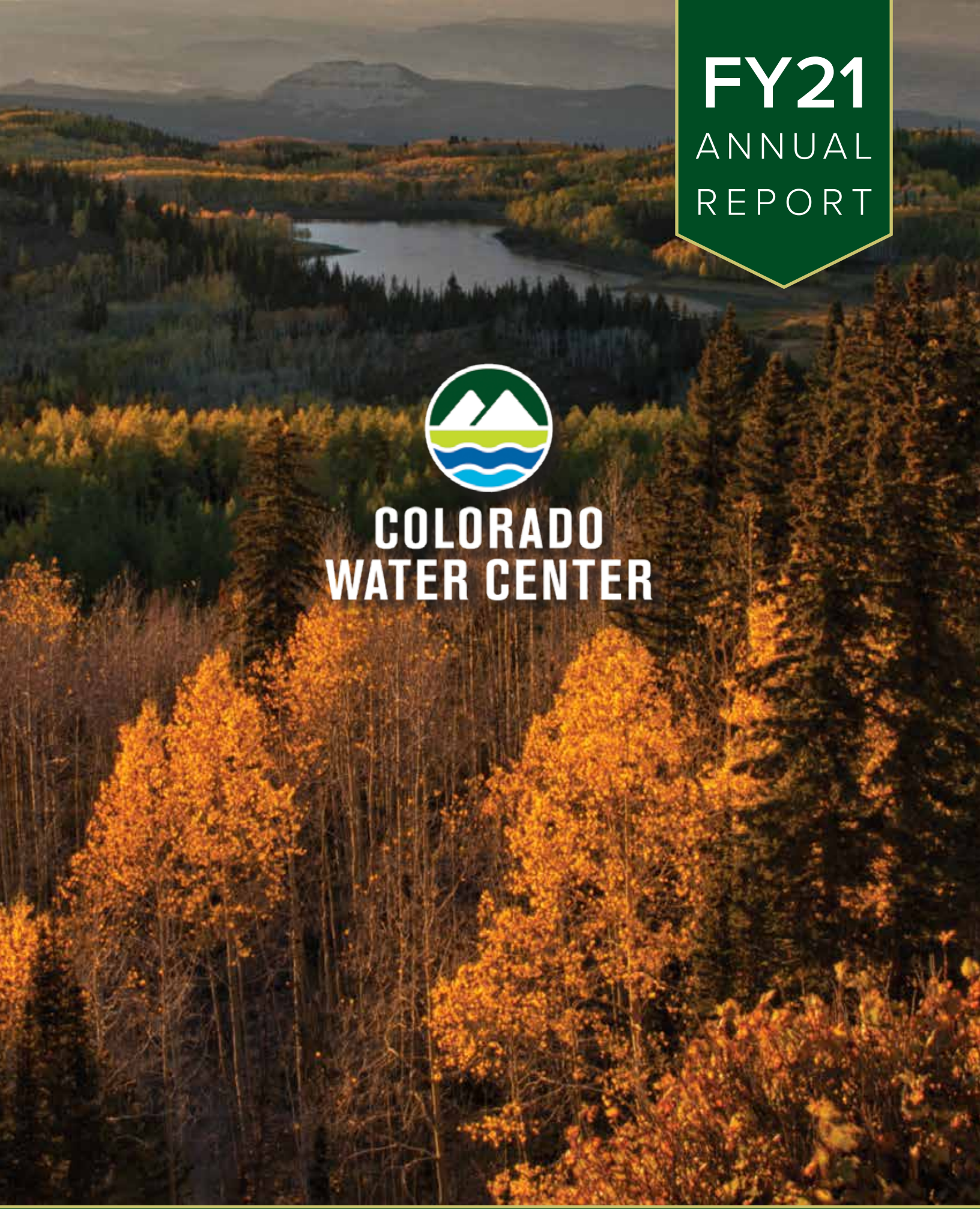


FY21 ANNUAL REPORT

COLORADO WATER CENTER

COLORADO STATE UNIVERSITY

COLORADO WATER CENTER

@COWaterCenter @ColoradoWaterCenter

Who We Are

The Colorado Water Center (CoWC) is one of 54 Water Resources Research Institutes created by the Water Resources Act of 1964, collectively forming the National Institutes for Water Resources. As a division under CSU's Office of Engagement & Extension, CoWC aims to connect water expertise in Colorado's higher education system with the research and education needs of the state's water managers and users.

The CoWC leads interdisciplinary research, education, and outreach to address complex and evolving water-related challenges in Colorado and beyond. We do so by fostering collaboration between higher education and water stakeholders, synthesizing objective water knowledge to inform decision-making, and inspiring the next generation of water leaders.

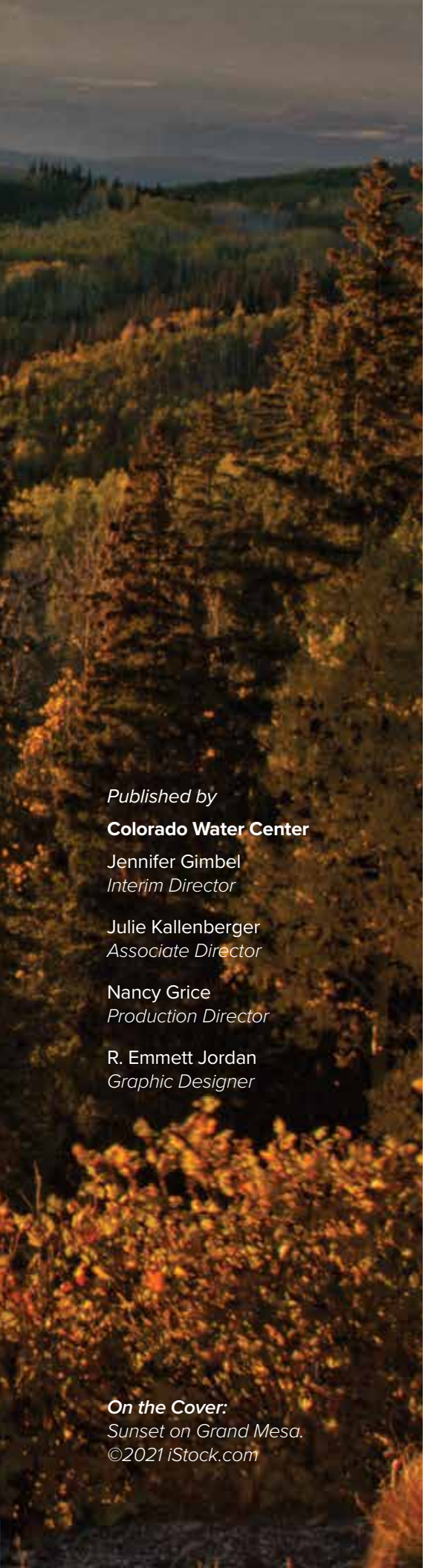
Outreach and Transfer

The CoWC collaborates with CSU Extension to house three regional water specialists throughout the state and operates several websites with up-to-date water information that has become a consistent source of knowledge for water professionals and community members alike.

Publications available on these sites include research reports and *Colorado Water,* a newsletter containing information on current research, faculty, staff, and students, program updates, climate, water history, Colorado State Forest Service (CSFS) updates, CSU Comptetivie Grant Program updates, and water-related events and conferences. The CoWC's outreach activities are conducted with other university centers, CSU Extension, the Colorado Agricultural Experiment Station, the CSFS, and the Colorado Climate Center. Our primary partners include water managers, water providers, and water agencies.

Training

One of the CoWC's primary missions is to facilitate the training and education of university students. To this end, the CoWC works with the U.S. Geological Survey and the Colorado Water Conservation Board to fund student interns, sponsor research grants, and manage student scholarships. Student researchers work with faculty members to gain valuable water expertise and knowledge of the research process.



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On the Cover:
Sunset on Grand Mesa.
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TABLE OF CONTENTS

Message from the Interim Director

Jennifer Gimbel

For the Colorado Water Center (CoWC) at CSU, this year has been one of transitions, challenges, accomplishments, and opportunities. Due to the pandemic, CSU closed in-person classes and offices. State and federal funding of water research was drastically cut or late in coming. Northern Colorado experienced the three worst fires in recorded history with over 400,000 acres burned. Drought and aridification continue in the West and western Colorado has especially suffered. After 34 years with CSU and 15 years as Director of the CoWC, Reagan Waskom retired and left behind his vision and capable staff to continue and advance our mission. I am honored to fill the gap on an interim basis as we search for a new director. Blake Naughton, Vice President for Engagement and Extension provided continuing support to the Water Center and assured its integration into his goals and those of President McConnell. CoWC appreciates the continuing support of the Faculty Executive Committee and the External Advisory Board, who help to guide our activities and research.

Challenges aside, the CoWC continued to serve its statutory mission under the federal Water Resources Research Act working with the other institutions of higher education throughout Colorado and as part of 54 centers and institutions associated with land grant universities in the United States. CoWC staff continued its effort in assisting in the planning and development of programs to be integrated into the new SPUR Campus, specifically supporting the new Hydro Building at the National Western Center in partnership with Denver Water. Part of that effort includes the creation of a western water policy institute to advance dialogue and study of challenging water issues as well as offering an online graduate certificate and Master's of Water and Climate Policy in the near future.

Our outreach and extension projects continue with expert research and assistance from the CSU Regional Extension Specialists, Joel Schneekloth, Blake Osborn and Perry Cabot. Their innovative work advanced our knowledge in water conservation and efficiency, drought and fire programs for the benefit of agricultural and urban stakeholders. Brad Udall's research is recognized nationwide for his efforts to understand the effects of climate change on water supplies in the West, especially in the Colorado River basin. Our thanks to Nolan Doesken for continuing to associate with the CoWC. Focusing on water education, outreach and facilitation, Julie Kallenberger became the new Associate Director of the Center. Nora Flynn advanced her research on agricultural water issues and leads important discussions on salinity issues in the South Platte. Nancy Grice oversaw USGS/NIWR submissions, kept us on target and focused and managed our student staff. Karen Kwon, former First Assistant Attorney General, joined our staff and produced a series of Colorado River papers that will be published in the near future.

The Colorado Water Center staff met incredible challenges with a positive attitude and innovated approaches to their work.

Although water research continued, many proposed projects by students and faculty went unfunded due to state and federal fiscal constraints. Consequently, this annual report is a bit leaner, though it highlights water research conducted on a global, national and local scale. CoWC could not meet its mission without the support of our federal, state, and private partners. We understand the budget constraints of this past year and look forward to working with USGS on the national level and CWCB on the state level as resources allow. Thankfully, CSU provided research dollars. The Colorado Water Center staff met incredible challenges with a positive attitude and innovated approaches to their work.

Jennifer Gimbel

Jennifer Gimbel
Interim Director

FY21 NEW RESEARCH

USGS/NIWR

Impacts of extreme events on forest recovery and streamflow across Colorado's forest-dominated ecosystems
Miranda Redmond et al., Colorado State University

Post-fire watershed conditions and climate in the 416 Fire, southwest Colorado and their influence on forest health and watershed recovery
Julie Korb et al., Fort Lewis College

CSU Faculty Grant Program

Effects of the Cameron Peak Fire on stream-riparian food webs along an elevational gradient
Dan Preston et al., Colorado State University

Fire, fungi, and flora: How plant and soil microbial succession drive hydrologic processes post-fire
Camille Stevens-Rumann et al., Colorado State University

Knowing rivers for life: Toward an ethic for flowing waters
Kurt Fausch et al., Colorado State University

Writing water: engaging underserved youth and adults through critical literacy and water education
Tobi Jacobi et al., Colorado State University

River investigators: Connecting youth and families to the Cache la Poudre River
Nicole Stafford et al., Colorado State University

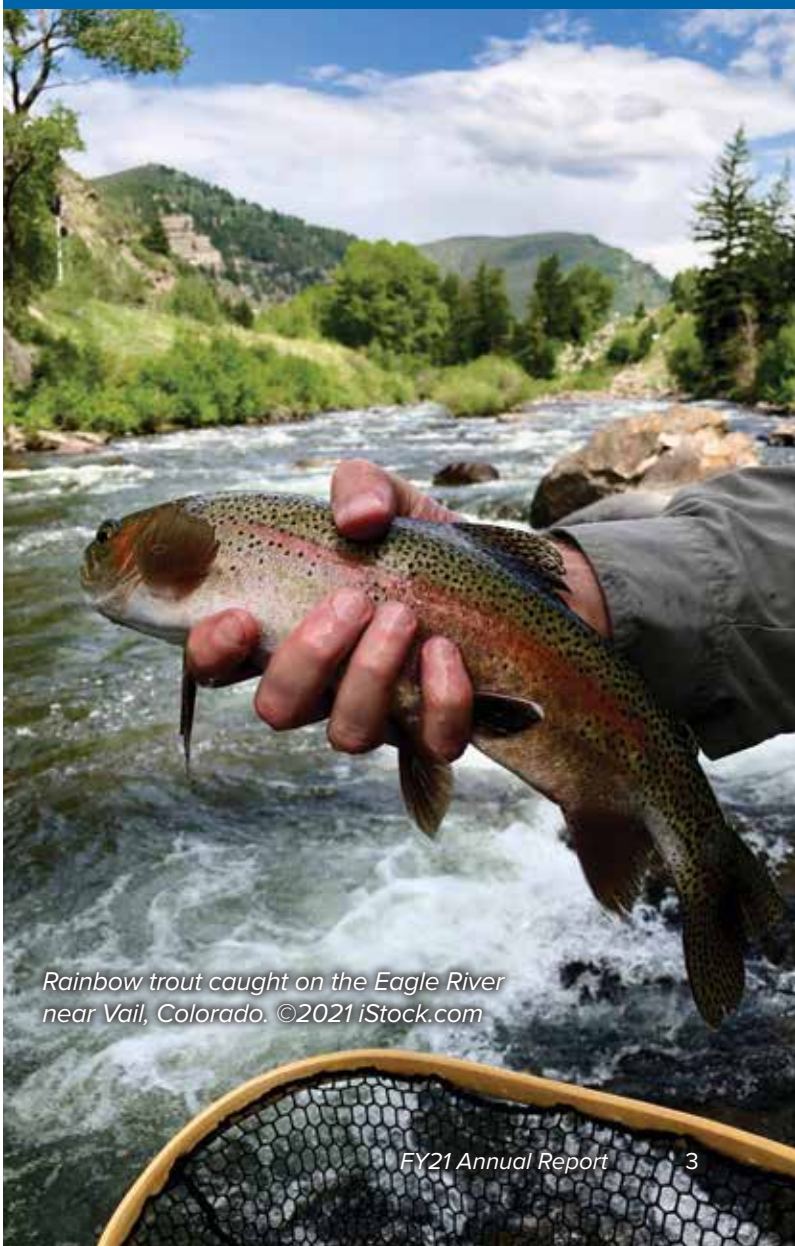
Using water isotopes in Colorado and New Mexico to understand hydroclimate in the Southwest: Implications for understanding and harnessing the geological record of past climate
Jeremy Rugenstein et al., Colorado State University

High elevation fire controls on reservoir and river algae blooms
Matthew Ross et al., Colorado State University

STAY UP-TO-DATE!

