

WESTERN WATER ASSESSMENT

BUILDING CLIMATE RESILIENCE BY DESIGN

2021-2022

2021-2022 ANNUAL REPORT



**WESTERN WATER
ASSESSMENT**
A NOAA RISA TEAM



University of Colorado
Boulder



THE
UNIVERSITY
OF UTAH®



UNIVERSITY
OF WYOMING



WESTERN WATER ASSESSMENT

A NOAA RISA TEAM

WESTERN WATER ASSESSMENT

Cooperative Institute for Research in Environmental Sciences

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Performance period covered in this report: June 1, 2021–May 31, 2022

Grants associated with this report: NA15OAR4310144, NA20OAR4310144A, and
NA21OAR4310309

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Cover photo: Capitol Reef National Park, Utah. Credit: Erica Clifford.



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Photo: Keystone, Colorado. Credit: Benét Duncan.

ABOUT WWA

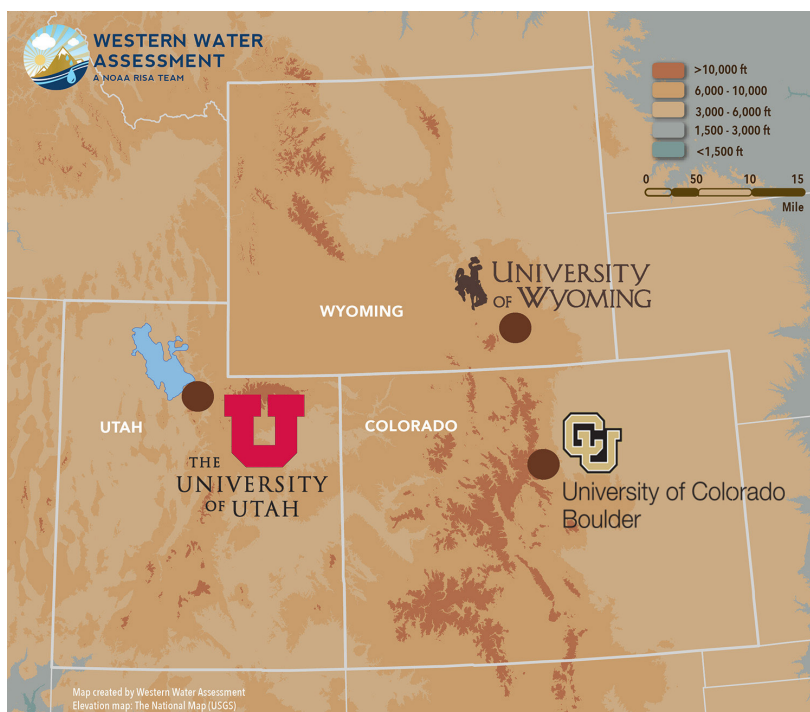
MISSION STATEMENT

The 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. While we are based in Boulder, Colorado, we work across the Intermountain West—Colorado, Utah, and Wyoming. 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.

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; we are therefore identifying needs and opportunities and integrating resilience tracking metrics to evaluate our success. Through this thoughtful approach to projects, we are advancing resilience science from theory to practice. Our work draws on our 20-year history of climate adaptation research and activities in the region, and the deep interdisciplinary social and natural science expertise on our team.

WWA is one of 11 teams in the NOAA-funded **Regional Integrated Sciences and Assessments (RISA) program**. In 2021, our research team grew to include physical and social scientists from the University of Colorado Boulder, the University of Wyoming, and the University of Utah. This newly-expanded team 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.

This annual report details accomplishments and impacts of projects supported by three different NOAA RISA grants. Activities supported under WWA's NOAA RISA funding from 2015-2022 are indicated by {★}, activities under funding from 2020-2022 are indicated by {☆}, and activities supported by our most recent award, which covers 2021-2026, do not have symbol designations.




