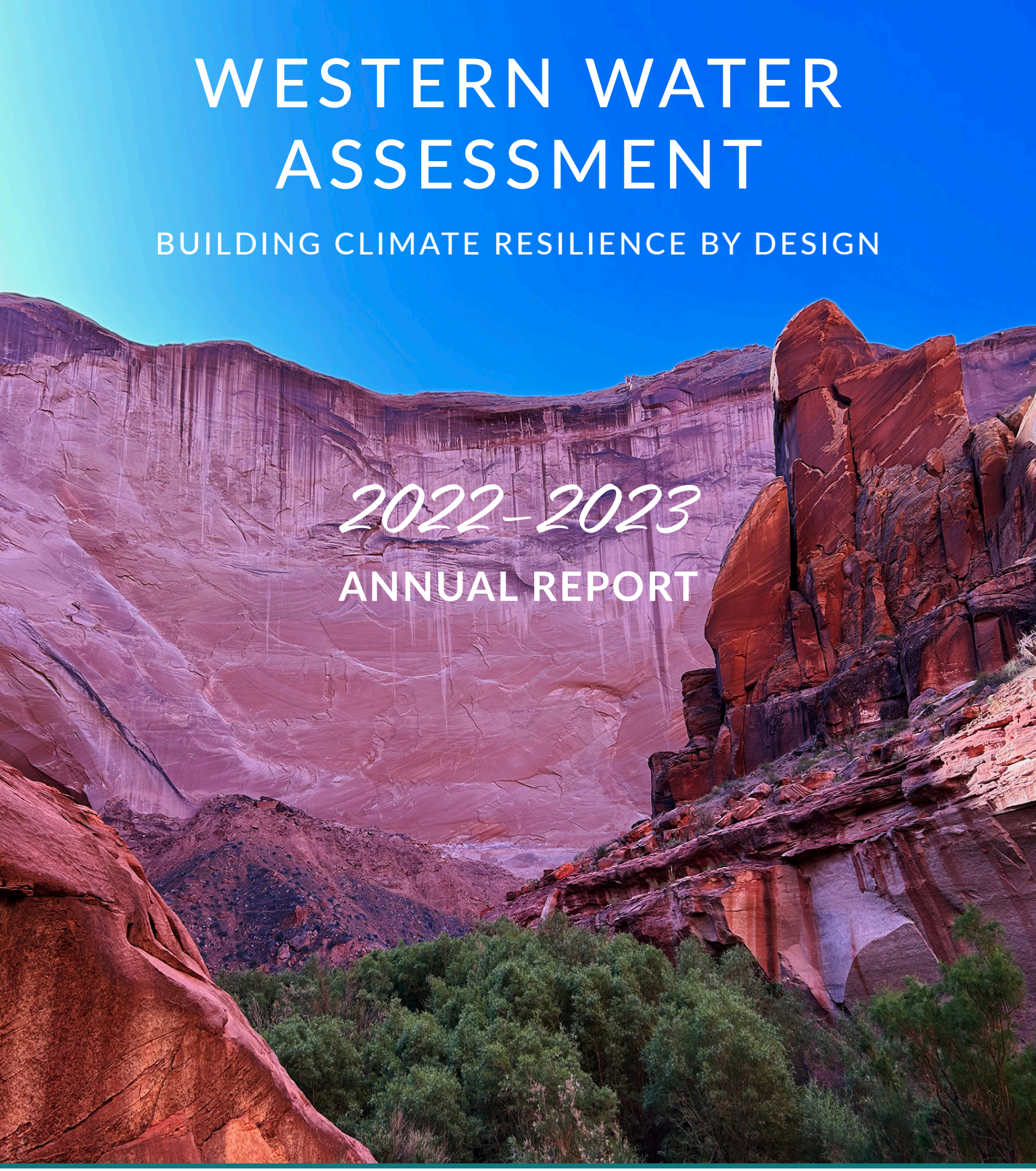
WESTERN WATER ASSESSMENT

BUILDING CLIMATE RESILIENCE BY DESIGN



2022–2023 ANNUAL REPORT

WESTERN WATER ASSESSMENT
A NOAA RISA TEAM

CIRES

University of Colorado Boulder

THE UNIVERSITY OF UTAH®

UNIVERSITY OF WYOMING

WESTERN WATER ASSESSMENT
A NOAA RISA TEAM

Cooperative Institute for Research in Environmental Sciences (CIRES)
University of Colorado Boulder

Global Change and Sustainability Center (GCSC)
University of Utah

Haub School of the Environment
University of Wyoming

wwa@colorado.edu
wwa.colorado.edu

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Principal Investigators
Ben Livneh, University of Colorado Boulder
Benét Duncan, University of Colorado Boulder

Co-Investigators
Karen Bailey, University of Colorado Boulder
Joseph Barsugli, University of Colorado Boulder (through 8/2023)
Lisa Dilling, University of Colorado Boulder (through 8/2023)
Corrie Knapp, University of Wyoming
Noah Molotch, University of Colorado Boulder
Court Strong, University of Utah
William Travis, University of Colorado Boulder (through 8/2023)

Annual Report Staff
Benét Duncan, Editor and Writer
Ethan Knight, Writer
Ben Livneh, Director
Ami Nacu-Schmidt, Layout and Design

Cover photo: Cow Canyon, Utah. Credit: Seth Arens

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Photo: Wildflowers in Superior, Colorado.
Credit: Ethan Knight.

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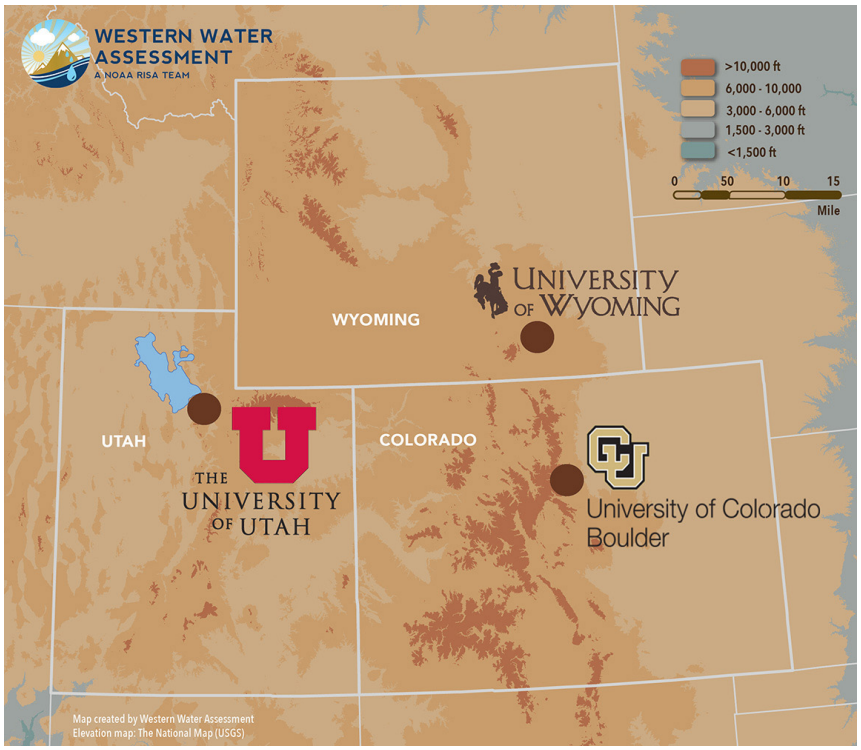
Photo: View from Vail Mountain in Colorado. Credit: Ethan Knight.

ABOUT WWA

Western Water Assessment (WWA) is a university-based applied research program that addresses societal vulnerabilities to climate variability and climate change, particularly those related to water resources. We work across the Intermountain West—Colorado, Utah, and Wyoming—and we are based at the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado in Boulder, CO, the University of Wyoming in Laramie, WY, and the University of Utah in Salt Lake City, UT. We conduct innovative research in partnership with communities and decision makers in the region, helping them make the best use of science in planning and managing for climate impacts.



WWA's vision is to build regional resilience to compound hazards, with a particular focus on underserved Indigenous and small rural communities and utilities.

Our vision is to build regional resilience to compound hazards, with a particular focus on underserved Indigenous and small rural communities and utilities. Our research projects fit within two themes—resilient water systems and resilient communities—and bring together interdisciplinary expertise from across our project team. In addition to our research projects, ongoing research integration activities help us to collaboratively identify needs and opportunities with our partners, and program evaluation activities help us to track our impact. Through this thoughtful approach to projects, we are advancing resilience science from theory to practice.

Our work draws on the deep interdisciplinary social and natural science expertise on our team, which includes experts in social science, co-production, adaptation and vulnerability research, atmospheric science, hydrology, climate assessment, climate impacts, and equity in adaptation. This unique combination of skills, combined with our 20-year history of climate adaptation research and activities, allows us to make an impact at a time when extreme weather events, climate change, and societal stressors are challenging the resilience of the Intermountain West like never before.

WWA is one of 12 teams in the NOAA-funded Climate Adaptation Partnerships program (CAP; formerly the Regional Integrated Sciences and Assessments, or RISA, program). This annual report details accomplishments and impacts of projects supported by three different NOAA CAP/RISA grants. Activities supported under WWA's NOAA CAP/RISA funding from 2015-2022 are indicated by {*O}, activities under funding from 2020-2022 are indicated by {*S}, and activities supported by our most recent award, which covers 2021-2026, do not have any symbol designations.