Subscribe to our e-newsletter, *The Current*, or our print newsletter, *Colorado Water*, for updates on research, water-related news, jobs, funding, scholarships, and more!

watercenter.colostate.edu



Rainbow trout caught on the Eagle River near Vail, Colorado. ©2021 iStock.com

FY21 CSU FACULTY GRANT PROGRAM

watercenter.colostate.edu/grants/

Toward Understanding the Global Impacts of Human Activities on Floodplain Integrity

Ryan Morrison et al., Colorado State University

SYNOPSIS

Humans have had a historical tendency to cultivate floodplains which has lead to harsh environmental and economical consequences. This project teamed up with international researchers who focused on evaluating floodplain changes in the U.S. and aimed to find new efforts to calculate long-term datasets of floodplain land use. The team began their research along the Mississippi River Basin (MRB) and discovered that thousands of square miles pertaining to wetland and forested land had dematerialized due to increasing agricultural practices.

From this study, it was uncovered that these irrivesibe alterations in floodplain composition not only reduce storage and transportation of natural flow, it also intensifies flood risks presented by climate change, ultimately leading to unhealthy ecosystems and decreases in human prosperity and well-being. The 60 years of floodplain changes illustrated in these data may become beneficial for guiding floodplain management in the MRB and the methods taken from the study can be applied in other river basins in the U.S. and internationally.

BACKGROUND

Riverine floodplains are vital and productive ecosystems that provide essential biological, geomorphic, and hydrologic functions. Floodplains—including regulation of disturbances (e.g., flood attenuation), water supply, and waste treatment—are valued at approximately U.S. 1.5×10^{12} per year globally (in 2007 U.S. dollars). Human development and encroachment continually threatened floodplains. Channelization and levee construction, which threaten a loss of floodplain-river connectivity, exacerbates habitat loss and hydrologic alteration.

Human modifications to floodplains have led to changes in land use. For instance, approximately 80-90% of floodplains across Europe were intensively cultivated, and 90% of floodplains in North America are non-functional due to cultivation. New developments in floodplains expose an increased population in the U.S. to flooding, and even a 1% chance of flooding can cause losses exceeding $78 billion per year in the U.S.

Flood-risk management efforts of the previous century focused on minimizing flood impacts on humans through large and expensive infrastructure projects. The changes came at the expense of floodplain ecosystem health and resilience. However, programs such as floodplain buyouts and conservation can produce co-benefits for economies and floodplain ecosystems. They require a comprehensive understanding of historic floodplain changes along the full river continuum to ensure sustainable and effective floodplain and flood-risk management.

Figure 1. Antonio Annis (Univeristà per Stranieri di Perugia) and Ryan Morrison in Fort Collins, CO. Ryan has been working with researchers in Italy to understand changes in floodplain ecosystems since 2015. Photo by Ryan Morrison.

No studies identify floodplain regions at large scales and integrate long-term data to examine changes across a river basin. Long-term data and large-scale floodplain land use are required to quantify floodplain functions and development trajectories effectively and for a holistic perspective on the future of floodplain management

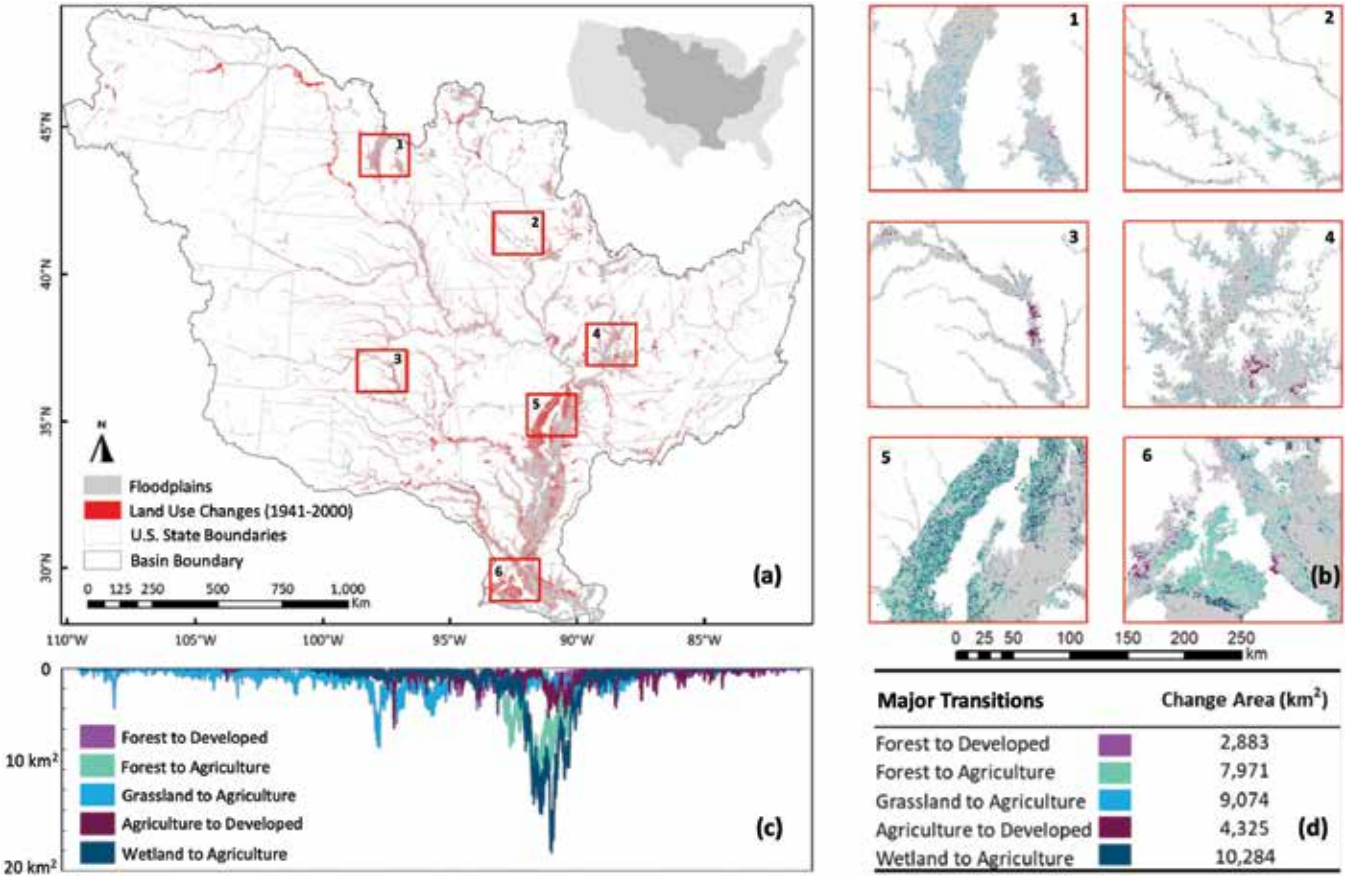


Figure 2. Land use change in the Mississippi River Basin (MRB) floodplains between 1941 and 2000. (a) The "change" in this map is defined as the non-uniqueness of individual land use grid cells between the two end years. (b) The maps 1-6 correspond to six objectively chosen domains across different geophysical settings and stream orders in South Dakota (1), Iowa (2), Kansas (3), Indiana (4), Arkansas (5), and Louisiana (6). Plot (c) graphically shows how the five major potentially irreversible land transitions vary along the latitude at every 250-m horizontal resolution. Plot (d) summarizes the areal extent (km²) of change between 1941 and 2000. Figure by Adnan Rajib.

and restoration and concomitantly flood-risk mitigation.

With the help of international researchers, my Water Fellow research goals focused on assessing floodplain changes in the U.S. and new efforts to evaluate long-term datasets of floodplain land use. A few select collaborators, including Dr. Fernando Nardi and Dr. Antonio Annis from WARREDOC, made these goals achievable in the Zoom-life of 2020. Other collaborators included:

- Dr. Adnan Rajib, Texas A&M University, lead author on the new study;
- Dr. Heather Golden, Dr. Charles Lane, Dr. Jay Christensen, U.S. EPA;
- Qianjin Zheng, Texas A&M University; and
- Dr. Quisheng Wu, University of Tennessee.

MISSISSIPPI RIVER BASIN FLOODPLAIN LAND USE

The first long-term dataset emerged from the collaboration to illustrate the drastic changes in floodplain composition throughout the MRB during the past 60 years.

The MRB covers 41% of the U.S. With a drainage area of more than 3,288,000 km², and it is the fourth largest river basin globally. MRB floodplains have supported essential ecosystem services for much of the country. However, the MRB is also one of the most engineered systems in the world, with vast numbers of levees, dams, and dikes. Runoff with excessive nutrient concentrations caused by the combination of agriculture and urban development is responsible for the "dead zone" expansion in the Gulf of Mexico.

Using remote sensing data, land cover data, and a new 250 meter-resolution global floodplain dataset (GFPLAIN; https://github.com/fnardi/GFPLAIN), Dr. Rajib led the collaborative team. We evaluated how floodplain land use—such as forest, wetlands, agriculture, and development—changed the MRB between 1941 to 2000. The floodplain area in the GFPLAIN dataset represents the flood-prone regions implicitly identified through analy-

ses of digital elevation models. The team used the National Land Cover Database and 30 years of LANDSAT imagery to classify land types in the MRB into categories: open water; developed area; barren land; forest; grassland; agriculture; and wetland. Finally, using a combination of transition matrix analysis and statistical approaches, we detected changes in land cover within the floodplains and developed "nature of change" matrices for every remote-sensing pixel.

Our results highlight the spatial and temporal extent of land-use changes within MRB floodplains, specifically agricultural and developed land expansion since 1940. More than 10,000 km² of wetland habitat and 8,000 km² of forested land have been lost because of agricultural growth. These irreversible transitions in floodplain composition reduce storage and conveyance of natural flow, amplify flood risks posed by climate change, and hinder ecosystems and human well-being.

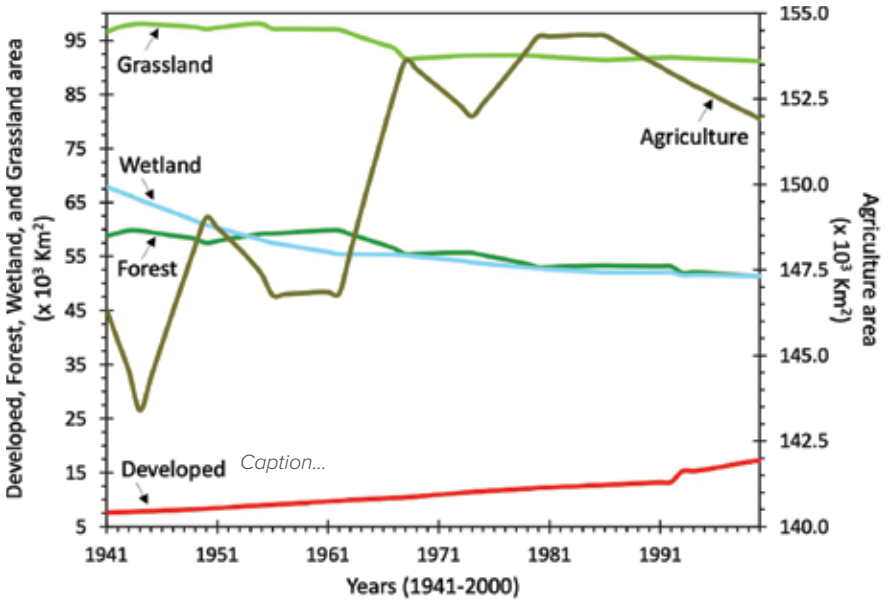


Figure 2. Time series graphs showing 60 years (1941-2000) of continuous changes in different land use classes. (Figure by Adnan Rajib)

DATA AVAILABILITY FOR FLOODPLAIN MANAGEMENT

The 60 years of floodplain changes we illustrate in our data may be helpful for guiding floodplain management in the MRB. A recent strategic plan of the Upper Mississippi River Restoration partnership, representing 0.5 million km² of the Basin, envisions "a healthier and more resilient Upper Mississippi River ecosystem that sustains the river's multiple uses." The planners can use our datasets to understand where floodplains have been most affected by human development. Furthermore, as the first long-term dataset on floodplain changes, in the U.S., our methods can be used to study other river basins in the U.S. and globally.

