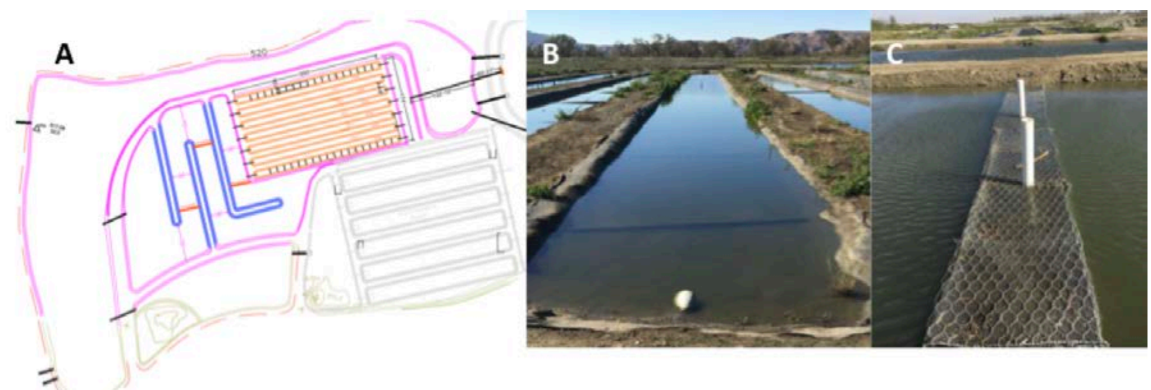


Figure 1: A schematic (A) of the recently developed unit-process wetland utilizing different permutations of (B) hydrologic bio-barriers in seven parallel cells that are (C) followed by a larger, serpentine wetland containing biowalls filled with woodchip and rock substrate.

Project Dissemination: In building upon prior work in our laboratory, a series of presentations and a peer reviewed publication (Jones et al., 2018) pulled in broader themes of the utility of the photosynthetic biomat and its capability to select for analogous self-colonizing microbial communities across systems. This offered a fantastic venue to highlight our new design and its potential value in engineered wetland systems and provides a foundation/test case for the microbial colonization expected in the newly constructed cells.

Publications:

1. Jones ZL, Mikkelson KM, Nygren S, Sedlak DL, Sharp JO. (2018) Establishment and convergence of photosynthetic microbial biomats in shallow unit process open-water wetlands. *Water Research*. 133:132-141. *https://doi.org/10.1016/j.watres.2018.01.021*

Presentations:

1. Invited talk by Sharp. Within the green box: contaminant attenuation in engineered treatment wetlands. Civil & Environmental Eng. Seminar, Rice University, Oct 27, 2017. Houston, Texas.
2. Invited talk by Sharp. Biogeochemical contaminant attenuation in shallow, open water treatment wetlands. Environmental Engineering Seminar, Colorado School of Mines, Oct 6, 2017.
3. Sharp, Jones, Vega, Mikkelson, Jasper, Sedlak, and Nygren. Intertwined nitrogen and sulfur biogeochemical cycling in a benthic microbial mat. The International Society of for Subsurface Microbiology (ISSM). Nov 6-10, 2017. Rotorua, New Zealand.

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 CWI 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, USDA-NIFA and other organizations to provide educational programs to address identified needs

Technology Transfer and Information Dissemination

Basic Information

Title:	Technology Transfer and Information Dissemination
Project Number:	2017CO341B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	CO-002
Research Category:	Not Applicable
Focus Categories:	None, None, None
Descriptors:	None
Principal Investigators:	Reagan M. Waskom

Publications

1. Colorado Water Newsletter, Volume 34 – Issue 2 (March/April 2017), Colorado Water Institute, Colorado State University, Fort Collins, Colorado, 40 pages.
2. Colorado Water Newsletter, Volume 34 – Issue 3 (May/June 2017), Colorado Water Institute, Colorado State University, Fort Collins, Colorado, 48 pages.
3. Colorado Water Newsletter, Volume 34 – Issue 4 (July/August 2017), Colorado Water Institute, Colorado State University, Fort Collins, Colorado, 44 pages.
4. Colorado Water Newsletter, Volume 34 – Issue 5 (September/October 2017), Colorado Water Institute, Colorado State University, Fort Collins, Colorado, 48 pages.
5. Colorado Water Newsletter, Volume 34 – Issue 6 (November/December 2017), Colorado Water Institute, Colorado State University, Fort Collins, Colorado, 46 pages.
6. Colorado Water Newsletter, Volume 35 – Issue 1 (January/February 2018), Colorado Water Institute, Colorado State University, Fort Collins, Colorado, 32 pages.
7. Osborn, B.; Anthony S., Orlando; Dana L., Hoag; Timothy K., Gates; James C., Valliant, 2017, The Economics of Irrigation in Colorado’s Lower Arkansas River Valley, Colorado Water Institute Special Report Number 32, Colorado State University, Fort Collins, Colorado, 1-49.
8. Castle, Anne; MaryLou, Smith; John, Stulp; Brad, Udall; Reagan, Waskom, 2017, Where Now with Alternative Transfer Methods—ATMs—in Colorado?, Colorado Water Institute Special Report Number 21, Colorado State University, Fort Collins, Colorado, 1-9.
9. Udall, Brad; Greg, Peterson, 2017, Agricultural Water Conservation in the Colorado River Basin: Alternatives to Permanent Fallowing Research Synthesis and Outreach Workshops,Colorado Water Institute Completion Report Number 232, Colorado State University, Fort Collins, Colorado, 1-219.
10. Cabot, Perry E.; Aman, Vashisht; Jose L., Chavez, 2017, Using Remote Sensing Assessments to Document Consumptive Use (CU) on Alfalfa and Grass Hayfields Managed Under Reduced and Full Irrigation Regimes, Colorado Water Institute Completion Report Number 231, Colorado State University, Fort Collins, Colorado, 1-62.
11. Wohl, Ellen; Kevin, Bestgen; Brian, Bledsoe; Kurt, Fausch; Mike, Gooseff; Natalie, Kramer, 2017, Management of Large Wood in Streams of Colorado’s Front Range: A Risk Analysis Based on Physical, Biological, and Social Factors, Colorado Water Institute Completion Report Number 230, Colorado State University, Fort Collins, Colorado, 1-44.