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

WWA BY THE NUMBERS

JUNE 1, 2021–MAY 31, 2022

TWITTER



314,200+ Tweet Views
46,133 Profile Visits
326 New Followers
1,061 Total Followers
153 Account Mentions




WEBINARS

Number of Webinars, Workshops, and Presentations

53+

YOUTUBE

882
YouTube Views



MAILING LIST

102
New Subscribers

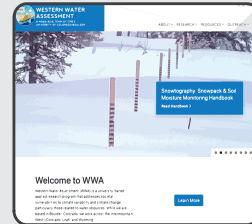
1,619
Total Subscribers



WEBSITE

16,755
Website Users

54,643
Page Views



NEWS & RESEARCH

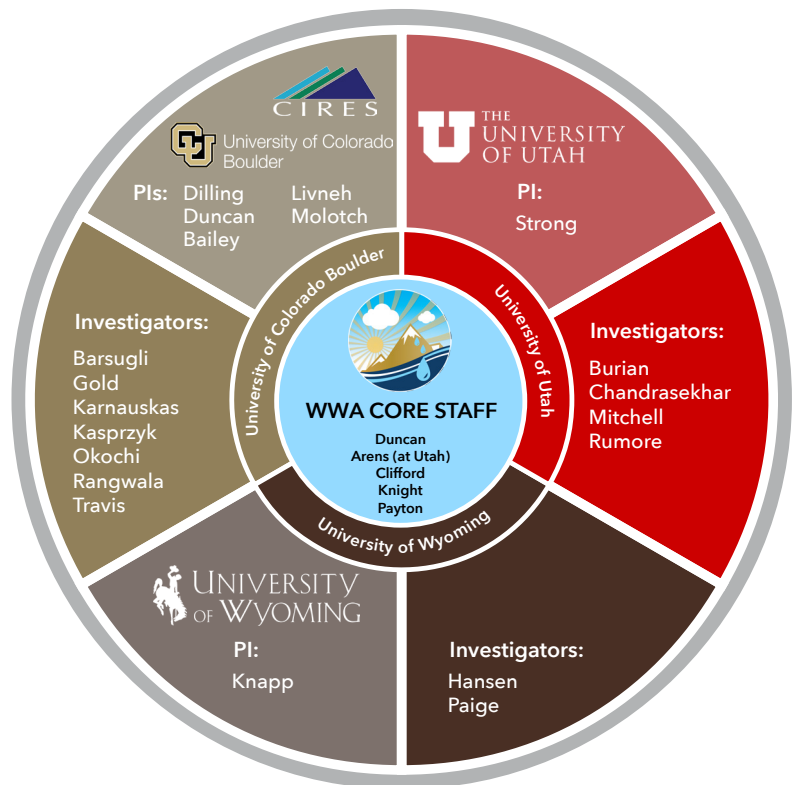
25 Research Publications

62 Media Mentions




WWA TEAM AND PROGRAM 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 interactions. 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.



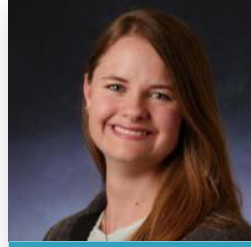
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- Corrie Knapp* (began 9/2021)
- Noah Molotch
- Bill Travis (through 8/2022)
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EXTERNAL ADVISORY BOARD

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- Dannele Peck (USDA Northern Plains Climate Hub)
- Mark Shafer (Southern Climate Impacts Planning Program)
- Amy Snover (University of Washington, Climate Impacts Group)
- Michelle Stokes (Colorado Basin River Forecast Center)

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- David Rosenberg
- Danya Rumore
- Rebecca Smith
- Christa Torrens+
- Olga Wilhelmi
- Travis Williams*
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* Indicates early career + Indicates student



KEY ACCOMPLISHMENT

UTAH HAZARDS PROJECT

The Utah hazards project was a collaboration between WWA and the Southern Climate Impacts Planning Program (SCIPP) {☆}. A primary goal of the project was to develop a hazard planning tool for Utah that built upon **SCIPP's Simple Planning Tool**, a climate information tool for hazard planners in Oklahoma. **Seth Arens** led the cross-RISA project for WWA. His role included developing the **Utah Hazard Planning (UHP) Tool** and conducting two stakeholder workshops to solicit feedback on the tools and to better understand needs for effective hazard planning in Utah. SCIPP's role was to provide expertise and guidance in developing the UHP Tool and to convene six stakeholder meetings. WWA and SCIPP worked together after all stakeholder workshops were completed to critically compare hazard planning in Oklahoma and Utah.



UTAH HAZARD PLANNING TOOL

April 2022



Photo above: Jordanelle Reservoir in Wasatch County, Utah. Credit: Central Utah Water Conservancy District.