We have made our data freely available through HydroShare, a public repository for water-related datasets:

https://bit.ly/3COKFJj
https://gishub.org/mrb-floodplain

❑

Farmland and forested areas in the Mississippi River Basin near St. Louis, Missouri, photographed from the air. © 2021 iStock.com.

Integrating Low-Tech, Process-Based Restoration Techniques to a Degraded Perennial Stream System: A Community

Blake Osborn et al., Colorado State University

SYNOPSIS

Low-tech, process-based river restoration can provide multiple benefits to previously degraded river systems. This project built a coalition of technical experts. They evaluated how restoration treatments may affect the hydrologic system, collected baseline topographic and geomorphic data, installed monitoring wells, and developed students' workforce skills and research experience.

BACKGROUND

Colorado's streams and rivers are often central figures in our state's economy, history, and identity. The natural waters inspired a new branch of legal doctrine. They stretch to meet economic demands, support thriving ecosystems, and inspire us. Our diverse state helps to shape our streams and rivers into place-based features that often provide multiple uses or multiple benefits. Each unique stream, and segments of the same stream, is managed for different outcomes.

Many factors, including locations and intended uses, help determine different management strategies. For example, streams that contain rare or important riparian species are managed for conservation values. Yet others are vital engines for land uses that provide food, fiber, or other products. Some are important for recreational and scenic values. Fortunately, it is increasingly common to find collaborative management plans or activities that recognize the importance of achieving multiple desired outcomes.

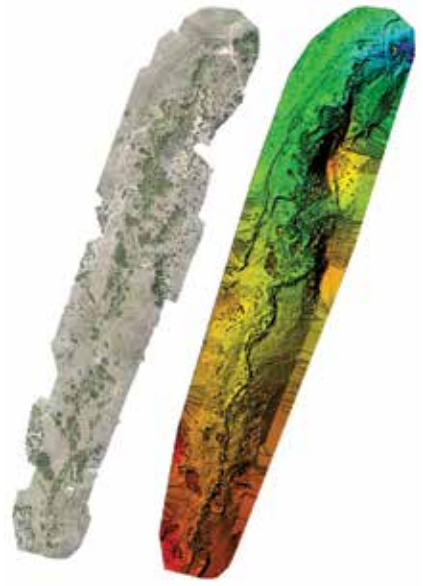
Today, many community organizations, private landowners, and government agencies know the value of restoring riverine systems historically managed for other uses. Low-tech and process-based (LT-PBR) stream restoration treatments continue to emerge as viable stream methods to restore natural functions to streams managed in the past for uses other than ecosystem integrity. LT-PBR treatments are popular because of their effectiveness, relatively simple design and implementation, and practitioners' and academics' acceptance. Although much of the hydraulic and fluvial impacts of LT-PBR methods are well documented, the hydrologic impacts of these treatments are relatively unknown. This project engaged the local community to fund and implement LT-PBR treatments to understand the hydrologic and ecological impacts better.

PROJECT RATIONALE

This project centered on LT-PBR methods and their impacts on the local hydrologic systems. And we decided to expand beyond the singular goal of assessing LT-PBR methods. The project team developed three main objectives for this project:

- Educate and train students and water professionals in natural river processes and restoration techniques;
- Improve Oak Creek hydrogeomorphic conditions; and
- Provide information to water managers on the impacts of process-based restoration on stream system hydrology.

Drilling shallow alluvial groundwater wells. Photo by Blake Osborn.



Georeferenced orthomosaic and digital surface m-sodel. Photo by Blake Osborn.

METHODS

This project relied on several partnerships for development, training, and funding. First, we developed and implemented a new honor-level high school course at Cañon City High School. The class, River Science, used the project as a field laboratory. Unfortunately, COVID-19 protocols and school closures limited our ability to implement field treatments. However, students did make two trips into the field and learned about LT-PBR methods while working remotely.

This project can only proceed at the speed and scale of expected hydrologic changes. Conditions such as sediment aggradation may change immediately after treatment implementation. Others, like aquifer recharge, may take years. The current activities allowed the team to collect baseline field data, including survey data to document geomorphic and topographic conditions. Baseline geomorphic and topographic data were collected using Structure from Motion techniques and a DJI Mavic drone. Images were processed using Pix4D software. Orthoimages and a Digital Surface Model were used in delineating existing geomorphic conditions and identifying LT-PBR treatment areas. We also installed six piezometric wells to monitor groundwater levels.

RESULTS AND IMPACT

We identified 71 locations for LT-PBR structures based on geomorphic analysis of the digital surface model. The most appropriate LT-PBR methods for this stream reach include mid-channel, bank attached, and channel spanning Post-Assisted Log Structures (PALS), as well as Beaver Dam Analogues (BDAs). To date, piezometer wells have not yielded any data. We do not expect groundwater levels to rise until LT-PBR implementation. Cañon City High School students in the River Science class will partially install and monitor the treatments.

Blake Osborn teaches students about geomorphic processes using a physical floodplain model. Photo by Carrie Trimble.

Despite setbacks from the COVID-19 pandemic, the project moved forward with the assistance of many local partners. First, the students and administration at Cañon City High School provided technical and financial assistance. Several local businesses and individuals supported the project as a tool to introduce workforce skills to students. Two local nonprofits, and the landowner we worked with to test methods and teach students, also supported the project. The momentum built community awareness around the importance of healthy rivers and streams, local training and workforce development, and complex issues around stream restoration and water use impacts.

Students learn about geomorphic and biological assessments and data collection along Oak Creek. Photo by Carrie Trimble.

CONCLUSIONS AND FUTURE RESEARCH

How LT-PBR methods impact reach scale ground and surface water dynamics remains to be seen. The nonprofit organization River Science will lead the project's next phase, and its curriculum will expand to other schools in Colorado. Funding was secured through the Colorado Water Conservation Board for Phase 2. Future research plans include analysis of water rights under different flow conditions and continued monitoring of surface and groundwater interactions/movement after installation of LT-PBR treatments. ❑

Building a Long-term Watershed Research Site at the CSU Mountain Campus

Sara Rathburn et al., Colorado State University

SYNOPSIS

The CSU Mountain Campus is being re-instrumented for hydrological and meteorological monitoring to support research and education. In 2020, a coordinated interdisciplinary team of CSU researchers generated a full year of high-quality hydrological and meteorological data from the monitoring network. They also completed detailed surficial geologic mapping, sediment coring, and geophysical surveys.

The instrumented monitoring network catalyzes inquiry into the area's hydrology, geology, climatology, and post-wildfire recovery. Initial results of a hydrological investigation of the South Fork Cache la Poudre River at the Mountain Campus documents, for the first time, a downstream transition from gaining to losing river water in the valley. The stratigraphic and geophysical evidence indicates the post-glacial sediment deposits are 13,900 years old. Erosion into these deposits formed two distinct terraces, and sedimentation of the modern floodplain occurred over the last 500 years.

Stephanie Kampf (ESS), Celeste Wieting (GEO), and Christoph Suhr (GEO) winterizing hydrologic monitoring equipment along the South Fork River at the CSU Mountain Campus. Photo by Sara Rathburn.

BACKGROUND

Situated between Comanche Peak Wilderness in the Roosevelt National Forest and Rocky Mountain National Park, the CSU Mountain Campus is well-positioned for interdisciplinary hydrology, geology, snow, and climate research. The South Fork is a vital tributary to the Cache la Poudre River. While the CSU Mountain Campus has long been an area of inquiry and educational exploration, streamflow and weather monitoring in the South Fork watershed was limited over the past few decades. The Colorado Water Center, Office of the Vice President for Research, and the Warner College of Natural Resources will refit the campus to support a new era of research. In 2020, an interdisciplinary team of CSU researchers strategically expanded the hydrologic and meteorological instrumentation. Here we summarize the monitoring network and research that advances understanding of the valley hydrology through surface water and groundwater well monitoring, surficial geologic mapping, sediment coring, and geophysical surveys.

THE INSTRUMENTATION NETWORK

The vision for Mountain Campus instrumentation was to initiate a long-term record of hydrological and meteorological data to serve as baseline data for future research and inquiry. A telemetered weather and river monitoring network was initially installed in 2018. Since then, the network expanded to include two telemetered weather stations, groundwater monitoring wells, two surface water gages, a precipitation gauge, a seismometer, and a webcam.

Weather monitoring includes:

- Air temperature
- Relative humidity
- Wind speed
- Wind direction
- Radiation
- Snow depth
- Rainfall
- Soil moisture
- Soil temperature

Stream monitoring includes river stage and discharge, turbidity, and a suite of other water quality parameters. The parameters are stream temperature, dissolved oxygen, pH, and conductivity. Groundwater wells are near each stream monitoring site, with two shallow wells and one

deep well on the adjacent terrace. Near real-time telemetered data and webcam footage of conditions at the Mountain Campus are available at http://datavis.warnercnr.colostate.edu. Other relevant datasets—a high-resolution orthoimage of the valley and temperature and relative humidity sensors to measure cold air drainage along a hillslope elevation gradient—are also archived.

HYDROLOGY OF THE SOUTH FORK RIVER VALLEY

An important objective of long-term hydrological monitoring is to better understand streamflow timing and water source areas throughout the year. The South Fork River interacts with a local groundwater system. It flows through permeable glacial outwash and modern river sediments. River-deposited sediments are at least 10 m deep, based on observations made during well drilling in 2019. Surface stream gauges and adjacent deep groundwater well monitoring revealed the South Fork River transitions from gaining to losing as it flows down the valley. A hydrogeological model is under development. It incorporates the physiography and mapped surficial geology to explore groundwater and river water.

In addition to logging water levels, this project included sampling stable isotopes (2H/1H, 18O/16O). They occur naturally as part of the water molecule and can be used as hydrologic tracers. Initial results illustrate different isotopic signatures for groundwater and surface water. The isotopic composition of stream water varies throughout the year, and likely reflects an increase in local groundwater contributions during the late summer and fall.

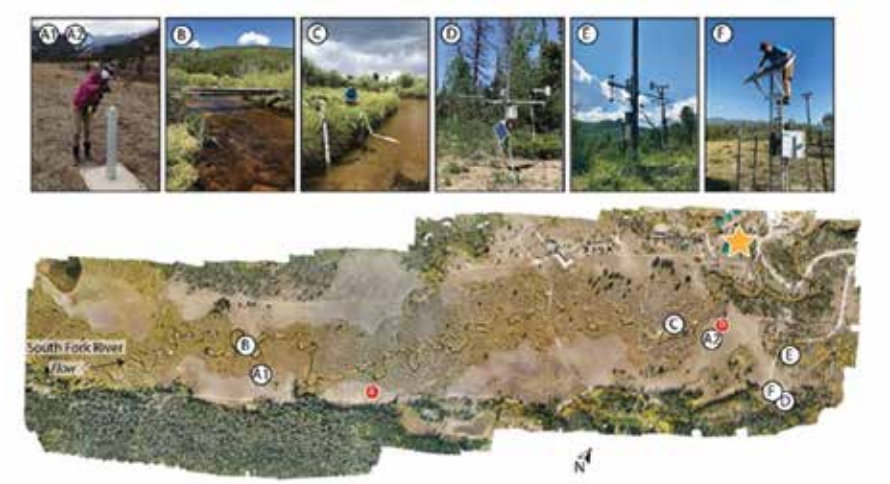


Figure 1. Established monitoring locations at the CSU Mountain Campus: A1. and A2. Deep groundwater wells (not telemetered, pictured: Valerie Doebley, MS Hydrogeology student); B. Upstream surface gauge (not telemetered); C. Downstream surface gauge (telemetered, pictured: Lucas Zeller, MS Geosciences student); D. Forest Weather Station (telemetered), E. Main Weather Station (telemetered); F. Seismic station (telemetered, pictured Hank Cole, MS Geosciences graduate). Telemetry base station (Research Building) marked with a star. General location of Figure 4 GPR transects marked with red circles.

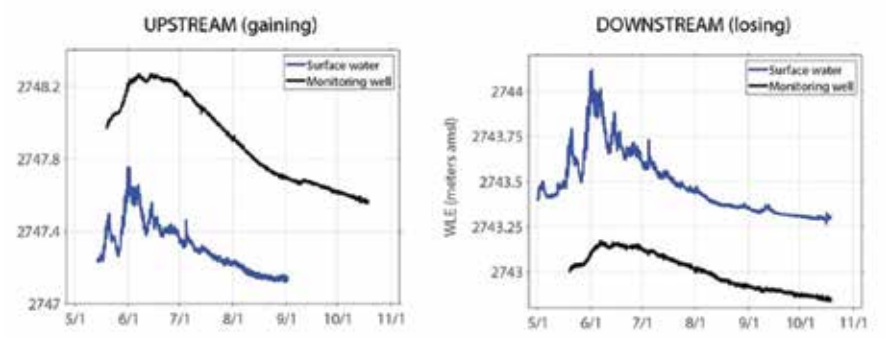


Figure 2. Water level elevation (WLE) measured during 2020 at stream gauges and co-located deep monitoring wells (locations shown in Figure 1) (M. Ronayne, unpublished data).