Colorado Water Institute Activities

- Water Management in Colorado, GRAD592, Fall 2017
- Colorado Water, Colorado Water Institute, March 2017 – February 2018
- Hydrology Days, March 2017
- World Water Day, March 2017
- Norm Evans Lecture Series, Eleanor Allen, March 2017
- CSU Earth Week and Earth Day Festival, April 2017
- UpRiver film screening, April 2017
- Poudre River Clean Up, May 2017
- Hach Walk for Water, May 2017
- UCOWR Conference, June 2017
- Western Water Symposium, July 2017
- CWC Summer Conference, August 2017
- How Sub-Saharan Africa Can Achieve Food Security, September 2017
- South Platte Forum, October 2017
- Shepherding Water in Colorado for Colorado River Compact Security, November 2017
- CWC Annual Conference, January 2018
- Poudre River Forum, February 2018
- Irrigation Innovation Consortium
- CSU Water Experts, http://www.cwi.colostate.edu/CSUWaterExperts/default.aspx
- Water Literate Leaders, http://waterliterateleaders.colostate.edu/
- South Platte HB1278 Research, http://southplatte.colostate.edu/
- The Poudre Runs Through It, http://prti.colostate.edu/

GRAD592

Interdisciplinary Water Resources Seminar
Fall 2017 *Water Management in Colorado*

Mondays 4:00 – 5:00 PM Behavioral Sciences Room 103

The purpose of the Interdisciplinary Water Resources Seminar is to prepare students for careers in water resources by increasing their understanding of how water is actually managed in Colorado.

Specifically, the seminar will:

1. Examine the roles of various local, state, and federal agencies in water quantity and quality and environmental management
2. Understand the role of the political process in water management
3. Prepare students for water-related careers by learning the analytical and data tools used in tracking and managing water in Colorado

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

Seminar Instructor: Jennifer Gimbel (jennifer.gimbel@colostate.edu)

Tentative Seminar Schedule

Aug 21 Introductions, Course Overview, and Overview of State and Federal Statutes

Aug 28 Overview of Online Tools and Databases at Colorado's Decision Support Systems (CDSS)
Steve Malers, Open Water Foundation

Sep 4 No Class, Labor Day

Sep 11 Federal, State, and Water User Entities Roles and Responsibilities
Jennifer Gimbel, CWI

Sep 18 Administration of Water Rights: Roles of Division Engineer and Water Commissioners
Dave Nettles, DWR
Steve Malers, Open Water Foundation

Sep 25 Changing a Water Right — The Process
Jennifer Gimbel, CWI
Erin Wilson, Wilson Water Group

Oct 2 Changing a Water Right — Lab Session
Steve Malers, Open Water Foundation
Erin Wilson, Wilson Water Group

Oct 9 Groundwater — Permitting, Exempt vs. Non-Exempt, Augmentation Plans, Using AWAS
Jeff Deatherage, Colorado Division of Water Resources

Oct 16 Water Quality: Compliance, Point and Non-Point Pollution, NPDES Permitting, WOTUS
Patrick Pfaltzgraff, Colorado Dept. of Public Health and the Environment

Oct 23 Project Development and Financing
Mike Brod, Colorado Water Resources and Power Development Authority
Kirk Russell, Colorado Water Conservation Board

Oct 30 Case Study: Development of NISP
Eric Wilkinson, Northern Water

Nov 6 Environmental Issues: Instream Flows, ESA, NGOs, Healthy Rivers, Recreational Flows, Wild and Scenic Designations; How to Use Databases to Recommend Instream Flows to CWCB
Linda Bassi, Colorado Water Conservation Board
Steve Malers, Open Water Foundation

Nov 13 Compacts and Downstream States; Political Process in Water Management
Jennifer Gimbel, CWI
John Stulp, Special Policy Advisor to the Governor for Water

Nov 20 No Class, Fall Break

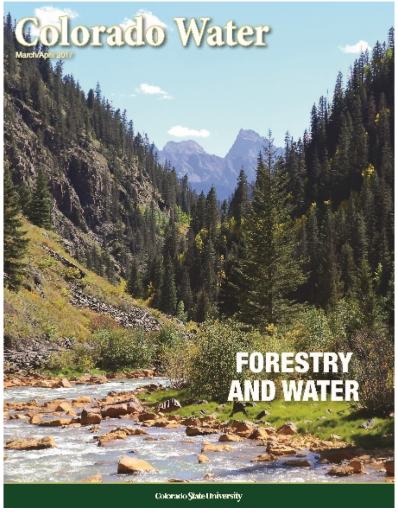
Nov 27 Wrap-Up and Review

Dec 4 Class Discussion, Semester Assignment Due (Attendance Required)

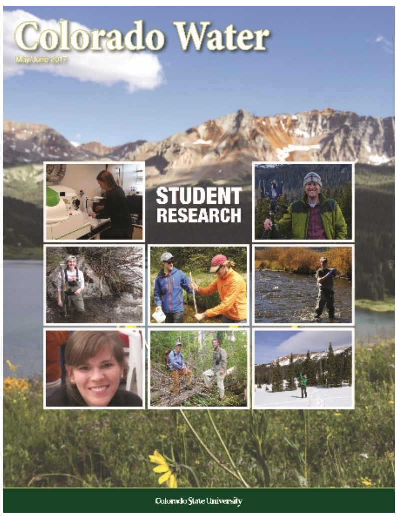
All interested faculty, students, and off-campus guests are encouraged to attend.