WWA activities during 2020-2022 included developing the draft UHP Tool, convening a workshop with Utah hazard planners, finalizing the UHP Tool, convening a second stakeholder workshop, and beginning work on converting the UHP Tool into an interactive, dashboard-style tool modeled after WWA's **Intermountain West Climate Dashboard**.

The UHP Tool is a climate information resource designed specifically for Utah hazard planners to get information about the past incidence, current risk, and future projections of natural hazards in Utah. The completed UHP Tool is currently available in a report format. It contains a section for each hazard (avalanche, cold temperature extremes, dam failure, debris flow, drought, extreme heat, heavy rainfall and flooding, landslide, wildfire, wind events, and winter storms) that provides 2-5 information sources about historical hazard incidence or current risks and any available projections of future hazard occurrence. Each entry for a climate information resource has a brief description of the data and instructions on how to use the resource. WWA used its extensive knowledge of existing regional climate information sources to provide a carefully selected list of the most useful resources for Utah hazard information. A key difference between SCIPP's Simple Planning Tool and the UHP Tool is a focus on climate change impacts to hazards. For all hazards, there is a brief summary of how climate change will impact the hazard, the direction of change expected, and the level of certainty in the change.

A final version of the UHP Tool was completed in January 2022 prior to the second UHP Tool stakeholder workshop. This workshop was designed to explore hazard planners' adaptation decision space. WWA sought to better understand the factors that lead to more successful hazard planning, climate adaptation, and plan implementation. Due to the COVID-19 pandemic and the desire to encourage participation from all corners of Utah, the workshop was held in a 2-hour virtual format. There were 42 registered participants representing federal agencies (Natural Resources Conservation Service, US Forest Service, Department of the Interior, FEMA, Bureau of Reclamation, and NOAA-NWS); state agencies (Division of Emergency Management, Division of Drinking Water, Utah Geological Survey, Division of Water Resources, the Governor's Office, and Department of Transportation); and local governments (Five Counties Association of County Governments [AOG], Mountainland AOG, Bear River AOG, Wasatch County, Provo, and Payson). Of the 42 registered participants, 18 participants were new stakeholders that did not attend the first workshop in March 2021.

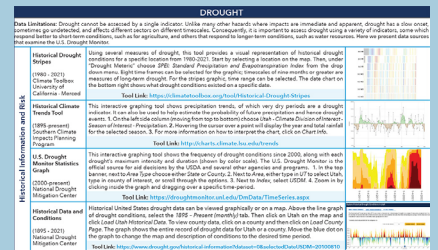
Most of the workshop time was spent in facilitated small group discussions where questions were asked about barriers to planning, assistance needed for planning, factors leading to successful plan implementation, and climate change planning. The discussions deepened relationships with Utah hazard planners, particularly the Utah Division of Emergency Management (DEM) which is responsible for state-level hazard planning. WWA learned that Utah DEM recently began considering climate change in all of their planning decisions and that additional help is needed to fully incorporate climate change adaptation into all of Utah DEM's activities. WWA and Utah DEM had a follow-up meeting in April 2022 to discuss how WWA can help with climate adaptation planning.

WWA began work on converting the report-style UHP Tool into an interactive, dashboard-style tool in May 2022. The Utah Hazard Planning Dashboard will be completed during summer 2022 and available on the WWA website.



The UHP Tool is a climate information resource designed specifically for Utah hazard planners to get information about the past incidence, current risk, and future projections of natural hazards in Utah.

The UHP Tool contains a section for each hazard that provides information sources about historical hazard incidence or current risks and any available projections of future hazard occurrence.





OTHER RESEARCH HIGHLIGHTS

HIGH-IMPACT EVENTS DATABASE

WWA PI **Bill Travis** and former WWA researchers **Jeff Lukas** and **Adam McCurdy** developed a [database of historical high-impact weather and climate events](#) that occurred in Colorado, Wyoming, and Utah from 1862–2017. The database is not a scientific dataset, but rather a collection of significant weather and climate-related events in Colorado, Utah, and Wyoming. The types of events included are avalanches, cold waves, dam failures, droughts, floods, hail, high winds, landslides, tornadoes, wildfires, and winter storms. On July 22, 2021, the database was used by the local CBS station in Denver, CO to explore the impacts of major flooding events in Colorado. This emphasized the importance and potential of this database for WWA, our website users, and our stakeholders, and we have been upgrading the contents and increasing the utility of the database since the launch of our new website in September 2021.