SURFICIAL GEOLOGY, SEDIMENT CORING, AND GEOPHYSICAL SURVEYS OF THE SOUTH FORK RIVER VALLEY

Groundwater and surface water processes along the South Fork River influence the characteristics and distribution of glacial and post-glacial river sediments deposited in the valley. Sediment cores were collected for radiocarbon analysis to determine sediment ages, and ground-penetrating radar (GPR) and seismic refraction surveys were completed to examine the stratigraphy and thickness of valley bottom sediments.

These analyses revealed key insights into the glacial and post-glacial history of the South Fork River Valley. The surficial geologic mapping identified two unique glacial till deposits (Qg1 and Qg2) formed by at least two episodes of glaciation; till mapped as Qg1 is older and more weathered, while till mapped as Qg2 was deposited more recently and displayed prominent glacial landforms. Radiocarbon analyses of sediments collected within the younger Qg2 till indicate the most recent glacial advance to reach the location of the Mountain Campus must have retreated before 13,900 years ago. This age relationship suggests that

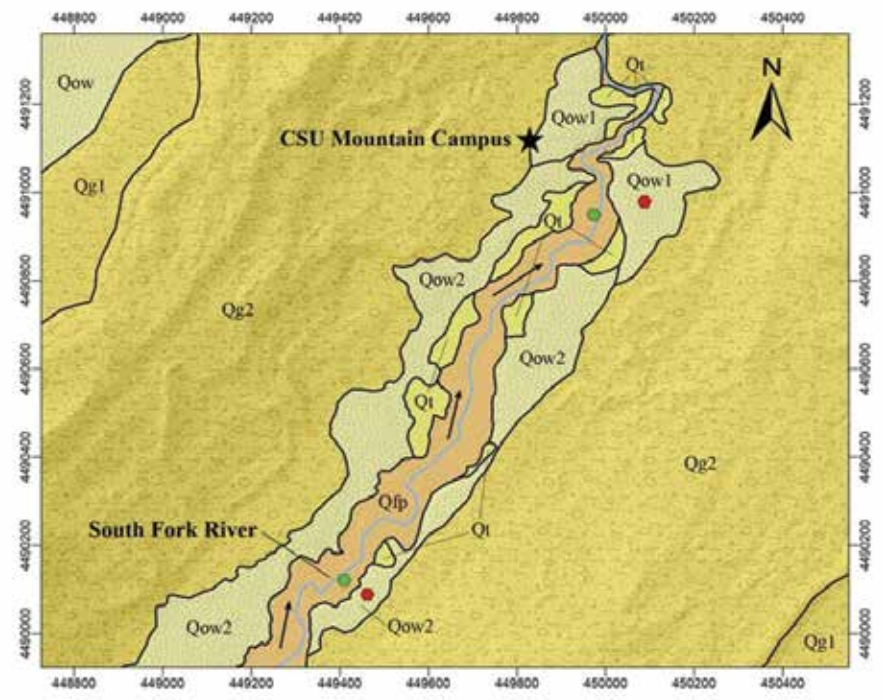


Figure 3. Sample geologic map of the South Fork River Valley at the CSU Mountain Campus. Units include glacial till (Qg1, Qg2), outwash terraces (Qow, Qow1, Qow2), fluvial terraces (Qt), and the active floodplain (Qfp). Locations tick marks are in WGS UTM zone 13N. The star indicates the main campus location, stream monitoring sites are marked as green hexagons, and deep groundwater wells are marked with red hexagons. Flow is from bottom left to top right, as indicated by arrows (modified from Suhr, et al., 2021, Report for USGS EDMAP Award)

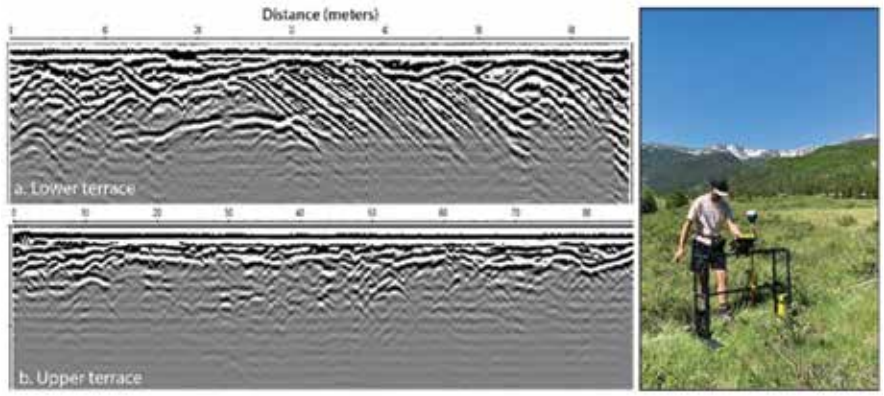


Figure 4. Ground penetrating radar (GPR) radargrams collected on a lower terrace (a), and an upper terrace (b) within the South Fork Valley at the CSU Mountain Campus. General location of transects indicated by red circles on Figure 1 map. Picture: Christoph Suhr, MS Geosciences student, operating the GPR) (modified from Rathburn and Suhr, 2020, Report for Natural Resources Research Award).

Qg2 glacial deposits formed during the Pinedale glacial period.

Following Pinedale deglaciation, over 10 m of glacial outwash was deposited within the South Fork Valley. Subsequent reworking of outwash sediments by the river formed two high terraces (Qow1 and Qow2). The topographically highest terrace (Qow1) represents the valley surface after deposition of post-glacial outwash, forming the sediment into which the deep downstream well is completed.

The Qow2 terrace represents the valley bottom after 1 to 2m of river incision into the Qow1 surface and consists of sediment into which the upstream deep well is completed. Sediment cores from lower, more recent river terraces (Qt) produce dates of 1,400 and 2,100 years old, while sediments collected on the modern floodplain (Qfp) date to approximately 500 years. Initial interpretation of the GPR data reveals distinct dipping reflections and horizontal reflection patterns, consistent with point bar migration and overbank deposition, respectively. Ongoing analyses will investigate the surface and groundwater interactions in the context of valley sediment and depositional environment. In addition, the varying reflection patterns from the GPR surveys will be analyzed in more detail to understand alluvial processes forming the South Fork River Valley landforms.

CONCLUSIONS AND FUTURE RESEARCH

The 2020 global pandemic and the Cameron Peak Fire limited access to Mountain Campus for research. The work completed established a solid foundation for research opportunities to continue to grow at the campus.

Telemetered data are currently viewable to the public and downloadable by request. We continue to expand data download and documentation resources to facilitate future educational benefits, including use in K-12 and university courses at the Mountain Campus and beyond. The instrumentation network also provides an opportunity to leverage further research prospects. One already occurred in the wake of the Cameron Peak Fire. Ongoing monitoring at the campus is now part of a larger funded effort to study the impact of the wildfire on snowpack, streamflow, sediment transport, and water quality throughout the Cache la Poudre River basin. ❑

Beaver ponds located within the study area in North Park, Colorado. Photo by Michael Wilkins.

Beaver-Generated Wetlands as Ecosystem Control Points for Post-Fire Transport of Sediment, Carbon, Nutrients, and Toxic Metals into Rocky Mountain Headwaters

Michael J. Wilkins et al., Colorado State University

SYNOPSIS

Beaver wetlands are increasingly common features within western U.S. watersheds. They can potentially influence the fate and transport of nutrients in the aftermath of wildfire. Our study used a series of beaver wetlands in a burned catchment along the Colorado-Wyoming border to determine whether these features retained carbon and nitrogen and how microorganisms might interact with these compounds.

Results indicated that organic compounds generated by wildfire were retained in the wetlands and were generally resistant to microbial degradation. Thus, beaver-generated wetlands within upland watersheds are likely important in controlling the downstream transport of potentially deleterious nutrients after a wildfire.

BACKGROUND

Wildfire is a key disturbance that structures forest ecosystems across the western U.S. that has affected 6.3% of the forested area over the past three decades. Moreover, the severity of wildfires in western North American conifer forests increased dramatically in recent decades. The escalation is predicted to continue as our climate changes. In 2020, the largest forest wildfire season in this region was recorded. More than six million acres burned across the West.

A critical event following a wildfire is the export of nutrients—mainly carbon and nitrogen—from terrestrial burned hillslopes to aquatic ecosystems, where they can significantly impact downstream water quality and drinking water treatability. For example, nutrient export can lead to increased eutrophication of downstream waters. It also has the potential to generate harmful disinfection byproducts during drinking water treatment. Therefore, understanding the fate and transport of these nutrients from burned watersheds is of the utmost importance.

Beavers actively divert large fractions of river flow onto the adjacent floodplains, even during low river flow. These diversions can substantially impact biogeochemical processes, including organic carbon storage, cycling of reactive nitrogen, and export of metals. Conventional wisdom was that before hunting

activities almost wiped out North American beaver populations, most upland catchments contained extensive beaver-generated floodplains. The wetlands supported abundant biodiversity; retained carbon, silt, and water; and stimulated aquifer recharge. Despite beavers' near extinction, the species returned to many western watersheds, including many affected by wildfire.

PROJECT RATIONALE

For this project, we aimed to determine how beaver wetlands influence the movement of carbon and nitrogen within burned watersheds. These wetlands have distinct chemical conditions relative to both adjacent floodplain and hillslope soils and free-flowing stream sections. They likely catalyze unique biogeochemical processes in the watershed. The return of beaver and predicted increases in wildfire activity are likely to play increasingly important roles in influencing water that is exported from burned landscapes.

METHODS

To understand post-fire biogeochemistry, we employed an interdisciplinary approach that coupled high-resolution chemical analyses of aqueous nutrients with profiling of the microorganisms that inhabit beaver wetlands and can drive transformations of nutrient species.

The work was performed within an area along the Colorado-Wyoming border that burned during the 2018 Ryan Fire. It hosted a series of interconnected free-flowing stream sections interspersed with multiple beaver wetlands. Time-resolved water samples were collected monthly throughout the summer of 2019 and 2020 from various locations along this transect. The focus

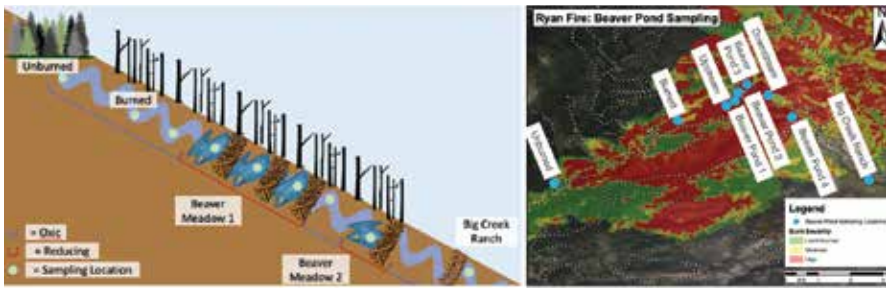


Figure 1. Water sampling locations along a transect through unburned and burned regions following the 2018 Ryan Fire. Graphic by Holly Roth.

Graduate students Holly Roth (main image) and Amelia Nelson (inset) collecting water samples from beaver wetlands. Photos by Holly Roth and Michael Wilkins.

was on up-gradient sections of the stream unaffected by the Ryan Fire and the beaver wetlands in the burned area. Furthermore, sediment samples from within the beaver wetlands were collected.

We employed a mass-spectrometry approach to characterize the dissolved

nutrients leaching from burned landscapes into the stream. We used analytical resources at the National High Magnetic Field Laboratory at Florida State University. We also extracted DNA from collected sediment samples and performed sequencing to analyze the composition and function of the microbial community.

RESULTS & IMPACT

Our spatial and temporal sampling scheme revealed dissolved organic carbon and dissolved total nitrogen accumulated in the beaver wetlands. In particular, high-resolution mass spectrometry analyses of nutrients in the water column indicated that compounds generated during a wildfire that contain nitrogen were enriched and retained in beaver wetlands.

The microbial community within the beaver wetland sediments was distinct from communities found in free-flowing river sediments and adjacent burned soils. These communities could tolerate the oxygen-free conditions encountered in the carbon-rich sediments but did not encode the genetic machinery necessary to degrade many of the aromatic hydrocarbons accumulated in these features. Many of the microbes inhabiting beaver pond sediments could degrade other compounds generated by wildfire—for example, dead microbial biomass likely produced when soils in the watershed burned. Moreover, the wetland microbes converted iron and manganese into aqueous species. This suggests beaver wetlands may contribute to elevated downstream fluxes of some metals.

Together, these results indicate beaver wetlands play a key role in retaining C and N compounds initially generated by wildfire and are susceptible to transport from burned hillslopes. The features likely play oversized roles in biogeochemical cycling in burned regions.