2022-2023 BY THE NUMBERS

SOCIAL MEDIA

Twitter
189,900+ Tweet Views
161 New Followers
1,222 Total Followers

Facebook
527 Total Followers

LinkedIn
47 Total Followers

Instagram
110 Total Followers

Mastodon
4 Total Followers

WEBINARS

5 Webinars
8 Workshops
59 Presentations
72 Total Events

YOUTUBE

935
YouTube Views

MAILING LIST

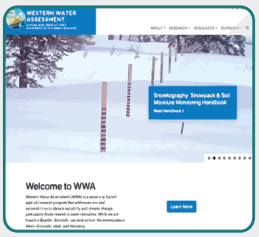
98
New Subscribers

1,717
Total Subscribers

WEBSITE

14,388
Website Users

34,010
Page Views



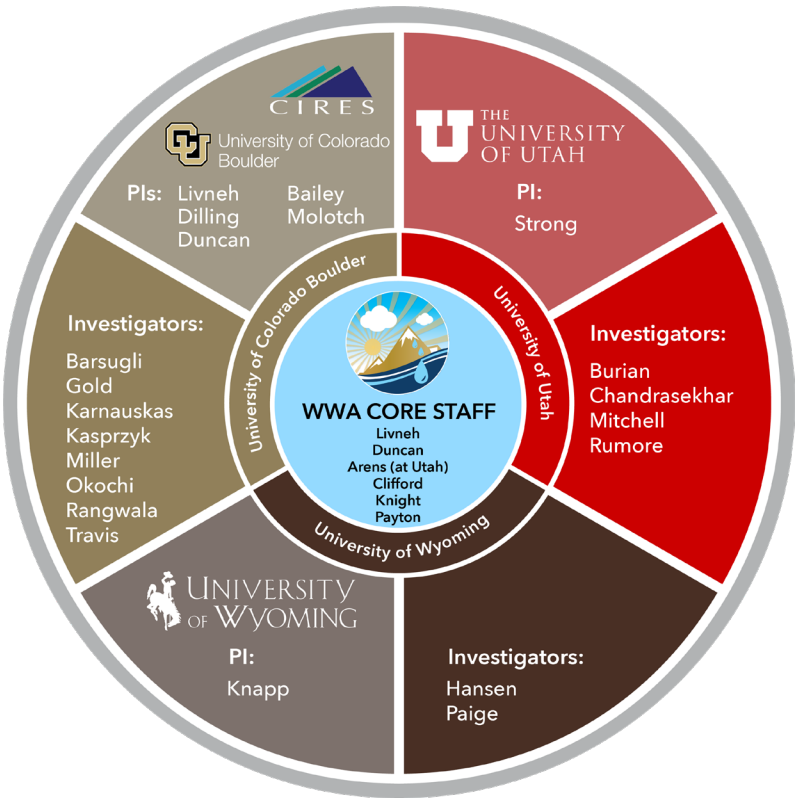
NEWS & RESEARCH

27 Research Publications

97+ Media Mentions

WWA TEAM AND ORGANIZATION

WWA is formally part of the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado Boulder (CU Boulder); the University of Wyoming; and the Global Change and Sustainability Center (GCSC) at the University of Utah. WWA is led by our Principal Investigator (PI) group; our full-time staff members focus on program management, research development and synthesis, and coordination of stakeholder science and collaborations. Our broader network of investigators and partners comes from universities and government institutions across our region and provides a wide range of expertise. The WWA External Advisory Board consists of national experts from across the science-policy landscape and provides critical programmatic guidance to the core staff and PIs. Taken together, this network represents a broad base of expertise and relationships that enable WWA to meet stakeholder needs and advance scientific understanding.



PROGRAM STAFF

BEN LIVNEH
Director

BENÉT DUNCAN
Managing Director

SETH ARENS
UT Research Integration Specialist

KATIE CLIFFORD*
CO Research Integration Specialist

ETHAN KNIGHT*
Associate Scientist

LIZ PAYTON
Water Resources Specialist

PRINCIPAL INVESTIGATORS

- Ben Livneh (Program Director; Co-lead PI)
- Benét Duncan (Managing Director; Co-lead PI)
- Karen Bailey*
- Joe Barsugli (through 8/2023)
- Lisa Dilling (through 8/2023)
- Corrie Knapp*
- Noah Molotch
- Bill Travis (through 8/2023)
- Court Strong

EXTERNAL ADVISORY BOARD

- Kathy Jacobs, Chair (University of Arizona)
- Richard Moss (Princeton University and Pacific Northwest National Laboratory)
- Dannele Peck (USDA Northern Plains Climate Hub)
- Mark Shafer (Southern Climate Impacts Planning Program)
- Michelle Stokes (Colorado Basin River Forecast Center)

INVESTIGATORS, STUDENTS, AND PARTNERS

- Natalie Bennett+
- John Berggren*
- Kaitlyn Bishay+
- Nels Bjarke+
- Paul Brooks
- Carli Brucker+
- Steve Burian
- Ethan Burns+
- Jeff Deems
- Anne Gold
- Kristiana Hansen
- Jen Henderson
- Jacob Hochard
- Kris Karnauskas
- Joseph Kasprzyk
- Eric Kennedy+
- Leanne Lestak
- Jeff Lukas
- Kelly Mahoney
- Steve Miller
- Toby Minear
- Logan Mitchell
- Rebecca Morss
- Ami Nacu-Schmidt
- Christine Okochi
- Rebecca Page*
- Ginger Paige
- Luca Palasti+
- Emily Peters+
- Balaji Rajagopalan
- Imtiaz Rangwala
- Andrea Ray
- David Rosenberg
- Danya Rumore
- Rebecca Smith
- Christa Torrens+
- Olga Wilhelmi
- Travis Williams*
- Heather Yocum

* Indicates early career

+ Indicates student

FEATURED ACCOMPLISHMENT

Western Water Assessment (WWA) made important strides in expanding our activities in Wyoming, thanks in large part to the leadership of Co-PI **Corrie Knapp**. One important component of this was the launch of our Adapting to Climate Change in Wyoming grant competition, led by **Knapp** in collaboration with core staff members **Katie Clifford** and **Benét Duncan**, and with investigator **Ginger Paige**. In May 2023, the competition awarded a total of $30,000 each to three projects over two years for climate adaptation planning or implementation for rural and tribal communities in the state. The project leads will receive funds and begin work on their projects in June 2023.

Wyoming communities face increasing climate-related risks including wildfire, drought, flooding, and heat waves. This funding competition provided a rare and important opportunity to directly support adaptation and build climate resilience in underserved communities in the state. Applicants provided brief, five-page descriptions of their projects. Proposals were ranked based on their demonstrated community interest, resources and networks in place to support the project, realistic budget and timeline, appropriate and sufficient partners, strong connection to their communities, clarity about how resilience or adaptation would be built through the project, their plan for communicating with WWA and leveraging of WWA resources, their plan for and potential impact of external outreach, and the quality, novelty, and innovation of their ideas. We particularly encouraged proposals from entities and communities who have been historically underserved including Indigenous and small rural communities.

During the performance period, **Knapp** worked with **Clifford** and **Duncan** to develop a funding announcement, identify areas of expertise and services that WWA core staff members could provide to funding recipients, and to launch the funding opportunity. We collaborated with staff member **Ethan Knight** to lead a webinar to share details of the competition. We received a total of seven applications that were considered by a proposal review committee assembled by **Knapp** that included **Clifford**, **Duncan**, and **Paige**.

Photo above: WWA scientist Seth Arens wades the Escalante River in Utah while conducting plant surveys. Credit: Seth Arens.

The following three projects were selected for funding:

HELPING RURAL WY ORGANIZE FOR CLIMATE ACTION

Led by the Wyoming Outdoor Council in collaboration with Lander Climate Action Network and Citizens United for Responsible Energy Development

Addressing climate change is particularly challenging in Wyoming, a sparsely populated rural state whose economy and communities are intricately tied to fossil fuel extraction. This project seeks to leverage the resources of the Western Water Assessment to bolster and unify Wyoming's growing climate movement by pr oviding a range of support to residents in Pinedale and Cody, WY. The project team's main objective is to remove barriers for citizens in Pinedale and Cody and help ensure they can access all available resources to bring about their homegrown climate solutions after the project ends. Wyoming Outdoor Council (WOC) will help these communities organize effectively and access vital information so they can influence public discourse and create local changes that build resilience over time.

AN INDIGENOUS YOUTH CULTURE AND CLIMATE CAMP

Led by the Haub School of Environment and Natural Resources, the Greater Yellowstone Coalition, and the Wind River Tribal Buffalo Initiative

The project leads will develop Indigenous Youth Culture and Climate Camps that will support Indigenous ways of knowing, climate adaptive strategies, and prepare the youth for the future on the Wind River Reservation. These intergenerational land-based camps will focus on preserving cultural traditions while fostering a passion for environmental sustainability. The project goals are: ***Cultural Empowerment***, providing a safe space for the youth to learn ancestral traditions from Elders. ***Environmental Stewardship***, to teach youth about protecting nature and local ecosystems. ***Climate Action***, to inspire youth as environmental ambassadors for positive change. ***Tribal Governance***, understanding Wind River's unique sovereignty to strengthen stronger communities and families. The camp hopes to accomplish a strong sense of place that is rooted in culture.