Over the last six months, led by **Ethan Knight** and supported by **Lineke Woelders** and **Liz Payton**, WWA has been actively populating the High-Impact Events Database with recent and missing historical high-impact weather and climate events in our region {★}. We have searched federal, state, county, and local databases, library archives, news accounts, and other sources for our collection. The majority of events included in this database are incidents that were identified as remarkable by one of the sources listed above. Some of the sources use metrics or thresholds, but most sources document events because of their impacts on communities or ecosystems. While we do not use explicit thresholds to determine whether to include an event, impacts such as total damage, fatalities, acreage, or other metrics of severity are factors that we consider when we review events for inclusion. Each event could have multiple factors or impacts that would merit its inclusion in this database.

Since societal exposure (e.g., population and infrastructure) to hazards has increased over time, and reporting of events and impacts has improved, recent events are more likely to be represented in the database, even if there is no trend in the underlying meteorological phenomenon.

One complementary feature to the database that we started this spring is our “On-This-Day-in-History” event posts on Twitter, where we post about historical high-impact events. This has proven to be an effective form of communication, creating public interest and engaging people and stakeholders with our database. Additionally, we created and published a set of monthly maps on the WWA website using NOAA’s National Center for Environmental Information (NCEI) Storm Events Database to better understand the spatial and seasonal patterns in event occurrence for six event types that are common in our region: flash floods, floods, hail, heavy snow, high wind, and wildfires. These event maps show the average number of events for each month of the year, by county, for the period of record available for that event type. They have also proven to be effective in connecting stakeholders with our database, and have been used in stakeholder reports, such as the Wyoming State Hazard Mitigation Plan (2021–2026).



Photo on page 6: View of the NCAR fire on March 26, 2022 taken from Davidson Mesa Trailhead in Louisville, CO. Credit: Ami Nacu-Schmidt.



Photo above: WWA's Seth Arens (left) leads the installation of a beta test site in the San Juan National Forest for Raymond Rose (center) and Danny Margoles (right) from the Dolores Watershed Resilient Forest Collaborative. Credit: Seth Arens.

SNOWTOGRAPHY: SNOWPACK AND SOIL MOISTURE MONITORING HANDBOOK

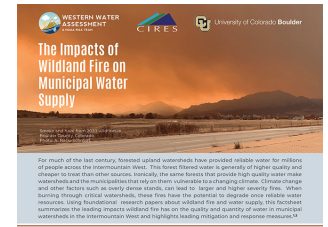
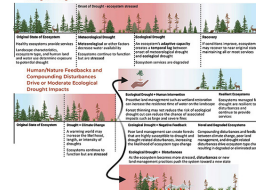
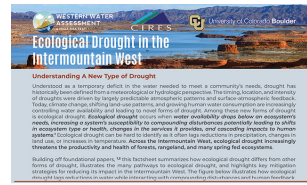
WWA's [Snowpack Monitoring in the Rocky Mountain West: A User Guide](#) and [Colorado River Basin Climate and Hydrology: State of the Science](#), both released in 2020, highlighted the need for additional snow monitoring data across the Intermountain West, particularly in locations and at elevations where the NRCS's SNOTEL and snow course sites are sparse. In 2021, WWA, in collaboration with The Nature Conservancy and the USDA-Agricultural Research Service, produced a "snowtopography" handbook to increase snow monitoring and data collection in forested settings. The handbook supports resource managers, researchers, and practitioners working in forested headwater settings where the arrangement and density of trees, or the size and severity of disturbances, affect snowpack persistence and soil moisture availability. At its most basic, snowtopography is a low-cost snowpack monitoring system composed of automated trail cameras and graduated snow stakes arranged in straight lines, or "transects," across a variable landscape. [Snowtopography: Snowpack and Soil Moisture Monitoring Handbook](#) guides readers through the process of establishing their own snowtopography and soil moisture monitoring stations. It offers guidance on site selection, snowtopography options, equipment requirements, and installation. The instructions were beta-tested by stakeholders at sites in Arizona and in the San Juan National Forest in southwestern Colorado, and their feedback informed the final handbook. **Liz Payton** was the lead author for the handbook, along with **Joel Biederman** from the USDA-Agricultural Research Service and **Marcos Robles** from The Nature Conservancy. **Seth Arens** also provided support as a beta tester and contributor to the handbook.

