Colorado Water

January 2020

COLORADO WATER CENTER
COLORADO STATE UNIVERSITY

RESEARCH REPORTS

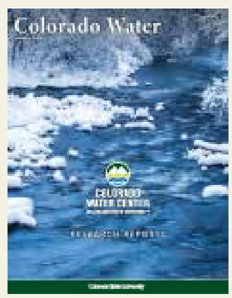
Table of CONTENTS

Features—Colorado Water Center Research Reports

From our Cooperators

Scholarships and Awards

In Every Issue



On the cover—The Fryingpan River in winter. Photo ©2019 iStock.com

References can be found in the online version of this newsletter at http://watercenter.colostate.edu/water-news

Cooperators include the Colorado State Forest Service, the Colorado Climate Center, and CSU's Water Resources Archive.

COLORADO **WATER**

Volume 37, Issue 1

Colorado Water is a publication of the Colorado Water Center. The newsletter is devoted to highlighting water research and activities at CSU and throughout Colorado.

Published by
Colorado Water Center
Reagan Waskom, Director

Editor
Beth Lipscomb

Design
R. Emmett Jordan

Production Director
Nancy Grice

Supported by
This publication is financed in part by the U.S. Department of the Interior Geological Survey, through the Colorado Water Center; College of Agriculture, Warner College of Natural Resources, Agricultural Experiment Station, and Colorado State University Extension.

COLORADO WATER CENTER
COLORADO STATE UNIVERSITY
watercenter.colostate.edu

Director's LETTER

If you live on Colorado's Front Range, what you notice is the increased traffic and construction, but that congestion is just a symptom of the population growth that the region is currently experiencing. Lack of affordable housing, reduced air quality, crowds at your favorite recreational site, noise, light pollution, etc. are other outcomes of this growth surge. While we understand that demand for water is also impacted by growth, what about our water supply, water quality, and the health of rivers and aquatic ecosystems? How do the values of "new" Coloradans change our collective water future? If affordability, transportation, health care and jobs are the political priorities, how will agriculture and the environment fare? The Colorado Water Plan, published in 2015, focused on how we will meet the water demands of a growing state while maintaining what we value in agriculture and the natural environment. Simply stated, Colorado does not have enough renewable water supplies to meet all of the demands within the state, and we are bound by law to meet our obligations to our downstream neighbors. Thus, we are in an era of water sharing and redistribution.

So, how are we doing on implementing the Colorado Water Plan and how does university research contribute? The Water Plan is of necessity a policy document but significant efforts have been made to bring sound science and engineering analysis into the process. Some have taken exception with the demographic and the demand projections in the original Plan. The Colorado Water Conservation Board (CWCB) has recently published an update to the Water Plan (https://www.colorado.gov/pacific/cowaterplan/analysis-and-technical-update). The Technical Update and its related tools build on a nearly 15-year legacy of CWCB water supply planning initiatives that began with the first Statewide Water Supply Initiative (SWSI) in 2004. It also leverages a 27-year investment in statewide water modeling efforts, which began in 1992. To that end, the Technical Update provides a significant improvement in the scope and approach to water supply planning that incorporates updated demographics, current scientific information on how climate change may impact future water supply and demand, as well as how water conserving practices and technologies will shape demand. In addition, an Environment and Recreation Flow Tool was developed to help assess potential stream flow conditions and associated ecological health in river segments in each river basin. Based on known agricultural water transfers currently in water court or deemed to be highly likely, the estimates of planned agricultural buy and dry transfers in the Technical Update are almost three times higher on the upper end than the data that informed the original Water Plan. Urbanization alone could result in the loss of an additional 152,400 irrigated acres by 2050. The Water Plan will of necessity continue to evolve as new data and new science inform the process.

This issue of *Colorado Water* provides updates on just a few of the research projects we fund annually at the Colorado Water Center. Colorado State University researchers are actively working on many topics that inform the Water Plan, including forest health, recreation, agriculture and urban sustainability. The new Water Innovation Center at the National Western Complex promises to be a strong partner in creating water solutions for Colorado and the West. While recognizing that policy, financing, and political will determine our water future, the infusion of objective scientific research and scholarship into the planning process will help ensure that Colorado remains a global leader in water management.

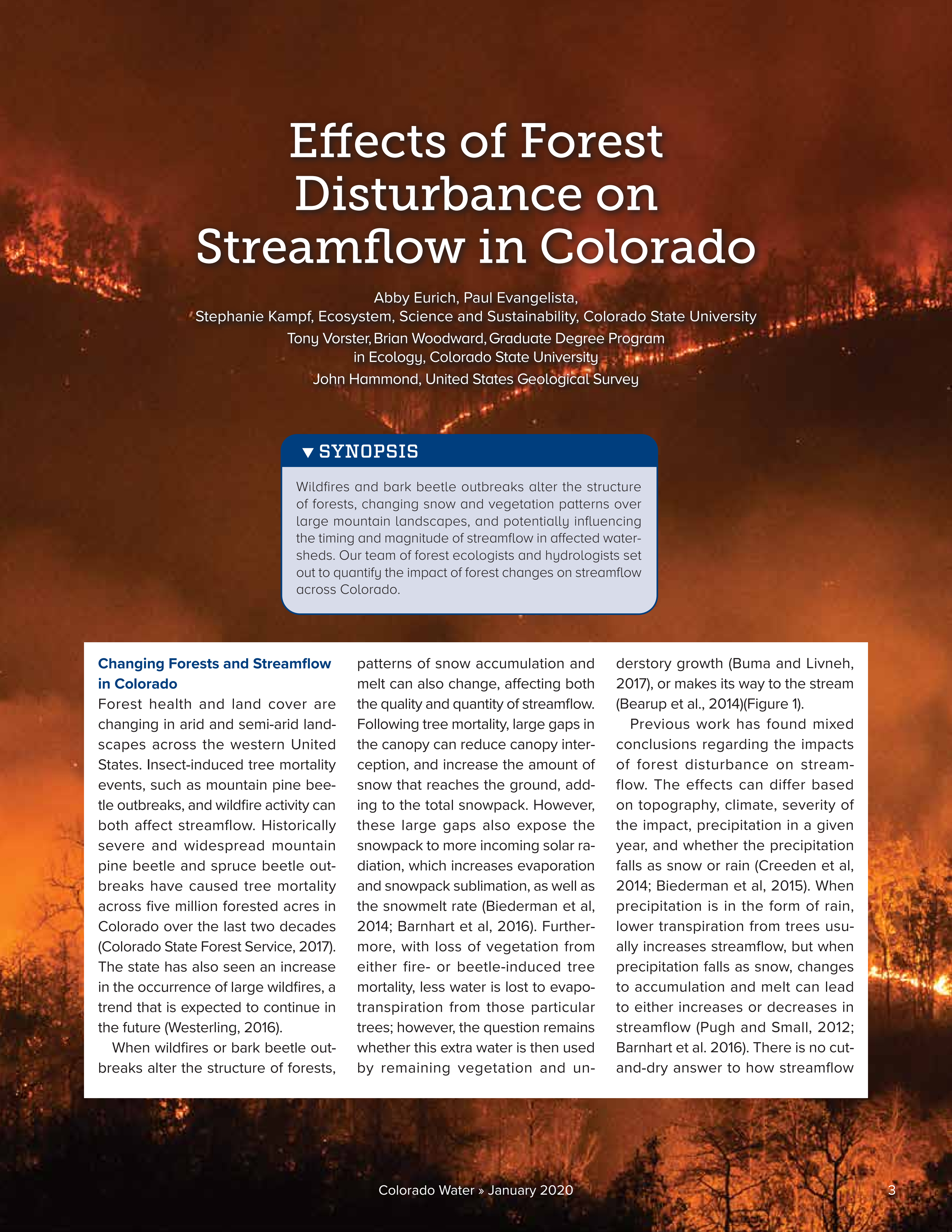
Reagan Waskom

Director, Colorado Water Center

Colorado Water Center FY20 New Research Awards

Name of Principal Investigator	Title	University	Sponsor	Budget
Fassnacht, Steven	Kids Poetry on Water—Creating K-12 Curriculum Integrating Water Science and Poetry	Colorado State University	Colorado Water Center	$6,500
Rasmussen, Kristen	The Current and Future State of Water Resources for the Colorado Rocky Mountains	Colorado State University	Colorado Water Center	$25,000
Ronayne, Michael	Numerical Modeling of Evolving Recharge-Discharge Sources in a Multi-Aquifer System	Colorado State University	Colorado Water Center	$7,773
Kremen, Amy	Development and Launch of a “Master Irrigator” Education and Training Program in Northeastern Colorado	Colorado State University	Colorado Water Center	$7,500
Kanno, Yoichiro	Assessing Gene Flow of Invasive Brook Trout to Restore a Meta-Population of Threatened Greenback Cutthroat Trout in the Upper Poudre River Basin	Colorado State University	Colorado Water Center	$10,000
Bhaskar, Aditi	Harnessing the Power of the Crowd to Monitor Urban Street Flooding	Colorado State University	Colorado Water Center	$25,000
Hribljan, John	Hydrologic Drivers of Peatland Development and Carbon Accumulation in Western Washington	Colorado State University	Colorado Water Center	$25,000
Redmond, Miranda Kampf, Stephanie	Impacts of Extreme Events on Forest Recovery and Streamflow Across Colorado's Forest-Dominated Ecosystems	Colorado State University	Colorado Water Conservation Board	$36,524
Cabot, Perry	Quantification of Industrial Hemp CU Rates, THC Levels, Weed Pressure, and Disease Effects Under Irrigated Conditions in Western Colorado	Colorado State University	Colorado Water Conservation Board	$49,887
Morrison, Ryan Gates, Tim	Relationship Between Irrigation Return Flows, Riparian Vegetation Water Use, and Soluble Pollutant Removal in the Lower Arkansas River Basin (Phase II)	Colorado State University	Colorado Water Conservation Board	$50,000
Covino, Tim Ross, Matt	Linking the Topology of Forest Disturbance to Water Quality to Enhance Forest and Water Resource Management in Colorado	Colorado State University	Colorado Water Conservation Board	$49,772
Korb, Julie Steltzer, Heidi Remke, Michael	Watershed Conditions, Climate and Post-Fire Mitigation for Two Wildfires in Southwest Colorado and Their Influence on Forest Health and Watershed Recovery	Fort Lewis College Fort Lewis College Mountain Studies Institute	Colorado Water Conservation Board	$49,945
Hogue, Terri Rust, Ashely Roberts, Scott	Aquatic Ecosystem Impacts and Recovery After Wildfire: Can Forest Health be an Indicator of Recovery	Colorado School of Mines	Colorado Water Conservation Board	$49,180
Bestgen, Kevin	Reproductive Ecology of Invasive Northern Pike Informs Management Actions to Reduce Their Abundance	Colorado State University	Colorado Water Conservation Board	$50,000

COLORADO WATER CENTER
COLORADO STATE UNIVERSITY



Effects of Forest Disturbance on Streamflow in Colorado

Abby Eurich, Paul Evangelista,
Stephanie Kampf, Ecosystem, Science and Sustainability, Colorado State University
Tony Vorster, Brian Woodward, Graduate Degree Program in Ecology, Colorado State University
John Hammond, United States Geological Survey

▼ SYNOPSIS

Wildfires and bark beetle outbreaks alter the structure of forests, changing snow and vegetation patterns over large mountain landscapes, and potentially influencing the timing and magnitude of streamflow in affected watersheds. Our team of forest ecologists and hydrologists set out to quantify the impact of forest changes on streamflow across Colorado.

Changing Forests and Streamflow in Colorado

Forest health and land cover are changing in arid and semi-arid landscapes across the western United States. Insect-induced tree mortality events, such as mountain pine beetle outbreaks, and wildfire activity can both affect streamflow. Historically severe and widespread mountain pine beetle and spruce beetle outbreaks have caused tree mortality across five million forested acres in Colorado over the last two decades (Colorado State Forest Service, 2017). The state has also seen an increase in the occurrence of large wildfires, a trend that is expected to continue in the future (Westerling, 2016).

When wildfires or bark beetle outbreaks alter the structure of forests, patterns of snow accumulation and melt can also change, affecting both the quality and quantity of streamflow. Following tree mortality, large gaps in the canopy can reduce canopy interception, and increase the amount of snow that reaches the ground, adding to the total snowpack. However, these large gaps also expose the snowpack to more incoming solar radiation, which increases evaporation and snowpack sublimation, as well as the snowmelt rate (Biederman et al, 2014; Barnhart et al, 2016). Furthermore, with loss of vegetation from either fire- or beetle-induced tree mortality, less water is lost to evapotranspiration from those particular trees; however, the question remains whether this extra water is then used by remaining vegetation and understory growth (Buma and Livneh, 2017), or makes its way to the stream (Bearup et al., 2014)(Figure 1).

Previous work has found mixed conclusions regarding the impacts of forest disturbance on streamflow. The effects can differ based on topography, climate, severity of the impact, precipitation in a given year, and whether the precipitation falls as snow or rain (Creeden et al, 2014; Biederman et al, 2015). When precipitation is in the form of rain, lower transpiration from trees usually increases streamflow, but when precipitation falls as snow, changes to accumulation and melt can lead to either increases or decreases in streamflow (Pugh and Small, 2012; Barnhart et al. 2016). There is no cut-and-dry answer to how streamflow

Tree mortality on Glacier Gorge Trail, Glacier Creek, RMNP. Photo by Abby Eurich.

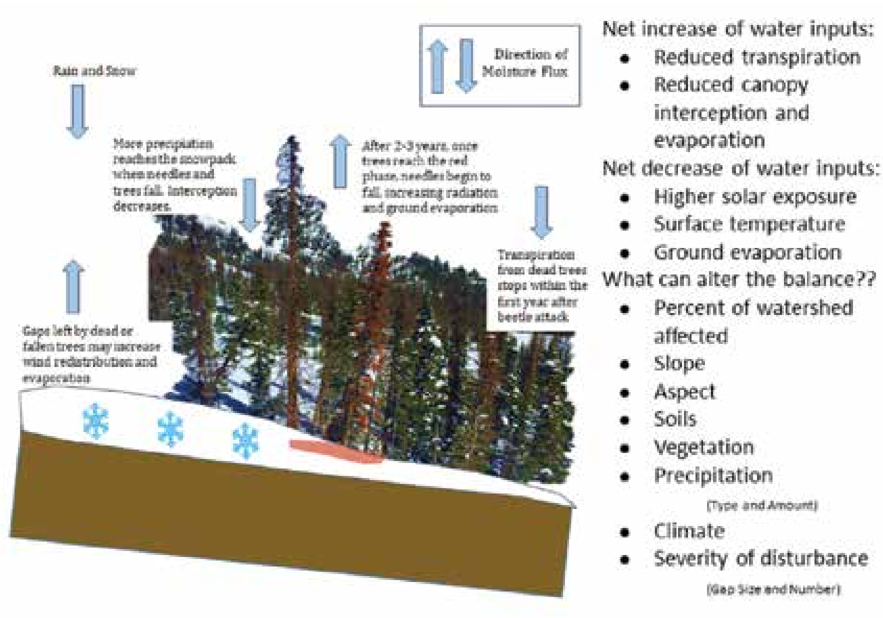


Figure 1. Schematic diagram illustrating the possible effects of Mountain Pine Beetle forest disturbance on snowpack and streamflow.

will respond to forest disturbance, or whether it will respond at all. Additionally, the percent of watershed disturbed, and the severity and dispersion of the disturbance, play key roles in the streamflow response.

Our team of forest ecologists and hydrologists set out to quantify the impact of forest changes on streamflow across Colorado. To do this, we generated forest disturbance maps delineating severity and timing of bark beetle outbreaks (2001-2013), and summarized wildfire data (Monitoring Trends in Burn Severity, 1984-2015). For watersheds that have stream gages with complete annual records for the years of disturbance data (US Geologic Survey, Colorado Division of Water Resources), we analyzed the relationship between streamflow anomalies and disturbance type and severity, while controlling for climatic influences on streamflow, such as precipitation and snow cover.

Mapping Bark Beetle Outbreaks Using New Remote Sensing Techniques

Outbreaks of native bark beetles have caused widespread tree mortality in lodgepole pine and spruce forests across Colorado since 2000. Insect and disease impacts on forests are assessed annually by trained human observers who conduct airplane flyovers to delineate tree mortality and damage. These Aerial Detection Surveys provide valuable information about trends in tree mortality over the last few decades. However, the use of satellite remote sensing offers an opportunity to produce finer resolution maps of forest insect and disease impacts, and to better capture the extent of complex tree mortality patterns, and the heterogeneity of this mortality. We utilized Landsat 5 imagery to map lodgepole pine mortality from 2001 to 2013 across Colorado, Wyoming, Montana, and Idaho. We then merged these maps with the Aerial Detection Surveys to characterize the timing and cause of mortality at each mapped pixel. The maps we produced more accurately represent the dead canopy area across all four states compared to the Aerial Detection Surveys. However, we were able to leverage the aerial surveys to characterize the cause of the mortality and the timing, outbreak details that are typically very difficult with remote sensing (Figure 2). We

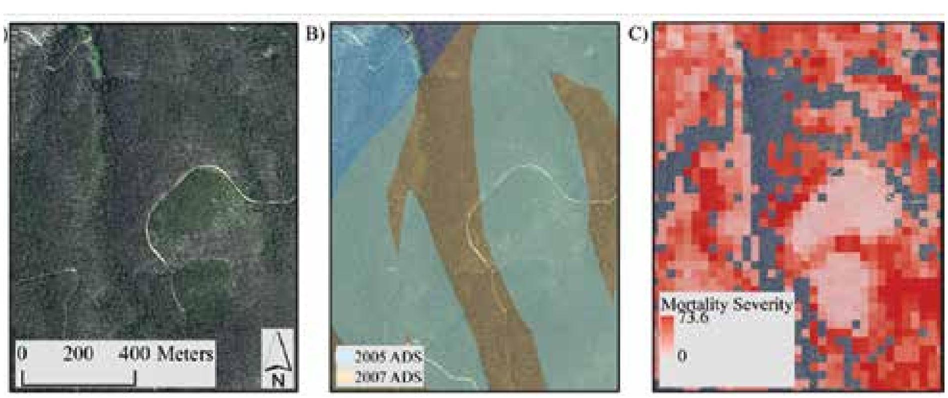


Figure 2. A) Aerial imagery showing mountain pine beetle-caused mortality in a lodgepole pine forest in northern Colorado. B) Aerial Detection Survey data for the same area indicating mortality in this area in 2005 and 2007. C) Mortality shown by our maps within the lodgepole pine forests, with each value representing the proportion of each pixel that is dead canopy. Aerial Detection Surveys are coarser, whereas our products capture heterogeneity in mortality.

Our group monitors streamflow on this snow-fed stream near Copper Mountain, 2018. Photo by Abby Eurich.

found that across these four states, Colorado had some of the most widespread and severe lodgepole pine mortality. These improved tree mortality maps present an opportunity to better investigate linkages between bark beetle outbreaks and streamflow. We summarized the lodgepole pine dead canopy area, and the timing of the outbreaks across each watershed in Colorado to pair with the stream gage data (Figure 3). We also used existing maps of fires across the state (Monitoring Trends in Burn Severity) to summarize annual area impacted by fire, and the severity of these fires in each watershed.