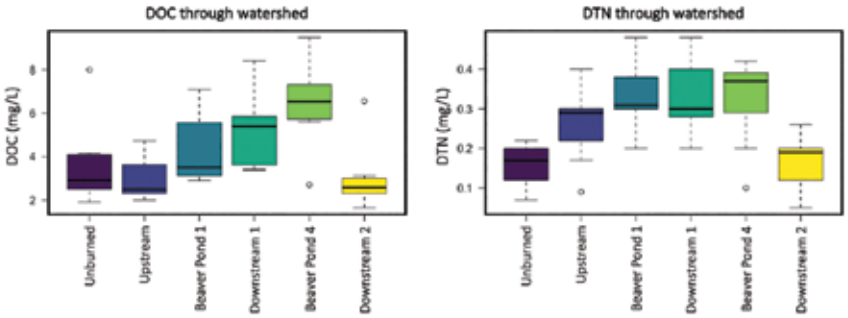
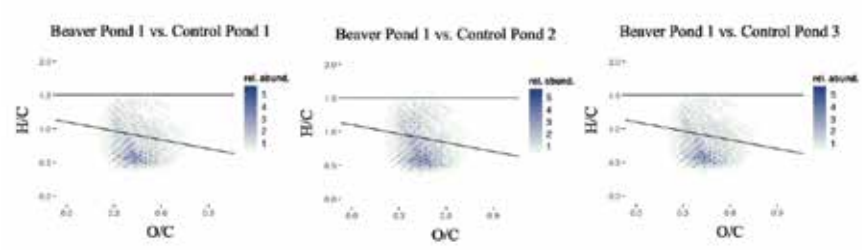


Figure 3. Dissolved organic carbon (DOC) and total dissolved nitrogen (TDN) through the Ryan Fire-impacted watershed. Each box and whisker plot consists of five samples, one each from June-October 2019. Graphic by Holly Roth.



Series of van Krevelen Diagrams depicting the enrichment of unique aromatic organic compounds in beaver ponds. Graphic by Holly Roth.

CONCLUSIONS AND FUTURE RESEARCH

This work revealed that beaver wetlands retain carbon and nitrogen compounds generated during a wildfire. By limiting the downstream transport of these molecules, problems often encountered after a wildfire—such as the formation of carcinogenic disinfection byproducts at water treatment plants—may be alleviated.

These wetlands also hosted unique microbial populations within the watershed. The microbes were distinct from those present in adjacent burned soils or river sediments. Many of the microbes could degrade some retained fire-generated compounds, but they also can mobilize metals.

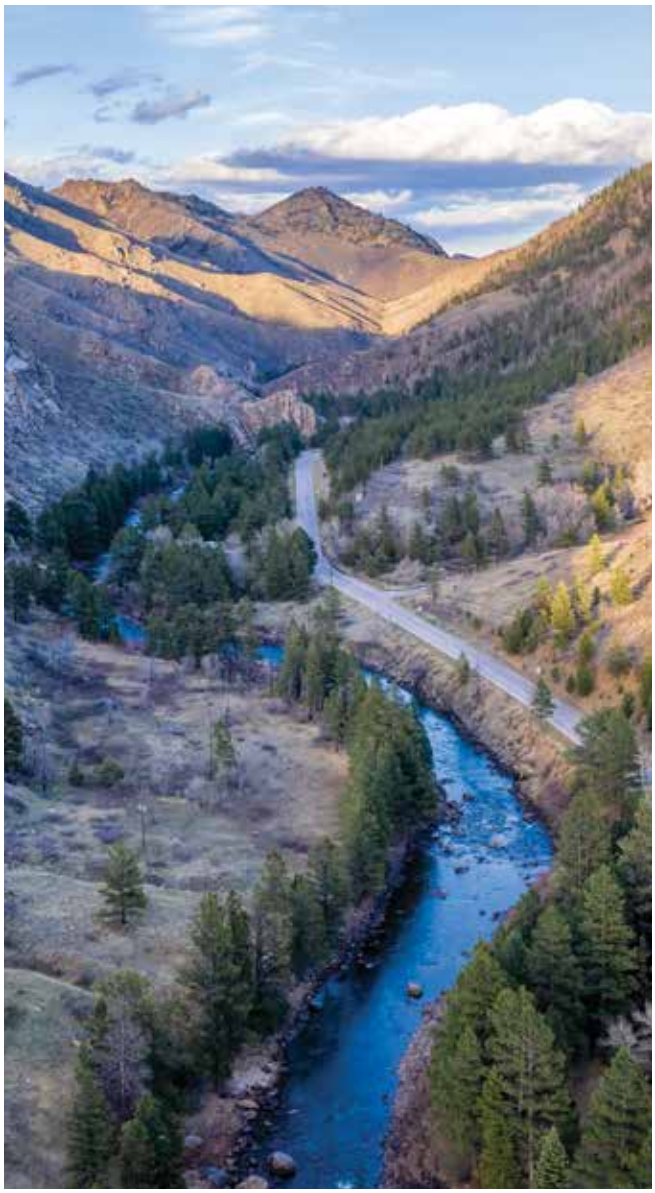
The implications of potential metal transformations are a key focus for future research. The work suggests beaver wetlands in burned catchments may play an important role in limiting the nutrient transport downstream and may limit the extent to which water quality is affected.

Acknowledging this study was performed in one catchment, future work will aim to expand observations to additional beaver wetlands, potentially in areas burned during the historic 2020 Colorado fire season. For example, there are many beaver wetland complexes in the Cameron Peak burn area. The complexes likely intercept nutrients that have leached from ash. Finally, beaver dam or wetland analogues are receiving increasing attention across the U.S. as a mechanism of controlling water flow and quality. These results suggest that such features could be a valuable tool in post-fire management in burned watersheds. ❑

Colorado Water Center
FY21 Staff Updates

Engaging Stakeholders and Community Leaders in Critical Water Discussions

Julie Kallenberger, Associate Director



The Poudre River photographed west of Fort Collins. ©2021 iStock.com.

Coloradans continue to play an active role in discussions, partnerships, decisions, and learning—all of which prove to be essential as our state continues to experience pressures on limited water supplies. Over the past year, the Colorado Water Center (CoWC) served local communities as an unbiased convener and facilitator. Two of the Center's prominent programs, Water Literate Leaders of Northern Colorado and the Poudre Runs Through It Study Action Work Group, allow time and space for stakeholders to confront tough conversations, trade-offs, and decisions associated with water.

WATER LITERATE LEADERS OF NORTHERN COLORADO

Among the many important values of Northern Colorado, citizens are preserving agricultural land and open space, ensuring high-quality drinking water, healthy rivers and environment, vibrant communities, and robust economies. For local leaders to make sound decisions related to water issues, they seek relationships with others throughout our Region and reliable, unbiased information from water experts.

Recognizing this need, CoWC (www.watercenter.colostate.edu/) developed the Water Literate Leaders of Northern Coslorado program in partnership with the Community Foundation of Northern Colorado's Hach Center for Regional Engagement (www.nocofoundation.org/the-hach-center/).

To date, the program has cultivated three cohorts consisting of 63 leaders from different sectors to raise the level of dialogue about water to the top decision-makers in the Region. Participants in the program engage in nine months of learning about the many facets of water, discuss complex issues and associated tradeoffs, exchange ideas, and work

towards how Northern Colorado can best achieve its goals for regional water collaboration.

Unfortunately, the COVID-19 pandemic did not allow us to convene a new cohort; however, past graduates and CoWC staff remained committed to discussions concerning our Region's water supplies. The fourth cohort of 20 community leaders from the Poudre and Big Thompson river basins will begin in September 2021. These leaders will invest their time and energy to learn from experts and empower themselves to meet our ever-changing water needs.

The Water Literate Leaders program is made possible through the following partners and sponsors: Community Foundation of Northern Colorado, City of Evans, City of Fort Collins, City of Greeley, City of Loveland, City of Thornton, Town of Windsor, and North Weld County Water District.

Interested in learning more about Water Literate Leaders? Visit our website at watercenter.colostate.edu/wll.

THE POUDRE RUNS THROUGH IT STUDY/ ACTION WORK GROUP

The Poudre Runs Through It Study/Action Work Group (PRTI), consisting of two dozen experts involved in various communities throughout the basin, continued to work towards their goal of making the Poudre the best example of a healthy, working river.

Adapting to a new virtual environment this past year, PRTI members continued to meet online to discuss a variety of topics and learn from one another and outside experts. One of their newest initiatives, a subcommittee of water users who share current flow conditions and identify opportunities to increase coordination, continued throughout the last half of the Water Year. Furthermore, PRTI members continued to expand the Poudre Basin Information Website using open source data available to water users and the public. New datasets include snowpack, local farms and CSAs, drought information, and major water projects. Additionally, PRTI members continued their work on Colorado House Bill 20-1037, passed in early 2020, which is one of many steps in a process that will allow owners of certain augmentation water rights to be able to "deposit" water into a new Poudre Bank. ❑

Learn more about PRTI at www.watercenter.colostate.edu/prti.

Values expressed by Northern Colorado citizens for the Poudre River (above) and other waterways are preserving agricultural land and open space, ensuring high-quality drinking water, healthy rivers and environment, vibrant communities, and robust economies. ©2021 iStock.com.

Emphasis on Water Resources for Western Colorado Research Center

Perry Cabot, Research Scientist and Extension Specialist

INTRODUCTION

Since 2013, the Colorado Water Center (CWC) has partnered with CSU Extension (CSUE) and the CSU Agricultural Experiment Station (AES) to engage with stakeholders in the Upper Colorado River Basin. In 2017, these three partners worked together to develop a new Concept and Engagement Plan for one of the Western Colorado Research Center (WCRC) units. Given the demand for water resources engagement, research and education in the Colorado Basin, the focus of this unit was altered to take on this responsibility. The transition has been underway every year, reflected by the acquisition of new projects and installation of new equipment. To highlight a benchmark for this transition and reflect the clientele served, this unit was renamed in 2021 as the WCRC-Grand Valley (WCRC-GV), which considers its research as being a set of nexus interests shared by its three main campus partners. Priority interests of the WCRC-GV include on-station and off-station consumptive use (CU) evaluations of cropping systems through remote-sensing, applied research on crops with lower water demands, irrigation-efficient systems and technology, and engagement with stakeholders, water resource management districts, other institutions of higher education and industry partners.

HIGHLIGHTED PROJECTS

The coordinated efforts between the CWC, CSUE, and AES have supported projects that focus on water issues shared by the missions of these partners.

Sub-Surface Drip Irrigation System

As mentioned in the 2020 report, a 5.8 acre research field was slated for transition from furrow irrigation (using siphon tubes and a concrete lateral) into dedicated subsurface drip irrigation (SDI) system. In Phase 1, the infrastructure and control system, along with 22 individually controlled plots (3,600 sf; 0.08 ac) was completed. Then in 2020, Phase II was completed, which involved valving and injecting tape for the next 22 plots, bringing the total number of operational plots to 44. By converting this field to SDI, the nature and number of experimental plots for water resources research was changed dramatically. Prior to this construction, all 80 acres at the WCRC-GV were irrigated using highly inefficient furrow practices, requiring much larger research fields without the ability to precisely control irrigation rates. In 2021, Phase III will be completed, finalizing the transition of this field to be equipped with 66 research plots for all forms of research on CU rates, alternative crops or irrigation technology. Several of these plots were utilized in 2021 to conduct a project for the Global Hemp Innovation

Figure 1. Aerial view of the Western Colorado Research Center at Grand Valley with highlighted fields under transition to subsurface drip irrigation (blue) and overhead sprinkler by linear move system (red).

Center, while other plots were used to grow sweet corn for the local hunger relief program. The construction of these plots now allows the WCRC-GV (Figure 1) to suspend intensive tillage and chemical applications to many of its other fields, reducing the overall footprint that the WCRC-GV budget and staff has to accommodate outside of purposeful research endeavors. The WCRC-GV is also pleased to report that it was awarded funding through the Colorado River District Community Partnership Program to begin construction of a linear-move overhead sprinkler system that will convert another field (12.5 acres) out of furrow irrigation. This project will again dramatically improve the availability of research experimental plots.

Conserved Consumptive Use Evaluations

The CWC continues to be lead for a collaborative project entering a second year of remotely sensed estimations of conserved consumptive use, strategies for reduced consumption, economic considerations, forage yield and quality impact of reduced pasture irrigation, and producer engagement. Multiple project fields totaling over 1,000 acres in Grand County (elev. 7,500 ft) were subjected to irrigation curtailments in 2020. The CU evaluations performed using an ensemble approach that averages 4 separate and diverse ET models: EEMETRIC (Allen et al., 2005; Allen et al., 2007), PT-JPL (Fisher et al., 2008), SIMS (Melton et al., 2012; Pereira et al., 2020), and SSEBop (Senay et al.,2014; Senay et al., 2018). Using this approach, CU rates of 17.0, 17.0, 16.7 and 17.1 inches for the May-August periods of 2016, 2017, 2018 and 2019.

Figure 2. Research enclosure in Grand County, Colorado of a field subjected to full-season irrigation curtailment in 2020, showing signs of positive recovery in 2021.

Figure 2. Research enclosure in Grand County, Colorado of a field subjected to full-season irrigation curtailment in 2020, showing signs of positive recovery in 2021.

After full-season irrigation curtailment, these fields exhibited a range of 42-45% reduction in CU, but have also begun to recover rapidly in 2021 despite the period of heavy stress brought on by lack of water in 2020. ❑

The WAVE program was developed, in part, to fill a gap in technical assistance available to landowners after wildfires and other large-scale hydrologic disturbances.

A Year Dominated By Fire and Its Aftermath

Blake Osborn, Water Resources Specialist, Southern Region

My work in 2020/21 can be summed up by one word: fire.