PARTICIPATORY PLANNING FOR EQUITABLE CLIMATE ACTION IN JACKSON, WY

Led by the Town of Jackson, WY and Voices JH

The Town of Jackson and Voices Jackson Hole (Voices JH) are collaborating to engage historically disadvantaged and vulnerable residents in the development of the Town of Jackson's Community Sustainability Plan. Jackson faces increased wildfire risk, flooding risk, sustained drought, and warming temperatures. Water pollution, air pollution, and hazards in the built environment contribute to growing public health risks. The Town of Jackson ranks worst in the country with respect to income inequality, which destabilizes the community and threatens to undermine its resilience to the shocks and stressors of climate change. To advance community resiliency, the Community Sustainability Plan must account for pre-existing risks, the vulnerabilities of marginalized community members, and the intersectionality of risks facing these community members. The project leads will deploy a participatory process that ensures that the Community Sustainability Plan is developed with robust input from Jackson's most vulnerable residents from the outset. At the completion of the two-year grant period, the Town will have identified mitigation, adaptation, and conservation needs and strategies that will be integrated into the data and community-driven Community Sustainability Plan. The participatory planning process will help forge a strong partnership between the Town of Jackson, Voices JH, and members of the community who are dedicated to improving their quality of life.

All three projects will receive funding and begin activities during summer 2023, and they will be completed by summer 2025. We are excited to collaborate with each of the project teams to help support and advance their innovative projects and build climate resilience in Wyoming. Each project will develop a public-facing reporting component, which we will share publicly on the WWA and University of Wyoming Haub School websites in summer 2025.

Photo: Lake Dillon, Colorado. Credit: Ethan Knight.

RESEARCH HIGHLIGHTS

ASSESSING NEEDS AMONG VULNERABLE COMMUNITIES IN WYOMING

WWA Co-PI **Corrie Knapp** and core staff member **Katie Clifford**, together with student **Emily Peters**, continued work on a project to improve our understanding of adaptation needs in carbon-dependent communities and explore opportunities for building resilience to compound hazards in Wyoming. **Peters** and **Knapp** assessed existing research efforts around climate change impacts and compound hazards in the state, including interviews with long-term researchers, managers, government officials, and NGOs, and a thorough literature review to highlight the status of existing work to provide a baseline of state-wide efforts. Results of the needs assessment helped to inform a second phase of the project: the Wyoming Small Grants Competition (see Featured Accomplishment, above). During the reporting period, **Peters** and **Knapp** completed interviews and analysis for the needs assessment component of the project, and they plan to submit a manuscript for peer-reviewed publication in 2023.

NATIONAL CLIMATE ASSESSMENT

Across the US, floods, droughts, heatwaves, wildfires, sea level rise, and other hazards are being amplified by climate change. To understand these changes, Congress mandates that the US Global Change Research Program prepare and submit a National Climate Assessment (NCA) every four years. The Fifth NCA (NCA5) is currently under development. Its 32 chapters will cover climate trends and projections for the coming decades and their implications for the nation, with topics ranging from Energy to Ecosystems. In 2021, WWA core staff member **Liz Payton** was appointed to lead the Water chapter, and Co-PI **Corrie Knapp** was appointed to lead the Northern Great Plains chapter. As chapter leads, **Payton** and **Knapp** have been responsible for selecting and managing author teams, chapter development and writing, and for ensuring that their respective chapter narratives are clear, accurate, and accessible to a broad audience. The NCA5 will be released in late 2023.

Photo below: National Climate Assessment Water Chapter team meeting. Credit: Liz Payton.

Photo above: The Dolores River in Paradox Valley, Colorado with the La Sal Mountains in the background. Credit: Seth Arens.

USABILITY OF MEDIUM-RANGE FORECASTING FOR WATER SYSTEM RELIABILITY

WWA Co-PI **Court Strong** is leading an effort that leverages existing research at the University of Utah to study the impacts of interconnected changes due to climate variability on water supply, demand, and water system reliability with the Salt Lake City Department of Public Utilities (SLCDPU). It builds on years of partnership working with the SLCDPU personnel to conduct climate impact assessments and develop adaptation measures. Working with SLCDPU, the real-world implications of projected conditions will increase understanding of water system performance in this understudied planning period. During the reporting period, **Strong** and collaborators finalized a climate vulnerability assessment of Salt Lake City's water systems and developed a stakeholder-motivated paper on multi-year controls on groundwater storage in seasonally snow-covered headwater catchments. In May 2023, **Strong** began work with WWA's **Imtiaz Rangwala** and **Seth Arens**, and student **Prasad Thota** to develop a new online tool that will be used to inform seasonal precipitation forecasts for SLCDPU and hence operational water management.

SENSE OF PLACE AND ADAPTIVE CAPACITY IN THE INTERMOUNTAIN WEST

WWA's **Karen Bailey**, **Katie Clifford**, and **Seth Arens** continued work on a project to better understand how sense of place might be leveraged to assist in adaptation efforts in rural communities across the Intermountain West. This project is looking at how drought and climate change impacts to reservoirs in the Upper Colorado River Basin influence sense of place, and how shifts in sense of place may impact adaptive capacity in locations experiencing visible change. It represents a deepening focus on compound hazards and will include case studies in rural areas that may have more

limited adaptive capacity. During the performance period, **Bailey** secured Institutional Review Board (IRB) approval on this work and supported students **Emma García**, **Shadia Nagati**, **Warren Cook**, **Jordan Lee**, **Levi Van Pelt**, **Jordan Matson**, and **Rebecca Briesmoore** to assist with data collection and analysis with a focus on three reservoir regions: Lake Powell in UT and AZ, Blue Mesa in CO, and Flaming Gorge Reservoir in WY. Initial findings highlight the role of various emotions (guilt, love, fear) in influencing perspectives on drought and drought adaptation. Results also point to challenges and opportunities around conflict management within and beyond communities. These research activities will contribute to one honors thesis and one dissertation.

BUILDING RESILIENCE TO COMPOUNDING IMPACTS OF WILDFIRE AND SNOWPACK DECLINES

WWA Co-PI **Noah Molotch** is working with Director **Ben Livneh** on a project that will utilize historical and future snowpack simulations to understand the evolving risk of wildfire across the WWA three-state region. By applying ground observations, satellite data, and modeling, Molotch and Livneh will improve our understanding of the connections between fire and snowpack regimes. They will also use a recently developed technique to consider the compounded effects of future snowpack loss and summer precipitation and temperature extremes on wildfire risk. This project has profound implications for future wildfire management and adaptation, particularly in the water sector. During the reporting period, **Molotch** and student **Eric Kennedy** analyzed forest productivity data in Colorado and showed that snowmelt and soil moisture are important variables that dictate forest productivity during the growing season. This result adds to the previous literature by tracking the influence of snowmelt on soil moisture during the growing season and relating that to forest health metrics such as productivity.

AFTER THE FIRE: INFORMING WATER SYSTEMS MANAGEMENT IN BURNED LANDSCAPES

After a fire, water suppliers face a critical decision on whether to divert low-quality water or let it bypass their intakes, risking their financial bottom line by not delivering anticipated water quantities to their municipal and agricultural customers. WWA Director **Ben Livneh** is working with student **Carli Brucker** to quantify post-fire hydrologic and water quality risks in the form of spatial "layers" of expected responses from varying wildfire severities, rainfall intensities, and catchment properties. They seek to provide guidance on how different watersheds may respond to fire and identify which watersheds are more likely to thrive in the future, versus which watersheds are likely to produce lower-quality post-fire water that will challenge operations. During the reporting period, they published a paper describing the state of the science on experimental simulators of post-wildfire water quality. They also submitted a manuscript that describes the outcomes from their own laboratory scale experiments in which they subjected soil samples to burning, rainfall, and different terrain slopes and collected and analyzed water quality samples. Lastly, they are preparing a manuscript that analyzes water quality from hundreds of basins across the western US, comparing pre- and post-fire water quality as well as burned and unburned locations. This work was highlighted in a presentation delivered by **Brucker** as part of the WWA webinar series in October 2022.

THE NUTS AND BOLTS OF CO-PRODUCTION

WWA's **Katie Clifford** led the development of a new paper sharing lessons and considerations for co-production with communities. This paper was written in partnership with **Jen Henderson**, **Zoë McAlear**, **Lisa Dilling**, **Benét Duncan**, **Samuel Ehret**, **Seth Arens**, **Rebecca Page**, and **Ursula Rick**. **Clifford** and coauthors identified a set of eight questions for researchers to consider when designing and conducting co-produced science with communities. The questions link to topics that include community recruitment, champion selection (i.e., identifying a local individual or entity to help lead a collaborative effort), participant makeup (i.e., including individuals with a range of backgrounds and expertise in collaborative community workshops), geography, clarifying expectations, timing, prioritization, and next steps. Their work provides insights across knowledge co-production and draws on lessons learned from WWA's 2018-2019 VCAPS pilot project {*O}.