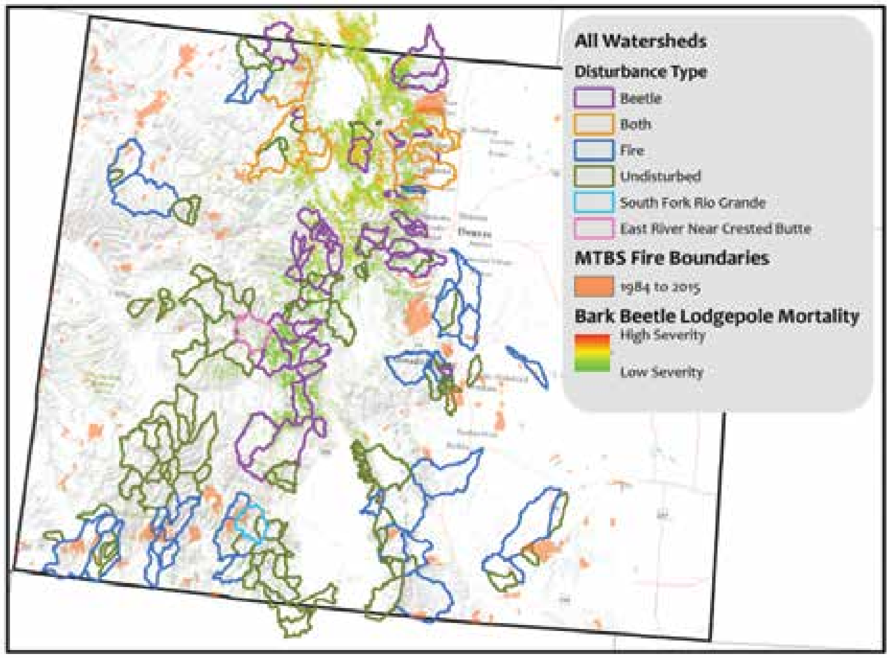


Figure 3. Site Map, illustrating all watershed boundaries, colored by disturbance type, corresponding with the years of streamflow data. South Fork Rio Grande and East River Near Crested Butte watersheds are used as examples in Figure 4.

Table 1. Percentage of stream gages with significant streamflow change post-disturbance (a=0.05), after controlling for precipitation variability.

	Annual Q	Low Flow Q	Minimum 7-day Q	Maximum 7-day Q
Fire	33%	21%	33%	17%
Beetle	5%	5%	2%	4%

Streamflow Response to Disturbance

We compiled a dataset of 200 watersheds across Colorado, using gages with drainage areas less than 1500 km^2 in order to better isolate different disturbance and forest types within a watershed. We excluded all stream gages with transbasin water diversions, leaving 55 watersheds that have experienced beetle mortality in lodgepole pine forests, and 42 watersheds that have experienced wildfire. Of these, 11 watersheds have experienced both beetle mortality and wildfire (Figure 3).

Multiple linear regression and ANOVA were used to determine whether there was any significant difference in annual streamflow response pre- and post- disturbance, while accounting for variability in annual precipitation, by including it as a predictor in the regression model. We used this method for four different streamflow metrics (Total Annual Streamflow, Total Streamflow during Low Flow Months Oct & Nov, Minimum 7-day Streamflow, and Maximum 7-day Streamflow, Table 1).

Significant differences pre- and post- disturbance were found for some sites, showing both an increase and decrease in streamflow. Precipitation is a strong driver of annual streamflow variability. On a plot of annual streamflow vs. precipitation, if the streamflow tends to plot higher in the years after disturbance than the years prior to disturbance, this indicates an effect of the disturbance causing streamflow to be higher, relative to the expected variation with precipitation (Figure 4). Table 1 summarizes the percentage of watersheds with a significant streamflow response for each disturbance type.

For fires, all watersheds with at least 15% of the area burned exhibited a significant change in total annual streamflow. So far, we have not found a similar threshold in the effect of beetle-induced mortality. Fewer watersheds had significant streamflow response to beetle-induced mortality than to wildfire disturbance (Table 1). This is likely because when trees die from beetle attack, they remain in-situ, and the surrounding vegetation is not impacted, sometimes even thriving with more resources and additional water available. This can mute the effects of large canopy gaps and snowpack changes, post-disturbance. Wildfires, however, tend to affect both the canopy and understory vegetation, and therefore are more likely to change streamflow (Table 1).

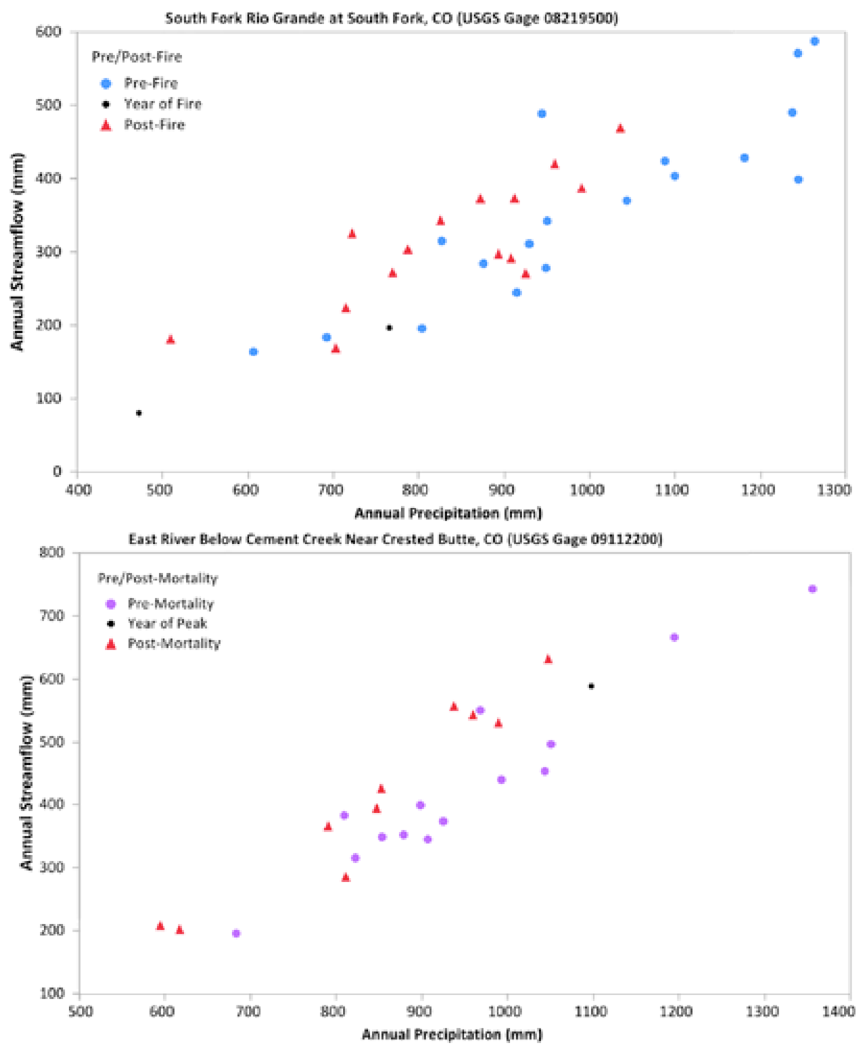


Figure 4. Graphs of annual streamflow vs. annual precipitation, colored by pre- and post-disturbance. Both stream gages shows a significant change in annual streamflow after disturbance (a=0.05).

Tree Mortality at Monarch Mountain Ski Resort, 2019. Photo by Abby Eurich.

Mountain Pine Beetle Mortality at Copper Mountain Ski Resort, 2019. Photo by Abby Eurich.

Continued Research, Lessons, and Challenges

The site-specific nature of streamflow response to forest disturbance begs the questions, what are the main controls on streamflow response, and can we anticipate the way watersheds will respond to future disturbance events across variable conditions? Our team is continuing to explore these questions by using the disturbance severity information from the remote sensing techniques tested in this study, as well as soil, geology, and vegetation information for each watershed with and without a significant streamflow response. We hope to understand why some watersheds respond differently from others, and whether there are clear predictive characteristics for their response. In addition, we plan to assess the impacts of spruce beetle mortality on streamflow, using maps produced by our group (Woodward et al., 2017). This will increase the number of watersheds in the analysis, adding to our overall impact detection.

One of the largest challenges of this work is identifying watersheds with both forest disturbance and stream gage data, where the streamflow is not altered by trans-basin diversions or reservoirs. Many watersheds in Colorado that have experienced large disturbance have reservoirs and water diversions that change streamflow, masking the less pronounced forest disturbance effects on streamflow. Understanding how disturbance events in increasingly-stressed headwater ecosystems impact water supply is vital to land and water managers across Colorado. Continuation of this work will help to identify the most likely impacts to streamflow in these valuable and vulnerable landscapes.

Acknowledgements

This project was supported by funds from the Colorado Water Center Water Research Team Grant, the Colorado Water Conservation Board, and by the Agriculture and Food Research Initiative Competitive Grant (Grant no. 2013-68005-21298) from the USDA National Institute of Food and Agriculture.

Evaluation of Flooding Variability and Risks to Housing Stock in the U.S.

Ryan Morrison, Assistant Professor, Civil and Environmental Engineering, Colorado State University

Ellison Carter, Assistant Professor, Civil and Environmental Engineering, Colorado State University

Kristen Rasmussen, Assistant Professor, Atmospheric Science, Colorado State University

Brooke Anderson, Assistant Professor, Environmental and Radiological Health Sciences, Colorado State University

▼ SYNOPSIS

Flooding is one of the most costly natural disasters in the United States. However, the risk of flooding to different population groups differs. We show that the type and frequency of flooding vary spatially within a river basin. Also, the type and number of homes impacted by floods depends on the location within a river basin and the size of the flood.

Introduction

Flooding events in the U.S. cause large economic and health burdens each year, and are the nation's second-deadliest weather-related natural disasters, with national economic losses conservatively estimated to be at least $50 billion annually. Strong climatological, meteorological, and changing land-use evidence indicates that the frequency and severity of flooding are intensifying in many regions, and will continue to increase in the future. Short-term mortality associated with flooding has been well documented, and forms the basis for present-day estimates of health impacts associated with flooding. Long-term and cumulative health effects associated with flooding, on the other hand, are poorly understood. Yet, this information

An aerial view shows flood damage in Colorado, Sept. 14, 2013, due to heavy rains. Photo by U.S. Army Staff Sgt. Wallace Bonner.

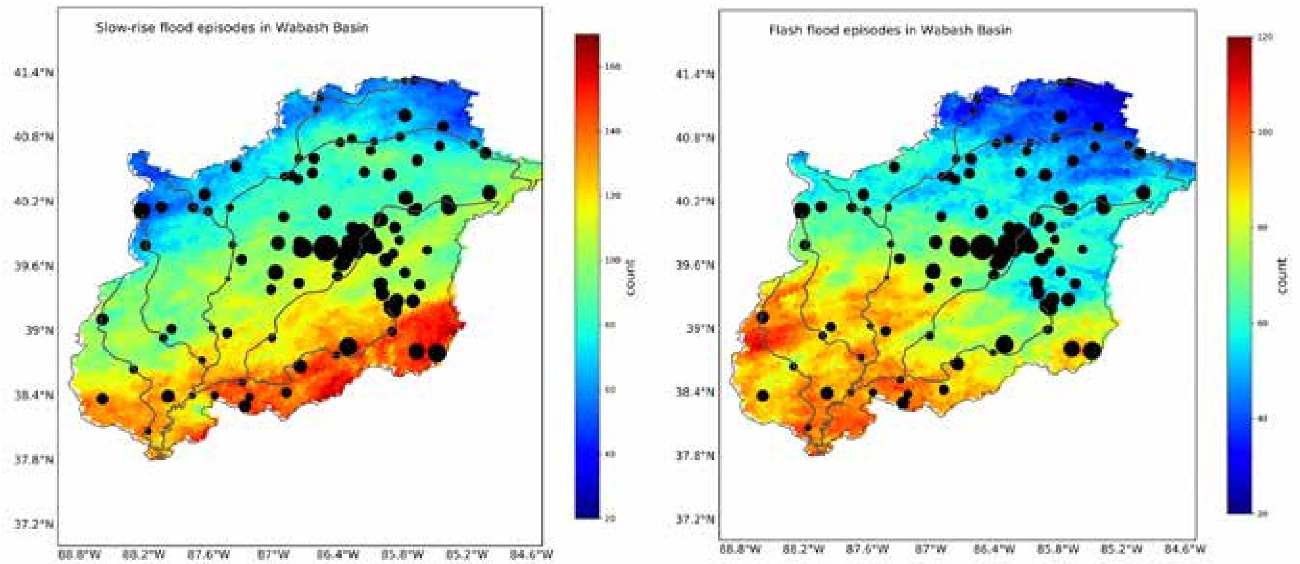


Figure 1. Number of slow-rise and flash flood episodes (fill) in the Wabash basin, based on a flood climatology from Dougherty and Ramusssen (2019, in press). Black dots are stream gage locations, with the dot size representing the average flash flood discharge (bigger dots= higher discharge). Black lines indicate major rivers in the basin. Figure by Erin Dougherty.

is greatly needed to develop a more comprehensive understanding of public health risk associated with flooding that would, in turn, improve future flood management and recovery response.

To build better flood management strategies, we need to understand both the population groups that may be disproportionately impacted by floods, and the characteristics of the floods that lead to more or fewer health risks. For instance, floods that occur rapidly (i.e., flash floods) cause different risks than floods that occur more slowly (slow-rise floods) and inundate homes for longer periods of time. Currently, there is no database linking flooding type (e.g. slow-rise or flash flood), population demographics, and susceptibility of population groups for floods of different sizes. Thus, in this work, we integrated mesoscale meteorology, as well as hydrological and housing data to estimate the spatial vulnerability of residential homes affected by different flood sizes.

This aerial view is looking north along the Willamette River at Oregon City, Oregon, during the flood of 1964-65. Photo courtesy of Portland Corps.

Methods

Our approach included three phases of data collection and analysis:

» First, we used historical records of precipitation and flooding to determine the frequency and type of flooding likely to occur in a region.

» Second, we gathered census information about housing stock (e.g. housing type by structure and age) to represent different population groups in a region.

» Finally, we spatially analyzed the intersection of flooding type and housing stock within flood inundation boundaries of different recurrence intervals.

A December 2016 NASA satellite image shows the receding floodwaters at the confluence of the Wabash and Ohio rivers.

Table 1. The approximate number of homes impacted by different flood sizes in each basin.

Flood Return Period	Number of Homes Impacted in Wabash Basin	Number of Homes Impacted in Willamette Basin
20 year	128,600	88,578
50 year	155,016	134,125
100 year	172,018	151,986

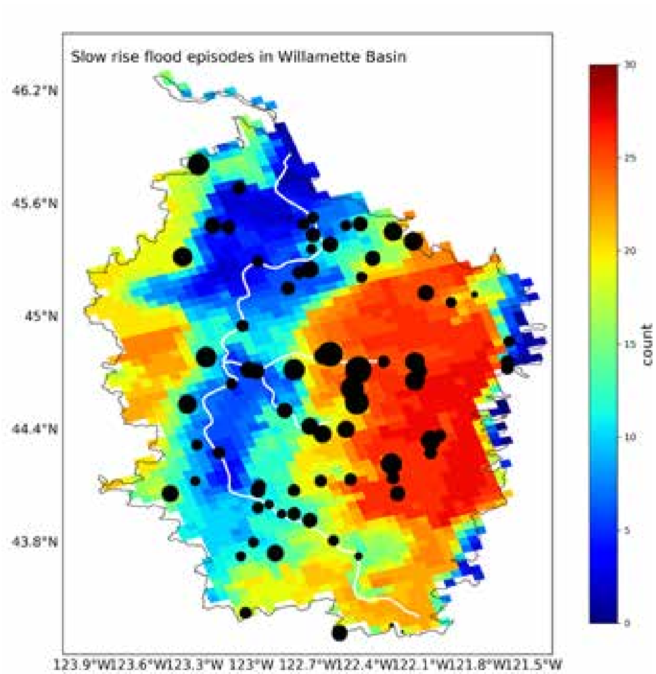


Figure 2. Number of slow-rise flood episodes (fill) in the Willamette Basin, based on a flood climatology from Dougherty and Ramusssen (2019, in press). Black dots are stream gage locations, with the dot size representing the average flash flood discharge (bigger dots= higher discharge). While lines indicate major rivers in the Basin. Figure by Erin Dougherty.

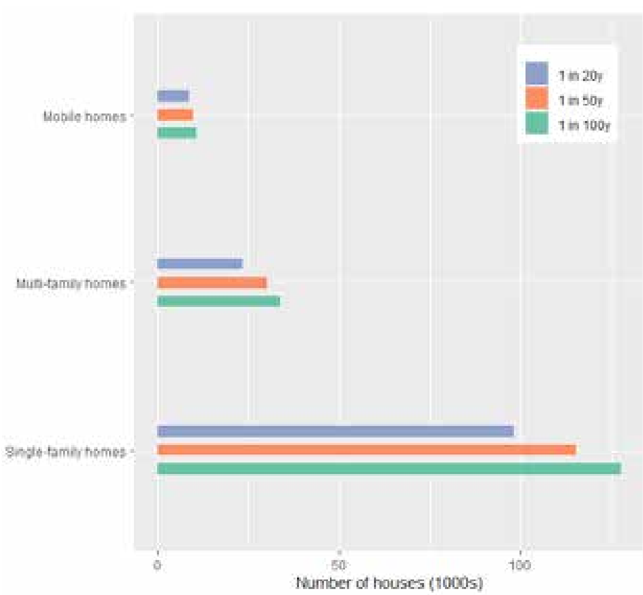


Figure 3. Number of homes located in flood boundaries for different recurrence intervals in the Wabash Basin. Figure by Oluwatobi Oke.

We used the Wabash River and Willamette River basins as study sites, and we chose these basins because each has distinct flooding characteristics driven by different hydroclimatic conditions.

We collected rainfall data from the Stage-IV multi-sensor (radar estimates combined with rain gage data) precipitation dataset on an hourly and 4-km resolution. The rainfall data were collected over the entire duration of flash and slow-rise floods that occurred in each basin, which were identified from flood-producing storm climatology by Dougherty and Rasmussen (2019, in press). The climatology identified flood-producing storms based on flood reports from the National Center for Environmental Information database that were within 200 km and 3 days of streamflow identified floods from a comprehensive database of flood events in the contiguous United States from 2002 to 2013 (https://ucwater.engr.uconn.edu/fedb). This database thus provides an indication of when and where the storms that produced flooding occurred, and where there was a notable hydrologic response. To ensure that only the heavy rainfall for each flood was captured, an object identifier tool in Python was used to isolate rainfall accumulations that met or exceeded the 75th percentile for each flood in the flood domain (+/- 5° degrees from the flood centroid). This method provides flexibility in capturing both small- and large-scale precipitation associated with flooding.

To analyze differences in housing stock impacted by flooding, we used 2017 United States Census American Community Survey estimates of median housing age, median household income, housing types by tenure (owner- or renter-occupied), and housing types by structure (single-family, multi-family, and manufactured homes) within census block groups for all the states of Indiana, Illinois, and Ohio (Wabash) and Oregon (Willamette). We classified single-family homes as a structure maintained and used as a single dwelling unit, even though some share one or more walls with another dwelling unit. We defined a multi-family unit as a structure that is designed for several different families in separate housing units (e.g. apartment complex), while manufactured homes, commonly called mobile homes, are defined as fabricated housing that is assembled in factories and transported to sites of use.