The wildfires of 2020 created a huge demand for our program, the Watershed Assessment and Vulnerability Evaluations (WAVE). I developed the WAVE program three years ago to build on my experience as a watershed hydrologist, specifically in "disturbance hydrology", and fill a gap in technical assistance available to landowners after wildfires or other large-scale hydrologic disturbances. This program was designed as a pipeline of services available to landowners, from basic consultation on post-fire recovery efforts to treatment implementation and applied research. The success of the program over the past year has built strong relationships with many different agency partners, water providers, and landowners. We have been asked to expand the program by training staff in other agencies and creating a shared methodology and data collection system that can be deployed across the state on future fires.

From August to December 2020, we completed more than 20 field assessments totaling more than 15,000 acres. Sometimes, we simply provided a technical report and recovery plan for affected landowners. In other cases, we helped landowners integrate their needs into the larger federally funded programs. Additionally, we were successful in securing funds to implement post-fire treatments and monitor water quality and erosion on our treatments.

CSU students helping install sediment fencing on severely burned hillslopes. Photo by Blake Osborn.

Water quality monitoring equipment near mulched areas. Photo by Blake Osborn.

POST-FIRE RESTORATION AND WATER QUALITY

We worked closely with one of our landowners, a private ranch in the Willow Creek Watershed, to stabilize severely burned hillslopes and mitigate the impacts of flooding and erosion/sedimentation. We successfully implemented five post-fire restoration treatments deployed three automated water quality sampling units to measure the water quality impacts from post-fire surface runoff from hillslopes treated with Best Management Practice (BMP) and from those without.

COLORADO WATER CENTER STUDENT FELLOWSHIP

2021 was an exciting year for the CWC Student Fellowship program, a legacy program started by MaryLou Smith five years ago. Nora Flynn and I are breathing new life into this program and successfully mentoring students in collaboration with partners in Denver. We have an exciting cohort of students for 2021/22. Additionally, one of our previous students and fellows, Daniel Dominguez, was awarded a prestigious Marshall Scholarship to study watershed management in the UK!

COMPARATIVE SENSOR STUDY

For the first time, all three water specialists (Perry, Joel and myself) are collaborating on a project. Our goal is to compare soil moisture sensors in a side-by-side test to evaluate accuracy, precision, and usability in a variety of soil types. At the time of this writing, this project is still collecting data and it will be evaluated in the coming months with publications and outreach materials expected over the next year.

Soil moisture sensor instrumentation in a field of dry beans. Photo by Blake Osborn.

ENGAGEMENT/OUTREACH ACTIVITIES

In addition to many outreach engagements from the three projects above, my customary outreach activities carried forward. I still serve as vice-chair of the Arkansas Basin Water Forum. We were not able to host a large forum in April but instead hosted three tours of various projects in the region. I serve on the advisory committee for the new San Luis Valley master irrigator course and the Water Education Colorado program committee. Look for our exciting edition of *Headwaters* magazine focused on wildfire and recovery (unless it's already published by the time of this reading, in which case I hope you enjoyed)! ❑

A Focus on Drought and the Colorado River

Brad Udall, Senior Water & Climate Scientist/Scholar

INTRODUCTION

The ongoing Colorado River drought continues to provide the focus for all my work. Runoff in 2021 was abysmal, about 60% of the 20th century average and the flow in last 22 years is just shy of a 20% decline compared to the 20th century. Runoff in 2020 was similar, with the result that Lakes Powell and Mead will be less than 30% full by spring of 2022. Low lake levels have resulted in the declaration of the first-ever Tier 1 shortage to be implemented starting in January of 2022. The ongoing flow and reservoir declines have sparked intense interest from stakeholders, the press, and the public. My report below is broken into sections on Outreach and Presentations, Publications and Datasets, Grants, Press Contacts, and Ongoing and Future Work.

OUTREACH AND PRESENTATIONS

I guest lectured in Sybil's Sharvelle's Interdisciplinary Training, Education and Research in Food-Energy-Water Systems (inTERFEWS) graduate class about Colorado River climate and management challenges. In Howard Ramsdell's undergraduate course on Western US water sustainability. I spoke on the implications of climate change on water resources. Unfortunately , COVID significantly reduced my outreach efforts.

PUBLICATIONS AND DATASETS

Along with multiple Utah State University authors, I wrote a paper on how declining Colorado River flows and increasing demands might affect the major Colorado River reservoirs and the ensuing reliability of water deliveries. John Fleck and I wrote an invited editorial in Science on how we should manage future risk in the Colorado River. With Connie Woodhouse, I submitted a paper on how the Gila River and its major tributaries, the Salt and Verde, are responding to climate change, including warming temperatures and changes in precipitation. With Jonathan Overpeck, I wrote a

During the summer of 2021, Lake Mead has declined to its lowest level since the reservoir was filled in the 1930s. ©2021 iStock.com.

short piece in the CWC newsletter summarizing recent findings from peer-reviewed literature on the impacts of climate change on the Colorado River.

GRANTS

Along with the Colorado Basin River Forecast Center (CBRFC) and the Southern Nevada Water Authority (SNWA), I submitted a 2-year approximately $200k grant to the Department of Interior to fund a postdoctoral researcher at CBRFC to help CBRFC investigate ways to make Colorado River annual flow volume forecasts more accurate. We have support from all major CRB water users including Denver Water, SNWA, Central Arizona Project, Metropolitan Water District of Southern California, Reclamation and others. We should hear about this in the next few months.

PRESS CONTACTS

Press interest in the Colorado River has been at an all-time high given the ongoing drought. During the year I worked with journalists from *The New York Times, Washington Post, Politico, The Guardian, The Economist,* *Circle of Blue,* CNN, the *New Yorker, The Weather Channel,* Colorado Public Radio, local CBS News, PBS, the *Arizona Daily Star,* and others to provide information about the drought. I was on two national NPR programs, *On Point* and *The Takeaway,* both of which were turned into podcasts.

ONGOING AND FUTURE WORK

Along with Julie Vano of the Aspen Global Change Institute and Jeff Lukas, I am building a wiki website, www.coloradoriverscience.org, to provide Decision Makers with continuing updates on new scientific developments in the Colorado River. The website covers data, science, projects, models, tools, and all other appropriate scientific endeavors in a wiki-like format. This is funded by the DOI Southwest Climate Adaptation Science Center and the Colorado Water Center.

With Lakes Mead and Powell projected to drop below 30% by next spring, I am interested in how accurate our Mead/Powell elevation/volume projections for future years are. My preliminary analysis suggests that Reclamation's minimum probable 24-month and 5-year projections provide an overly rosy view of the future—the hydrology driving these models is too wet. I will continue to investigate this issue and offer methods to improve these projections.

In 2020 I created some 'temperature-adjusted' natural flows that can be used in Reclamation's CRSS Colorado River model to investigate how the system might respond to lower future flows caused by increasing temperatures. This dataset continues to spark interest from different users and ongoing support throughout the year will be needed.

Connie Woodhouse and I will resubmit our Gila River climate change paper (see above) in response to reviewer comments.

At CSU, I am working with the new Climate Adaptation Partnership, an effort led by Courtney Schultz and Leisl Carr Childers and sponsored by the Vice President for Research. I have also been active with the new Climate Response Working group led by Peter Backlund (SOGES) and Jeffery Muhs (Energy Institute). We are planning a climate conference in the spring of 2021 focused on the state of Colorado.

I continue to support the activities of the Northern Plains Climate Hub including participation on quarterly calls and other responsibilities as needed.

I've been working with Denver Water, and a number of CSU employees to design the Western Water Policy Institute, to be housed at CSU's new SPUR Campus in Denver. ❑

Glen Canyon Dam jet tubes releasing water into the Colorado River for a high flow experiment. The increase in flow of the river downstream of the dam mobilizes sand and that sand rebuilds sandbars in Grand Canyon. Photo courtesy of USGS.

A flood-irrigated grass pasture near Cimarron, Colorado. Photo by Nora Flynn.

Seeking Collaborative Solutions for Water Users

Nora Flynn, Agriculture Water Specialist

In my first year as a Research Associate at the Colorado Water Center I've had the opportunity to start several new projects in collaboration with diverse water users.

INVESTIGATING THE INTERSECTION OF IRRIGATION MANAGEMENT AND SOIL HEALTH

In collaboration with the Colorado Water Trust and Trout Unlimited we are exploring the impacts of limited irrigation on soil health in high elevation grass pastures. These pastures are a critical part of our Colorado agricultural ecosystem and economy but not enough is known about how they change in response to limited water. The ranchers involved in this project want to better understand how participating in stream flow enhancement programs that benefit the river ecosystem will impact the health and productivity of their pastures.

BUILDING THE COLORADO WATER CENTER STUDENT FELLOWS PROGRAM

Together with Blake Osborn and Dr. Aditi Bashkar of CSU's civil and environmental engineering department, we are building the Colorado Water Center Student Fellows Program.

This program provides mentoring and research opportunities for students from previously underrepresented minorities in water. Our first project, which is supported by a grant from CSU's Center for Collaborative Conservation is an effort to create a water quality improvement plan for a section of the South Platte River in Adams County. Our talented CoWC Student Fellows created hands-on activities for Denver and Adams county youth to learn about river health and contemplate the relationship their local community has with the South Platte River. The Colorado Water Congress and CSU OEE have been exceptional supporters. This program continues to be refined to better serve students and their communities.

Water Student Fellows and Denver youth observe the South Platte River downstream of the Burlington Ditch diversion. Photo by Nora Flynn

The South Platte River corridor upstream of the Burlington Ditch diversion. Photo by Nora Flynn.

FACILITATING THE SOUTH PLATTE SALINITY STAKEHOLDER GROUP

Salinity is of growing concern in the South Platte Basin due to its impacts on crop production and the cost of removing salts from drinking water. So much so that a group of municipal, agricultural, and industrial water managers have come together to form the South Platte Salinity Stakeholder Group as means to increase collective understanding of the sources and impacts of salinity on not just their own but each other's sectors. This group has asked the CoWC to facilitate and provide technical expertise as needed. In its first year this group has created a list of priority research activities including studying the sources and fate of salinity and quantifying the cost of salinity to each economic sector.

SUPPORTING THE AGRICULTURE IMPACT TASK FORCE

Governor Jared Polis activated the Agriculture Impact Task Force in 2020 as a part of the State's drought response. The AITF continually monitors the physical and economic impacts of drought and makes recommendations for aid and mitigation to state leaders. The AITF has also added a focus on the impacts of drought on the mental health of Colorado's agricultural producers. While the AITF has historically deactivated during the winter months, we remained active all year and will continue to remain so in recognition that the impacts of drought on agriculture are long lasting and that dry conditions are expected to worsen due to climate change. ❑

Water Management Issues in Northeast Colorado

Joel Schneekloth, Water Resources Specialist, Northern Region

Water is a constant issue within Colorado for both irrigated and dryland production. In 2021, we began several projects looking at water conservation and management for both irrigated and dryland production systems. Several of these projects have been with the "push" from producers and companies within NE Colorado.

ALTERNATIVE CROPS

One of my long-term goals has been to obtain a greater understanding of water management for alternative crops that may have the potential to greater increase diversity while understanding irrigation management strategies for reduced irrigation potential. One of the newer crops we are looking at is cowpeas under both dryland and alternative irrigation management strategies. From previous observations, cowpea appears to have a greater drought coping mechanism than other dry edible beans and yield results from a dryland plot at Akron increased my interest in them during a drought year. With this project, we are collaborating with a company promoting cowpeas as a dryland crop while also trying to gain irrigated acres without a knowledge of irrigation management other than they seem to not respond to full irrigation practices. In 2021, we began a project looking at alternative water management strategies in cowpeas at Akron, CO under a rainout shelter. Preliminary data shows from 2021 shows interesting results on reduced water management potential.

PRECISION FARMING—WATER MANAGEMENT

Precision farming practices have been of producer interest with the development of technology to alter seeding and fertility rates. Although not based upon irrigation management, the USDA-ARS research station has started a long-term dryland precision management study looking at the factors that influence yields within larger scale fields. Within this project, I am leading the information and analysis of influences of water upon determining management zones and the impact of other practices such as seeding rates and fertility management. One of the major factors is determining the optimal seeding rates within a zone knowing the beginning soil moisture. We are currently working on developing response functions for numerous potential populations for dryland production of corn. Corn currently has the most potential for seeding rate changes for yield potential as well as economic impacts to producers.

One of the major obstacles to producer management is knowledge of beginning stored soil moisture within fields. We are working with Veris technology to determine if this has potential for understanding soil moisture changes within a field. According to previous research, if you have

Figure 1. Picture of cowpea irrigation treatments on August 27, 2021. Dryland (upper left), 4" allocation (upper right), 8" allocation (lower left) and full irrigation (lower right).

a knowledge of soil textural and salinity changes within a field, the Veris technology has the potential to determine soil moisture changes. We currently only have one year of data available with this data and will hire a post doc to work on this data.