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

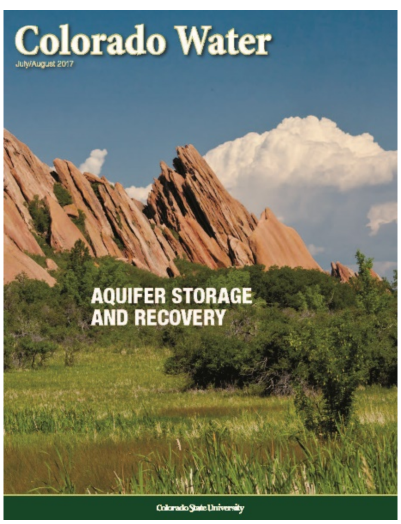
Colorado Water Institute   Colorado State University   WATER CENTER COLORADO STATE UNIVERSITY



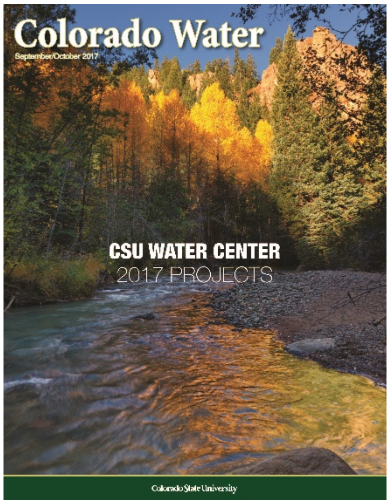
Colorado Water
Volume 34, Issue 2
Forestry and Water



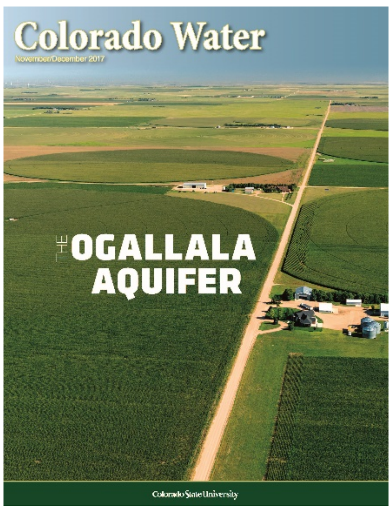
Colorado Water
Volume 34, Issue 3
Student Research 2017



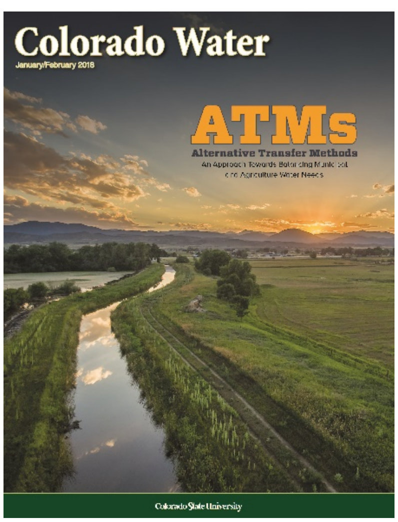
Colorado Water
Volume 34, Issue 4
Aquifer Storage and Recovery



Colorado Water
Volume 34, Issue 5
CSU Water Center:
2017 Projects



Colorado Water
Volume 34, Issue 6
The Ogallala Aquifer



Colorado Water
Volume 35, Issue 1
Alternative Transfer Methods:
An Approach Towards Balancing
Municipal and Agriculture Water
Needs

Conference Program

AGU Hydrology Days 2017

March 20 - March 22, 2017

Program at a Glance

	March 20		March 21		March 22
9 am	Registration	9 am	Registration	8 am	Registration
				8 am	Hydraulics
	Mid-morning break		Mid-morning break		Mid-morning break
10 am	Global Water - BMPs - Irrigation - Water Quality	10 am	Eco-Hydrology	10 am	Ground Water - Contaminants - Remediation
12 - 2 pm	Lunch Borland Lecture in Hydrology	12 - 2 pm	Lunch Hydrology Days Award Lecture	12 - 2 pm	Lunch Borland Lecture in Hydraulics
2 pm	Water Management	2 pm	River Morphodynamics	2 pm	River Mechanics
					Confucius Institute Session I: Challenges
	Mid-afternoon break		Mid-afternoon break		Mid-afternoon break
4 pm	Soil Moisture - Climate - Hydrology	4 pm	Poster Session	4 pm	Erosion and Sedimentation
					Confucius Institute Session II: Opportunities
					World Water Day Celebration **Hydrology Days Ends**