Finally, we spatially combined flood inundation boundaries for the 20-year, 50-year and 100-year floods, census block group housing data, and flood types for each basin,

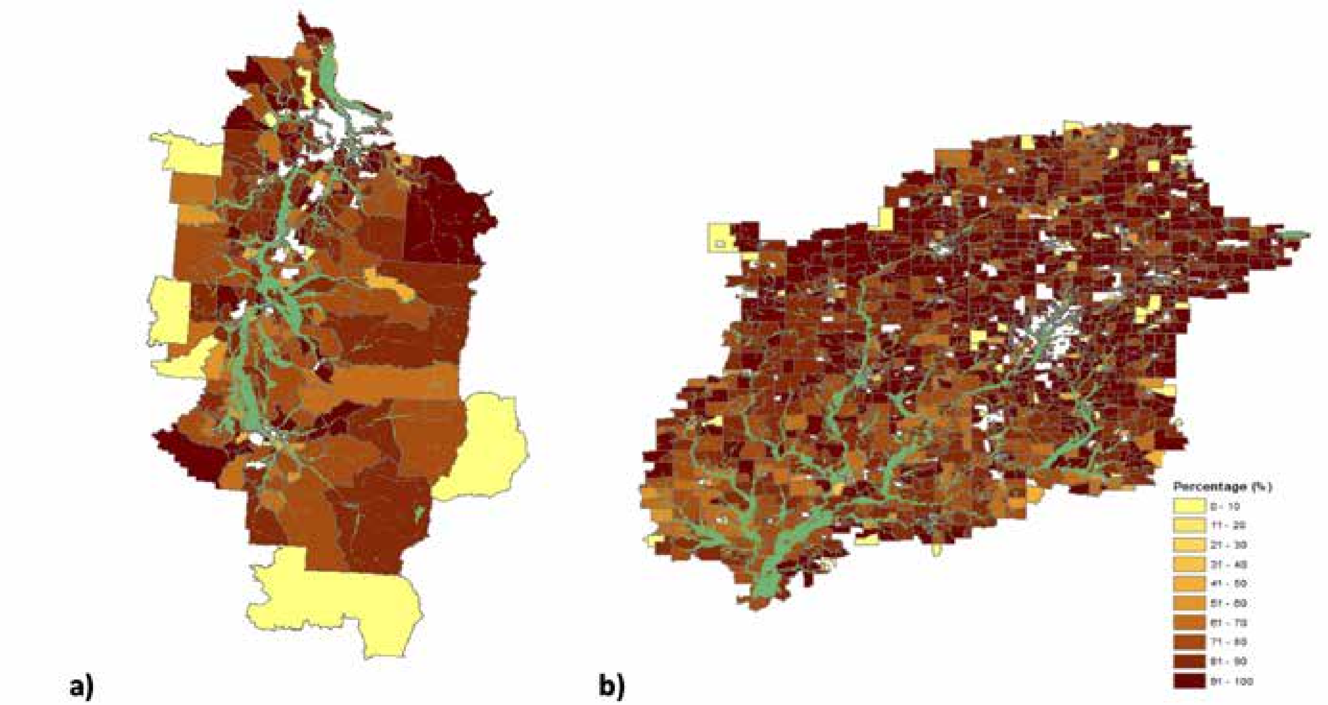


Figure 4. Percentage of single-family homes in each census block group in the a) Willamette Basin and b) Wabash Basin. The 100-year flood boundaries are also shown. Figure by Oluwatobi Oke.

and we analyzed differences in housing statistics within each flood boundary. We collected the longitude and latitude of different locations in the basin showing average rainfall, discharge, number of flash flood and slow-rise episodes between the year 2002 and 2013, and we matched these locations with the census block groups.

Results and Discussion

The frequency and spatial distribution of flood types varied in each basin. For example, Figure 1 shows how patterns of slow-rise and fast floods vary in the Wabash Basin. These patterns are different between basins, as shown in Figure 2 when comparing the frequency of slow-rise floods in the Wabash (maximum of 160 floods) and Willamette (maximum of 30 floods) basins. We expect that the frequency and spatial distributions of slow-rise and flash flooding in each basin are largely controlled by orthographic drivers of precipitation. For instance, large atmospheric rivers over the Willamette Basin cause low intensity, long duration precipitation events, and a greater frequency of slow-rise floods compared to flash floods. A clear correlation between flooding magnitude and type of flood is not present.

When housing stock attributes were spatially analyzed within flood boundaries for 20-, 50-, and 100-year events, we unsurprisingly found that more homes may be impacted by flooding during the 100-year event compared to smaller events (Table 1). Single-family homes were more prevalent in flood boundaries of all sizes, and mobile homes were the least prevalent (Figure 3 for the Wabash Basin), but the proportion of mobile homes stayed relatively consistent for all flood sizes in each basin. Spatial distributions of single-family homes varied, however, as shown in Figure 4, for both basins. We are continuing to further analyze the spatial distributions of housing stock and flood boundaries to determine how flooding risks vary among demographic groups.

Conclusion and Future Research

This research is the first step toward developing a novel approach for estimating demographic risks attributable to flooding in the U.S. Although this work is still ongoing, we found large differences in the type of flooding and frequency of flooding in different basins. In addition, the spatial distribution of housing types impacted by different sized floods varied in each basin. These findings highlight the need to examine more fundamental hydrometeorological processes of flooding across large spatial scales, and to explore the disparate impacts of flooding on different demographic groups. In future work, we would like to expand this analysis nationally and establish a dataset of housing demographics and geospatial flood regime topology linking flood characteristics to recurrence interval and flooding extent. This research may be useful for national emergency response policies for flooding (e.g. temporary housing following floods), and we expect it may also inform urban resiliency and health planning under climate change.

Funding for this project was provided by a Colorado Water Center Research Team Grant.

The Hydro-Social Cycle of an Extreme City:
Tijuana, Mexico

Ned Molder, Anthropology Department, Colorado State University
Melinda Laituri, Department of Ecosystem Science and Sustainability, Colorado State University

The chief executive officer of Dow Chemical Company states, "Water is the oil of the 21st century" (2008), and World Vision experts termed the 21st century as the urban century (2013). According to the UN World Water Development Report (2018), by 2050, at least one in four people is likely to live in a country affected by chronic or recurring shortages of freshwater, and cities are growing by 60 million people each year. Within this context, we examine extreme cities.

Extreme cities are urban environments on the bleeding edge of climate change, socio-economic inequality, and with limited access to basic resources. Innovative solutions are needed to address the intersection of rapidly growing urban areas, limited water resources, and stressed water systems. Using the hydro-social cycle—the intersection of the accelerating hydrologic cycle with water's social and political nature (Linton and Budds 2014)—we study an extreme city, Tijuana, Mexico, located on the U.S.-Mexico border.

The hydro-social cycle is a framework to examine water from a holistic perspective (Figure 1). We operationalize the utility of the hydro-social cycle as way to assess and understand water planning and development. The hydro-social cycle is diagrammed to assess the existing water resource availability, the current water policy for water management, and the city context for demand and need. A change detection analysis of the city extent provides the basis to identify how and where the city has outgrown infrastructure, and identify gaps in services, along with data requirements to track future water needs.

Tijuana, Mexico. Photo by Cbojorquez75 via Wikimedia Commons.

Extreme Cities and Water Management

Extreme cities are characterized by stark inequality in residents' access to resources, as well as spatial differentiation by race, class, gender, and exposure to environmental harms. Extreme cities result from rapid population growth coupled with unplanned urban development and inadequate public infrastructure to serve marginal communities. Water management is one of the most critical issues in extreme cities. Unplanned growth results in the development of informal settlements with little or no access to public water services. These communities often are established in marginal environments such as unstable hillslopes likely to experience landslides or floodplains prone to repeat flooding. Residents of extreme cities are vulnerable to water events—excess water runoff and flooding, water borne disease, and water scarcity due to climate change and inadequate distributive infrastructure for water. Water is an intersectional resource and is inherently a socio-political element.

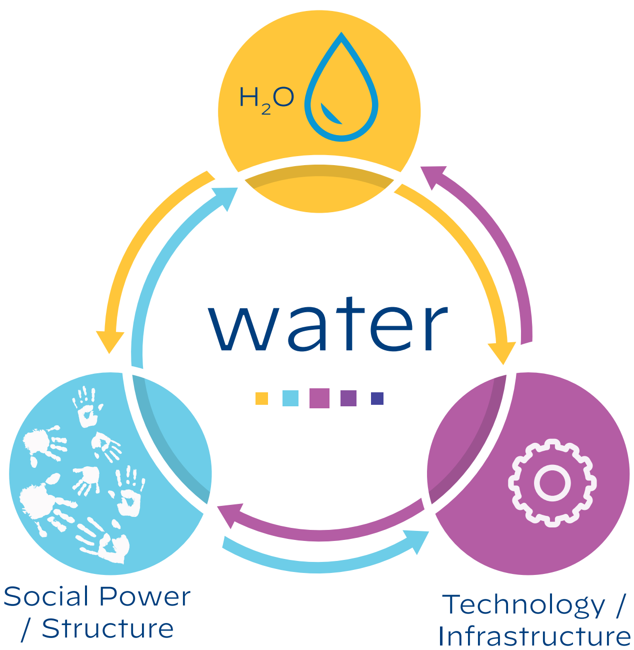


Figure 1. The hydro-social cycle (from Linton and Budds 2014).

The Hydro-Social Cycle

The hydro-social cycle is a political-ecological framework for analyzing water's inherently social dimensions (Linton and Budds, 2014). In cities, water and society are intimately linked in a relationship that shifts with different hydrologic, political, and social contexts. While the H_2O in floodwater, groundwater, and desalinated ocean water has the same molecular structure, each form has different social implications when analyzed in a broader context of governance, social structure, technology, and infrastructure. Analysis of water issues through the hydro-social cycle can illuminate the complexity of water issues across multiple contexts, and provide an integrated approach to identifying potential solutions for residents of extreme cities.

Water Policy in Tijuana

The city of Tijuana is an ideal case study to apply the hydro-social cycle to water delivery in extreme cities. Tijuana has a semi-arid climate with most of its approx. 9 inches of rain per year falling during the winter months. As a result, most of Tijuana's freshwater resources come from the Colorado River through a network of canals and pipelines. Binational water allocation was originally negotiated in the 1944 Water Treaty. The International Boundary Water Commission (IBWC) was tasked with determining appropriate methods for water distribution to both countries (Silva-Rodriguez de San Miguel 2018). Local distribution in the U.S. and Mexico is managed by state and local agencies. Mexican border states generally lack adequate resources to implement local management plans. Water allocation in cities such as Tijuana is managed by national and state policies. As a result, the local water issues associated with rapid growth in Tijuana are not accounted for in broader government water policies.

Methods

We utilized several data sources to diagram the hydro-social cycle of domestic water distribution in Tijuana, and to seek answers to the following questions:

- » How is water distributed in Tijuana? How can the hydro-social cycle illuminate inequalities in water distribution?
- » Where are the data gaps in water distribution, and how can these be filled to increase equitable water distribution?

Academic literature (Navarro-Chaparro, et al, 2016; Sliva-Rodriguea de San Miguel, 2018; Williams, 2018), City of Tijuana government documents, and existing geospatial data were reviewed to identify the social power/structure components of the hydro-social cycle, information on water supply, and the technology/infrastructure components. This information was used to diagram the hydro-social cycle framework of water distribution in Tijuana. Services data were acquired from Open Street Map, and official city boundary data were acquired from INEGI. A change detection analysis was conducted to understand where population and built-up area has occurred. These data were acquired from the Global Human Settlement Layer (GHSL) and overlaid on a Digital Elevation Model derived from NASA's Shuttle Radar Topography Mission (SRTM). Maps were created to show the location of recent population growth, relative to critical services, streams/rivers, topography, and official Tijuana municipal boundaries.

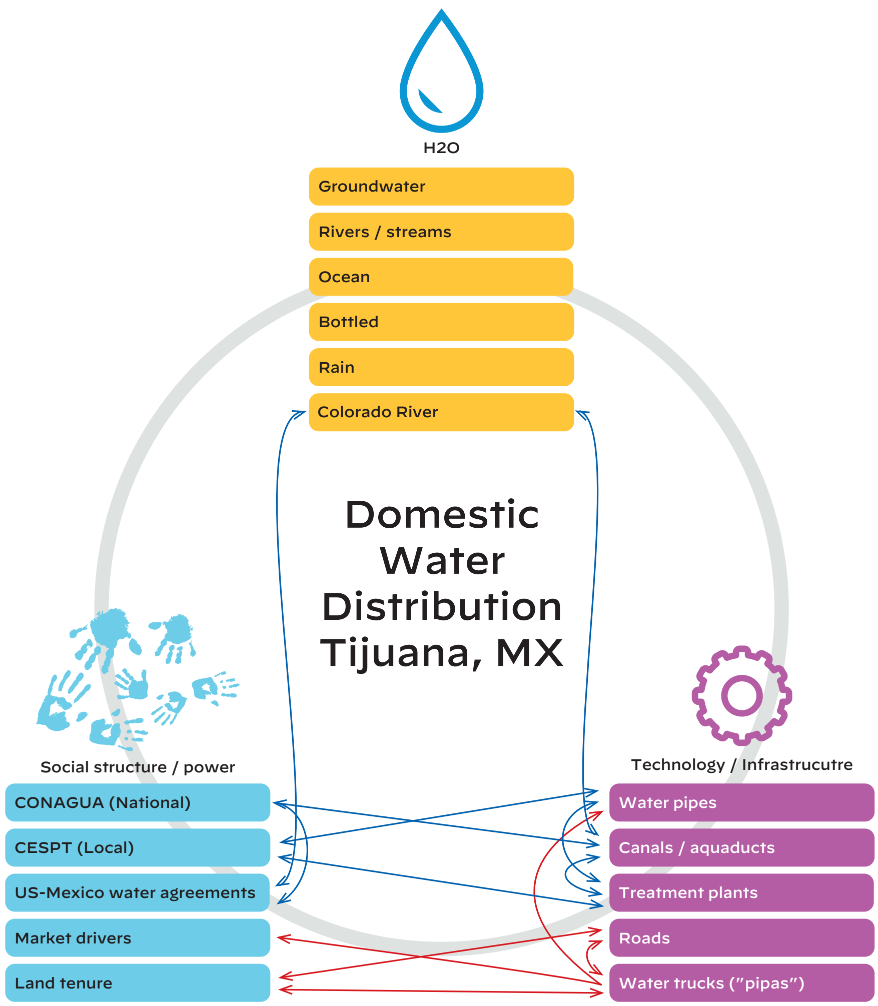


Figure 2. The hydro-social cycle of domestic water distribution in Tijuana. Blue arrows represent distribution for residents with formal land ownership; red arrows represent distribution for informal settlements.

The Hydro-social Cycle in Tijuana

The hydro-social cycle was diagrammed for domestic water distribution in Tijuana (Figure 2). The blue arrows represent distribution pathways for households formally recognized by city land tenure laws, while the red arrows represent the additional pathways required for residents of informal settlements. For residents of informal settlements, Comision Estatal de Servicios Publicos de Tijuana (CESPT)-authorized resellers are often the only source of freshwater (Navarro-Chaparro et al., 2016). Resale water may be exchanged between transporters and sellers multiple times before reaching informal settlements, at which point the end user cost is up to eight times higher than that of direct CESPT customers (Navarro-Chaparro et al., 2016). As a result, water consumption is significantly less in informal settlements than in formal settlements.

Beyond Water Supply Fixes

The National Water Program and CONAGUA reported that 94% of Tijuana residents had access to drinking water in 2006, with a goal of 97% access by 2012. However, it is unclear whether these estimates account for residents of informal settlements whose population has expanded dramatically since 2012.

This top-down perspective is likely due to the state's management system that fails to consider location-specific water and infrastructure issues. Publicly available spatial data on water infrastructure is limited, so official reports and secondary sources provided much of the data for this study. Tijuana officials recognize the need for improvements in water delivery, especially in areas of recent population growth. Between 2000 and 2014, growth has occurred mostly on the eastern edge of the city's municipal boundaries, and outside of the city's southern border (Figure 3). A representative satellite image from Google Earth reveals that much of the newly built-up area is unplanned, with residences forming close together along dirt or gravel roads. These informal settlements likely lack access to official CESPT water distribution, and must purchase water from a reseller. The construction of a new desalination plant has been approved in the nearby city of Rosarito, and will provide fresh water to San Diego and Tijuana (Williams, 2018). The plant will operate through a public-private partnership and deliver desalted water to city water authorities in the binational region. Through a hydro-social lens, however, simply increasing the supply of freshwater in Tijuana will not resolve issues of water scarcity for informal settlements, if these residents are unable to access formal CESPT distribution infrastructure.

Spatial Distribution of Population and Services

The densest population correlates with areas of recent built-up area, and the largest cluster on the eastern side of the city is on a flood plain between two mountain peaks. Other population clusters are in stream channels, or outside the municipal boundary. Figure 4 shows the location of critical services relative to population. Most services are located close to the U.S. border along main roads near the Tijuana River, while few services are located near the largest population clusters in the east.

The Tijuana River as seen from a pedestrian bridge in Tijuana, Baja California, Mexico. Photo by Blazersand2000 via Wikimedia Commons.

Conclusion

The results of this hydro-social analysis demonstrate both the lack of infrastructure data and the ease with which residents not formally recognized by Tijuana's land tenure system are hidden from view in official water management plans.

CESPT's management plan calls for 100% of residents to have access to water in the next few years. However, without accounting for recent population influx and regular displacement of uprooted individuals and families, this goal is unlikely to be met. Following this initial study, we recommend the following actions to improve water access for Tijuana's most vulnerable populations:

- » Improve public data availability for water delivery infrastructure
- » Expand public water delivery infrastructure to informal settlements
- » Regulate CESPT reseller market to minimize cost increase to customers
- » Facilitate the transition of informal settlements to formal land ownership

Systemic reforms take significant economic and political resources, as well as cooperation across multiple scales and social organizations. Framing water issues in a strictly biophysical context is much simpler, and techno-political fixes to increase overall water supply (e.g. desalination) are appealing for their economic and political complementarity with existing systems. However, without significant reconsideration of the social, technological, and biophysical components of Tijuana's water system in a dialectical relationship, existing inequalities will remain.