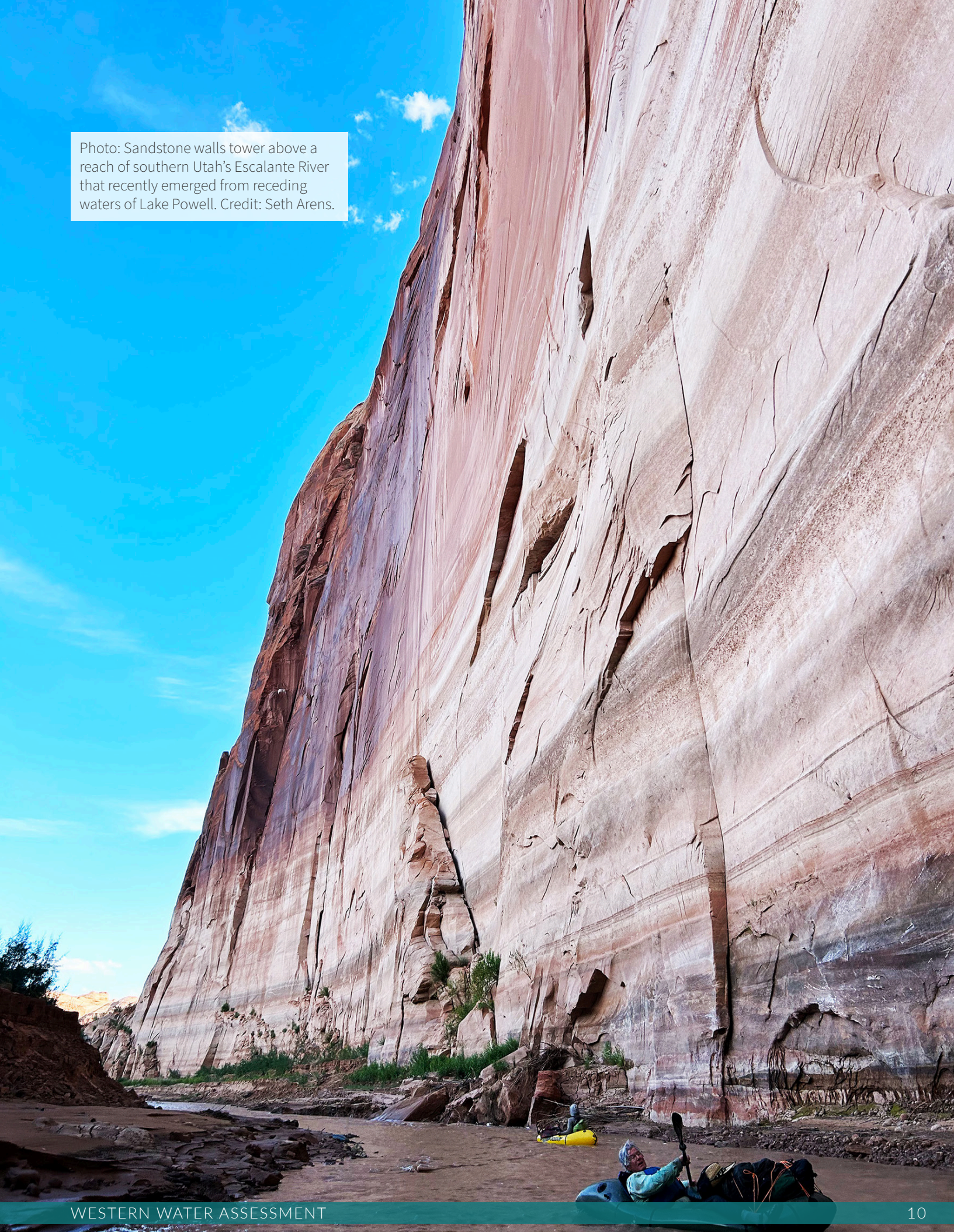


Photo: Sandstone walls tower above a reach of southern Utah's Escalante River that recently emerged from receding waters of Lake Powell. Credit: Seth Arens.

NEW AREAS OF FOCUS AND PARTNERSHIPS

UNDERSTANDING SOCIAL NETWORKS TO FACILITATE RESILIENCE

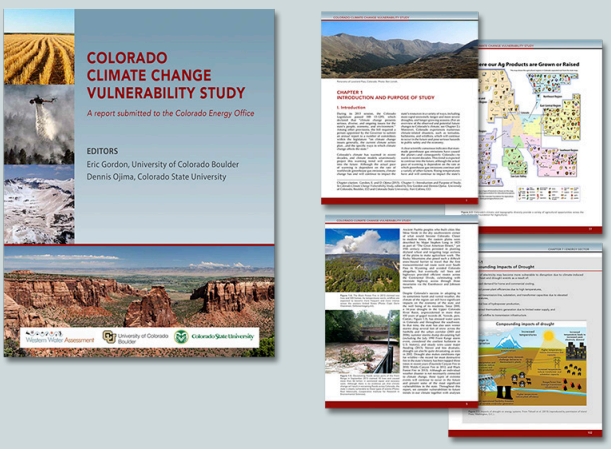
Interpersonal connections are important for effective response to compound hazards. In this project, Co-PI **Corrie Knapp** and graduate student **Alec Wallen** are exploring how actors are connected and interact with one another for wildfire response as well as how those connections could be built to improve responsiveness. **Knapp** and **Wallen** also conducted community outreach resulting in identification of a key partner with the Medicine Bow-Routt US Forest Service Office that is interested in collaborating on this project. They plan to conduct interviews with key preparedness actors to understand how they work together currently and host a workshop to facilitate relationship and network building in the future. Based on feedback from their partners, **Knapp** and **Wallen** are also interested in exploring the effectiveness of fire communications based on the Mullen Fire, which burned over 100,000 acres west of Laramie, WY in September 2020. They are currently scoping the project to assess whether they can pursue one or both of these activities.

BUILDING NEW PARTNERSHIPS ACROSS THE WWA REGION

WWA remains committed to better serving communities and water systems at the frontline of climate change, including Indigenous, Latinx, and small rural communities. As full-time Research Integration Specialists, WWA's **Katie Clifford** and **Seth Arens** are particularly focused on deepening connections with these communities, with the goal of identifying science and adaptation needs and working to leverage expertise across the WWA team to help meet those needs through co-designed projects. **Clifford** is leveraging her expertise by working on environmental justice issues, co-production, and issues of environmental inequalities to develop new relationships with Latinx community groups, including Green Latinos and Protégete, and with city, county, state, and academic groups engaged in increasing resilience of manufactured housing communities in Colorado. **Clifford** is also engaging with environmental justice professionals in Colorado state agencies, and with rural communities through the Western Rural Water Users Association. **Arens** and **Clifford** are also engaged with rural mountain communities across the Intermountain West through the Mountain Towns 2030 organization.

INVESTIGATING OPPORTUNITIES FOR AN UPDATED COLORADO VULNERABILITY STUDY

Published in 2015, the Colorado Climate Change Vulnerability Study has proven to be a useful resource for state resource managers. The original report was supported by the Colorado Water Conservation Board (CWCB) and developed by WWA. It synthesized the key vulnerabilities that climate variability and change pose to Colorado's economy and resources. With support from CWCB, WWA's **Heather Yocum** and **Ethan Knight** are leading an analysis of the 2015 report to identify opportunities for an updated vulnerability study. Their initial findings indicate that the revision would benefit from: (1) updated data, references, and information on extreme events from the recently-revised Climate Change in Colorado Report; (2) document design and outreach efforts to communicate high level findings to key stakeholder groups; and (3) inclusion of frontline and Indigenous communities through case studies in each chapter and by the addition of a chapter on Indigenous peoples.



The Colorado Climate Change Vulnerability Study prepared for the Colorado Energy Office in 2015.

OUTREACH AND ENGAGEMENT

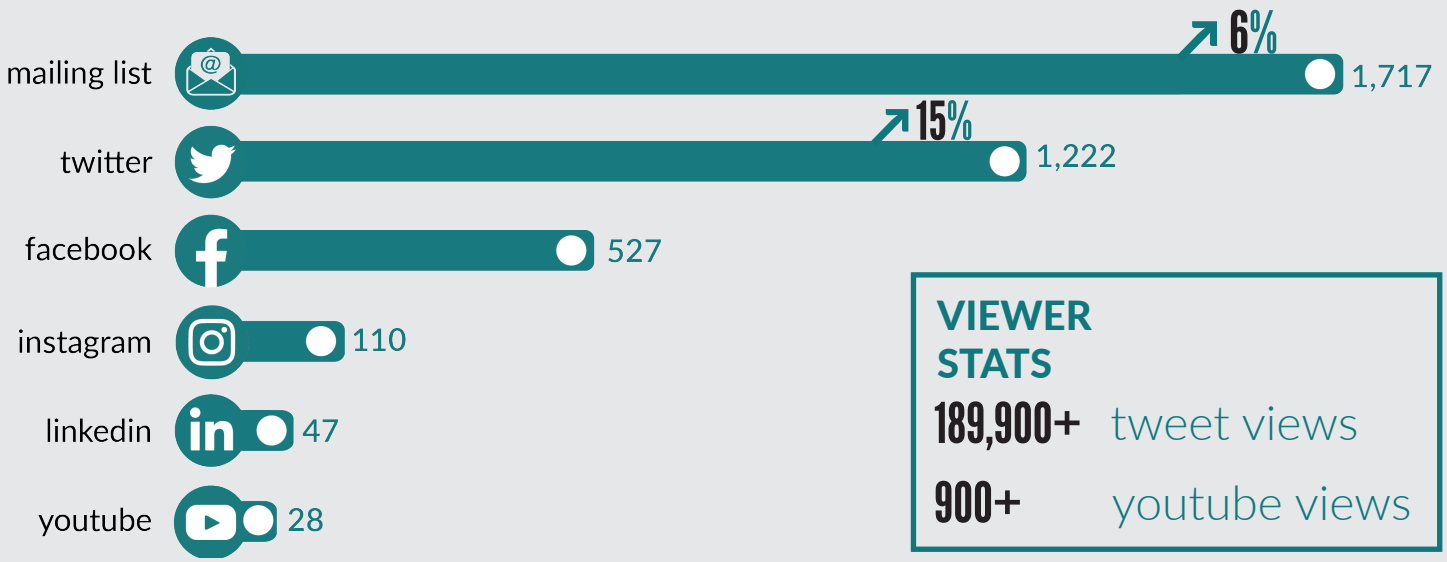
Outreach and engagement are central to WWA, as they enable us to center partner priorities and needs in the work we do, and they help to maximize our impact in scientific and stakeholder communities, which include municipalities, resource managers, and state and federal agencies. Throughout our research and engagement activities, we prioritize mentorship for students and early career professionals through internships, research assistantships, fellowships, and staff positions.