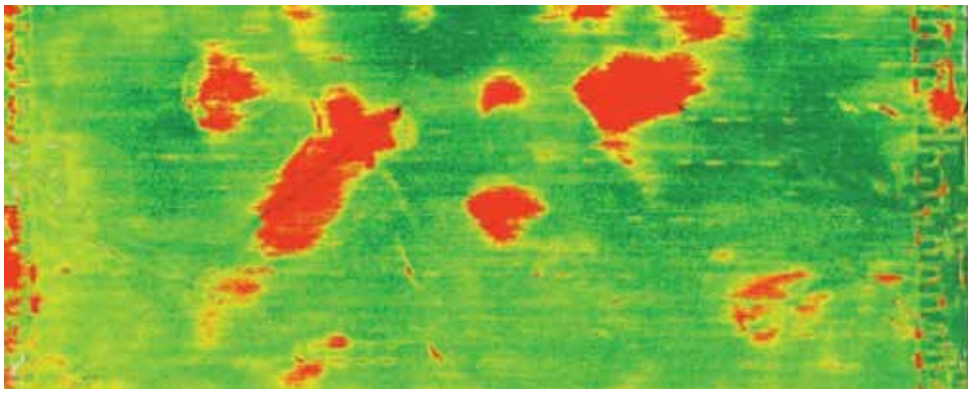
TECHNOLOGY TRANSFER FOR IRRIGATION MANAGEMENT

In 2020, a USDA Conservation Innovation Grant was obtained for a multi-state project looking at technology transfer for irrigation management. This project is based upon the University of Nebraska Testing Ag Performance Solutions (TAPS). The major component of this project is a producer competition based in Nebraska and Oklahoma on crop production management decisions for irrigation, fertility and marketing. These competitions are based at University research locations in these two states where producers make all of the decisions related to crop production with input from multiple layers of technology that are available to producers. This allows producers to utilize and test these technologies without any financial consequences on their own farms and allow them to incorporate these technologies into their operations that they deemed had the most impact on their management decisions.

The technologies available to participants include multiple soil moisture measurement platforms, crop health monitoring systems as well as aerial imagery related to crop performance such as infrared and NDVI imagery. Participants have the output of that technology available as they make day to day decisions on irrigation and in-season fertility management. Important outcomes of this in-field program include not just yield, but economic viability and input efficiency. Awards are given out based on efficiency of water, nitrogen and variety selection relating to yield output and total economic returns based on your management decisions. The yield award is tied to the economic returns so participants must take into account the economic impacts of their decisions which would infer that spending large amounts of dollars on inputs is not rewarded due to economic costs of those inputs.

> ...cowpea appears to have a greater drought coping mechanism than other dry edible beans and yield results from a dryland plot at Akron increased my interest in them during a drought year.

A final output of this project is an educational program looking at technologies available and the utilization of them within a multitude of water availability systems around the Ogallala Aquifer region. This programming will include discussions and input from participants of the TAPS program and how they utilized different technologies in their management decisions and what technologies transferred to their operations and management changes. ❑



NDVI imagery is available to participants in the TAPS program. The sample NDVI crop map at left shows variability in crop vigor in greater detail than a standard color image. Red indicates "drowned out" area and yellow areas show water stressed zones. Image courtesy of Iowa State University.

YEAR IN REVIEW

GRAD592

The CoWC organizes and conducts a graduate level course offered in the fall at CSU. GRAD592 is taught by Jennifer Gimbel, CoWC's Senior Water Policy Scholar, and hosts interested students in a variety of degree fields and academic ranks.

Described as an interdisciplinary water resources seminar, GRAD592 offers its attendees the opportunity to learn from and engage with distinguished lecturers from a variety of fields on the basis of each semester's theme.

In fall 2020, the course theme was "Western Water Law, Policy, and Institutions" and covered a multitude of sub-topics including:

- Federal and State, Regional and Local Water Law and Institutions
- Environmental Aspects of Water Policy and Politics
- Recreation: Water Law and Policy
- State Water Administration
- Science and Water Policy
- Reserved Water Rights
- Municipal Water Policy and Politics

While offered for school credit at CSU, the course is also open to the public and welcomes anyone who wishes to educate themselves on the issues and challenges that Colorado water managers and users face.

By going virtual with the class, participation increased to 41 attendees from the base of 5 students.

To learn more and watch previously recorded lectures, please visit **watercenter.colostate.edu/grad592**

COLORADO WATER CENTER
COLORADO STATE UNIVERSITY

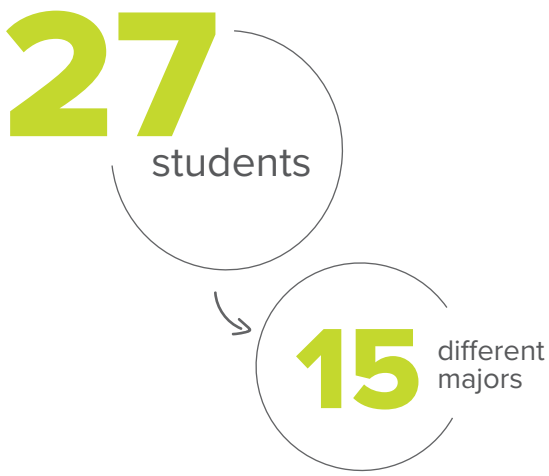
Presentations by:
Jennifer Gimbel, *Colorado Water Center*
Becky Mitchell, *Colorado Water Conservation Board*
Brad Wind, *Northern Water*
Jeni Arndt, *State Representative, HD 53*
Nicole Rowan, *Colorado Department of Public Health & Environment*
Ian Stafford, *American Whitewater*
Greg Kernohan, *Ducks Unlimited*
Kevin Rein, *Colorado State Engineer*
Brad Udall, *Colorado Water Center*
John Echohawk, *Native American Rights Fund*
Jim Lochhead, *Denver Water*

GES120 WATER SUSTAINABILITY IN THE WESTERN U.S.

GES120 is a 100-level course for CSU undergraduates interested in exploring and learning about various water-related topics. The curriculum was designed to familiarize students with the role that water plays in supporting different water users, the history of water development, processes and organizations that govern water allocation, tradeoffs that come with limited water supplies, and how to ensure the sustainability of water in an arid region such as the West. Students who complete GES 120 can apply three credits towards the SWIM program. Learn more about this course at watercenter.colostate.edu/ges120

Virtual and in-person offerings to accommodate different learning styles during the COVID-19 pandemic.

IMPACT HIGHLIGHTS



SUSTAINABLE WATER INTERDISCIPLINARY MINOR PROGRAM

Training future water experts

The Sustainable Water Interdisciplinary Minor (SWIM) is open to all majors and provides students with the opportunity to gain deeper knowledge about the many dimensions of water and prepare for a career in water or graduate study. Since the program was revamped in 2015, 50 students representing 20 different majors have graduated with the minor. The program is offered in partnership with the School of Global and Environmental Sustainability (SoGES) at Colorado State University. Learn more about the program at watercenter.colostate.edu/swim.

50 Graduates >> **20** Different Majors

15 graduates in Fiscal Year 2021

Virtual advising provided in partnership with our new SWIM Advisor, Ryan Deming, SoGES

"The SWIM program has educated me on a profusion of water-related issues, topics, and opinions throughout Colorado and the West. The program advisors will go out of their way to help you identify courses, internships, and careers paths. This program has helped me obtain student positions with the U.S. Army Corps of Engineers and the Colorado Water Center. My goal once I graduate is to tie my two fields of study together and work along the Front Range with a water sustainability-focused company."

—Champ Lindahl,
current SWIM student, majoring in business with a concentration in marketing

PUBLISHED REPORTS

Educating the public on recent research

For an archive of publications, please visit **watercenter.colostate.edu/publicationsdatabase**

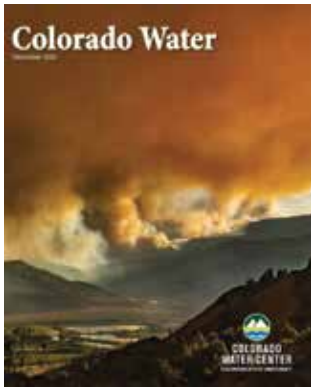
The CoWC has published hundreds of water-related research reports and studies dating back to 1965. CoWC reports for all funded projects are available for public access on the CoWC website. The following types of publications are in addition to the ***Colorado Water*** newsletter and ***The Current*** e-news, which frequently include summaries of research projects and their impacts on Colorado water managers and users.

Completion Reports	**Information Series**	**Technical Reports**
Special Reports	**Open-File Reports**	**Water in the Balance**

COLORADO WATER

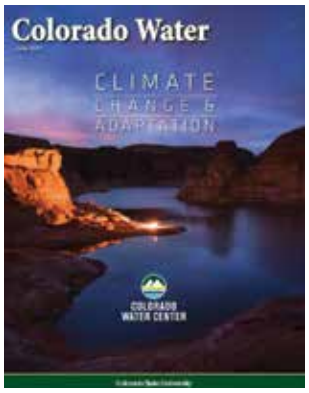
CoWC's Print Newsletter

For an archive of newsletters, please visit **watercenter.colostate.edu/colorado-water-archive**



Vol. 38, Issue 1
June 2021
Climate Change & Adaptation
Delivered to 928 recipients online with 685 total opens

Vol. 37, Issue 3
December 2020
2019-2020 Colorado Water Center Research, Education, and Engagement Projects



Subscribers
2,885
Hard Copy Subscribers
1,850
e-Readers
1,035

SUBSCRIBE
to *Colorado Water* to learn about research funded by the Colorado Water Center
tinyurl.com/CoWater-subscribe

THE CURRENT CoWC's monthly e-newsletter

For an archive of e-newsletters, please visit **watercenter.colostate.edu/the-current-archive**

Water-related research, education, events, jobs, grants, scholarships, and community partner news

The Colorado Water Center (CoWC) connects with the community through our e-news, *The Current,* with a readership of 1049 subscribers. Over the past year, CoWC published 12 issues that featured water-related updates including outstanding university researchers in Spotlight articles, important events, new data tools, educational resources, funding and scholarship opportunities, and much more. 18 students and 10 faculty and staff were showcased throughout the year for their contributions to water research and teaching. Several of those researchers were funded through the CoWC's various grant programs. These conversations shed light on what motivates their cutting-edge science and the impact they are working to achieve. All share a passion for improving how water resources are managed and conserved. CoWC made deeper connections through these informal interviews, which allowed for sharing more personal experiences beyond the data and research.

We've also had opportunities to spread awareness of new data tools and other resources. Among several new projects shared are CLASIC (Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs) (clasic.erams.com), a screening tool utilizing a lifecycle cost framework to support the feasibility and planning of stormwater infrastructure prepared by our partners at CSU's One Water Solutions Institute and sponsored by The Water Research Foundation; as well as the new interactive map with drought information statements developed by NOAA's National Integrated Drought Information System. The Current also featured a two-part series on the important and timely work of the CSU COVID-19 Wastewater Sampling Team and accompanying research.

SUBSCRIBE to *The Current* to keep up with the Colorado water community **tinyurl.com/TheCurrent-subscribe**

SOCIAL MEDIA Connecting with Colorado water managers and users

Follow the CoWC on all your favorite platforms: @COWaterCenter @ColoradoWaterCenter

Platform	Total Posts	Engagement *(Likes, Comments, etc.)*	Audience Increase
Twitter	197	4,519	**+3.7%**
Facebook	81	2,498	**+1.5%**
Instagram	124	2,026	**+7.8%**

Total Cross Engagement
9,043

Total Cross Posts
402

Net Social Media Audience Increase
+4.3%

EVENTS Engaging current and future water leaders

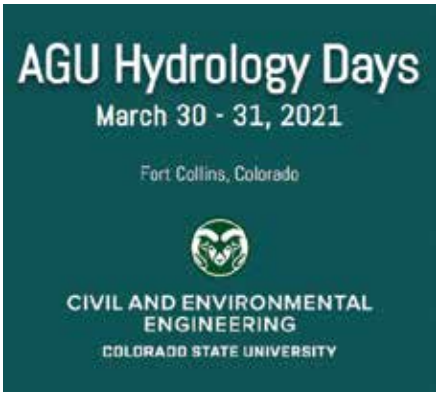
Throughout the past year, the Colorado Water Center (CoWC) sponsored, co-hosted, and partnered on several water-related events. The health precautions prompted by COVID-19 forced the cancellation of several other events, though many were offered virtually. Events were promoted through social media platforms, CoWC publications, electronic emails, and by sharing information at other events and meetings.

CoWC co-hosted the webinar "Whose Water Is It? Environmental Injustice and Water Privatization" in partnership with CSU's Center for Environmental Justice on April 19th 2021. A panel of experts came together on the critical topics of water equity, access, and security. They discussed investment and speculation, rural community and Tribal impacts, inequities affecting the Global South, and Water as a Human Right. In recent years, alarms have blared as water rights are sold to the highest bidder excluding local communities in favor of massive potential profits. Stakeholders from around the region and beyond are collaborating in unique ways to protect future water users. Panelists discussed diverse perspectives with an environmental justice lens. The recording of the webinar can be found at https://watercenter.colostate.edu/waterjustice/.

CSU brings new and prospective students to campus throughout the year to learn about the resources and programs offered. Together with our partners at the School of Global Environmental Sustainability, we promoted the Sustainable Interdisciplinary Water Minor, plus opportunities for undergraduates to engage in water activities at CSU. Student engagement is highly encouraged at CoWC hosted and partnered events. CoWC regularly supports students to attend events—like the Poudre River Forum and AGU Hydrology Days—by covering their registration fees. The Hydrology Days event, as well as CSU Earth Week, were both adapted to be held virtually, and CoWC staff worked with organizers to adapt content into compelling virtual programming. Hydrology Days featured 50 webinar presentations over two days. Presentations were given by eight undergraduate students and 42 graduate-level students. We welcomed over 210 registrants online, representing 75 organizations, including 21 national academic institutions, 28 international institutions, seven federal agencies, 15 private consulting firms, and 2 non-profit organizations.