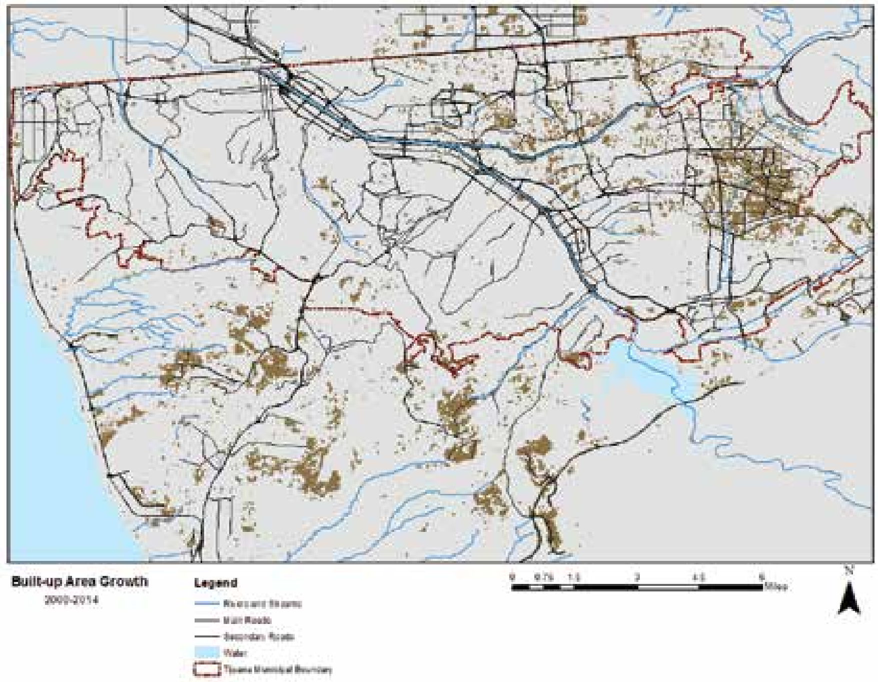


Figure 3. Built-up area growth between 2000-2014 relative to Tijuana municipal boundary. (Data source: GHSL)

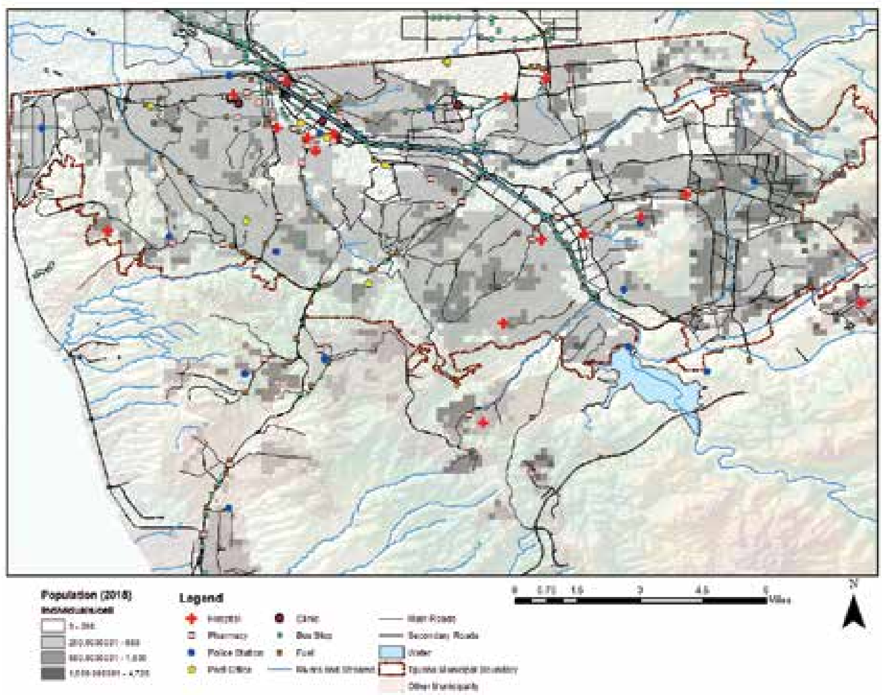


Figure 4. Tijuana services relative to population centers. (Services data source: Open Street Map; population data source: GHSL)

This grant was funded by the Colorado Water Center Competitive Grants program.

Addressing Non-Salmonid Fish Passage in Semi-Arid Regions: **Converging Paths, Continents Apart**

Christopher A. Myrick, Fish, Wildlife and Conservation Biology, Colorado State University

▼ SYNOPSIS

The ecological connectivity of rivers can be restored to some degree by well-designed fish passage structures. This project was designed to allow a Colorado fish passage researcher to interact and work with fish passage researchers from other semi-arid regions who specialize in the passage of non-salmonid fishes to explore possible similarities between fish passage needs and approaches in Australia's Murray-Darling River system and Colorado's Eastern Plains.

Background—Why Barriers to Fish Migration are a Problem

Rivers worldwide provide important habitat for a wide variety of fish, from tiny Empire Gudgeons (*Hypseleotris compressa*) and Brassy Minnows (*Hybognathus hankinsoni*), to medium-sized fish like Cutthroat Trout (*Oncorhynchus clarkii*) and Australian Silver Perch (*Bidyanus bidyanus*), to large and iconic predators like the Colorado Pikeminnow (*Ptychocheilus lucius*) and the Australian Murray Cod (*Maccullochella peelii*).

Despite ranging in size from less than an ounce to well over 100 pounds, a common thread with these and most other riverine fishes is that they rely on the ability to move freely between the habitats they need for spawning, feeding, or avoiding harsh environmental conditions such as droughts or floods. Even in rivers that flow through semi-arid regions such as Colorado's Eastern Plains, the Iberian Peninsula in Europe, or Australia's Murray-Darling River system, you find many species of fish that move, frequently for long distances, over the course of their lives.

The rivers that flow through semi-arid regions serve another purpose: They provide water for agricultural and urban needs, for power generation, and, in some cases, for recreation. In order to manage the rivers for these purposes and to minimize loss of life and property during flood events, resources managers often rely upon the presence of instream structures such as dams or diversions; unfortunately these can serve as barriers to the migration of fishes and other aquatic organisms. This issue can be particularly pervasive in arid and semi-arid regions where the scarcity of water increases the likelihood that existing sources will be intensively managed and modified.

Water resource managers have long recognized that

The confluence of the Darling and Murray Rivers pictured at Wentworth, NSW. Photo by Jjron via Wikimedia Commons.

these instream structures can be migration barriers. Interdisciplinary teams of biologists and engineers have worked for more than 100 years on effective means of restoring fish passage, ranging from installing the classic pool-and-weir fish ladders to the out-of-the-box Whooshh Innovations' "salmon cannon," and even the wholesale removal of dams, weirs, and diversions. In the United States, the majority of the effort has focused on developing passage techniques for migratory populations of salmon and trout (i.e., the salmonids); interest in developing passage techniques for smaller non-salmonid fishes has only really gained momentum in the last 10 to 20 years—yet these are the fishes that are most prevalent in semi-arid regions, such as rivers flowing through Colorado's Eastern Plains.

In other regions, such as Australia, there were no native salmonids, but initial fish passage efforts used approaches that had worked for salmonids. Researchers such as Dr. Martin Mallen-Cooper quickly realized that fish passage designs optimized for salmon and trout often failed when it came to allowing movement of the majority of the native fish fauna. Because the persistence of populations of many of their culturally and recreationally important species such as Murray Cod, Silver Perch, Golden Perch (*Macquaria ambigua*), and even the Barramundi (*Lates calcarifer*) was contingent on maintaining the migratory corridors, there was significant pressure to develop effective fish passage structures for these species. Thus, the Australians became pioneers in the development of non-salmonid fish passage techniques.

In Colorado, pioneering research on nonsalmonid fish passage has been underway at Colorado State University's Fish Physiological Ecology Laboratory (FPEL) over the past fifteen years. The FPEL, in concert with Colorado Parks and Wildlife, Wyoming Game and Fish, and the U.S. Fish and Wildlife Service are developing fish passage guidelines and recommendations for non-salmonid fishes in our semi-arid region. Rather than reinvent the wheel, it seemed logical to try to learn as much as possible from others who work in this arena of fish passage, including the Australian experts.

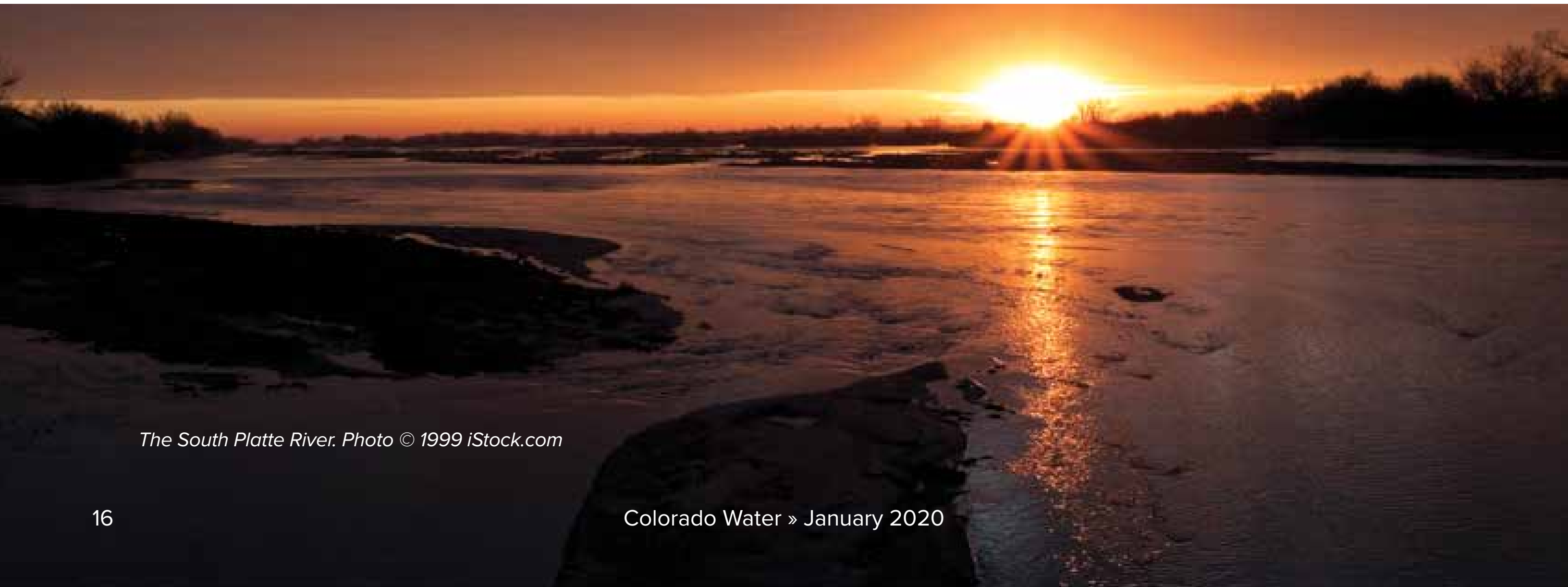
A migratory Murray Cod (Maccullochella peelii) *collected on the Murrumbidgee River, N.S.W., Australia. Photo courtesy of Chris Myrick.*

Project Rationale: Exchanging Ideas and Approaches, Spawning New Collaborations

The "Fish Passage 2018—International Conference on River Connectivity" in Albury, Australia, presented a unique opportunity to both participate in the premier fish passage conference in the world, and to exchange ideas with some of the leading figures in non-salmonid fish passage such as Dr. Martin Mallen-Cooper, Dr. Lee Baumgartner, and Dr. Jason Thiem. Additionally, I would be able to take a course on fish passage design and monitoring to further bolster my skills as a fish passage researcher here in Colorado. As the principal investigator of the FPEL, this was an opportunity too good to miss, and through the generous support of a Colorado Water Center Faculty Fellowship, I was able to attend.

Methods and Results—Be a Sponge

Unlike a traditional research project, which have well-defined materials and methods, my project as a Colorado Water Center Faculty Fellow required me to travel to Australia, meet and work with as many global experts on non-salmonid passage as possible, and exchange information with



The South Platte River. Photo © 1999 iStock.com

Part of the Department of Primary Industries Fisheries Research station in Narrandera, N.S.W., Australia.

them, while exploring the boundaries of the field. What follows is a summary of the key observations and lessons gained during my two weeks in Australia.

Different Continents, Parallel Problems

The Australian state of New South Wales, where the conference was held, has a similar agency structure to Colorado. They have the N.S.W. Department of Primary Industries Fisheries division, which has its own internal Fisheries Research group. In Colorado, we have the Division of Parks and Wildlife in the Department of Natural Resources, and they, too, have their own research group—and like the Australians, they work closely with local universities. Over the course of a couple of days spent with the staff at the Narrandera Fisheries Research Station , it became apparent that both states face eerily similar fisheries challenges.

» In Australia's Murray-Darling system, non-native fish species, and in particular Common Carp (*Cyprinus carpio*) are a huge problem because of their impact on the environment and native fishes. In Colorado, we also have non-native fish species that cause management problems, including Northern Pike (*Esox lucius*) and Yellow Perch (*Perca flavescens*).

» Water demands often exceed water availability. Much like the situation in some of Colorado's river basins, the demand for water in parts of the Murray-Darling system can exceed the supply depending upon the type of water year. This leads to tough decisions on who, or what, gets water during periods of low flow.

» There is a constant tension between the need to preserve native fishes, irrespective of their potential for supporting sport or commercial fisheries, and the need to provide the angling public with recreational fishing opportunities.

» The presence of large numbers of instream diversions, weirs, and dams poses an ongoing challenge to "reconnecting" the river to restore ecological connectivity. Efforts are underway in both regions to install effective fish passage structures where possible.

Contrasts and Congruence in Fish Passage Approaches

Both N.S.W. and Colorado are working to improve fish passage on their river systems, and the two states have some similarities in how they are doing so. In both states, rock ramp fishways (sometimes referred to as constructed riffles) are viewed as one of the best choices for non-salmonid fishes because they do not force the fish to jump from pool to pool, and rely instead on providing the fish with a hydraulic environment that allows the fish to swim upstream over or around the obstacle. Rock ramp fishways are likely the most common type used in both states, but the Australians have two other types that they also use, particularly when dealing with highly variable flows (as you might encounter in a semi-arid region) or large vertical drops. The first is the vertical slot fishway, a design that originated in the salmonid passage world, but which they have optimized to work for their fish, including very small (< 2") juveniles that are migrating back into the rivers after hatching in estuaries. The second is the cone fishway, which uses a series of cone-shaped baffles to create the ideal hydraulic conditions for the upstream movement of small and large fishes. In each case, the key to maximizing passage seems to be reducing the amount of turbulence within the fishway.

Because the Australian resource agencies have developed a set of passage guidelines and criteria, they have been able to install fishways at a more rapid pace than we have in Colorado. Both states still customize each installation to match local conditions; the Australians further fine-tune the installations during "wet testing," and as we gain more experience in Colorado, we can hopefully begin to match their output.

Parallel Approaches and Growing Collaboration

While the Australians are clearly ahead when it comes to the design and installation of fishways for their non-salmonid fishes, where we begin to achieve parity is in our ability to test new fishway designs under laboratory conditions. The presentations I delivered on the large variable-geometry flume at the FPEL, and associated studies on the effects of fishway configurations on fish passage success, drew a lot of attention at the conference and led to a growing collaboration with Dr. Rebecca Cramp and Dr. Craig Franklin at the University of Queensland, and Dr. Matthew Gordos with New South Wales Fisheries division. The University of Queensland laboratory uses

In Australia's Murray-Darling system, non-native fish species, and in particular Common Carp (Cyprinus carpio) are a huge problem because of their impact on the environment and native fishes.

A local Australian angler holds an invasive Common Carp (Cyprinus carpio), caught in an impounded stretch of the Murray River.

a similar approach to evaluate improvements in fishway design as we do at the FPEL, and we worked together to write a book chapter entitled "Using physiological and experimental tools to unlock barriers to fish passage in freshwater ecosystems," which is currently under review at the Oxford University Press.

Conclusions and Next Steps

The opportunity afforded to me by the Colorado Water Center Faculty Fellowship was without parallel. I was able to participate in the premier conference on fish passage, presenting our research results on non-salmonid fish passage in a three-day symposium devoted to that topic, and interacting with the leaders of that field. I was also able to work closely with a number of fisheries researchers from Australia to learn about their fisheries management challenges, with a focus on how they are tackling non-salmonid passage issues and, at the same time, was able to show them the approaches that we are using here in Colorado to do the same.

New collaborations and indeed friendships have been forged, and my understanding and appreciation of the challenges of restoring ecological connectivity to rivers in semi-arid regions has definitely grown. Despite being continents apart with very different native fish fauna, the similarities in fisheries challenges, and even some of the "bad actors" that are causing those challenges, were hauntingly similar. Clearly, establishing and maintaining the intercontinental lines of communication should prove fruitful as we strive to improve the conservation and management of global freshwater fisheries resources. This past December, the FPEL hosted Dr. Matthew Gordos at CSU for a visit and presentation to regional fish passage practitioners.

Sunset on the Murrumbidgee River, a native fish stronghold.

I would like to thank the Colorado Water Center for awarding me one of the 2018 Faculty Fellowships. The award allowed me to significantly advance my understanding of non-salmonid fish passage and has spawned new collaborations that should, over the next few years, allow for greater coordination and new advances in fish passage in semi-arid regions.

Water Justice in the Rio Grande River Basin

Findings from the Environmental Justice Research Team

Stephanie A. Malin, Sociology, Colorado State University

Melinda Laituri, Ecosystem Science and Sustainability, Colorado State University

The Rio Grande/Rio Bravo (Rio Grande-Bravo or RGB) River Basin flows 1,896 miles from its headwaters in the San Juan Mountains of Southern Colorado. It winds through New Mexico along the western border of Texas, U.S., and four Mexican states—Chihuahua, Coahuila, Nuevo Leon, and Tamaulipas—draining a total of 182,200 square miles (Figure 1). The region encompasses diverse ecosystems, ranging from mountainous alpine zones, to semi-arid rangelands and the high Chihuahuan desert, to the humid subtropics where the mouth empties into the Gulf of Mexico.

The populations and socio-economic fabrics of communities along the Rio Grande-Bravo River Basin are equally diverse, given that the basin includes multiple U.S. and Mexican states. The Basin is also home to eighteen of the nineteen Tribal Pueblos of New Mexico (with only the Zuni outside the region) and four additional Tribal nations. Water industries in the Basin include agriculture (water use estimated at 75% of available supplies), oil and gas, tourism and recreation, and commercial fishing.

Although there are only four major urban centers along the mainstem of the Rio Grande (Albuquerque Metropolitan area, El Paso-Ciudad Juarez, and the corridor that runs along the river between Laredo-Nuevo Laredo and Brownsville-Matamoros), municipal water demand is expected to increase by one hundred percent in the next fifty years, and industrial water use will increase by forty percent (IBWC, https://www.ibwc.gov/CRP/riogrande.htm). These physical and social characteristics are compounded by a changing climate, which has resulted in severely depleted waters.

The Rio Grande as seen near Taos, New Mexico. Photo ©2019 iStock.com

These pressures set the context for an examination of competing demands for water through an environmental justice (EJ) lens. The research of the Rio Grande Basin Environmental Justice Research Team (Dr. Stephanie Malin; Dr. Melinda Laituri; Dr. Josh Sbicca; Kelsea MacIlroy, MS, ABD; Kathyrn Powlen, MS; Joshua Reyling; Dr. Stephen Mumme; and Dr. Sybil Sharvelle) explores the intersectional EJ issues and opportunities for just transitions in a transboundary watershed.

We are especially concerned with issues at the Food-Energy-Water nexus. We have used a broad lens to examine EJ issues experienced across of the entire RGB Basin through our geospatial justice investigations, webinar, and mapping. We have also focused on specific issues and communities in northern New Mexico through our Roundtable, and work with Pueblo communities. Each is described below.

A Systems Perspective: Spatial Justice & Creating an EJ Geospatial Database

By Melinda Laituri, PhD

The RGB is under-examined from an EJ perspective. However, it exemplifies critical water concerns that are deeply tied to EJ issues, including: water supply imbalances (quality and quantity), inadequate infrastructure, risks of extreme weather and other climate change impacts, population growth and urbanization, international border

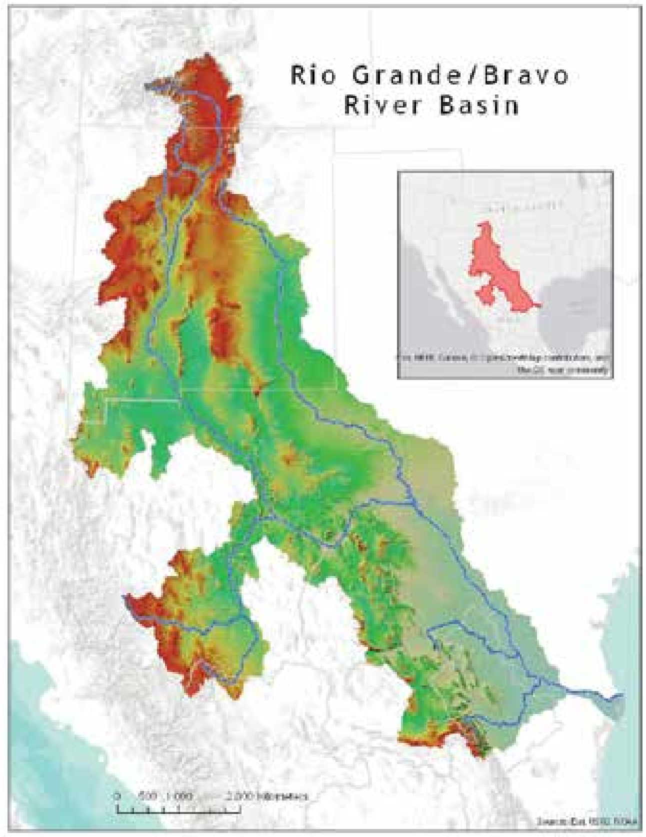


Figure 1. The Water Justice study site. Rio Grande-Bravo River Basin with shaded geologic relief. (delineated by Hydrological Unit Code 2 USGS Watershed Boundary Dataset (https://nhd.usgs.gov/wbd.html).