WWA continues to make effective communication and outreach a priority by implementing the communications strategy developed in 2020 by **Ethan Knight**. The plan aligns core communications goals with key stakeholder sectors and spans a range of communication channels, including email outreach, quarterly newsletters, our website, social media, and in-person or virtual meetings. We continue to use our communications plan, website, and other engagement to help us strengthen relationships and share resources with stakeholders across the Intermountain West.

Since the launch of our new website in 2021, we have increased the utility of the site's resources for our team and for visitors. For example, our site's most popular and critical tools, such as the Intermountain West Climate Dashboard and the High-Impact Events Database {*S}, are more accessible and functional. Our website continues to have a consistent number of users, page views, and other types of engagement (clicks, scrolls, etc.) each year. During the reporting period, our website had a total of **14,388 users** and **34,010 page views**. Since website analytics tracking began in 2013 for our site, we have had an average of **14,406 users** and **35,651 page views** per year.

Another way in which we continue to increase our online presence is through our social media accounts, managed by **Knight**. We use Twitter, Facebook, Instagram, LinkedIn, and Mastodon to stay connected with our current stakeholders, while also reaching a wider and more diverse audience to share our research and other regionally relevant climate information. During the reporting period, our Twitter account gained **161 new followers** for a total of **1,222 followers** and got **189,900+ tweet views**. Our rebooted Facebook account has a total of **527 followers**, our new Instagram

Photo above: NCAR Trail, Boulder, Colorado. Credit: Ethan Knight.



account has **110 followers**, our new LinkedIn has **47 followers**, and our new Mastodon has **four followers**. We also continue to upload webinars to our YouTube account, which got **935 views** during the reporting period and now has **28 subscribers**. Lastly, we continue to send out quarterly newsletters, climate briefings, and more through our mailing list, which gained **98 new subscribers** during the reporting period for a total of **1,717 subscribers**.

TARGETED ENGAGEMENT WITH PARTNERS

WWA is committed to engaging with communities and decision makers across our region, and with the broader scientific community. During the reporting period, we conducted a broad range of outreach activities. The following are highlights from this work.

WWA researchers and staff worked with communities and resource managers within and beyond the Intermountain West to connect them with information about climate impacts to support planning and resilience-building efforts. **Katie Clifford** attended a Tri-Ute climate workshop in Montrose, Colorado with other climate service providers, and was one of only three providers invited back for a second workshop. Through this, we developed grant-making plans and have regular climate conversations approximately every 1-2 months with Tribal representatives and climate service providers. Our goal is that the three Tri-Ute Tribes are able to develop climate adaptation plans through the Tri-Ute climate working group and that we build relationships to support more climate information in decisions through building capacity, sharing or building tools, and potentially co-developing new research.

Court Strong continued to work on western US hydroclimate in collaboration with a dozen staff members from the Salt Lake City Department of Public Utilities (SLCDPU), including the Director, engineers, topical experts, and public outreach and messaging coordinators.

To support regional decision makers in their use of water supply forecast information, **Ben Livneh**, **Benét Duncan,** and **Joseph Kasprzyk** conducted meetings with key stakeholders. They updated stakeholders on research progress related to which sources of environmental information were shown to be most informative, e.g., snowpack conditions, versus other meteorological and landscape variables, as well as which types of models may be the most resilient to both dry and variable conditions, including process-based, statistical, and machine learning models. These meetings also helped them to garner input on next steps. In September 2022, they met with partners at the Colorado Basin River Forecast Center, Seattle Public Utilities, and the Colorado Climate Center. These conversations helped them to learn more about the challenges and concerns these entities are facing regarding changing snowpack and streamflow.

OUTREACH WITH SCIENTIFIC AND ADAPTATION PRACTITIONER COMMUNITIES

As a NOAA CAP/RISA team, WWA places a strong emphasis on contributing to the broader base of knowledge about the impacts of climate variability and change and advancing adaptation science. An important component of this is regular engagement with the academic and adaptation practitioner community. This type of engagement helps us to identify opportunities to conduct research that both advances scientific understanding and meets stakeholder needs.

Liz Payton was appointed the Water Chapter Lead for the Fifth National Climate Assessment (NCA5). The NCA5 is a congressionally mandated report that summarizes the current and future impacts of climate change. As Water Chapter Lead, **Payton** has selected a team of authors with expertise in assessing climate impacts to the nation's surface and groundwater resources and the consequences of those impacts to human and natural systems, with an emphasis on the authors' ability to bring diverse perspectives to the team. She is responsible for chapter development and writing, ensuring that the chapter tells a clear and compelling narrative. **Payton** led a webinar on the draft Water chapter of the NCA5 to present highlights and answer questions from the public. **Corrie Knapp** has the same role with the NCA5 for the Northern Great Plains chapter. **Imtiaz Rangwala** is an author on the Water chapter. The NCA5 is expected to be released in late 2023.

Benét Duncan is a Science Advisor on the NSF-funded We Are Water project led by the CIRES Education and Outreach team. **Ethan Knight** also worked with the We Are Water project on developing learning materials, a social media campaign, and event outreach. The goal of the project is to engage with water-stressed communities in the Four Corners region by developing educational and accessible podcast-videos to inform these communities about where their water comes from, how much water is available, and more. **Knight** traveled to Aztec, New Mexico in June 2022 to host We Are Water's Mini Film Festival at the Aztec Public Library focusing on water quality, access, and scarcity challenges in the region. **Duncan** also served as an advisory board member for the Local Science Engagement Network, and as a mentor in the American Society of Adaptation Professionals mentorship program, helping to provide guidance to an early career adaptation practitioner.

Katie Clifford and **Liz Payton** convened a workshop with the Colorado Chapter of the American Planning Association (APA) and presented on climate change impacts to flooding in Colorado as part of a cross-CAP/RISA project with the Great Lakes Integrated Sciences and Assessments (GLISA) CAP/RISA team {*S}. **Payton** also presented our Intermountain West Climate Dashboard and methods to use the dashboard in the classroom at an educator workshop convened by the Summer Climate Change Institute in July 2022. In February, **Payton** and **Seth Arens** shared their Colorado River and climate change expertise with Mykenzie Sanchez's Fourth Grade class at Broadway Elementary School in Grand Junction, Colorado. This school year, the students tackled the Colorado River drought and its impacts on water supply and the environment in their problem-based learning cycle called "Save the River." During the reporting period, **Arens** delivered a number of presentations, media interviews, and served on a panel about his ecological work in Glen Canyon; he lectured at the University of Utah about using climate projections and working with stakeholders to develop usable science; offered seminars on climate change and drought in the West; and delivered a keynote lecture on the future of flooding in Utah at the Utah Floodplain and Stormwater Management Association's Annual Conference. **Ben Livneh** gave almost 30 presentations on topics including changes in hydrology, streamflow, water storage, flooding, and aridification. In addition, he held media interviews about his work with **Fangfang Yao** that was published in the journal *Science*, focused on shrinking freshwater lakes around the world, which highlighted important challenges for reservoirs like those in the Intermountain West.

WWA also maintains a close relationship with the USGS North Central Climate Adaptation Science Center (NC CASC) and the USDA Northern Plains Climate Hub. We continue to meet twice a year at "Three Centers Retreats," which provide opportunities for us to coordinate and collaborate across our programs. This often includes presentations about existing research projects; discussions about how to leverage our existing work to meet stakeholder needs; and identification of opportunities to conduct new collaborative projects that help to advance scientific knowledge in stakeholder-relevant ways. Due to the COVID-19 pandemic, the Three Centers Retreat was held virtually over multiple days in November 2022.

ENGAGING WITH OUR BROAD STAKEHOLDER COMMUNITY

In 2020, we established the WWA webinar series to share research highlights and timely climate information with our broad stakeholder network. We continued the webinar series during this reporting period with five webinars, starting with Extreme Heat in the West in August 2022, featuring WWA's **Seth Arens** and **Katie Clifford**, along with WWA graduate student **Nels Bjarke**, discussing how a changing climate is impacting the frequency and severity of extreme heat events. In October 2022, we hosted Planning for Fire: Wildfire, Water Quality, and Local Preparedness in the West, featuring WWA graduate students **Natalie Bennett** and **Carli Brucker** who discussed local fire risk reduction planning and water quality planning in the face of wildfire risk. In January 2023, we hosted Climate change and the water cycle: Call for public comment on the draft Fifth National Climate Assessment, featuring WWA's **Liz Payton** who presented highlights from the draft Water chapter of the NCA5, followed by Q&A with members of the chapter author team. In February 2023, we hosted New Climate Information Tools: A User Guide to Climate Change Portals and the Utah Hazard Planning Dashboard, featuring **Arens** who provided an overview and demonstration of our new Utah Hazard Planning Tool, and **Jeff Lukas** of Lukas Climate Research and Consulting and **Julie Vano** of the Aspen Global Change Institute who walked through A User Guide to Climate Change Portals and the six types of curated information resources that are highlighted in the guide. Lastly, in March 2023, we hosted Adapting to Climate Change in Wyoming: Small Grants Competition, featuring WWA's **Benét Duncan** and **Corrie Knapp** who announced the Adapting to Climate Change in Wyoming grant competition and discussed the details, followed by a Q&A.