Dr. Norm Evans Endowed Lecture

In conjunction with CSU Hydrology Days

and World Water Day

ELEANOR ALLEN

CEO, Water For People

Keeping Water Flowing For Generations to Come

Wednesday March 22, 2017 | 5:30 PM Refreshments, 6:15 PM Presentation

CSU Lory Student Center Theater | FREE AND OPEN TO ALL

Colorado Water Institute

WATER CENTER
COLORADO STATE UNIVERSITY

water for people
everyone | forever

www.watercenter.colostate.edu | www.facebook.com/events/371594419887182/

CSU PREMIERE

Thursday, April 6th - 4:30 pm Clark A202

Intro by filmmaker & FWCB/GDPE alumnus Jeremy Monroe at 4:15 pm

Presented by

WATER CENTER
COLORADO STATE UNIVERSITY

FISH, WILDLIFE, AND CONSERVATION BIOLOGY
COLORADO STATE UNIVERSITY

Graduate Degree Program in ECOLOGY

2017 UCOWR/NIWR Annual Conference
"Water in a Changing Environment"

June 13-15, 2017
Colorado State University
Lory Student Center
Fort Collins, CO

UCOWR
UNIVERSITIES COUNCIL ON WATER RESOURCES

NIWR
THE NATIONAL INSTITUTES FOR WATER RESOURCES

Conference Sponsors

The Ivanhoe Foundation

Northern Water

Colorado Water Institute
A division of the Office of Engagement

Colorado State University

Special Events

TUESDAY

UCOWR Delegate Business Luncheon (see pg. 6)
11:30 AM - 1:00 PM

Effective Science Communication (see pg. 33)
For students and early career professionals!
12:00 PM - 12:50 PM

Welcome Reception & Poster Session (see pg. 11)
5:30 PM - 7:00 PM

Water Quality Regulation Discussion (see pg. 13)
7:00 PM - 8:00 PM

Graduate Student Happy Hour (see pg. 33)
7:00 PM - 8:30 PM

WEDNESDAY

Breakfast Roundtable Discussions (see pg. 14)
7:30 AM - 8:30 AM

Authors' Plenary Luncheon Session (see pg. 18)
12:00 PM - 1:30 PM

Student Speed Networking Event (see pg. 33)
4:45 PM -5:45 PM

Awards Banquet (see pg. 34)
6:00 PM - 7:30 PM

THURSDAY

Mountain Whitewater Descents Rafting Trip (see pg. 25)
Must be pre-registered.
1:45 PM - 7:00 PM

WESTERN WATER Symposium & Barbecue

Water Optimism and Innovation

Morning Session • Barbecue Lunch • Afternoon Session • Reception

Monday, July 24, 2017
10 a.m. - 6 p.m. (registration from 9-10 a.m.)
Morgan Library, Colorado State University

Directions

Colorado has been home to significant innovation in water law, policy, technology, and institutions. Innovation was often driven by passionate optimism for big results. Although both may seem to be in short supply, history demonstrates that something new and exciting can appear on the horizon at any time. Join us and a dynamic group of speakers for engaging conversations about optimism that inspired important innovations, where those have taken us, and how forward-thinking perspectives and promising innovations are leading us locally and nationally.

Jennifer Gimbel
Senior Research Scientist, Colorado State University
Symposium emcee

Justice Gregory J. Hobbs, Jr.
Senior Water Judge and University of Denver Law School Faculty
"The Poudre River's Heritage, Turn Back or Move Forward?"

John Stulp
Special Policy Advisor to the Governor for Water and Interbasin Compact Committee Director
"Water's Innovative Future"

Jennifer Pitt
Colorado River Program Director, National Audubon Society
"We're All in It Together: Crafting Colorado River Management for the 21st Century"

Patrick O'Toole
President, Family Farm Alliance
"What's Old is New, What's New is Old"

Special panel of innovators: Louann DeCoursey, Mazdak Arabi, Greg Fisher, Pat O'Toole, David Stewart and Reagan Waskom (moderator)