The Rio Grande divides El Paso, USA, and Ciudad Juarez, Mexico, as seen from space. Satellite image ©2019 iStock.com.

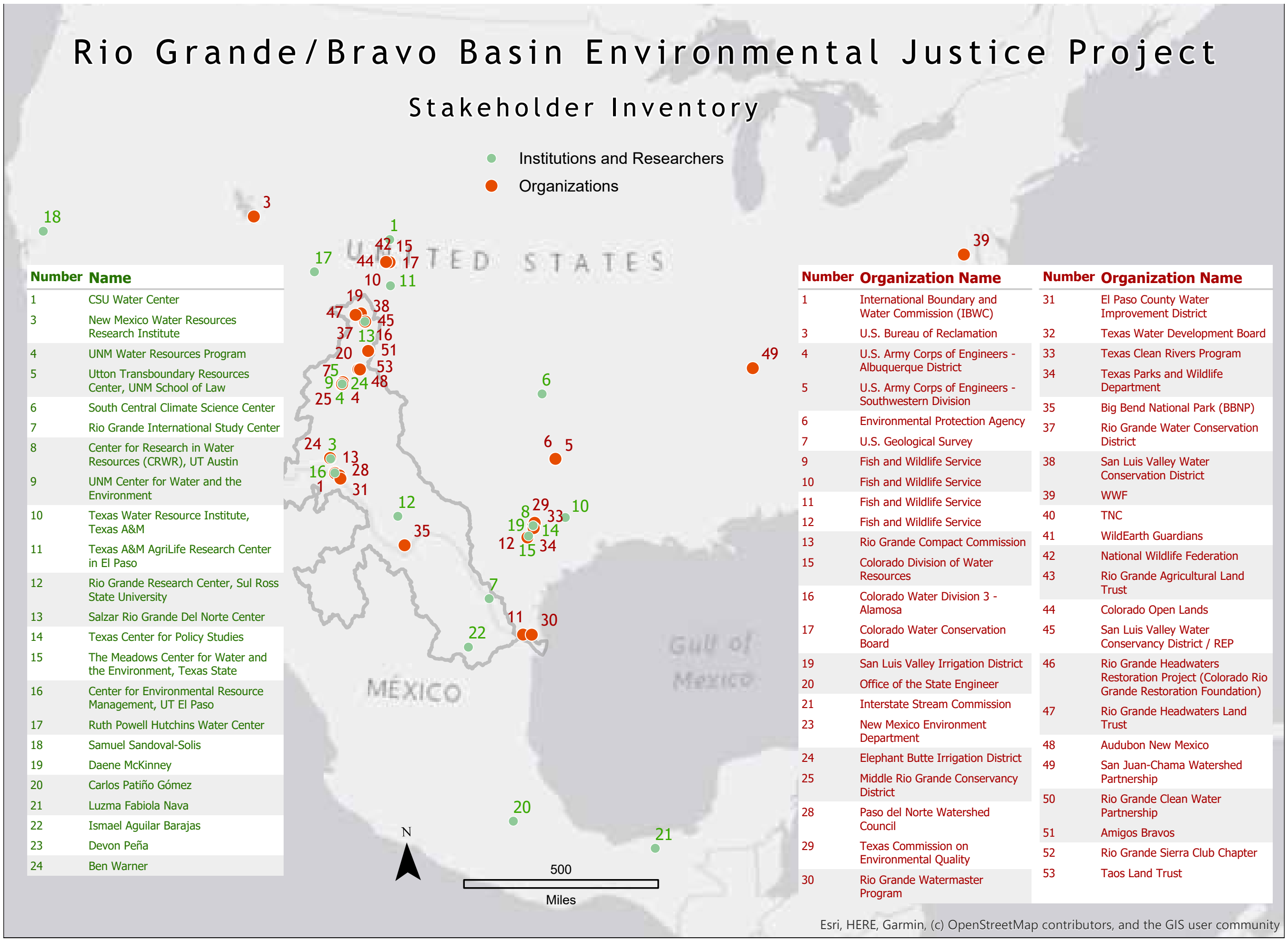


Figure 2. Names and locations of RGB stakeholders.

relations, and poverty. Foundational to understanding EJ issues in the RGB is spatial justice—making explicit through maps and geospatial data the consequential geography of distributional and procedural justice outcomes on the landscape.

Our approach to understanding the consequential geography of spatial justice is twofold:

1. developing a geospatial inventory of EJ stakeholders across the RGB Basin; and
2. creating a geospatial database of the RGB watershed

These products are the basis for an interactive PDF map being developed to enable us to share with stakeholder groups the location of EJ themes, as well as where these themes intersect.

The stakeholders inventory defines key players in the RGB Basin, and locates communities of interest, vulnerable populations, and critical issues related to EJ. The resulting map (Figure 2) reveals a broad cross-section of non-governmental organizations, university centers, and government agencies across the Basin.

Importantly, these issues are intersectional and embedded in the complex geography of the RGB. A geospatial inventory of stakeholders reveals those who have been engaged in research, education, and/or advocacy activities within the Basin. Creating this inventory connects these groups to achieve stronger communication within the Basin, to better identify EJ issues and create partnerships and/or collaborative groups with similar interests and goals.

The geospatial database is foundational to developing a repository for data necessary to identify the EJ issues—the spatial justice landscape—and to conduct analyses on concerns identified by stakeholders (Figure 3). Due to differences in priorities and foci across the municipalities, organizations, counties, states, and countries in the Basin, the availability and quality of data is disparate.

This database begins to identify and close these data gaps to create complete data sets necessary to analyze issues of different groups in a systemic fashion that can be expanded to the entire Basin. For our project, this helped us identify participants in our Webinar, and possible partners and locations for our community-level work.

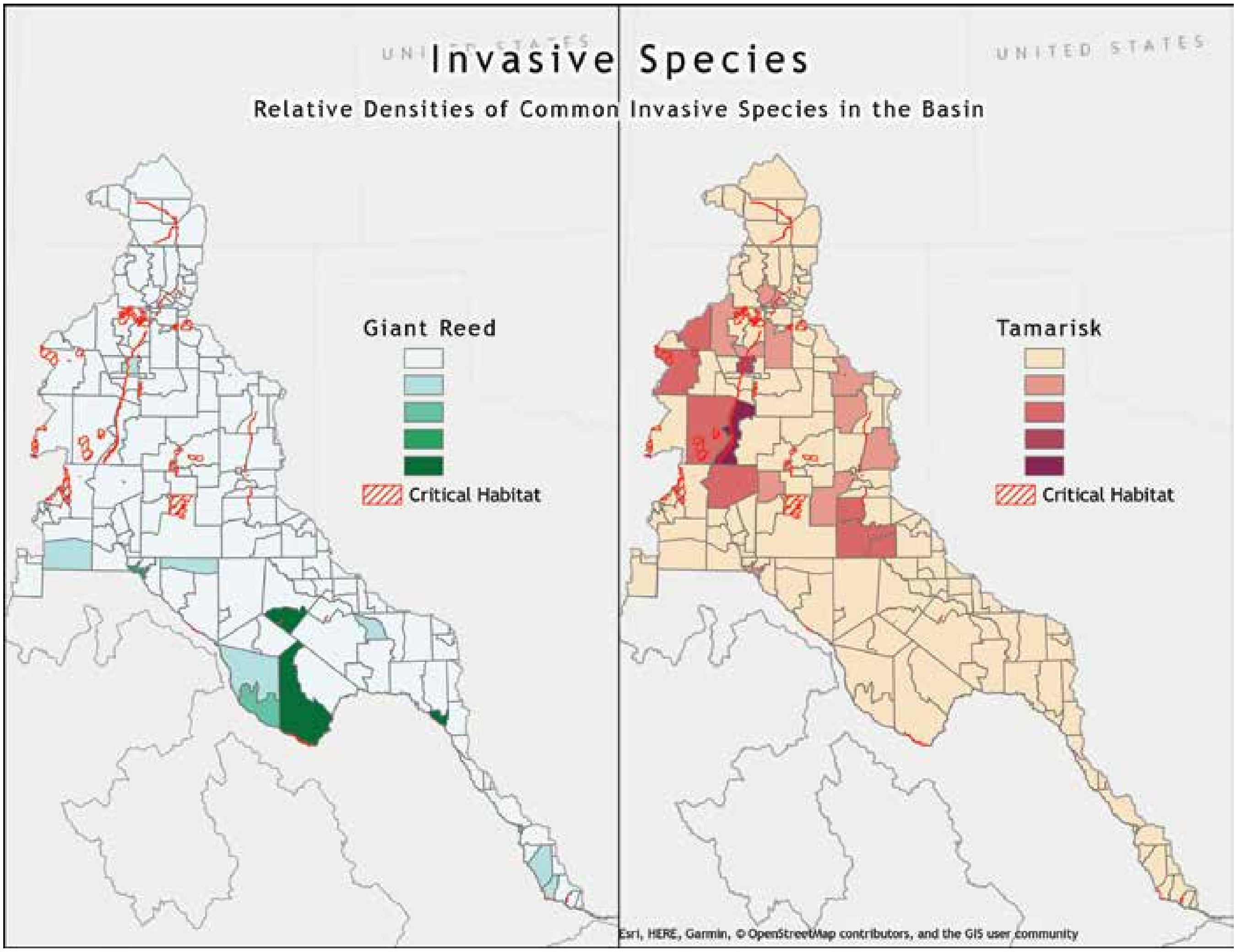


Figure 3. Community-based mapping of invasive species: Giant Reed (left) and Tamarisk (right) in the RGB. Source: EDDmapS (Early Detection & Distribution Mapping Systems, https://www.eddmaps.org/).

EJ Issues and Community Perspectives: Notes from the Environmental Justice Roundtable

By Stephanie A. Malin, PhD

After conducting our initial research and fieldwork, we held the New Mexico Tribal Environmental Justice Roundtable. The Santo Domingo Pueblo generously hosted this event, and Cynthia Naha (Director of the Natural Resources Department for the Santo Domingo Pueblo) and Sharon Hausam (Planning Program Manager for the Laguna Pueblo and a Research Associate at the University of New Mexico) acted as the main organizers of the event.

Given the participatory aspects of this study, we co-organized the Roundtable after months of working with community leaders and organizations to identify the most mutually productive focus of our initial research efforts, to support robust activities already occurring in the region. The Roundtable was attended by about 30 Pueblo/Tribal Environmental Professionals, who represented 10 of the 19 different Pueblos across New Mexico.

Our goals were simple: We wanted to create space for discussions on EJ, and to enhance collaborative spaces Tribal staff and members have already created to address issues related to complex issues—water, energy development, legacy contamination, and climate change.

After a brief overview of EJ concepts, we asked participants to reflect on environmental injustices in their daily lives, how they impact communities these participants serve, and strategized ways that Tribal voices can have more meaningful opportunities to participate, and more seats at the table when we make decisions about environmental policies.

Roundtable discussions focused on the ways in which EJ impacts tribal members' daily lives and environments. Examples from the New Mexico region quickly emerged, from complicated legacies to contemporary challenges, with water often at the center. We learned about water contamination around Los Alamos National Lab, oil and gas production throughout the state—and near sacred lands such as Chaco Canyon—as well as the ongoing impacts of open-pit uranium mining around the now-defunct Jackpile Mine, and the health impacts and pollution that can haunt communities for decades.

We learned some key lessons from the stories and histories people shared. We learned that people's health is affected in most of these cases of environmental injustice, and that this is a deeply held concern across Pueblo and Tribal communities. We learned that youth and women from Tribal communities play important roles in addressing environmental injustice and climate injustice—and that they need a more substantial seat at the table within Pueblo and Tribal communities. Finally, we learned that people's concerns over water quality and water scarcity intersect with almost every other experience of environmental injustice we discussed throughout the day.

Participants have shared that two of the most useful concepts in the meeting were Distributive Justice and Procedural Justice—two central components of the larger concept of EJ. (Once you learn them, you can see these outcomes all around you.)

"Distributive justice" refers to a snapshot of where societies put their environmental "goods" (like bike paths, public transit, and public lands) and "bads" (like toxic waste storage or extractive activities). Sociologists such as myself analyze what groups of people are inequitably exposed to larger shares of environmental "bads."

Hundreds of studies show that poor communities and/or communities of color are exposed to an inequitable share of "bads" like contamination, toxic pollution, and pollution facilities. The Roundtable discussed this concept in relation to all the examples of toxic, nuclear, and other legacy contamination issues affecting Pueblos and Tribal communities.

"Procedural justice" refers to longer-term decision-making processes, specifically who has a seat at the table when we make decisions about how we interact with the earth and other beings, and how we "use" land, water, and air. Procedural equity also requires that people have public access to information about a given issue; information that is useful, reliable, and translated for the public to use, without having expertise. Groups with little political and economic power are often excluded from these processes, and do not get to meaningfully participate in making decisions that affect them and their communities.

Next steps center on how to make these concepts and approaches useful for Pueblo and Tribal communities. Our Center for Environmental Justice at Colorado State University will continue to build space for collaborative, community-based, and interdisciplinary research, policy, and engagement around issues of EJ and health.

Our Research Team appreciates the Colorado Water Center's support in initiating these relationships.

Portions of this section have been published in Green Fire Times' coverage of the Roundtable: https://bit.ly/2OYBvE6

The Rio Grande as seen near Los Alamos, New Mexico. Photo ©2019 iStock.com.

Who Changes the Rain?

Pat Keys, School of Global Environmental Sustainability, Colorado State University
Kathy Galvin, Department of Anthropology, Colorado State University
Randy Boone, Natural Resource Ecology Laboratory, Colorado State University

▼ SYNOPSIS

During 2018-2019, the Water Research Team explored new perspectives on understanding how sustainability efforts may interact with the atmospheric branch of the water cycle. In addition, this team hosted a three-day symposium on Water in Africa, developed new partnerships with international colleagues, and secured NASA funding to continue the research through 2021.

"I don't only look at water as an access issue I think it's really important to look at who's managing the water and who is getting access and environmental justice issues around that. I think it's a huge topic right now."

—Dr. Colleen Vogel, Keynote Speaker at Water in Africa Symposium, 2019

During 2018-2019, the Water Research Team (WRT) for "Who Changes the Rain?" developed new research directions, aimed to secure external funding, and hosted a symposium on Water in Africa. This article will briefly describe some of those activities, and touch on some of the key highlights of the year.

New research focused on the Sustainable Development Goals

The core of this WRT was to develop a new, interdisciplinary CSU-based team of scientists that aim to explore the coupled dynamics of how changes to landscapes (e.g. deforestation) can modify the atmospheric water cycle, and subsequently impact subsistence communities downwind. The research builds on the existing work of principal investigator Pat Keys (School of Global Environmental Sustainability), as well as the past work of co-investigator Kathy Galvin (Dept. of Anthropology), and Randy Boone (Natural Resource Ecology Laboratory).

The core of this WRT was to develop a new, interdisciplinary CSU-based team of scientists that aim to explore the coupled dynamics of how changes to landscapes (e.g. deforestation) can modify the atmospheric water cycle, and subsequently impact subsistence communities downwind. Photo ©2019 iStock.com.

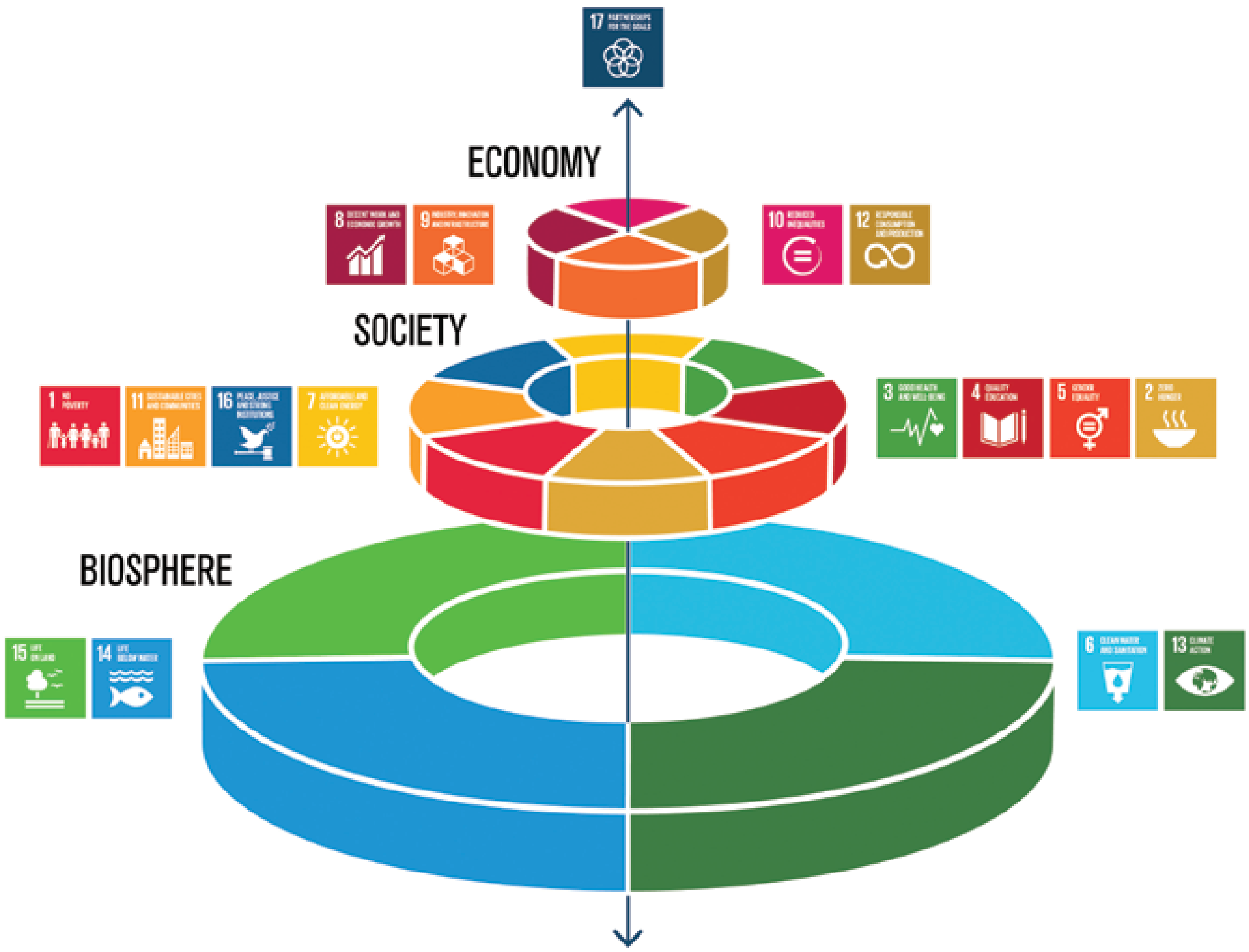


Figure 1. Diagram of the UN Sustainable Development Goals, emphasizing a possible clustering and nesting of the 17 goals in the categories of the "biosphere," "society," and "economy." Image credit: Stockholm Resilience Centre.