A sample of WWA's YouTube videos.

A number of significant international, national, regional, and local news outlets have featured WWA team members, research, tools and resources, or our organization as a whole over the reporting period, including 12News, 5280 Magazine, 8NewsNow.com, AAAS EurekAlert!, ABC News, AOL, AP News, Al Jazeera, Aspen Daily News, Axios, bioGraphic, CBC News, CNN, CU Boulder Today, Climate Program Office News, Climate.gov, Coloradan Alumni Magazine, Coloradoan, Coyote Gulch, Denver7, Devdiscourse, Discover, Down to Earth (India), Earth.com, Euronews, FOX31 News, Fortune, Fronteras KJZZ, Gunnison Country Times, Inside Climate News, KCPW, List23, Los Angeles Times, MSN, Montrose Daily Press, Morning Sun, NASA Earth Observatory, NASEM, NBC Bay Area, NBC Right Now, NPR, Nature, NewsDrum, Newsweek, Newswise, Our Community Now, Post Independent, Reuters, Revyuh, Science News, Snow Brains, Steamboat Pilot, Tech Explorist, The Colorado Sun, The Daily Camera, The Guardian, The Salt Lake Tribune, The Saratoga Sun, The Washington Post, Thred, University of Wyoming News, Vail Daily, WUSF, WyoFile, Wyoming Public Media, Wyoming Tribune Eagle, Yahoo! News, and more.

MAKING AN IMPACT

WWA's work is grounded in our deep relationships with resource managers, communities, researchers, and other stakeholders, and a commitment to co-production and collaboration to design and conduct our projects. This means that our projects are intended to build regional adaptive capacity and support climate-informed decisions and planning in the Intermountain West. Feedback and decisions from a range of stakeholders demonstrate the tangible, on-the-ground impact of our recent program activities.

INTERMOUNTAIN WEST CLIMATE DASHBOARD AND HIGH-IMPACT EVENTS DATABASE

WWA continued to maintain the Intermountain West Climate Dashboard on our website, where **Seth Arens** and **Ethan Knight** also publish monthly Intermountain West Climate Briefings. Recent analyses of website traffic indicate that the dashboard continues to be a very useful 'one-stop shop' for up-to-date climate and water information for WWA's three-state region. The monthly climate and weather summaries have proven to be very popular, with a high open and click-through rate, and requests from stakeholders to continue to produce them. **Knight** also continued to maintain the High-Impact Events Database. Since its major update in 2021, the database has been used by media and other stakeholders to place extreme weather and climate events in a historical context. Our "On-This-Day-in-History" event posts on social media have proven to be an effective form of communication, creating public interest and engaging stakeholders with our database.

These online tools are among the most-visited pages on the WWA website, and they are used by communities, researchers, water managers, educators, and journalists to inform decisions and support outreach. Through this, WWA has built and maintained valuable climate information assets and boosted learning outcomes, helping to shift mindsets.

Photo above: A view of Salt Lake City, Utah from Mount Wire. Credit: Seth Arens.

SOCIAL SCIENCE AND ETHICAL ENGAGEMENT EFFORTS

Katie Clifford has deepened connections with Latinx, Tribal, and other frontline communities in Colorado and built relationships with community-based organizations, researchers, and government officials working on climate impacts for frontline communities. This will help WWA to better engage and serve these communities. **Clifford's** paper, "Natural Exceptions or Exceptional Natures? Regulatory Science and the Production of Rarity" has been recognized in media, including Nature, KNEP, an upcoming book, and others. It has been recognized by the academic community, winning the 2023 Outstanding Article of the Year award from the Cultural and Political Ecology (CAPE) specialty group of the American Association of Geographers (AAG), and it has impacted policy and planning for state and regional air quality. After she shared findings with officials from EPA Region 8 about the risks and unintended consequences of the exceptional events rule, they revised their draft plan and included it in the EPA Region 8 Climate Change Adaptation Implementation Plan.

Clifford has also led our team in advancing the larger CAP/RISA program goals of equitable engagement with frontline communities. She proposed and co-organized an AAG session bringing together geographers on different CAP/RISA teams that resulted in greater cross-CAP/RISA dialogue and the discussion of a CAP/RISA Frontline Engagement Community of Practice (CoP) to bring together social scientists working on frontline engagement. Since then, she has supported development of the CoP and built relationships across CAP/RISA teams to support their efforts and facilitate peer learning. **Clifford** has also served and collaborated with many different groups around climate and social sciences and ethical engagement. She shared research and met with members of the Dust Alliance for North America (DANA) to expand the group's social science capacity and better think about policy relevance and social dimensions of dust. Also, her expertise is being used by the CPO as well as CIRES leadership, fielding requests to meet with researchers to help them think about ethical engagements with frontline communities. She has received media coverage about the climate justice impacts of the EPA's Exceptional Events Rule and has met with a journalist about mobile home park (MHP) climate risks. Lastly, **Clifford** developed grant-making plans and regular climate conversations approximately every 1-2 months with Tribal representatives and climate services providers from the Tri-Ute climate workshop.

Photo below: Katie Clifford and WWA team leading a hazard diagramming process at a community workshop focusing on flood risk in Lander, Wyoming. Credit: Wilzave Quiles-Guzmán.

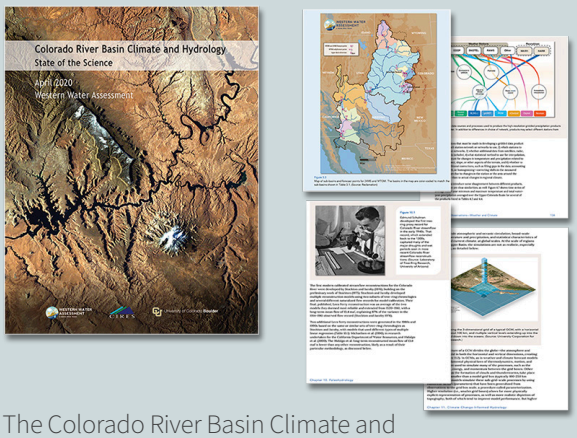
USABILITY OF MEDIUM-RANGE FORECASTING FOR WATER SYSTEM RELIABILITY

Since **Court Strong** and fellow researchers finalized the climate vulnerability assessment of Salt Lake City's water systems (see Research Highlights above), the Salt Lake City Department of Public Utilities (SLCDPU) requested an online tool to help them access up-to-date information about the Atlantic Quadpole Mode, which **Strong** and colleagues have shown is strongly predictive of seasonal precipitation in Utah. Tool development is being led by **Strong** in partnership with WWA's **Imtiaz Rangwala** and **Seth Arens**, and student **Prasad Thota**. SLCDPU plans to use this tool in their operational water management.

ESTIMATING FUTURE HIGH-MOUNTAIN SNOWPACK

Ben Livneh, **Joe Barsugli**, and fellow researcher **Justin Pflug** have been creating better models of future snowpack and snowmelt-driven flows to support future species status assessments (SSAs) in high-mountain systems of the Rocky Mountains, and to understand subsequent snowmelt-driven changes on streams in these regions. The U.S. Fish and Wildlife Service (USFWS) requested these higher resolution future snow projections in order to complete their SSA for the wolverine—to understand its viability given changes to its snow-adapted habitat. **Livneh** and **Pflug** provided USFWS with snow projections that leverage existing NASA modeling and inform SSAs and other key assessments of habitat. These projections were used as part of a SSA report that will be made public in July 2023. This work is supported by a grant from the North Central Climate Adaptation Science Center.

IMPACT CASE STUDY: CLIMATE-INFORMED WATER MANAGEMENT IN THE COLORADO RIVER BASIN



The Colorado River Basin Climate and Hydrology: State of the Science report.

Released in April 2020, the Colorado River Basin Climate and Hydrology: State of the Science report {*O} creates a shared understanding of the physical setting and the latest data, tools, and research underpinning the management of Colorado River water resources. It was co-edited and co-written by **Liz Payton** and **Jeff Lukas**, and a 17-member author team, with support and guidance from over a dozen federal, state, and local water agencies. Over the past year, it played a critical role in the Department of the Interior's Draft Supplemental Environmental Impact Statement (SEIS) for the Colorado River Basin. The Hydrologic Sciences section states, "The Colorado River Basin Climate and Hydrology: State of the Science (State of the Science) (Lukas, J. and Payton, E. 2020) report provided a comprehensive assessment of Basin hydroclimate conditions and trends through 2019. Key findings from the report are summarized below…"

This use of the State of the Science report demonstrates that it has continued to guide water resource managers and researchers in efforts to improve the short-term and mid-term forecasts and long-term projections for the basin's water supplies. In May 2022, Southern Nevada Water Authority's **Seth Shanahan**, who coordinates the Colorado River Climate and Hydrology Workgroup that sponsored the report, shared that:

> "The State of the Science report continues to serve as a blueprint for our multi-agency basinwide (aka, Colorado River Climate and Hydrology Work Group) research to operations agenda… The SOS continues to serve as our chief tool for engaging with the research community and educating our constituencies. We frequently refer academics to the report so they can improve their understanding of the biggest challenges (needs) in the Basin and, specifically, the tools that are in use… Regarding education, the SOS continues to be unparalleled in its breadth and depth and is often cited in agency reports, presentations, interviews, etc. for numerous purposes. Simply put, the SOS report continues to be profoundly impactful."