CONSIDERATIONS FOR CO-PRODUCTION WITH COMMUNITIES

Katie Clifford is collaborating with **Zoë McAlear**, **Lisa Dilling**, and other WWA colleagues to apply lessons learned in WWA's 2017-2019 [Vulnerability, Consequences, and Adaptation Planning Scenarios \(VCAPS\) pilot project](#) to broader considerations for co-production with communities around climate adaptation planning {★}. Their analysis is currently under revision for publication in the Bulletin of the American Meteorological Society (BAMS) (Clifford et al 2022).

SUMMER STUDENT RESEARCH HIGHLIGHTS

During the summer of 2021, with the generous support of a private donor, WWA hosted two CU Boulder graduate research fellows to expose additional students to the RISA model of usable, partnership-driven science. PhD student **Aislyn Keyes** worked with **Liz Payton** to evaluate flood risk and resilience in manufactured housing communities (Keyes 2021). Master's student **Ethan Burns** worked with **Benét Duncan** to develop fact sheets about **ecological drought** and **wildfire impacts on water systems and communities**, in collaboration with WWA, the North Central Climate Adaptation Science Center, and the USDA Northern Plains Climate Hub (Burns 2021a,b).



WATER MANAGEMENT AND CLIMATE CHANGE IN THE COLORADO RIVER BASIN

The National Science Foundation is funding a collaborative research project between Michigan State University and CU Boulder called **ACCESS** (Anthropogenic water management, Climate Change, and Environmental Sustainability in the Southwestern US). Led by Michigan State's **Yadu Pokhrel** and **Lifeng Luo** and WWA's **Ben Livneh** and **Liz Payton**, the 3-year project will examine whether future water demands in the southwestern US can be met under projected climate and current water management practices while maintaining environmental flow requirements, and if not, whether there are alternative approaches to achieving sustainability. The team engaged Colorado River basin stakeholders during a workshop in March to explore options for key aspects of the research with the goal of ensuring deliverables that are of the greatest value for improved water resource management.

UNDERSTANDING REGIONAL WATER MANAGEMENT RELIANCE ON WATER SUPPLY FORECASTING

WWA's **Ben Livneh** is collaborating with **Joe Kasprzyk** and **Benét Duncan** on an interdisciplinary, stakeholder-driven project that is developing and evaluating new techniques for anticipating and predicting drought that do not rely purely on snow-based methods, harnessing alternative techniques to improve capabilities to predict and respond to drought. This research is supported by an award from the NOAA Modeling, Analysis, Predictions and Projections (MAPP) program and leverages WWA stakeholder connections and expertise. It is being conducted with the needs of western U.S. water management entities in mind, considering regional characteristics and shifts to a warmer, less snow-dominated future climate. The team collected direct input from a wide range of regional stakeholders through an online survey administered in the fall of 2021 to help shape the modeling and machine learning work and assess the feasibility of alternative strategies for seasonal water supply forecasting.

EXPANDING UNDERSTANDING OF THE VALUE OF GRASS-CAST

A project led by WWA's **Bill Travis**, **The Economic Value of Grass Cast**, studies the added value of weather and climate information in agriculture on the Great Plains, with a focus in Colorado, Wyoming, and Nebraska, covering a large portion of the WWA region {☆}. The project was designed in collaboration with the USDA Northern Plains Climate Hub and regional extension professionals, and is aimed at improving the use of USDA and NOAA weather and climate information by agricultural decision makers in adjusting to climate variability and building more resilient operations.



NEW AREAS OF FOCUS OR PARTNERSHIP

Over the past year (June 2021–May 2022), WWA has widened our focus to include several new areas of focus and partnership. These efforts are a reflection of our deep connections in the region and an ever-growing recognition across the Intermountain West of the need to advance adaptation and develop usable climate knowledge.

In September 2021, we inaugurated WWA’s next five years as the Intermountain West NOAA RISA team with an expanded team and new areas of focus. The WWA team now features PIs, staff, and investigators from beyond the University of Colorado Boulder, and our first official formal partnerships with the University of Wyoming and University of Utah. We are committed to increasing our impact in underserved communities and have a continued emphasis on advancing stakeholder-driven, cutting-edge social and physical science research projects that help build resilience in Colorado, Wyoming, and Utah.