The primary research question of this WRT was to understand some of the consequences that could result from the achievement of certain Sustainable Development Goals (SDGs) in Kenya. The SDGs are a set of global goals related to many aspects of sustainable development, including aspects of the biosphere, society, and economy (Figure 1). In this case, we were focused on SDG #15 related to the sustainability of "Life on Land." Specifically, we aimed to understand whether changes to forest cover in Kenya might lead to unexpected changes in the atmospheric water cycle, and then to potential changes in how much rain falls on both agricultural and rangelands, elsewhere in Kenya. Prior work led by PI Keys reveals the surprising importance of the vegetation on land (e.g. forests, wetlands, farmlands) for providing evapotranspiration to the atmosphere that will fall as rain elsewhere. As a result, our research team began developing a system of models that could collectively simulate these changes.

This full model coupling has been a complex learning experience for the WRT, and remains ongoing, but we do want to share a few of the interesting insights and tools that have been developed as a part of this project.

First, to better understand the social dynamics of how communities respond to changes in rainfall, we explored how drought can be understood from both satellite- and on-the-ground perspectives. Working with a PhD student in the Graduate Degree Program in Ecology (Tomas Pickering), and an undergraduate research intern from the University of Notre Dame (Abigail Stokes), we discovered that the process of drought classification via satellite data has the potential to miss very important information related to both the adaptability of pastoral herding communities on the ground, as well as the role of social processes in determining the lived-experience of drought. This research continues, and will feed into the eventual coupled modeling system.

Second, in order to better understand Kenya's sources of precipitation (aka its precipitationshed, or "watershed of the sky"), as well as the fate of its evaporation (aka its evaporationshed), we produced a set of analyses that examine this moisture recycling for all locations in Kenya. This data is

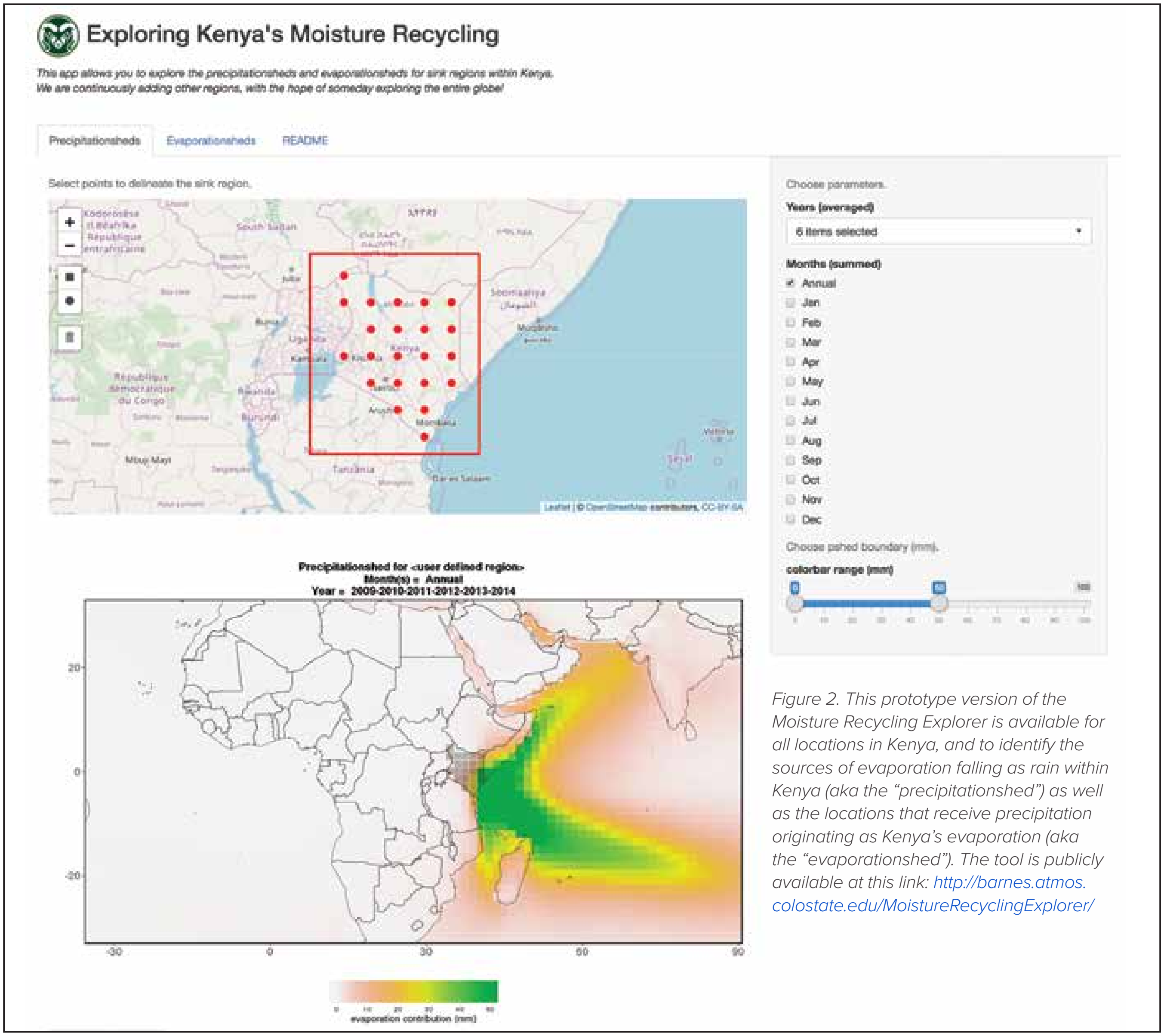


Figure 2. This prototype version of the Moisture Recycling Explorer is available for all locations in Kenya, and to identify the sources of evaporation falling as rain within Kenya (aka the "precipitationshed") as well as the locations that receive precipitation originating as Kenya's evaporation (aka the "evaporationshed"). The tool is publicly available at this link: http://barnes.atmos.colostate.edu/MoistureRecyclingExplorer/

presented in a publicly-accessible web application, entitled "Moisture Recycling Explorer," which is a prototype for how to share and present these results in the future (Figure 2).

This ongoing research was presented at two conferences during the year: the 2018 Fall Meeting of the American Geophysical Union, and 2019 CSU Hydrology Days. It was also highlighted at the NASA Biodiversity and Ecological Forecasting Team Meeting in April 2019.

Research will continue through 2021

In addition to the research activity, the team drafted and submitted a proposal to the National Aeronautics and Space Administration (NASA) Earth Science Division—and NASA selected the proposal for funding. This three-year NASA grant will fund much more detailed research into the model coupling that was first proposed for this WRT. As a result of the NASA funding, the team of investigators will be able to extend the initial concepts much further, including dialogue with stakeholders in Kenya to co-develop land-use change scenarios that are locally-relevant, as well as advancing the modeling considerably via incorporation of remotely-sensed satellite data.

The NASA grant will continue from 2019 to 2021, funding the three investigators of the WRT, as well as a post-doctoral fellow, and additional graduate student research. Two workshops will be held in Nairobi, Kenya to guide the process of model development, and to ground the research in the needs of stakeholders.

Water in Africa Symposium brings international experts to CSU

A key element of the WRT was to host a half-day workshop on the findings of the research team, and to more broadly discuss the SDGs as they relate to water. However,

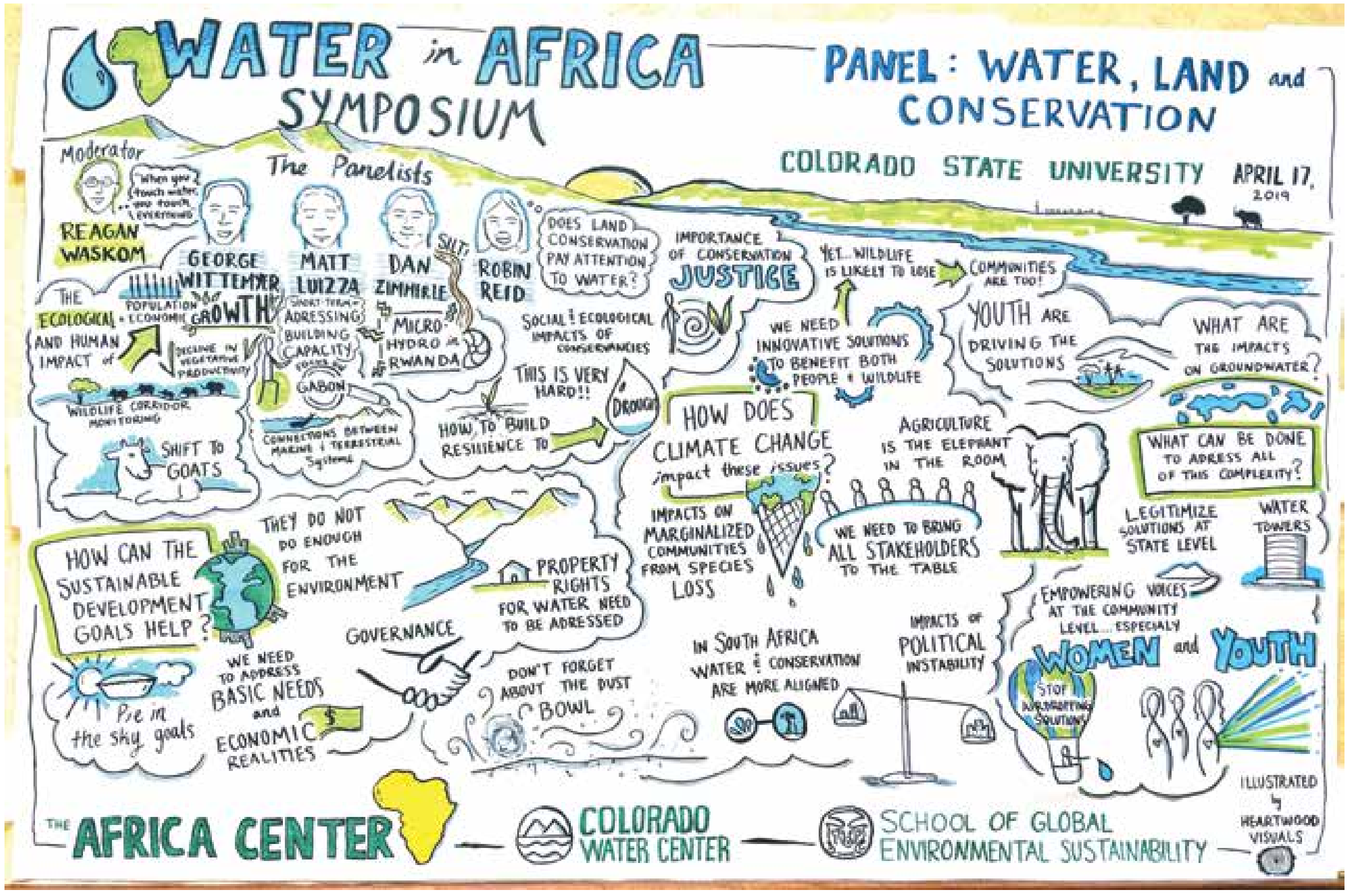
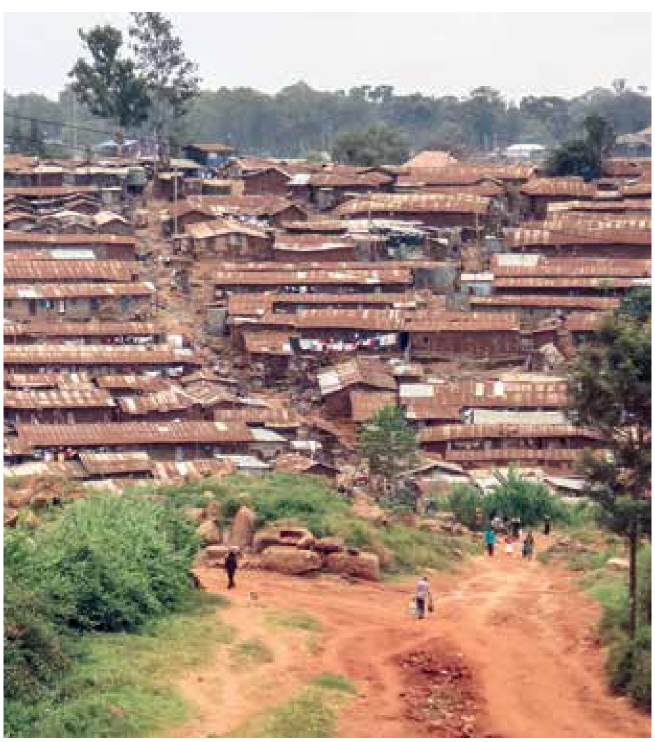


Figure 3. Graphic recording of the Water in Africa Symposium panel on "Water, Land, and Conservation." Three such panels were produced and are available at The Africa Center website. Graphic used here with permission, and produced by Heartwood Visuals (www.heartwoodvisuals.com).



The WRT examined impacts of climate change on marginailzed communities. ©2019 iStock.com.

this event was expanded to a multi-day symposium taking place over three days, with three international keynote speakers, three themed panel discussions (highlighting CSU expertise), and a student poster session of both graduate and undergraduate students. In addition to the Colorado Water Center, the symposium was co-funded by the Africa Center, the School of Global Environmental Sustainability, the Office of the Provost, and the Office of the Vice President for Research.

The symposium included fantastic dialogue, discussion, and shared learning about the present and future challenges related to water throughout the continent. The three keynote speakers, Dr. Line Gordon (Stockholm University, Sweden), Munira Anyonge-Bashir (The Nature Conservancy, Kenya), and Dr. Colleen Vogel (University of Witwatersrand Johannesburg, South Africa) also shared their thoughts in brief audio recordings, which are available at The Africa Center website (africacenter.colostate.edu).

In addition to the insights, the panel discussions were "graphically recorded" (Figure 3), which provided an artistic and creative approach to synthesizing the panel findings, as well as providing an engaging point for discussion about the symposium proceedings.

Munira Anyonge-Bashir honored as Dr. Norm Evans Distinguished Speaker

In addition to this, one of the Keynote speakers was Ms. Munira Anyonge-Bashir, the Country Director for The Nature Conservancy (Figure 4). She was honored as the Dr. Norm Evans speaker for 2019, and she presented on the ongoing water and sustainability work that The Nature Conservancy is conducting within Kenya. Moreover, Ms. Anyonge-Bashir is a key partner in the Water Research Team's continuing NASA work, and is a key focal point for facilitating the in-country workshops that will situate the research with local, stakeholder-driven priorities and concerns.

Figure 4. Munira Anyonge-Bashir, invited Keynote speaker at the Water in Africa Symposium and recipient of the Dr. Norm Evans Distinguished Speaker award, shares her experiences as the Kenya Country Director for The Nature Conservancy. Photo by Patrick Keys.

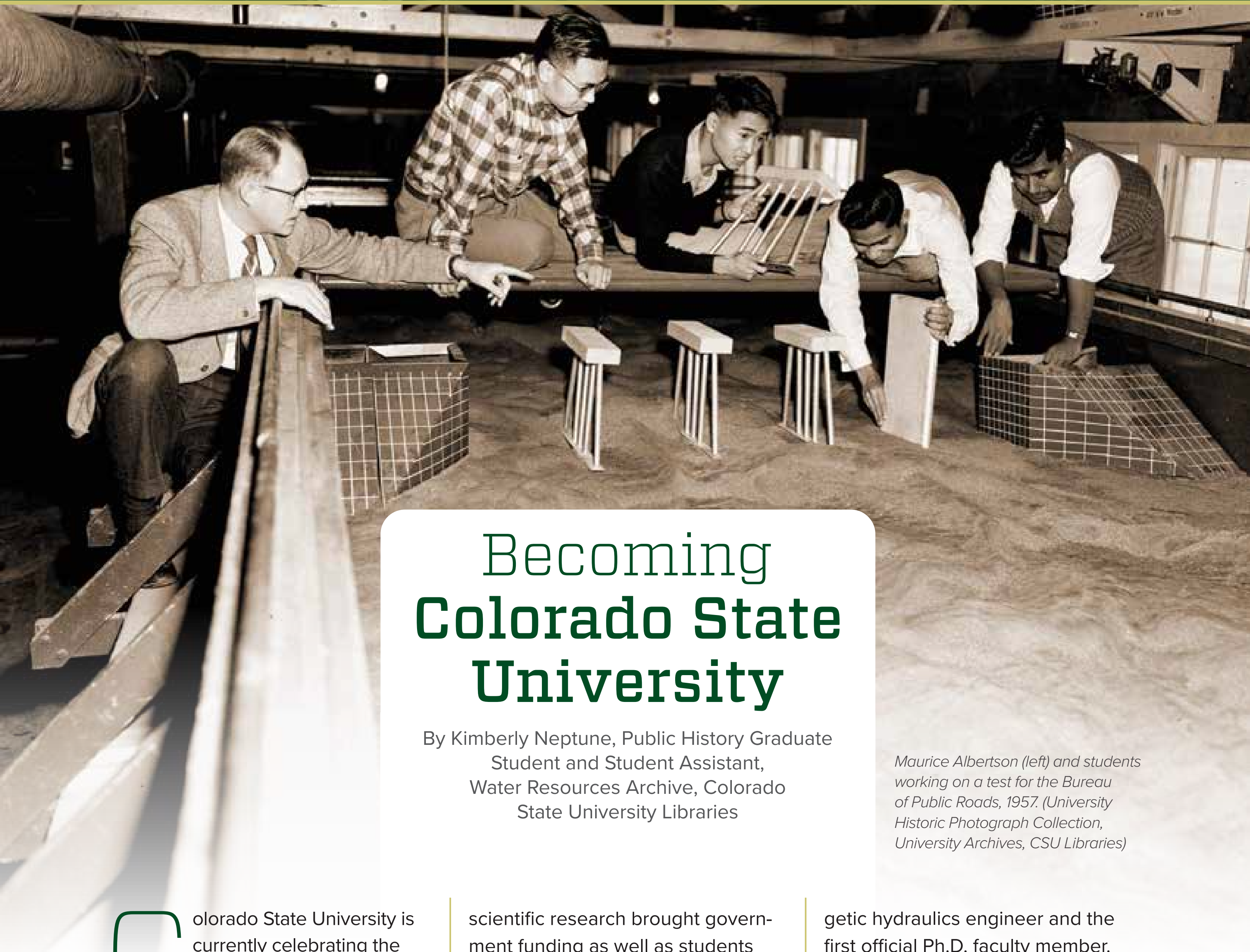
An exciting future ahead for this Water Research Team

The next steps for this work are numerous, and many are already underway. Presently, we are summarizing and disseminating the content from the WRT, especially the insights from the Water in Africa symposium. The WRT is continuing the coupled modeling work under the auspices of the NASA grant, and the work has led to the establishment of relationships between CSU and international partners, which will advance the core focus of this WRT related to SDG achievement.

Finally, we want to say thank you to the Colorado Water Center for supporting this effort. The WRT grant has launched a new, CSU-based research team, helped bring considerable funds to CSU, and has strengthened the reputation and visibility of integrated water and sustainability research at CSU and in Colorado more broadly. Without the support of the Colorado Water Center, it is almost certain that none of this work would have happened. On behalf of the Co-Investigators we express our gratitude for launching this research and outreach effort, and we look forward to the multiple years of activity that it has set in motion.