WWA PROGRAM EVALUATION

During the 2022-23 performance period, WWA finalized and began to implement our updated approach to program evaluation. **Benét Duncan** and **Katie Clifford** are working closely with Investigators **Anne Gold** and **Christine Okochi** to lead the evaluation design and implementation with support from **Ethan Knight**. Drawing from a framework developed by **Gigi Owen** and **Allison Meadow** at the Climate Assessment for the Southwest (CLIMAS) CAP/RISA team, our evaluation approach includes ongoing tracking and evaluation of our program impact, tracking communications and outreach metrics, and an evaluation of our internal program operations. This thoughtful and integrated evaluation approach is designed to ensure that our program activities remain closely aligned with stakeholder needs, and to track our effectiveness in meeting program goals and building resilience in the Intermountain West. WWA's evaluation activities are guided by the following questions:

WWA CAP/RISA program-level evaluation:

- To what extent is WWA reaching its key audiences and goals?
- In which ways does WWA prioritize justice and equity in their work?
- In which ways do WWA activities impact stakeholders/audiences such as project partners, event attendees, and communities?
- How could WWA activities and offerings be improved?

WWA project-level evaluation:

- To what extent are WWA projects reaching their project goals?
- In which ways are WWA projects reaching their key audiences and building relationships, partnerships, and networks?
- How does WWA project work communicate usable science and in which ways does it impact communities?

Over the remaining years of the project, the WWA evaluation team will conduct a series of activities to answer our evaluation questions and optimize our program operations. These activities have been strategically designed to elicit perspectives from our partners and the WWA PI and staff team.

We will explore partner perspectives on our program's process and impacts through project participant surveys and interviews administered at strategic points in each project (led by **Gold** and **Okochi**), webinar attendee surveys (led by **Okochi**, **Clifford**, and **Knight**), and a broad survey of WWA's large stakeholder and partner community in 2026 (led by **Gold** and **Okochi**). **Knight** will also work with **Gold** and **Okochi** to support an analysis of WWA outreach tracking information. The participant surveys, webinar attendee surveys, and outreach tracking information will all contribute to a midterm evaluation report, and results from the 2026 large stakeholder survey and partner interviews will be incorporated into a final summative program evaluation (led by **Gold** and **Okochi**).

We are using a combination of approaches to understand the WWA PI and staff team perspectives on our program impact, our collaboration and co-production processes with partners, and our internal program structure and operations. During the summer of 2023 and again in 2026, **Clifford** will conduct interviews with the WWA PI group. These interviews will be designed to answer three key questions:

1. Did our work impact society?
2. Did our own research practices or perspective change?
3. Are we focusing co-production on accessible and manipulatable decision-making levers?

To deepen our understanding of PI and staff project trajectories and impacts, **Duncan** and **Knight** are administering a quarterly project reporting form and a yearly detailed project questionnaire. In 2024 and 2026, the detailed project questionnaire will incorporate additional questions that will contribute to a midterm evaluation report and final summative evaluation, respectively (led by **Gold** and **Okochi**).

We are also deeply interested in understanding PI and staff experiences at a program level and identifying opportunities for improvement or growth. To that end, **Gold** and **Okochi** will lead a midpoint program reflection in 2023. Building on the rose-bud-thorn evaluation framework, they will administer a brief reflection survey with the WWA PI and staff teams, and then lead a focus group discussion that provides a safe space for team members to share their insights and experiences. This timing will give WWA leadership an opportunity to make program-level adjustments to ensure that all team members feel included, heard, and valued. The process will be repeated in 2025 to allow for new insights that can help to shape our program in the future.

LOOKING TO THE FUTURE

During the coming year, WWA will advance user-driven projects that build community and water system resilience to compound hazards in the Intermountain West. We will also continue to expand our connections with partners in the region, with a particular emphasis on underserved and frontline communities that are disproportionately affected by climate impacts. Two initiatives are highlighted below:

COMMUNITY CLIMATE WORKSHOP IN LANDER, WY

During the summer of 2023, WWA will host a community climate workshop in Lander, WY. Working with partners at the Wyoming Outdoor Council and the Lander Energy and Environment Board, WWA's **Katie Clifford**, **Benét Duncan**, and **Seth Arens** are leading this project. We are excited to host NOAA Lapenta Intern **Wilzave Guzmán**, who will also help to coordinate and advance the workshop and develop post-workshop reporting products for the community. The workshop will focus on the impacts of flooding in Lander and will center community expertise to identify flooding impacts and actions that the community can take to build resilience. This is an extension of WWA's Vulnerability, Consequences, and Adaptation Planning Scenarios (VCAPS) pilot project, which we led in 6 communities in Utah and Colorado from 2018-2019. First developed by the Carolinas Integrated Sciences and Assessments (CISA) program, the VCAPS process provides a framework for community-based adaptation planning workshops that also draws on the expertise of community members.

BUILDING RESILIENCE IN MANUFACTURED HOUSING COMMUNITIES

Mobile, or manufactured, home parks (MHPs) are the largest form of unsubsidized affordable housing in the country, and they disproportionately serve Latinx and Indigenous populations in the Intermountain West. Their residents are often more at risk to climate hazards than residents of fixed-foundation housing. WWA lead social scientist **Katie Clifford** has been building relationships with community advocates, nonprofits, and government officials on the topic of climate risk to mobile home parks over the past year and is in the process of developing research projects on a range of climate hazards that disproportionately affect MHPs including extreme heat, poor air quality, flooding, and hazard evacuation issues.

Clifford is leading the hiring of a new, two-year engaged social science postdoc to focus on these issues. During the coming year, the postdoc will work full-time to deepen relationships and co-develop a project with MHP community leaders and related agencies to build climate resilience in MHPs in the region. We understand this topic of MHP resilience is broad, intersectional, multifaceted, and impacted by factors including climate hazards and variability, park ownership and governance models, zoning policies, racial and ethnic dynamics, geography, displacement, and larger structural issues. We are committed to producing usable science or research that will contribute to resilience in these communities. This research is timely as the State of Colorado has also focused on this issue of resilience in MHPs. The State recently passed a "mobile home bill of rights" and other legislation is currently being developed, making this an opportunity to help shape policy and community resilience.

Photo above: Lake Dillon, Colorado. Credit: Ethan Knight.

APPENDIX

WWA PUBLICATIONS

Bailey, Karen M., Katie R. Hooker, Anne A. Loggins, Alex D. Potash, Donald W. Hardeman, and Robert A. McCleery. 2022. "It Pays to Get Paid: Factors Influencing Wildlife-related Employment Success." Wildlife Society Bulletin 46 (1). https://doi.org/10.1002/wsb.1252

Barnhart, Katherine R., Veronica Y. Romero, and Katherine R. Clifford. 2023. "User Needs Assessment for Postfire Debris-Flow Inundation Hazard Products." Report 2023–1025. Open-File Report. Reston, VA. USGS Publications Warehouse. https://doi.org/10.3133/ofr20231025

Bishay, Kaitlyn, Nels R. Bjarke, Parthkumar Modi, Justin M. Pflug, and Ben Livneh. 2023. "Can Remotely Sensed Snow Disappearance Explain Seasonal Water Supply?" Water 15 (6): 1147. https://doi.org/10.3390/w15061147

Brucker, Carli P., Ben Livneh, J. Toby Minear, and Fernando L. Rosario-Ortiz. 2022. "A Review of Simulation Experiment Techniques Used to Analyze Wildfire Effects on Water Quality and Supply." Environmental Science: Processes & Impacts 24 (8): 1110–32. https://doi.org/10.1039/D2EM00045H

Clifford, K. R., J. Henderson, Z. McAlear, L. Dilling, B. Duncan, S. Ehert, S. Arens, R. Page, and U. Rick. 2023. "The 'Nuts and Bolts' of Doing Coproduction: Exploring Implementation Decisions in Climate Adaptation Research with Stakeholders." Bulletin of the American Meteorological Society 104 (4): E872–83. https://doi.org/10.1175/BAMS-D-21-0292.1

Clifford, K.R., Goolsby, J.B., Cravens, A.E., and Cooper, A.E., 2022, Rapidly assessing social characteristics of drought preparedness and decision making: A guide for practitioners: U.S. Geological Survey Techniques and Methods 17-A1, 41 p. https://doi.org/10.3133/tm17A1

Clifford, Katherine R, Amanda E Cravens, and Corrine N Knapp. 2022. "Responding to Ecological Transformation: Mental Models, External Constraints, and Manager Decision-Making." BioScience 72 (1): 57–70. https://doi.org/10.1093/biosci/biab086

Clifford, Katherine R. 2022. "Natural Exceptions or Exceptional Natures? Regulatory Science and the Production of Rarity." Annals of the American Association of Geographers, June, 1–18. https://doi.org/10.1080/24694452.2022.2054768

Photo above: As Lake Powell receded, a perched lake was left near Explorer Canyon on the Escalante River, Utah. Credit: Seth Arens.