LECTURE & BOOK SIGNING

WOLDEZION MESGHINNA

WEDNESDAY :: 2017

SEPT 13

LORY STUDENT CENTER
GREY ROCK ROOM 290

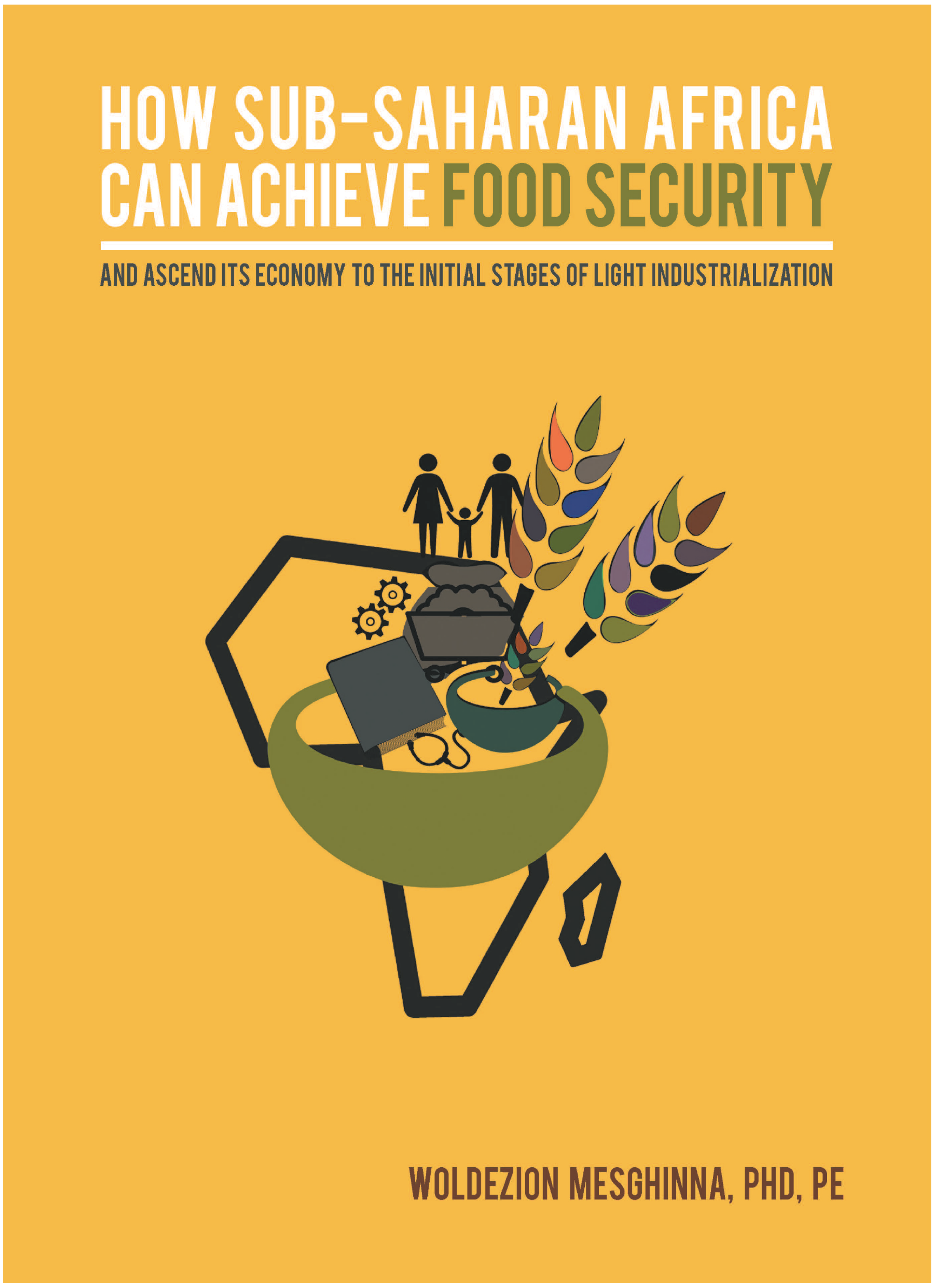
4:00PM *to* **5:30PM**

Copies of the book available for purchase and refreshments served

THE AFRICA CENTER
COLORADO STATE UNIVERSITY

WATER CENTER
COLORADO STATE UNIVERSITY

SCHOOL OF GLOBAL ENVIRONMENTAL SUSTAINABILITY
COLORADO STATE UNIVERSITY



Sub-Saharan Africa (SSA) is facing an ever-worsening food security crisis due to rapid population growth, inadequate domestic food production, and a general lack of sound resource management. In his innovative new book, Dr. Woldezion Mesghinna addresses the root cause to this problem: dependence on subsistence agriculture. Join us as Dr. Mesghinna explains current farming practices in the subcontinent, and introduces science- and engineering-based methods aimed at helping SSA countries achieve food security, attain access to safe and sustainable water supplies, and ascend to the initial stages of light industrialization. Book website: www.FoodSecurityAfrica.com

Dr. Mesghinna will be available for book signing

DR. WOLDEZION MESGHINNA President and Principal Engineer

Dr. Mesghinna is an Eritrean American who immigrated to the United States in the 1970s. He attended Cornell University, where he received his Bachelor of Science and Master of Engineering degrees in civil engineering, and later attended Utah State University, where he received his PhD in agricultural engineering, with a primary focus in irrigation and drainage engineering. Dr. Mesghinna is a registered professional engineer in California, Colorado, Wyoming, Arizona, New Mexico, and Utah, and has testified extensively as an expert witness on water rights cases in the United States. Company website: www.NRCE.com

africacenter.colostate.edu/content/africa-center-guest-speaker-series-dr-woldezion-mesghinna