The WRT discovered that the process of drought classification via satellite data has the potential to miss very important information related to both the adaptability of pastoral herding communities on the ground, as well as the role of social processes in determining the lived-experience of drought. Photo ©2019 iStock.com.

What's In a Name?



Maurice Albertson (left) and students working on a test for the Bureau of Public Roads, 1957. (University Historic Photograph Collection, University Archives, CSU Libraries)

Becoming **Colorado State University**

By Kimberly Neptune, Public History Graduate Student and Student Assistant, Water Resources Archive, Colorado State University Libraries

Colorado State University is currently celebrating the sesquicentennial of its 1870 founding. As a university, however, it has really only existed since 1957. The transformation from college to university was driven in large part by water resources faculty.

In 1946 at Colorado A&M College, as it was then named, the end of World War II brought numerous returning soldiers ready to continue their education. Additionally, increased demand for university-led scientific research brought government funding as well as students with new interests. Nephi Christensen, the dean of the Department of Civil Engineering, wanted to continue the accomplishments of Ralph Parshall and Charles Lory in irrigation engineering and water resources after their departure from campus, and meet the needs of scientific research.

The creation of a doctoral program was Christensen's solution. He hired Maurice Albertson, an energetic hydraulics engineer and the first official Ph.D. faculty member. Albertson in turn hired specialized faculty, created new courses and departments, and increased grants and contracts for research, helping lay the foundation for the Ph.D. program. The Civil Engineering Department fueled the movement for greater doctoral success and more advanced scientific research to transform the school.

This drive for doctoral education led A&M towards being a reputable

President Chamberlain speaking at the 1970 Founder's Day Celebration. (University Historic Photograph Collection, University Archives, CSU Libraries)

institution for research and scientific studies. This was highlighted by the foundation of the doctoral program that Albertson and others had organized and gotten authorized in 1951. Doctoral programs in other departments followed three year later, although very few such degrees were pursued outside of the sciences. A. R. Chamberlain, future president of the university, received the first Ph.D. awarded at the college. He received it in Irrigation Engineering from the Department of Civil Engineering in 1955.

The energy and output of the Civil Engineering Department as well as the growing student population and economic boom of the 1950s led President William Morgan to propose a drastic change. President Morgan "believed that an individual earning this [Ph.D.] degree deserved to hold it from an institution bearing the name 'university'."[1]

On July 26, 1956, President Morgan presented an institutional name and

Colorado A&M vehicle used on one of Maurice Albertson's field trips, 1952. (Albertson Papers, Water Resources Archive, CSU)

status change to the Colorado State Board of Agriculture. It took less than a year to be approved and finalized. On May 1, 1957, Colorado Agricultural and Mechanical College officially became Colorado State University.

This was not a superficial change. Although the institution had seen four prior name changes, this was the most important for the future of the school. It affected administration, the change from departments to colleges, an increase in degrees offered, and construction to build new classrooms, dormitories, and facilities.

These changes were evaluated in 1959 by the North Central Association of Colleges and Schools (NCA), which failed the university for not meeting their required criteria. The NCA stated that "there is a special strength in Engineering, Forestry, Veterinary Medicine, and Agriculture. There is need for a more dominant role and greater strength in liberal education and the humanities…"[2]

These discrepancies continued for several years as the university tried to balance the old and the new. Eventually, a diverse campus developed that slowly shifted away from agricultural and mechanical roots to accommodate more humanities and liberal arts, although some still felt second best to the dominating fields.

As the school continued to diversify academically, the Civil Engineering Department continued to impact campus. It developed new degrees and increased the amount of Ph.D. faculty as well as Ph.D. candidates.

Shifts within the department affected the type of research done and allowed people such as Albertson to branch away from the department to serve the university at large.

Albertson continued to secure funds and contracts both out of state and internationally and to teach. As a result of his efforts, the CSU Research Foundation (previously known as the Colorado Agriculture Research Foundation) elected him as the first director in 1957.

In 1960, Albertson's connections led to the creation of an important international organization. Because of his experience and tenacity for acquiring grants and funding, Albertson had the skills needed to begin the process. Along with Pauline Birky and a committee formed at the university, Albertson secured a contract to conduct the first feasibility reports to establish the Peace Corps.[3] In 1963, Albertson created the Office of International Programs to further aid the university's international relationships and research.

Chamberlain continued his career at the University after he received his Ph.D. and began teaching in 1956. A year later, he was appointed as chief of civil engineering research as well as a professor. He continued to branch out into different roles of administration, climbing his way through the ranks. With skills like intense organization and budgeting, he became executive vice president before becoming president of the university in 1969. Chamberlain's background in engineering allowed him to think critically and seek solutions for the greater good of the school as it faced academic and social challenges.

An addition to the Watershed Science Department in this new era was James Meiman. In 1962, he received his Ph.D. from CSU in watershed science and began teaching the same subject to further

James Meiman and Bob Johnston at CSU Mountain Campus, 1967. (Meiman Papers, Water Resources Archive, CSU Libraries)

the department's growth. He championed the snow hydrology program and continued to increase water resources research at the University. Outside the University, he worked with several federal agencies including the U.S. Forest Service. Similar to Albertson, Meiman branched out of his department to assist the University. Their dedicated work continued to benefit the campus, even as it struggled economically, socially, and academically.

1970 was simultaneously a celebratory and tumultuous year for Colorado State University. The centennial "Founder's Day" celebration led by President Chamberlain helped build community and honor the institution's first 100 years. Also in 1970, however, the Old Main building burned to the ground in a suspected arson act of protest. Chamberlain's presidency also saw war, gender equality, and civil rights protests along with economic turbulence. Because of his training in engineering and administrative work, he was prepared to handle these difficult situations. By the time he stepped down as president in 1978, he stabilized the budget, received recognition for overall university academic and research achievements, and spurred administrative success.

Albertson continued his international work through the 1970s, working on dams and irrigation systems in places such as China and Pakistan. He also continued to work with the Office of International Programs as well as many other facilities and departments with the same enthusiasm he always had. Meiman became the dean of graduate students and director of international programs in 1975. He inspired increased levels of graduate work and scientific research. By 1981, he continued his position of director of international programs and became the associate vice president for research.

The progress of the 1970s, especially as seen in Civil Engineering and Watershed Sciences, continued the advancement of the university. In 1976, with President Chamberlain at the helm, Colorado State University achieved the Carnegie Classification status of a Research 1: Doctoral University. This is given to universities that participate in the highest levels of research. This reflected the overall progress and success of the university since the name change was first presented, almost twenty years prior.

Colorado State University continues to flourish because of the faculty, staff, and students who carry on the research and academic traditions. CSU has long prided itself on the unique discoveries and contributions it makes as a research institution. Dedicated and enthusiastic faculty members of the Civil Engineering and Watershed Sciences departments made many of these accomplishments possible during a time of transition. Their passion for education, research, and international relationships helped transform Colorado State University into the institution it is today.

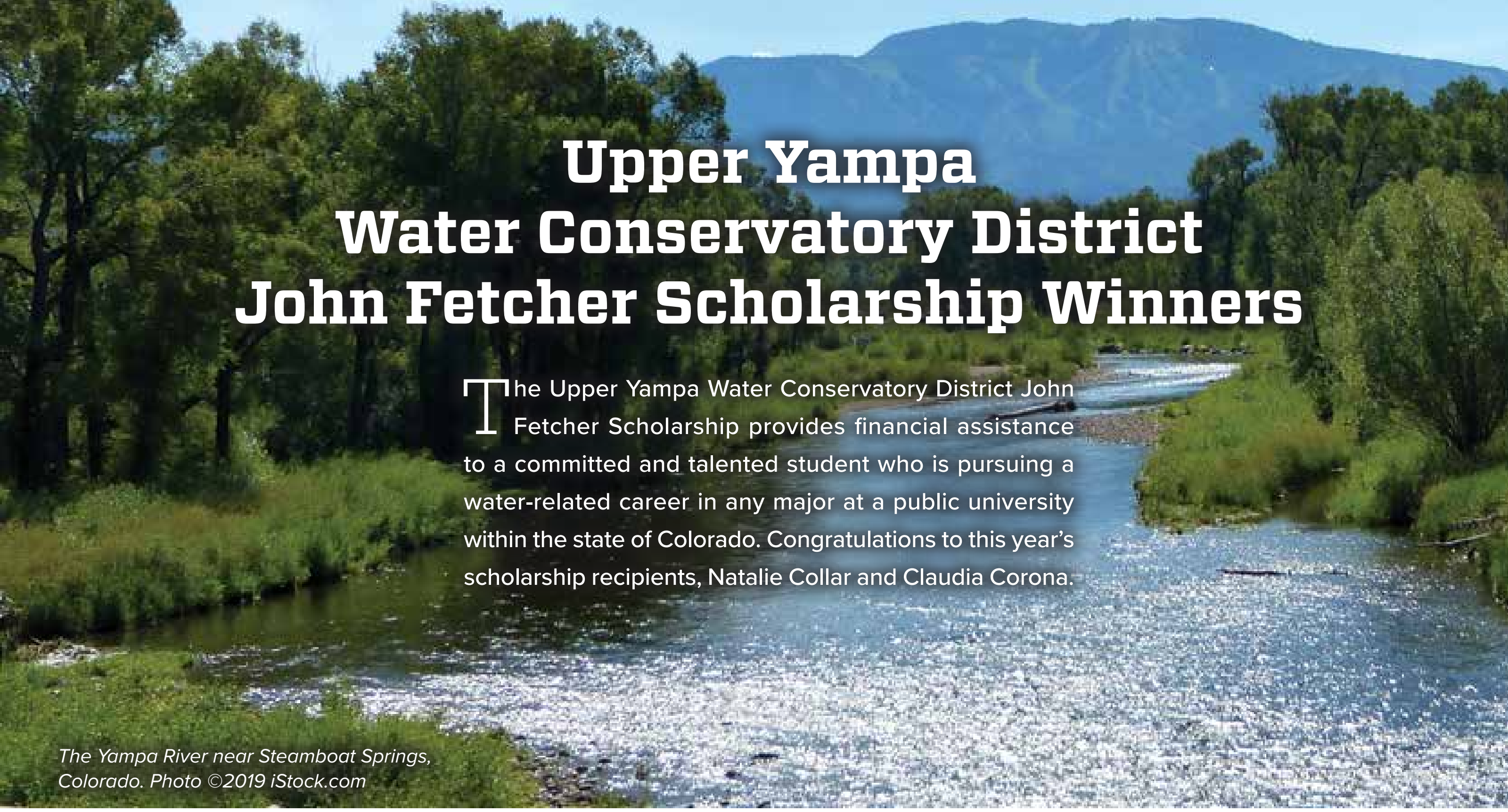
---

1 James E. Hansen, *Democracy's College in the Centennial State: a History of Colorado State University* (Fort Collins: Colorado State University, 1977), p.388.

2 Hansen, p.405.

3 Maurice L. Albertson, *Fifty Years at Colorado State University* (Fort Collins: Colorado State University, 1998), p.26.

Upper Yampa Water Conservatory District John Fetcher Scholarship Winners



The Upper Yampa Water Conservatory 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 scholarship recipients, Natalie Collar and Claudia Corona.

The Yampa River near Steamboat Springs, Colorado. Photo ©2019 iStock.com

Natalie Collar

Name: Natalie Collar

University: Colorado School of Mines

Anticipated Graduation: May 2022

Major: Hydrologic Science and Engineering

Minor Area of Interest: Post-fire modifications to surface and subsurface hydrology

Collar has a bachelor's and master's degree from the University of California Santa Barbara in biological science, focusing on ecology, evolution and marine biology and water resources science. She is commencing her doctoral work at Colorado School of Mines in the Hydrological Science and Engineering department with her dissertation focusing on post-fire hydrology with an emphasis on impacts to runoff volume. Her last 14 years have been spent studying and working in the realms of water supply and water quality and she is embarking on a PhD that will assess the ways in which fire changes the partitioning of water in the landscape. Along with going back to school to get her doctorate, Collar has worked for three and a half years at Denver's Wright Water Engineers, Inc. as a certified floodplain manager becoming a leader in her company for her peer group. Ideally, her goal is to be instigating change as a program director at a federal agency when her career culminates.

Claudia Corona

Name: Claudia Corona

University: University of Colorado Boulder

Anticipated Graduation: May 2022

Major: Geological Sciences

Minor Area of Interest: Extreme precipitation and groundwater response in Colorado

Since beginning at CU Boulder in 2018, Corona joined the steering committee for the Annual Hydrologic Sciences Symposium and has been an integral member of the committee, contributing to many decisions and projects she was involved in, including writing two successful grant applications to the American Geophysical Union. She is also involved with UNAVCO's Research Experiences in Solid Earth Science for Students as a mentor for a disadvantaged undergraduate student studying within the same field. She will work with her assigned student for 10 weeks over the summer to help them achieve the goal of completing an original project they get to present to UNAVCO and their peers. Corona also remains strongly involved with the Mono Lake Committee as an advocate and guest teacher for the Outdoor Experiences Program. The goal for her career is to spearhead projects concerning what happens to infiltration before it becomes recharge and ultimately have the ability to give back to the community through volunteering, teaching, and mentoring the next generation of inquiring minds.

CSU Water Research Projects

July 1-November 15, 2019

Name of Principal Investigator	Title	Lead Unit	Sponsor	Amount
Suter, Jordan	2019COSHENG: 104B State Water Resources Research Institute Program Fiscal Year 2019	Agricultural + Resource Economics	DOI-USGS-Geological Survey	$4,951
Goemans, Christopher G.	Evaluating Alternative Water Institution Performance in Snow-Dominated Basins: Are Food Productions Systems at Risk from Changing Snow Water Availability?	Agricultural + Resource Economics	University of Nevada	$114,184
Schumacher, Russ Stanley	Colorado Weather Station Operation and Maintenance	Atmospheric Science	DOI-Bureau of Reclamation	$78,750
Poff, N. LeRoy	CESU-RM: A Tool to Support Resource Management Decisions Related to Control of Invasive Tamarix in the Western U.S.	Biology	DOI-USGS-Geological Survey	$48,999
Poff, N. LeRoy	CESU-RM: Effects of Streamflow and Irrigation on Riparian Vegetation Restoration Efforts in the Colorado River Basin	Biology	DOI-USGS-Geological Survey	$49,300
Poff, N. LeRoy	CESU-RM: Elwha River Dam Removal Vegetation Studies	Biology	DOI-USGS-Geological Survey	$48,000
Herron, Christopher Michael	Preble's Meadow Jumping Mouse Habitat Management, USAFA	CEMML	DOD-ARMY-Corps of Engineers Savannah	$425,984
Venkatachalam, Chandrasekaran	Hydrometeorological and Water Resources Research	CIRA	DOC-NOAA-Natl Oceanic and Atmospheric Admn	$446,415
Bailey, Ryan T.	Investigating the Impact of Recharge Ponds, Pumping, and Drought on Groundwater Levels and Return Flows in the LaSalle/Gilcrest Area during 2013-2018	Civil + Environmental Engineering	Colorado Water Conservation Board	$50,000
Morrison, Ryan Richard	Relationship Between Irrigation Return Flows, Riparian Vegetation Water Use, and Soluble Pollutant Removal in the Lower Arkansas River Basin	Civil + Environmental Engineering	Colorado Water Conservation Board	$50,000
Niemann, Jeffrey D.	Quantifying Impacts of Hydrologic Parameter Uncertainty on Dam Safety Analysis	Civil + Environmental Engineering	Colorado Water Conservation Board	$50,000
Ettema, Robert	Proposal for a Hydraulic-Model Study of the Stepped Spillway for Gross Dam, Colorado	Civil + Environmental Engineering	AECOM	$80,635
Julien, Pierre Y.	Linking Morpho-Dynamic and Biological-Habitat Conditions on the Middle Rio Grande	Civil + Environmental Engineering	DOI-Bureau of Reclamation	$382,565
van de Lindt, John W.	Experimental and Numerical Study to Improve Damage and Loss Estimation due to Overland Wave and Surge Hazards on Near-Coast Structures	Civil + Environmental Engineering	University of North Carolina at Chapel Hill	$75,000
Sale, Thomas C.	Field Trials for Sensor-Based Groundwater Monitoring	Civil + Environmental Engineering	Chevron Corporation	$100,000
Arabi, Mazdak	Modeling Ecosystem Services in Agricultural Watersheds	Civil + Environmental Engineering	USDA-ARS-Agricultural Research Service	$30,790
Bailey, Ryan T	Integration of SWAT+/MODFLOW and Inclusion in the Geospatial Modeling Interface	Civil + Environmental Engineering	USDA-ARS-Agricultural Research Service	$30,000
Arabi, Mazdak	Hydrological Modeling to Assess Vulnerability of Water Supply in the Contiguous US	Civil + Environmental Engineering	USDA-USFS-Rocky Mtn. Rsrch Station - CO	$40,000
Thornton, Christopher I	Zink Dam Physical Model Study	Civil + Environmental Engineering	Merrick and Company	$51,835
Morrison, Ryan Richard	Measuring Hydraulic and Thermal Conditions of High Elevation Headwater Streams in Regions of North-Central Colorado	Civil + Environmental Engineering	DOI-USGS-Geological Survey	$39,000
Morrison, Ryan Richard	Assessing Status of Water Quality and Environmental Health of our Nation's Rivers	Civil + Environmental Engineering	DOI-USGS-Geological Survey	$49,999
Handwerk, Jill E.	Assessment of Urban Wetlands in the City of Aurora,CO	Colorado Natural Heritage Program	EPA-Environmental Protection Agency	$66,416
Culver, Denise R.	Revised Survey and Assessment of Critical Wetlands in the Roaring Fork Watershed, Colorado	Colorado Natural Heritage Program	EPA-Environmental Protection Agency	$110,625
Schorr, Robert	Preble's Meadow Jumping Mouse Monitoring Plan Development	Colorado Natural Heritage Program	DOI-USFWS-Fish and Wildlife Service	$30,344
Waskom, Reagan M.	2019COTECHTRANSFER: 104B State Water Resources Research Institute Program Fiscal Year 2019	Colorado Water Center	DOI-USGS-Geological Survey	$48,190
Winkelman, Dana	Laboratory Study of Temperature and Winter Duration Requirements for Reproductive Success in Johnny Darter, Etheostoma Nigrum (Percidae), in the South Platte River Basin, Colorado	Cooperative Fish + Wildlife Research	Colorado Division of Parks and Wildlife	$43,631
Winkelman, Dana	TO# 2001 Control of Sucker Spawning Migrations in a Major Tributary of the Gunnison River to Increase the Production of Native Sucker Larvae	Cooperative Fish + Wildlife Research	Colorado Division of Parks and Wildlife	$49,513