Crausbay, Shelley D, Helen R Sofaer, Amanda E Cravens, Brian C Chaffin, Katherine R Clifford, John E Gross, Corrine N Knapp, et al. 2022. "A Science Agenda to Inform Natural Resource Management Decisions in an Era of Ecological Transformation." BioScience 72 (1): 71–90. https://doi.org/10.1093/biosci/biab102

Culler, Elsa S., Ben Livneh, Balaji Rajagopalan, and Kristy F. Tiampo. 2023. "A Data-Driven Evaluation of Post-Fire Landslide Susceptibility." Natural Hazards and Earth System Sciences 23 (4): 1631–52. https://doi.org/10.5194/nhess-23-1631-2023

Dilling, Lisa, Meaghan E. Daly, William R. Travis, Andrea J. Ray, and Olga V. Wilhelmi. 2023. "The Role of Adaptive Capacity in Incremental and Transformative Adaptation in Three Large U.S. Urban Water Systems." Global Environmental Change 79 (March): 102649. https://doi.org/10.1016/j.gloenvcha.2023.102649

Dunham, Jason, Joseph R. Benjamin, David J. Lawrence, and Katherine Clifford. 2022. "Resist, Accept, and Direct Responses to Biological Invasions: A Social–Ecological Perspective." Fisheries Management and Ecology, June. https://doi.org/10.1111/fme.12574

Frisvold, George B., Linda M. Fernandez, Flavio Lehner, Stephanie A. McAfee, Sharon Megdal, Elizabeth Payton, Jack Schmidt, Julie Vano, and Connie Woodhouse. 2022. "Featured Collection Introduction: Severe Sustained Drought Revisited: Managing the Colorado River System in Times of Water Shortage 25 Years Later — Part I." JAWRA Journal of the American Water Resources Association 58 (5): 597–603. https://doi.org/10.1111/1752-1688.13062

Frisvold, George B., Linda M. Fernandez, Flavio Lehner, Stephanie A. McAfee, Sharon Megdal, Elizabeth Payton, Jack Schmidt, Julie Vano, and Connie Woodhouse. 2022. "Featured Collection Introduction: Severe Sustained Drought Revisited: Managing the Colorado River System in Times of Water Shortage 25 Years Later — Part II." JAWRA Journal of the American Water Resources Association 58 (6): 1049–52. https://doi.org/10.1111/1752-1688.13085

Gaughan, Andrea E., Nicholas E. Kolarik, Forrest R. Stevens, Narcisa G. Pricope, Lin Cassidy, Jonathan Salerno, Karen M. Bailey, Michael Drake, Kyle Woodward, and Joel Hartter. 2022. "Using Very-High-Resolution Multispectral Classification to Estimate Savanna Fractional Vegetation Components." Remote Sensing 14 (3): 551. https://doi.org/10.3390/rs14030551

Great Salt Lake Strike Team. 2023. "Great Salt Lake Policy Assessment: A Synthesized Resource Document for the 2023 General Legislative Session," February. https://gardner.utah.edu/wp-content/uploads/GSL-Assessment-Feb2023.pdf?x71849

Hale, K.E., A.N. Wlostowski, A.M. Badger, K.N. Musselman, B. Livneh, and N.P. Molotch. 2022. "Modeling Streamflow Sensitivity to Climate Warming and Surface Water Inputs in a Montane Catchment." Journal of Hydrology: Regional Studies 39 (February): 100976. https://doi.org/10.1016/j.ejrh.2021.100976

Hale, Katherine E., Keith S. Jennings, Keith N. Musselman, Ben Livneh, and Noah P. Molotch. 2023. "Recent Decreases in Snow Water Storage in Western North America." Communications Earth & Environment 4 (1): 170. https://doi.org/10.1038/s43247-023-00751-3

Heldmyer, Aaron J., Nels R. Bjarke, and Ben Livneh. 2023. "A 21st-Century Perspective on Snow Drought in the Upper Colorado River Basin." JAWRA Journal of the American Water Resources Association 59 (2): 396–415. https://doi.org/10.1111/1752-1688.13095

Heldmyer, Aaron, Ben Livneh, James McCreight, Laura Read, Joseph Kasprzyk, and Toby Minear. 2022. "Evaluation of a New Observationally Based Channel Parameterization for the National Water Model." Hydrology and Earth System Sciences 26 (23): 6121–36. https://doi.org/10.5194/hess-26-6121-2022

Holland, Melanie, Chris Thomas, Ben Livneh, Stephanie Tatge, Alex Johnson, and Evan Thomas. 2022. "Development and Validation of an In Situ Groundwater Abstraction Sensor Network, Hydrologic Statistical Model, and Blockchain Trading Platform: A Demonstration in Solano County, California." ACS ES&T Water 2 (12): 2345–58. https://doi.org/10.1021/acsestwater.2c00214

Knowles, John F., Nels R. Bjarke, Andrew M. Badger, Max Berkelhammer, Joel A. Biederman, Peter D. Blanken, Mario Bretfeld, et al. 2023. "Bark Beetle Impacts on Forest Evapotranspiration and Its Partitioning." Science of The Total Environment 880 (July): 163260. https://doi.org/10.1016/j.scitotenv.2023.163260

Kroepsch, Adrianne C., and Katherine R. Clifford. 2022. "On Environments of Not Knowing: How Some Environmental Spaces and Circulations Are Made Inscrutable." Geoforum 132 (June): 171–81. https://doi.org/10.1016/j.geoforum.2021.05.009

Magness, Dawn R, Linh Hoang, R Travis Belote, Jean Brennan, Wylie Carr, F Stuart Chapin, Katherine Clifford, Wendy Morrison, John M Morton, and Helen R Sofaer. 2022. "Management Foundations for Navigating Ecological Transformation by Resisting, Accepting, or Directing Social-Ecological Change." BioScience 72 (1): 30–44. https://doi.org/10.1093/biosci/biab083

Modi, Parthkumar A., Eric E. Small, Joseph Kasprzyk, and Ben Livneh. 2022. "Investigating the Role of Snow Water Equivalent on Streamflow Predictability during Drought." Journal of Hydrometeorology 23 (10): 1607–25. https://doi.org/10.1175/JHM-D-21-0229.1

Pokhrel, Yadu, Ahmed Elkouk, Lifeng Luo, Liz Payton, Ben Livneh, and Yifan Cheng. 2023. "Impact of Model Parameters on Runoff Sensitivities in the Community Land Model: A Study on the Upper Colorado River Basin." EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-10644. https://doi.org/10.5194/egusphere-egu23-10644

Rader, Alana M., Christine Biermann, Stephen M. Chignell, Katherine R. Clifford, Lisa C. Kelley, and Rebecca Lave. 2023. "Practicing Critical Physical Geography: New Trading Zones and Interactional Expertise in an Expanding Field." The Canadian Geographer / Le Géographe Canadien 67 (1): 10–16. https://doi.org/10.1111/cag.12828

Rangwala, I. (2022). Grim 2022 drought outlook for Western US offers warnings for the future as climate change brings a hotter, thirstier atmosphere. The Conversation. May 19, 2022. https://theconversation.com/grim-2022-drought-outlook-for-western-us-offers-warnings-for-the-future-as-climate-change-brings-a-hotter-thirstier-atmosphere-182640

Riley, R., D. Bertrand, and S. Arens, 2022: Connecting Climate Adaptation and Hazard Mitigation Planning in Climate Discourse-Sensitive Regions: A Cross-RISA Collaborative Project. Southern Climate Impacts Planning Program and Western Water Assessment, 22 pp. https://wwa.colorado.edu/sites/default/files/2022-07/CAHMPCrossRISA.pdf

Strong, Courtenay, Luke Stone, Paul Brooks, Meg Wolf, Logan Jamison, Baylee Olds, Steve Burian, Ryan Johnson, and Danyal Aziz. 2023. "Climate Vulnerability Assessment of Salt Lake City's Water Systems: Year 5 Report." University of Utah. https://www.inscc.utah.edu/~strong/climate_vulnerability/Year_5/Climate_Vulnerability_Y5_Report_02Feb23.pdf

Western Water Assessment, 2022. Utah Hazard Planning Tool, S. J. T. Arens, ed., Western Water Assessment, Cooperative Institute for Research in Environmental Sciences. https://wwa.colorado.edu/sites/default/files/2022-05/Utah%20Hazard%20PLanning%20Tool_051822.pdf

Williams, A.P., B. Livneh, K.A. McKinnon, W.D. Hansen, J.S. Mankin, B.I. Cook, J.E. Smerdon, A.M. Varuolo-Clarke, N.R. Bjarke, C.S. Juang, and D.P. Lettenmaier, 2022: Growing impact of wildfire on western United States water supply, Proceedings of the National Academies of Science, 119(10) e2114069119. https://doi.org/10.1073/pnas.2114069119

Wobus, Cameron, Eric Small, Jared C. Carbone, Parthkumar Modi, Hannah Kamen, William Szafranski, and Ben Livneh. 2022. "Water Allocation, Return Flows, and Economic Value in Water-Scarce Environments: Results from a Coupled Natural-Human System Model." Water 14 (20): 3280. https://doi.org/10.3390/w14203280

Wolf, Margaret A., Logan R. Jamison, D. Kip Solomon, Courtenay Strong, and Paul D. Brooks. 2023. "Multi-Year Controls on Groundwater Storage in Seasonally Snow-Covered Headwater Catchments." Water Resources Research 59 (6): e2022WR033394. https://doi.org/10.1029/2022WR033394

Yang, Kehan, Keith N. Musselman, Karl Rittger, Steven A. Margulis, Thomas H. Painter, and Noah P. Molotch. 2022. "Combining Ground-Based and Remotely Sensed Snow Data in a Linear Regression Model for Real-Time Estimation of Snow Water Equivalent." Advances in Water Resources 160 (February): 104075. https://doi.org/10.1016/j.advwatres.2021.104075

Yao, Fangfang, Ben Livneh, Balaji Rajagopalan, Jida Wang, Jean-François Crétaux, Yoshihide Wada, and Muriel Berge-Nguyen. 2023. "Satellites Reveal Widespread Decline in Global Lake Water Storage." Science 380 (6646): 743–49. https://doi.org/10.1126/science.abo2812

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