Throughout the year, CoWC hosted, co-hosted, or sponsored the following events, in cooperation with campus and community partners:

- 2020 CSU Spur Water in the West Symposium
- American Geophysical Union (AGU) Hydrology Days
- CSU Earth Week: Earth Day Virtual Trivia Game
- Whose Water Is It? Environmental Injustice and Water Privatization



UPPER YAMPA WATER CONSERVANCY DISTRICT
JOHN FETCHER SCHOLARSHIP 2020-2021 AWARD RECIPIENTS

The Colorado Water Center partners in supporting the John Fetcher Upper Yampa Water Conservancy District Scholarship each academic year.

The Upper Yampa Water Conservancy District provides two $2,000 one-year scholarships for full-time university student(s) who are pursuing a water-related career in any major at a public university within the state of Colorado. The Colorado Water Center administers the scholarship.

Congratulations to 2020-2021 scholarship recipients Sierra Mitchell and Tanya Petach.

SIERRA MITCHELL

Sierra Mitchell, Graduate Student, Environmental Science Engineering, Colorado School of Mines

Throughout her undergraduate education at Colorado Mesa University, Sierra Mitchell became heavily involved in water. As a research assistant at the Ruth Powell Hutchins Water Center, she gained experience in the science and policy of the Colorado River Basin.

Sierra contributed to a project designing scrubbers to remove selenium from irrigation water before it enters the river's ecosystem which she presented at the Upper Colorado River Basin Forum in November 2019. Working with engineering professors, Sierra analyzed snowpack on the Colorado National Monument and the Grand Mesa. Their research seeks to quantify the impacts of aridification and other environmental changes in the region. Sierra will begin her graduate studies at the Colorado School of Mines this fall.

Sierra plans to become a hydrologist for a state or federal government agency. She explains in her application "the further I was into my degree the more I realized how intertwined policy and the environment really are." She sees how valuable her combined expertise in science and policy will be for her future career.

TANYA PETACH

Tanya Petach, Doctoral Student, Environmental Engineering, University of Colorado Boulder and Graduate Research Fellow, National Science Foundation

Tanya Petach describes her interest in water, "Colorado water management is awash with creative ideas, novel implementation, and bold decision making", and it is clear how her work and career path fits right in. Currently, in her graduate research, she investigates the impact management decisions have on water quality in time and space. She uses 200 million data points from across Colorado to assess which management decisions are associated with the greatest change in water quality over a 40-year period. She is comparing streams with both beneficial and detrimental changes.

Looking to the future, Tanya considers the conditions of our water resources that the next generation will face. She understands the importance of educating the youth to achieve sustainable solutions. During the summers, Tanya works with the Headwaters Alliance running a week-long acid mine drainage camp for elementary-age children, and she teaches fourth-graders by conducting hands-on water labs.

Tanya is continuously learning and striving to better understand the complex system of water in Colorado. Networking at local events such as workshops at the Getches-Wilkinson Center at CU Boulder and attending stakeholder watershed meetings gives Tanya valuable experience to further her understanding of how engineering connects with the larger picture of Colorado water management. ❑

FY21 CoWC Staff

Ally Altimore
Accounting Intern

Amanda Barngrover
Administrative Assistant

Perry Cabot
Research Scientist & Extension Specialist (Western Region)

Theresa Centola
Water Research Assistant

Cameron Denison
IT Technician Intern

Nolan Doesken
Former State Climatologist

Emma Enebo
Program Assistant

Nora Flynn
Agriculture Water Specialist

Jennifer Gimbel
Interim Director

Angelique Giraud
Water Outreach Coordinator

Nancy Grice
Assistant to the Director

Emmett Jordan
Graphic Designer

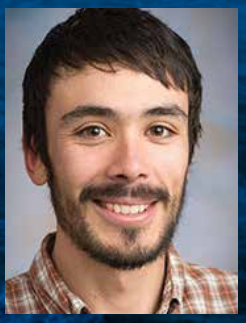
Julie Kallenberger
Associate Director

Karen Kwon
Water Policy Specialist

Melissa Mokry
Editor

Panagiotis Oikonomou
Affiliate

Jake Ornes
IT Technician Intern



Blake Osborn
Water Resources Specialist
(Southern Region)

Emily Pantoja
Graphic Designer

Joel Schneekloth
Water Resources Specialist
(Northern Region)

Molly Smith
Accounting Procurement
Intern

Swee Tee
Water Research
Assistant

Brad Udall
Senior Water & Climate
Scientist/Scholar

Reagan Waskom
Director

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Executive Director, Southeastern Colorado Water Conservancy District

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General Manager, Republican River Water Conservation District

Alexandra Davis

Division Manager, Aurora Water, City of Aurora

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Manager, San Luis Valley Water Conservancy District

Kate Greenberg

Commissioner, Colorado Department of Agriculture

David Kanzer

Deputy Chief Engineer, Colorado River District

Eugene Kelly

Professor, Deputy Director, Asst. Dean for Extension; AES, College of Agricultural Sciences

Ken Knox

Director of Water Resources, Extraction Oil & Gas

Eric Kuhn

Retired, Colorado River District

Mike Lester

State Forester and Director, Colorado State Forest Service

David Mau

Director, USGS Colorado Water Science Center

Rebecca Mitchell

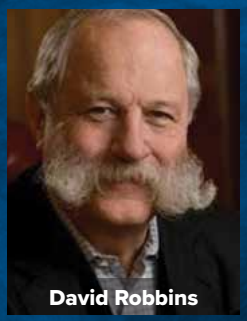
Director, Colorado Water Conservation Board

Chris Piper

Legislative Liaison and Policy Analyst, Colorado Energy Office

Kevin Rein

State Engineer & Director, Colorado Division of Water Resources



David Robbins

President & Co-Founder, Hill & Robbins, P.C. CoWC External Advisory Board Chair

Travis Smith

Western Water Conservation Coordinator, National Wild Turkey Federation

Eric Wilkinson

Policy Advisor, Northern Colorado Water Conservancy District

CoWC CSU Faculty Executive Committee

Allan Andales

Professor, Agricultural Sciences

Peter Backlund

Assoc. Director School of Global Environmental Sustainability

Troy Bauder

Asst. Deputy Director, Agricultural Experiment Station

Kevin Bestgen

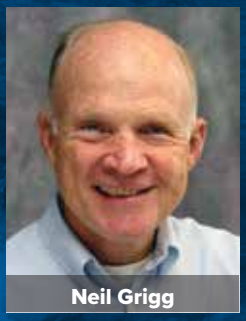
Sr. Research Scientist, Dept. of Fish, Wildlife, and Conservation Biology, Warner College of Natural Resources

Rob Ettema

Professor, Dept. of Civil and Environmental Engineering, College of Engineering

Chris Goemans

Assoc. Professor, Dept. of Agricultural Resource Economics, College of Agricultural Sciences



Neil Grigg

Professor, Dept. of Civil and Environmental Engineering, College of Engineering

Kelly Jones

Assoc. Prof., Dept. of Human Dimensions of Natural Resources, Warner College of Natural Resources

Stephanie Kampf

Professor, Dept. of Ecosystem Science and Sustainability, Warner College of Natural Resources

Eugene Kelly

Professor, Deputy Director, AES, College of Agricultural Sciences, Associate Dean for Extension

Stephanie Malin

Asst. Professor, Dept. of Sociology, College of Liberal Arts

Jeff Niemann

Professor, Dept. of Civil and Environmental Engineering, College of Engineering

LeRoy Poff

Professor, Dept. of Biology, College of Natural Sciences

Howard Ramsdell

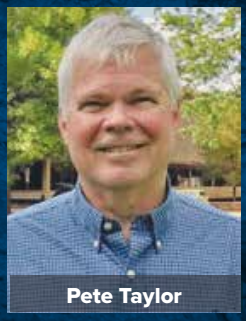
Assoc. Professor, Dept. of Environmental and Radiological Health, College of Veterinary Medicine and Biodemical Sciences

Patricia Rettig

Head Archivist, Water Resources Archive, CSU Morgan Library

Bill Shuster

Master Instructor, Dept. of Management, College of Business



Pete Taylor

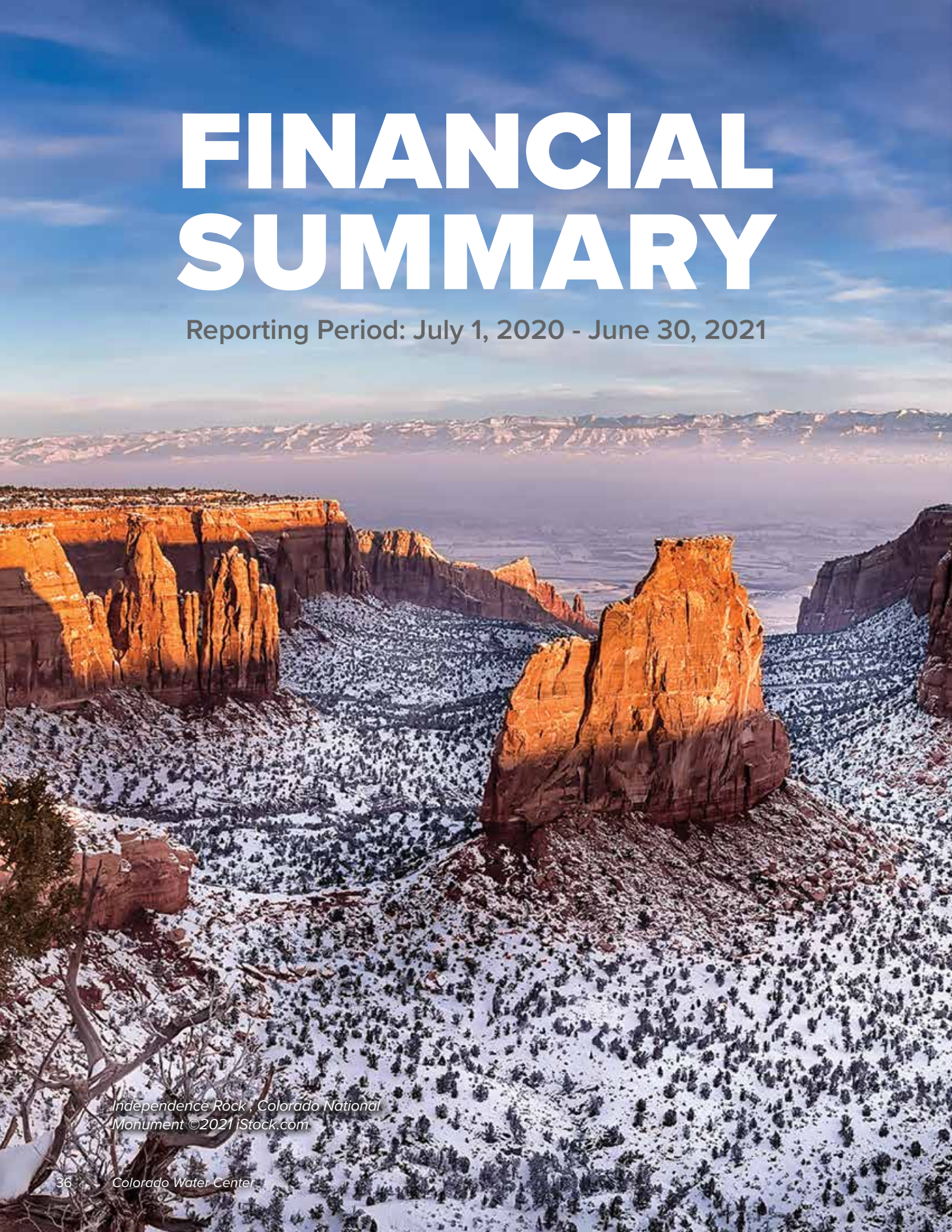
Chair, Professor, Dept. of Sociology, College of Liberal Arts

Reagan Waskom

Former Dir. and Committee Chair, Colorado Water Center

FINANCIAL SUMMARY

Reporting Period: July 1, 2020 - June 30, 2021



Independence Rock , Colorado National Monument ©2021 iStock.com

SUMMARY BREAKDOWN

CoWC Base Funding	**$ 751,135**

CoWC RESEARCH FUNDING SOURCES

Foundation	$ 101,324
USGS	$ 430,079
CSU Provost Research Support	* $ 64,302
Total	** **$ 595,705**

ACTIVE PROJECT TYPE

Research	20
Outreach	2
Training	1
Total	**23**

STUDENT DEGREE LEVEL ON PROJECTS

Undergraduate	15
Masters	12
Ph.D.	6
Total	**33**

*CSU Provost Research Support of $64,302 is included in FY 21 CoWC Base Funding of $751,135.

**Multiple research projects being conducted during a multi-year timeframe can cause overlap in funding.

COLORADO
WATER CENTER
COLORADO STATE UNIVERSITY

1033 Campus Delivery
Fort Collins, CO 80523-1033
970-491-6308 **watercenter.colostate.edu**

ENGAGEMENT
AND EXTENSION
COLORADO STATE UNIVERSITY

USGS
science for a changing world

NIWR
THE NATIONAL INSTITUTES
FOR WATER RESOURCES

Pawnee National Grasslands, ©2021 iStock.com