Name of Principal Investigator	Title	Lead Unit	Sponsor	Amount
Fassnacht, Steven	2019COKINGSTON: 104B State Water Resources Research Institute Program Fiscal year 2019	Ecosystem Science + Sustainability	DOI-USGS-Geological Survey	$4,241
Covino, Timothy P.	2019COPALM: 104B State Water Resources Research Institute Program Fiscal Year 2019	Ecosystem Science + Sustainability	DOI-USGS-Geological Survey	$4,992
Fassnacht, Steven	2019COSANOW: 104B State Water Resources Research Institute Program Fiscal Year 2019	Ecosystem Science + Sustainability	DOI-USGS-Geological Survey	$2,600
Fassnacht, Steven	2019COSANOW: 104B State Water Resources Research Institute Program Fiscal Year 2019	Ecosystem Science + Sustainability	DOI-USGS-Geological Survey	$2,400
Covino, Timothy P.	Collaborative Research: How Do Interactions of Transport and Stoichiometry Maximize Stream Nutrient Retention?	Ecosystem Science + Sustainability	NSF-National Science Foundation	$123,758
Kampf, Stephanie K.	Stream Trackers: Monitoring Intermittent Streams in National Forests	Ecosystem Science + Sustainability	USDA-USFS-Forest Research	$25,000
Laituri, Melinda J.	Make Federal Water Data Available to States and the Public	Ecosystem Science + Sustainability	DOI-NPS-National Park Service	$184,300
Ross, Matthew Richard Voss	Tools for Improving Knowledge of Reservoir Water Quality in the Front Range of Colorado	Ecosystem Science + Sustainability	Colorado Water Institute	$49,991
Kampf, Stephanie K.	Streamflow Estimation in Colorado Ungauged Basins	Ecosystem Science + Sustainability	Colorado Water Conservation Board	$50,000
Covino, Timothy P.	Post Wildfire Watershed Nitrogen Retention Processes	Ecosystem Science + Sustainability	USDA-USFS-Rocky Mtn. Rsrch Station - CO	$80,000
Kampf, Stephanie K.	CESU-RM: Watershed Assessment Framework for National Park Service Wild And Scenic Rivers	Ecosystem Science + Sustainability	DOI-NPS-National Park Service	$12,234
Schaeffer, Joshua William	After the Flood: Investigating the Health Consequences of Mold Growth in Homes Damaged during Hurricane Harvey	Environ + Radiological Health Sciences	HHS-NIH-Natl Inst of Environ Health Serv	$190,961
Myrick, Christopher A.	Native Fish Passage in Front Range Transition Zone Streams	Fish, Wildlife + Conservation Biology	Colorado Division of Parks and Wildlife	$54,188
Hawkins, John A.	BOR New 5 Year Agreement: KR143007- Proj. #125NNF Management Yampa River	Fish, Wildlife + Conservation Biology	DOI-Bureau of Reclamation	$470,897
Bestgen, Kevin R.	BOR New 5 Year Agreement: KR143008 - Proj.# 128 Green River PikeMinnow Est.	Fish, Wildlife + Conservation Biology	DOI-Bureau of Reclamation	$59,157
Myrick, Christopher A.	Developing "Freshwater Cod" or Burbot (Lota lota) into a Viable Commercial Aquaculture Species in the United States	Fish, Wildlife + Conservation Biology	University of Washington	$48,682
Clements, William H.	Post-Restoration Assessment of the Upper Arkansas River: A Watershed-Level Analysis of Responses to Improvements in Habitat and Water Quality	Fish, Wildlife + Conservation Biology	Colorado Division of Parks and Wildlife	$85,896
Bestgen, Kevin R.	Validating Modeled Streamflow Transport Dynamics and Floodplain Habitat Connectivity for Larval Endangered Fish of the Middle Green River, Utah	Fish, Wildlife + Conservation Biology	DOI-USGS-Geological Survey	$48,534
Sueltenfuss, Jeremy	CESU-RM: Grand Ditch Restoration Adaptive Management Monitoring	Forest + Rangeland Stewardship	DOI-NPS-National Park Service	$115,371
Nagel,Linda M.	Enhancing Drought Resilience via Assessment, Collaboration and Coordination_CLP	Forest + Rangeland Stewardship	USDA-ARS-Agricultural Research Service	$20,000
Schook,Derek Michael	CESU-RM: Evaluation of NPS Surface Water Resources, with Focus on Improving Management of the Degraded Rio Grande Riparian Corridor in Big Bend National Park	Forest + Rangeland Stewardship	DOI-NPS-National Park Service	$123,006
Ronayne, Michael J.	Studies Supporting Sustainable Use of the Denver Basin Aquifers in the Vicinity of Castle Rock	Geosciences	Town of Castle Rock, Colorado	$12,500
Sanford, William E.	Evaluate NPS Geohydrology and Sustainable Groundwater Management, Including a Focus on the Cottonwood / Smoke Tree Sub-Basin in Joshua Tree National Park	Geosciences	DOI-NPS-National Park Service	$67,713
Rathburn, Sara L.	CESU-RM: Channel Change and Floodplain Forest Establishment in the Colorado River Basin	Geosciences	DOI-USGS-Geological Survey	$67,000
Covino, Timothy P.	Using Landsat Imagery to Monitor the Effects of Landscape Recovery on Nutrient Export in Fire-affected Watersheds	Natural Resource Ecology Laboratory	NASA-National Aeronautics and Space Administration	$45,000
Andales, Allan A.	Understanding Water Use and Plant Responses of Crops Due to Deficit Irrigation	Soil + Crop Sciences	USDA-ARS-Agricultural Research Service	$73,154
Andales, Allan A.	Determination of Consumptive Water Use of Winter Wheat in the Arkansas Valley (Year 2)	Soil + Crop Sciences	Colorado Water Conservation Board	$50,178
Wardle, Erik M.	Farmer Driven Evaluation of agricultural non-point source pollution control - Best Management Practices (BMPs) in an Impaired Watershed	Soil + Crop Sciences	Big Thompson Water Conservation District	$122,904

USGS Fiscal Year 2019 Publications

Data Releases

O'Shea, P.M., 2018, Topographic Survey and Streambed-Sediment Data of Fountain Creek between Colorado Springs and the Confluence of Fountain Creek at the Arkansas River, Colorado, 2018: U.S. Geological Survey data release, https://doi.org/10.5066/P9FP632Q

Henneberg, M.F., and Richards, R.J., 2019, Cross-Section Geometry and Sediment-Size Distribution Data from Muddy Creek and North Fork Gunnison River below Paonia Reservoir, western Colorado, 2018: U.S. Geological Survey data release, https://doi.org/10.5066/P9SA0MTI

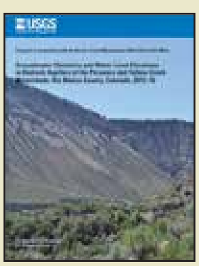
Kohn, M.S., 2019, MODFLOW2000 model and ZONEBUDGET computer program used to simulate the Upper Big Sandy Designated Groundwater Basin alluvial aquifer, Elbert, El Paso, and Lincoln Counties, Colorado, 2016: U.S. Geological Survey data release, https://doi.org/10.5066/P9DEOYGZ

Verdin, K.L., and Bock, A.R., 2019, Drainage basins and characteristics for selected streamgages within the Southern Rockies Landscape Conservation Cooperative domain: U.S. Geological Survey data release, https://doi.org/10.5066/P9LR2L6J.

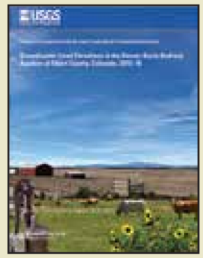
Journal Articles

Sanow, J.E., Fassnacht, S.R., Kamin, D.J., Sexstone, G.A., Bauerle, W.L., and Oprea, I., 2018, Geometric Versus Anemometric Surface Roughness for a Shallow Accumulating Snowpack: Geosciences, v 8(12), 463, p. 1 - 10. https://doi.org/10.3390/geosciences8120463

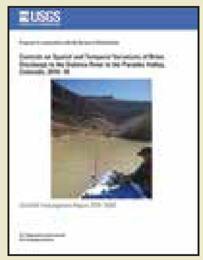
USGS Scientific Investigations Reports



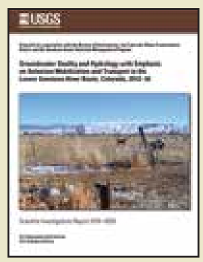
Thomas, J.C., and McMahon, P.B., 2018, Groundwater chemistry and water-level elevations in bedrock aquifers of the Piceance and Yellow Creek watersheds, Rio Blanco County, Colorado, 2013–16: U.S. Geological Survey Scientific Investigations Report 2018–5142, 26 p., https://doi.org/10.3133/sir20185142.



Penn, C.A., and Everett, R.R., 2019, Groundwater-level elevations in the Denver Basin bedrock aquifers of Elbert County, Colorado, 2015–18: U.S. Geological Survey Scientific Investigations Report 2019–5014, 50 p., https://doi.org/10.3133/sir20195014



Mast, M.A., and Terry, N., 2019, Controls on spatial and temporal variations of brine discharge to the Dolores River in the Paradox Valley, Colorado, 2016–18: U.S. Geological Survey Scientific Investigations Report 2019–5058, 25 p., https://doi.org/10.3133/sir20195058



Thomas, J.C., McMahon, P.B., and Arnold, L.R., 2019, Groundwater quality and hydrology with emphasis on selenium mobilization and transport in the lower Gunnison River Basin, Colorado, 2012–16: U.S. Geological Survey Scientific Investigations Report 2019–5029, 69 p., https://doi.org/10.3133/sir20195029

Kohn, M.S., Oden, J.H., and Arnold, L.R., 2019, Water-budget analysis of the Upper Big Sandy Designated Groundwater Basin alluvial aquifer, Elbert, El Paso, and Lincoln Counties, Colorado, 2016: U.S. Geological Survey Scientific Investigations Report 2019-5049, 25 p., https://dx.doi.org/10.3133/sir20195049

Cooperator Report

Morris, K., A. Mast, G. Wetherbee, J. Baron, J. Cheatham, J. Bromberg, L. Devore, J. Hou, K. Gebhart, M. Bell, D. Gay, M. Olson, T. Weinmann, and D. Bowker. 2019. 2017 Monitoring and tracking wet nitrogen deposition at Rocky Mountain National Park: February 2019. Natural Resource Report NPS/NRSS/ARD/NRR—2019/1905. National Park Service, Fort Collins, Colorado.

Water Calendar

January 2020

14 **Webinar Series: Water Well with CWEL**
Center for Water-Efficient Landscaping
2:00-3:00 PM

24 **UCOWR/NIWR 2020: Abstracts Due**

29-31 **CO Water Congress Annual Convention**
The Westin Westminster
10600 Westminster Blvd, Westminster, CO 80020

February 2020

4-6 **2020 Riparian Restoration Conference**
Grand Junction, CO

11 **Webinar Series: Water Well with CWEL**
Center for Water-Efficient Landscaping
2:00-3:00 PM

26 **Governor's Forum on Colorado Agriculture**
Renaissance Hotel
3801 Quebec St, Denver, CO 80207

28 **Poudre River Forum**
Embassy Suites Conference Center
4705 Clydesdale Pkwy, Loveland, CO 80538

March 2020

10-12 **Western Collaborative Conservation Network: Confluence 2020**
Colorado State University, Fort Collins, CO, 80523

10 **Webinar Series: Water Well with CWEL**
Center for Water-Efficient Landscaping
2:00-3:00 PM

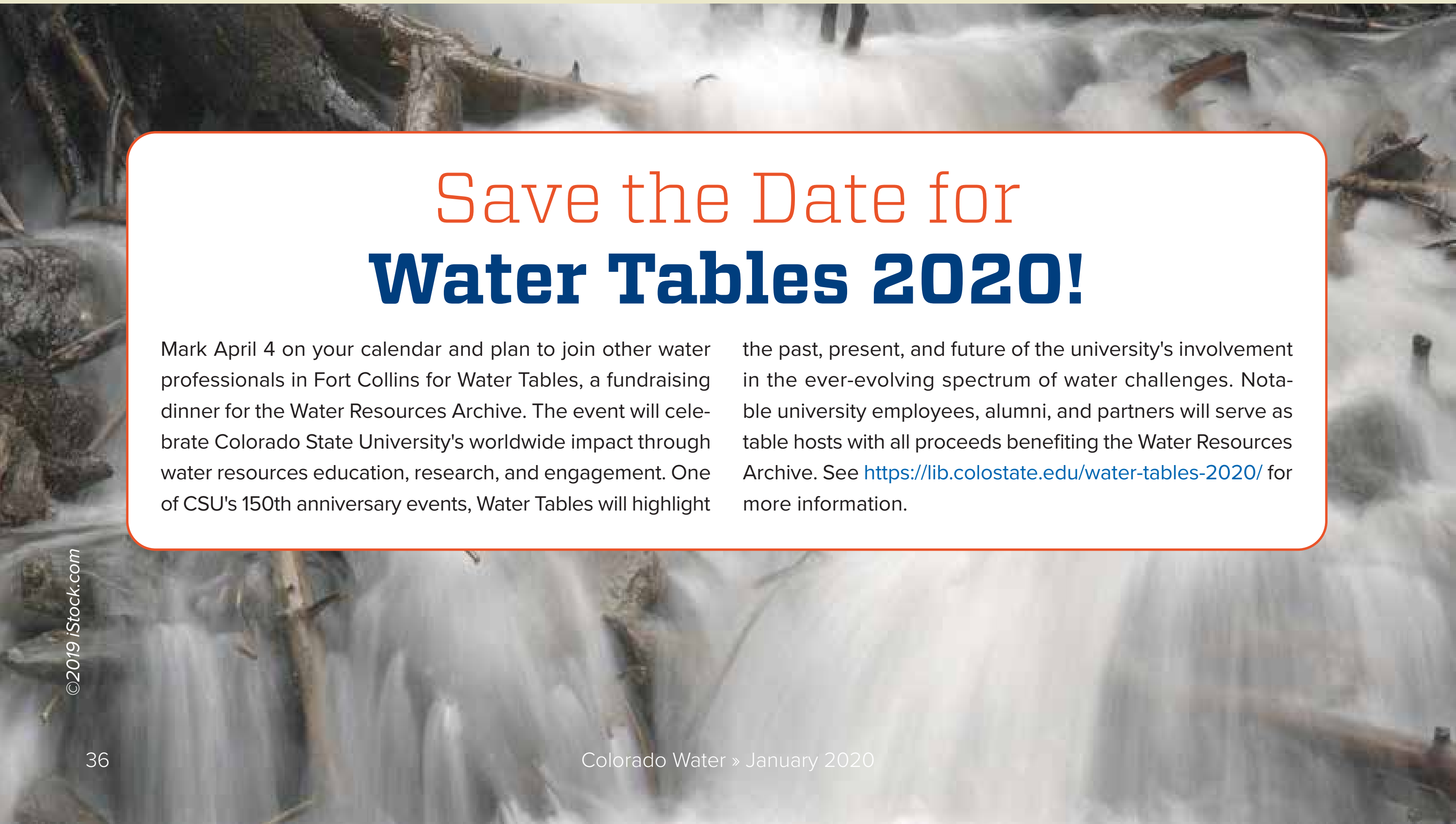
21 **National Ag Day**

22 **World Water Day**

Emmett Jordan

Save the Date for **Water Tables 2020!**

Mark April 4 on your calendar and plan to join other water professionals in Fort Collins for Water Tables, a fundraising dinner for the Water Resources Archive. The event will celebrate Colorado State University's worldwide impact through water resources education, research, and engagement. One of CSU's 150th anniversary events, Water Tables will highlight the past, present, and future of the university's involvement in the ever-evolving spectrum of water challenges. Notable university employees, alumni, and partners will serve as table hosts with all proceeds benefiting the Water Resources Archive. See https://lib.colostate.edu/water-tables-2020/ for more information.



©2019 iStock.com

7th Annual
POUDRE
River Forum

QUALITY COLLABORATIONS

Coming together to ensure clean water for a healthy, working river

OPEN TO ALL WHO DEPEND ON WATER FROM THE POUDRE RIVER TO FARM, HYDRATE, BREW, AND RECREATE

FRIDAY
FEB 28, 2020
Embassy Suites Conference Center
Loveland, CO

- Discount and student scholarships available
- Presentation of the 2020 Poudre Pioneer Award

REGISTER TODAY! #PoudreRiverForum

WaterCenter.ColoState.edu/Poudre-River-Forum

Presented by The Poudre Runs Through It Study/Action Work Group

Colorado State University

Colorado Water Center
1033 Campus Delivery
Fort Collins, Colorado 80523-1033

NONPROFIT
ORGANIZATION
U.S. POSTAGE
PAID
Fort Collins, Colorado 80523
Permit Number 19

COLORADO WATER CENTER
COLORADO STATE UNIVERSITY

Colorado Water Online

Visit watercenter.colostate.edu/water-news to access a PDF version of our current newsletter. To download past issues of our newsletter, click on Newsletter Archives.

Attention Subscribers

Please help us keep our distribution list up to date. If you prefer to receive the newsletter electronically or have a name/address change, please visit watercenter.colostate.edu and click on Subscriptions.

Colorado Water is financed in part by the U.S. Department of the Interior Geological Survey through the Colorado Water Center, College of Agriculture, College of Engineering, Warner College of Natural Resources, Agricultural Experiment Station, and Colorado State University Extension.

The seventh Annual Poudre River Forum will be held on February 28, 2020 at the Embassy Suites Conference Center in Loveland, Colorado. Photograph © 2019 iStock.com

Visit Our Website *Colorado Water Center: watercenter.colostate.edu*

References

Effects of Forest Disturbance on Streamflow in Colorado

Barnhart, T., Molotch, N., Livneh, B., Harpold, A., Knowles, J., & Schneider, D. (2016). Snowmelt rate dictates streamflow. Geophysical Research Letters,43(15), 8006-8016.

Bearup, Linsay A., Reed M. Maxwell, David W. Clow, & John E. Mccray. (2014). Hydrological effects of forest transpiration loss in bark beetle-impacted watersheds. Nature Climate Change, 4(6), 481-486.

Biederman, Brooks, Harpold, Gochis, Gutmann, Reed, . . . Ewers. (2014). Multiscale observations of snow accumulation and peak snowpack following widespread, insect-induced lodgepole pine mortality. Ecohydrology, 7(1), 150-162.

Biederman, J.A., Somor, A.J., Harpold, A.A, Gutman, E.D., Bredhears, D.D., Troch, P.A., ...Brooks, P.D. (2015). Recent tree die-off has little effect on streamflow in contrast to expected increases from historical studies. Water Resources Research, 51(12), 9775-9789.

Buma, Brian and Ben Livneh. (2017). Key Landscape and biotic indicators of watersheds sensitivity to forest disturbance identified using remote sensing and historical hydrography data. Environmental Research Letters, 12(7), 074028/1-074028/10. Colorado State Forest Service, 2017. Report on the Health of Colorado's Forests: Fire and Water. 32 pp. Fort Collins, CO.

Creeden, Hicke, & Buotte. (2014). Climate, weather, and recent mountain pine beetle outbreaks in the western United States. Forest Ecology and Management, 312, 239-251.

Harpold, A., Biederman, J., Condon, K., Merino, M., Korgaonkar, Y., Nan, T., . . . Brooks, P. (2014). Changes in snow accumulation and ablation following the Las Conchas Forest Fire, New Mexico, USA. Ecohydrology, 7(2), 440-452.

Li, D., Wrzesien, M., Durand, M., Adam, J., & Lettenmaier, D. (2017). How much runoff originates as snow in the western United States, and how will that change in the future? Geophysical Research Letters, 44(12), 6163-6172.

Pugh, E., & Small, E. (2012). The impact of pine beetle infestation on snow accumulation and melt in the headwaters of the Colorado River. Ecohydrology, 5(4), 467-477.

Westerling, A. (2016). Increasing western US forest wildfire activity: Sensitivity to changes in the timing of spring. Philosophical Transactions Of The Royal Society B-Biological Sciences, 371(1696).

Woodward, Brian D, Ex, Seth, Evangelista, Paul, Davis, Thomas, & Falkowski, Mike. (2017). Evaluating Mortality Dynamics during a Spruce Beetle Epidemic in the Southern Colorado Rocky Mountains. CSU Thesis.