DEEPENING RELATIONSHIPS WITH FRONTLINE COMMUNITIES

Our activities over the coming five years will increase the resilience of communities and water systems, with a particular focus on those at the frontline of climate change, including Indigenous, Latinx, and small rural communities. WWA’s **Katie Clifford** is leveraging her expertise on working on environmental justice issues, co-production, and issues of environmental inequalities to develop new relationships with Latinx community groups, including Green Latinos and Protége, 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. She and WWA’s **Seth Arens** are also engaged with rural mountain communities across the Intermountain West through the Mountain Towns 2030 organization.

EXPANDED COLLABORATIONS IN WESTERN COLORADO

WWA has also broadened and deepened relationships with new organizations and regional partners in Western Colorado. For example, through development of the snowtopography handbook, WWA’s **Liz Payton** and **Seth Arens** developed new partnerships with The Nature Conservancy’s Colorado River Program, the USDA Agricultural Research Service (ARS) and the Dolores Watershed Resilient Forest Collaborative,

Valley of the Gods, Utah. Credit: Bureau of Land Management/Creative Commons.

an NGO that brings together federal and state agencies, local governments, water managers, industry representatives, and nonprofits to promote forest, community, and watershed resilience in the Dolores Watershed.

GROWING NEW RELATIONSHIPS WITH COMMUNITY PLANNERS

WWA's **Katie Clifford** and **Seth Arens** are building new relationships with the Colorado and Utah Chapters of the American Planning Association (APA) to expand our connections with community planners in Colorado and Utah. Katie will be leading a virtual training workshop on climate change and flooding in the summer of 2022 for the Colorado chapter of the APA.

SENSE OF PLACE AND ADAPTIVE CAPACITY IN THE INTERMOUNTAIN WEST

WWA's **Karen Bailey**, **Katie Clifford**, and **Seth Arens** launched a **new 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 will look 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. Karen and her team are still waiting for final IRB approval on this work and soon will be reaching out to gauge interest in the research and begin to assess how it can be most valuable for their needs.

ASSESSING NEEDS AMONG VULNERABLE COMMUNITIES IN WYOMING

WWA's **Corrie Knapp** and **Katie Clifford**, and student **Emily Peters**, recently launched a **new project** that will improve our understanding of adaptation needs in carbon-dependent communities and those with significant Latinx populations, and explore opportunities for building resilience to compound hazards in our region. Carbon-dependent communities are facing increasing economic pressures as fossil fuel industries decline, creating a major societal stressor in these communities. At the same time, they also face worsening climate impacts and other hazards, which can cause increasing vulnerabilities concurrent with decreasing adaptive capacity. This project prioritizes the needs and perspectives of rural communities to support long-term resilience and build networks for future engagement and planning.

USABILITY OF MEDIUM-RANGE FORECASTING FOR WATER SYSTEM RELIABILITY

WWA's **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. During the reporting period, he presented an overview and key initial results from the project to the Metropolitan Water District of Salt Lake and Sandy. Research from this project and a previous project with Weber Basin Water Conservancy District was published in *Water Resources Research* in October 2021 (Brooks et al. 2021).

PARTNERSHIP WITH THE GNAR INITIATIVE

During the reporting period, the University of Utah's **Gateway and Natural Amenity Region (GNAR) Initiative** and WWA officially began to partner. Led by WWA Investigator **Danya Rumore**, the initiative leverages research, education, and capacity-building to assist communities, land managers, and others in gateway and natural amenity regions throughout the West in preparing for and responding to planning, development, natural resource management, and public policy challenges. **Seth Arens** is collaborating with Rumore to leverage the infrastructure and relationships developed by the GNAR Initiative to identify underserved, rural community concerns related to natural hazards and collaboratively develop tools and resources to increase their socio-economic and environmental resilience. Additionally, the GNAR Initiative has formed partnerships with a number of gateway communities in the WWA region, which may be useful for future WWA work with those communities.