South Platte Forum 2017

Voted the World's Best Conference on the South Platte River – 28 YEARS RUNNING

❖❖❖

Conference Schedule: Wednesday, October 25th

Time	Session	Panel
7:30-8:15	Registration & Breakfast	
8:15 AM	Welcome **Reagan Waskom** Director at the Colorado Water Institute	
8:20 AM	Keynote Introduction **David Skuodas** Project Manager at Urban Drainage & Flood Control District	
8:25AM-9:10AM	Opening Keynote Speaker **Jeremy Solin** National Program Manager ThinkWater	
9:10AM-9:20AM	Q&A for Jeremy Solin	
9:20AM-9:30AM	Break	
9:30AM-9:35AM	Moderator Introduction **David Skuodas** Project Manager at Urban Drainage & Flood Control District	***The Best and the Brightest:*** Education & Communication
	Panelist Presentations	
9:35AM-9:50AM	**Jayla Poppleton** Executive Director Colorado Foundation for Water Education	
9:50AM-10:05AM	**Matt Bond** Youth Education Program Manager Denver Water	
10:05AM-10:20AM	**Mike Sukle** Creative Director and President Sukle Advertising	
10:20AM-10:30AM	Q&A	
10:30AM-10:45AM	Break	
10:45AM-10:50AM	Moderator Introduction **Sean Cronin** Executive Director at St. Vrain & Left Hand Water Conservancy District	***The Colorado River's Got Nothin' On Us:*** Recreation & Tourism
	Panelist Presentations	
10:50AM-11:05AM	**Gary Nichols** Director of Recreation Development Park County	
11:05AM-11:20AM	**Luis Benitez** State Director Outdoor Recreation Industry office for the State of Colorado	
11:20AM-11:35AM	**Alex Dean** Colorado the Beautiful Project Manager	
11:35AM-11:45AM	Q&A	
11:45AM-11:50AM	Transition to Canyon Maple Room	
11:50AM-12:30PM	Lunch	
12:30PM-12:45PM	2017 Friends of the South Platte Award Introduction by Kevin G. Rein **Dick Wolfe** State Engineer Colorado Division of Water Resources	
12:45PM-12:50PM	Afternoon Keynote Introduction **Brian Werner** Communications & Records Department Manager at Northern Water	
12:50PM-1:25PM	Afternoon Keynote Speaker **Joey Bunch** Senior Correspondent Colorado Politics	
1:25PM-1:35PM	Q&A for Joey Bunch	
1:35-1:50PM	Break/Transition Back to Mountain Holly Room	
1:50PM-1:55PM	Moderator Introduction **Peter Ismert** Watershed Coordinator, EPA Region 8	***The Greatest Story Ever Told:*** Urban Conservation
	Panelist Presentations	
1:55PM-2:10PM	**Mazdak Arabi** Borland Professor of Water Resources Colorado State University	
2:10PM-2:25PM	**Ruth Quade** Water Conservation Coordinator City of Greeley	
2:25PM-2:40PM	**Carol Cochran** Owner of Horse & Dragon Brewing Company & BreWater	
2:40PM-2:50PM	Q&A	
2:50PM-3:05PM	Break - Snack Served	
3:05PM-3:10PM	Oil & Gas Panel Introduction **Sean Cronin** Executive Director at St. Vrain & Left Hand Water Conservancy District	***With Great Power Comes…*** Energy
3:10PM-3:25PM	Moderator: **Joe Ryan** Environmental Engineering Professor University of Colorado	
3:25PM-4:00PM	**Erik Anglund** Water Resource Engineer Anadarko **Rich Belt** Sr. Water Resource Analyst Xcel **Christopher Fields** Fuels and Water Resources Engineer Platte River Power Authority	
4:00PM-4:15PM	Q&A for all speakers from moderator and audience	
4:15PM-4:20PM	Closing Announcements **Sean Cronin**	
4:20PM-7:30PM	Oktoberfest Reception *Brought to you by Colorado Water Congress POND (Professional, Outreach, Networking and Development) Committee* In the Canyon Maple Room	

Shepherding Water in Colorado for Colorado River Compact Security

Workshop - November 14, 2017

Brief Summary

A workshop on shepherding water within the State of Colorado for the purpose of providing security under the Colorado River Compact was hosted by the Colorado Water Institute and the Getches-Wilkinson Center for Natural Resources, Energy and the Environment on Nov. 14, 2017 in Summit County. The purpose of the workshop was to obtain perspectives from the participants about shepherding and the larger context of Compact security that it is part of. Attendees included individuals associated with state and local government, water providers and users, municipalities, industry, conservation and conservancy districts, and environmental groups.

Presentations were made on the risk of curtailment under the Colorado River Compact, the State Engineer's authorities to deal with Compact compliance and related issues, the role of the Upper Colorado River Commission, and various proposals about how to accomplish water shepherding for Compact security. All participants, including the presenters, were expressing their personal views and not the positions of their organizations.

Small discussion groups guided by specific questions allowed for candid conversation among the attendees about water shepherding and the many other issues associated with Compact security. A detailed report on the workshop and discussions is available at http://www.cwi.colostate.edu/. The areas in which there was great consensus among the workshop participants, the areas of disagreement or in which there were multiple ideas about how to proceed, and the areas of need for further information or additional discussion are listed below. All agreed that this was a timely conversation, that the workshop was merely a first step, and that significant additional outreach and discussion must follow.

Areas of Agreement

1. We need to be discussing Compact security and shepherding water right now.
2. This workshop is a good first step but we need broader participation in these discussions.
3. We need to recognize that shepherding is part of a larger problem and that Compact security as a whole must be addressed.
4. We have insufficient stakeholder awareness of Colorado River Compact risk and agreement on the urgency of the problem.

5. The Upper Colorado River Commission should be involved in this discussion.
6. Legislation, if needed, should be part of a larger package addressing Compact security overall.

Areas of Disagreement or Varying Ideas

1. Is it better to wait and allow curtailment to occur or to take proactive steps soon to avoid curtailment?
2. How soon and in what manner do we need to act to avoid loss of power production from Glen Canyon Dam and the likelihood of curtailment of Colorado water uses?
3. Will legislation be required at some point to implement a Compact security program including providing for the shepherding of water?
4. The appropriate leaders for the discussions on Compact security and shepherding within Colorado and in the Upper Basin.
5. When do other states get involved?

Areas Where More Information or Additional Discussion Is Needed

1. What is the risk of Compact curtailment/loss of hydropower production? It should be noted that the sentiment was expressed that we currently have all the information on this issue that we are reasonably able to develop at this time. Others noted that this issue is still being addressed in the Risk Study, now jointly managed by the Colorado River Water Conservation District and the Colorado Water Conservation Board, and elsewhere.
2. How much risk is acceptable?
3. How much water is needed in Lake Powell to avoid compact curtailment or the loss of hydropower production?
4. How would Compact curtailment be implemented? What would be the impacts? What could be done to minimize those impacts?
5. What would a proactive Compact security program look like?
6. Do we need a water bank in Lake Powell to manage this water? If so, how would this bank be operated? Would having a credit/ debit account in Powell to counter evaporation, separate from system water, be feasible? Could Colorado have a credit account if other Upper Basin states don't participate?
7. Is the accumulation of wet water in Lake Powell an effective approach or could a virtual water bank that relies on water lease options be sufficient? What amount of such leases would have to be under option and at what cost? Are there sufficient sources of Compact security water to make a difference?
8. Where would Compact security water come from and what are the primary and secondary impacts associated with making this water available?
9. Where would the funding come from?
10. How do we account for this water and who does the accounting?
11. How should new depletions be treated to avoid undermining the effect of conservation?

5th Annual POUDRE River Forum

Listening to Understand

February 2, 2018 | 8:00am – 4:30pm | Island Grove Events Center, Greeley



Each year, the Forum brings together those who farm on the Poudre, drink beer from the Poudre, manage water from the Poudre, or advocate for Poudre health to learn from one another and to explore how we might move from conflict to collaboration in regard to the Poudre.

This year's program gives us the opportunity to see how well we can listen and ask questions instead of postulating positions, to help us bridge ideological barriers.

The Forum is brought to you by the **Poudre Runs Through It Study/Action Work Group (PRTI)** and its **Poudre River Forum Committee.** PRTI is facilitated by **Colorado Water Institute**, an affiliate of Colorado State University.

Poudre River Forum Committee
John Bartholow | Eric Brown | Rob Johnson | Corey Odell
Karen Scopel | Sean Conway | John Stokes | Robert Ward | Brad Wind
MaryLou Smith, Convener
Jennie Haley & Kendal Perez, Assistants

We are grateful to this year's Forum Sponsors who are listed on the back of this program, to Cable 14 for their videotaping expertise, and to all who volunteered to make this day possible. Visit our website prti.colostate.edu to soon see linked videos and program materials from today. Feel free to contact us at poudreriverforum@gmail.com.

Special thanks to

2018 POUDRE RIVER FORUM SPONSORS

$3,500
Poudre Heritage Alliance for the Cache la Poudre Heritage Area

$3,000
City of Greeley Water & Sewer

$2,000
Boyd Irrigation Company
Northern Water

$1,500
City of Fort Collins Natural Areas

$1,000
Cache La Poudre Water Users Association
City of Thornton
CSU Water Center
Colorado Water Institute

$500
Anderson Consulting Engineers
Colorado Corn
Colorado State Forest Service
Ducks Unlimited
Fischer Brown Bartlett & Gunn
FlyWater
In-Situ Inc.
Rocky Mountain Flycasters (Trout Unlimited)
Thomas & Tyler, LLC
Town of Timnath
Town of Windsor

$400
CSU Conservation Leadership Through Learning MS
UNC Community & Civic Engagement

$250
A. Bruce Johnson & Associates
American AgCredit
BBA Water Consultants
BHA Design
Buena Vida Farm
Caring for Our Watersheds
Central Colorado Water Conservancy District
Chrisland Real Estate Companies
Colorado Livestock Association
Colorado Open Lands
Fort Collins Downtown Development Authority
MMSolutions Accounting
Otak, Inc.
Poudre Learning Center
Ridge West Property Services
Spronk Water Engineers, Inc.
Vranesh and Raisch, LLP
West Range Development
Westervelt

$150
UNC Earth & Atmospheric Sciences

In-Kind
CSU Bookstore
CSU Water Resources Archive
KUNC / The Colorado Sound
Mountain Whitewater
Northern Feed & Bean
Water Education Colorado
Odell Brewing Co.

Irrigation Innovation Consortium

The Colorado Water Institute (CWI) has been awarded a $10 million-dollar grant from the Foundation for Food and Agriculture Research (FFAR) to aid in the Irrigation Innovation Consortium (IIC), led by Principal Investigator Dr. Reagan Waskom. The purpose of the IIC is to accelerate the development and adoption of novel water and energy efficient irrigation technologies and practices through public-private partnerships between higher education, industry, and non-governmental organizations. While the consortium will be based at Colorado State University's Irrigation Technology Center, research will be located at: Colorado State University, California State University Fresno, Kansas State University, the Daugherty Water for Food Global Institute at the University of Nebraska, and Texas A&M AgriLife Research. Focusing on technology development and filling research gaps through demonstration and training in a pre-competitive space, major research theme projects include: 1) water and energy efficiency; 2) remote sensing and big data applications for improving irrigation water management; 3) system integration and management; and 4) irrigation technology acceleration.

USGS Summer Intern Program

Basic Information

Start Date:	3/1/2017
End Date:	2/28/2018
Sponsor:	DOI-USGS-Geological Survey
Mentors:	David Clow
Students:	Michele Basile

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

Was a highly useful and valuable experience.

Basic Information

Start Date:	3/1/2017
End Date:	2/28/2018
Sponsor:	DOI-USGS-Geological Survey
Mentors:	Roland Viger
Students:	Melissa Valentin

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:	3/1/2017
End Date:	2/28/2018
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

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	13	0	0	0	13
Masters	3	1	2	0	6
Ph.D.	3	0	1	0	4
Post-Doc.	0	3	0	1	4
Total	19	4	3	1	27

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, Jacob Park. Jacob is currently studying Environmental Science and Technology with a minor in Watershed Science at Colorado Mesa University.

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 2017-2018 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, Raeann Magill, is a student at Colorado State University's Department of Soil and Crop Sciences.

2017CO338B - Effects of snow persistence on soil water nitrogen along the Colorado Front Range
Alyssa Anenberg received the Francis Clark Soil Biology Scholarship to further her research.

Climate Risk Informed Decision Analysis (CRIDA)

A proposal to train municipalities and decision makers in CRIDA was accepted and funded as a Project Support Facility grant from the Council of Baltic Sea States (CBSS). AGWA successfully co-organized three one-day training workshops on new climate adaptation methodologies for the urban context in the Baltic Region.

The UNECE has allotted funding to implement the CRIDA methodology in the Dniester River Basin of eastern Europe. This is part of a broader GEF-funded project to create a Dniester reservoir model and implement training in the region.

John Matthews of AGWA taught a course as part of OSU's Natural Resources Leadership Academy in June 2017. The one-week immersive course focused on "Resilient and Robust Resource Management." Portions of the CRIDA manuscript were part of the required reading and the methodology was discussed as part of the curriculum.

CRIDA was emphasized in the curriculum of the three-week course "Planning and Delivery of Flood Resilience" at the IHE Delft Institute for Water Education that took place 24 April – 12 May, 2017. After reading and studying the methodology, students used CRIDA to work through a series of exercises and case studies.

2016CO320B - Changes in Water, Sediment and Organic Carbon Storage in Active and Abandoned Beaver Meadows
DeAnna Laurel received the John T. and Carol D. McGill Research Award from the Geological Society of America.

Publications from Prior Years

1. 2015CO316G ("Trace Organic Contaminants (TOrCs) in Urban Stormwater and Performance of Urban Bioretention Systems: a Field and Modeling Study") - Articles in Refereed Scientific Journals - Burant, A.; W., Selbig; E., Furlong; C.P., Higgins, 2018, Trace Organic Contaminants in Urban Runoff: Associations with Urban Land-Use, Environmental Pollution.
2. 2016CO319B ("Watershed monitoring across the snow transition zone: an east slope-west slope comparison") - Other Publications - Hammond, J.C.; G., Richard; S. Kampf, 2017, Watershed Monitoring Across the Intermittent-Persistent Snow Transition Zone, in Colorado Water, 6-11.
3. 2016CO319B ("Watershed monitoring across the snow transition zone: an east slope-west slope comparison") - Other Publications - Guiden, M., 2018, Research Team Monitors Snow Melt that Feeds Colorado Streams and Rivers,CSU Source.
4. 2015CO316G ("Trace Organic Contaminants (TOrCs) in Urban Stormwater and Performance of Urban Bioretention Systems: a Field and Modeling Study") - Other Publications - Brown, J.; Hogue, TS; Bell, CD; Higgins, CP; Selbig, WR (2018). Trace organic contaminants (TOrCs) in urban stormwater and performance of urban bioretention systems: a field and monitoring study. Poster Session at NSF ERC for Re-inventing the Nation's Urban Water Infrastructure (ReNUWIt) Annual Meeting, 2018 May 21-23; Stanford, CA.
5. 2016CO326B ("Comparing fine scale snow depth measurements at rocky and flat surfaces using lidar and photogrammetry derived digital elevation models") - Other Publications - Gilbert, Allen Jr.; Fassnacht, Steven R., Comparing Fine Scale Snow Depth Measurements Using LiDAR and Photogrammetry, in Colorado Water, 2-5.
6. 2016CO319B ("Watershed monitoring across the snow transition zone: an east slope-west slope comparison") - Other Publications - Hammond, John; Moore, Craig; Kampf, Stephanie; Richard, Gigi, Watershed Monitoring Across the Intermittent Persistent Snow Transition Zone, in Colorado Water, 6-11.
7. 2016CO322B ("Evaluating wood jam stability in rivers") - Other Publications - Scott, Dan; Wohl, Ellen, Evaluating Wood Jam Stability in Rivers, in Colorado Water, 12-14.
8. 2016CO318B ("Investigating relationships between drought managment strategies and factors contributing to their selection in analysis of adaptive capacity of South Platte River Basin water providers") - Other Publications - Childress-Runyon, Amber; Ojima, Dennis, Evolution of Drought Management of South Platte Water Providers and Implications for their Capacity to Cope with Water Stress, in Colorado Water, 15-18.
9. 2016CO325B ("Microbial community responses to metals contamination: mechanisms of metals exposure and bioaccumulation in a stream food web.") - Other Publications - Wolff, Brian; Clements, William; Hall, Ed; Microbial Community Responses to Metals Contamination: Mechanisms of Metals Exposure and Bioaccumulation in a Stream Food Web, in Colorado Water, 22-25.
10. 2016CO320B ("Changes in water, sediment and organic carbon storage in active and abandoned beaver meadows") - Other Publications - Laurel, DeAnna; Wohl, Ellen, Changes in Water, Sediment, and Organic Carbon Storage in Active and Abandoned Beaver Meadows, in Colorado Water, 26-28.
11. 2016CO324B ("Water sampling and the effects of plastic absorption on heavy metals") - Other Publications - Sir, Haley; Brazeau, Randi; Schliemann, Sarah, Water Sampling and the Effects of Adsorption on Aqueaous Heavy Metals, in Colorado Water, 30-32.
12. 2016CO323B ("Channel restoration monitoring of the Upper Colorado River, Rocky Mountain National Park, CO") - Other Publications - Sparacino, Matt; Rathburn, Sara, Effects of River Restoration on Surface Water-Groundwater Interactions, Upper Colorado River, Rocky Mountain National Park, in Colorado Water, 33-36.