OUTREACH AND ENGAGEMENT

NEW WWA WEBSITE AND INCREASING PUBLIC ENGAGEMENT

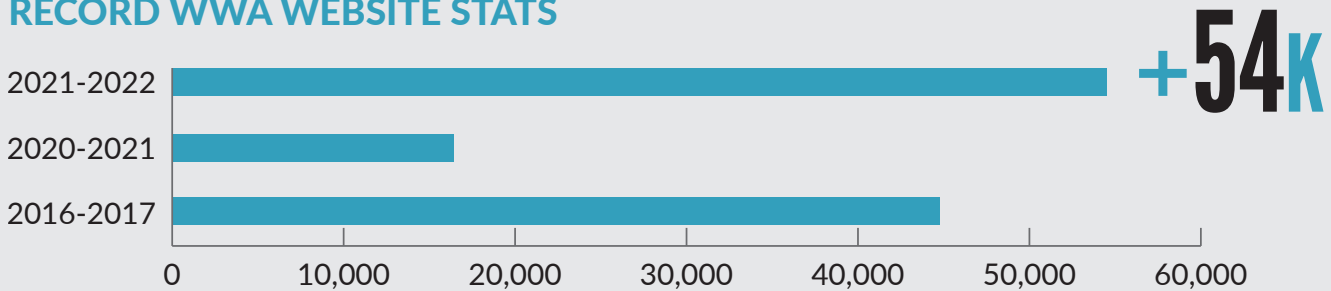
WWA continues to make effective communication and outreach a priority by implementing the communications strategy developed in 2020 by **Ethan Knight**. The plan aligns core communications goals with key stakeholder sectors and a range of communication channels, including email outreach, quarterly newsletters, our new 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.

During the past year, we have continued to make exciting progress in increasing our online presence. In September 2021, we officially launched the new WWA website {★}, with a fresh new look, usable interface, and cleaner layout of our pages and tools. Led by Knight and the CIRES IT team, especially **Matt Price**, the new website was rebuilt under a new content management system, reorganized in its content and site layout, and updated in its design. The new website is now much easier to edit and update internally at WWA, making it easier to keep up-to-date.

This system transition, along with reorganization of the website itself, has 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**, are more accessible and have added functionality. During the reporting period, our website had a total of 16,755 visitors and 54,643 pageviews. These statistics are the highest they have ever been for our website since site analytics tracking began in 2013, surpassing the user record of 16,394 during the June 1, 2020–May 31, 2021 reporting period and the pageviews record of 44,765 during the June 1, 2016–May 31, 2017 reporting period.

Photo above: Estes Park, Colorado, known as the Gateway to Rocky Mountain National Park. Credit: Adobe Stock.

RECORD WWA WEBSITE STATS



2022 TWITTER STATS

326 new followers

314,200+ tweet views

1,061 total followers

46,133

profile visits

46%

Another way in which we continue to increase our online presence is through our **Twitter account**, managed by Knight. We use Twitter 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, we gained 326 new followers for a total of 1,061 followers, 314,200+ ‘impressions’ or tweet-views, 46,133 profile visits (an all-time high), 153 account mentions, and thousands of ‘engagements’ or tweet interactions (including clicks, likes, retweets, and replies). This is a significant increase over the reporting periods from June 2013–May 2020 before the implementation of our updated communications plan.

TARGETED ENGAGEMENT WITH STAKEHOLDER GROUPS

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. Following are highlights from this work:

ENGAGING WITH COMMUNITIES AND RESOURCE MANAGERS

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. **Liz Payton** and **Ben Livneh** co-led a workshop on the future of Colorado River streamflows. The goals of the workshop were to understand collaborators’ systems, settings, and information gaps; solicit input from them on project goals; and ensure that the project scope is relevant to, and aligns with, collaborators’ needs. Collaborators represented five major water resource agencies in the Colorado River basin: the Colorado River Board of California, Denver Water, the New Mexico Interstate Stream Commission, the Upper Colorado River Commission, and the US Bureau of Reclamation. Researchers from Michigan State University and WWA represented the project team.

Court Strong worked on western US hydroclimate in collaboration with a dozen staff members from Salt Lake City Department of Public Utilities (SLCDPU), including the Director, engineers, topical experts, and public outreach and messaging coordinators. Strong and fellow researchers are providing this group with observation- and model-driven water management tools that enable informed decision making at lead times significantly longer than conventional practices. **Imtiaz Rangwala**, **Bill Travis**, and **Katie Clifford** engaged with the City of Boulder to evaluate their ongoing efforts on building climate resilience in different systems (water, flooding, fire, ecosystems). **Karen Bailey** has identified several local and regional decision makers (particularly related to water management) who she and the rest of the Sense of Place project team will be interviewing in the coming months. Investigator **Danya Rumore** has been working closely with a number of gateway communities across the West as part of an ongoing study on planning and

development challenges in western gateway communities, many of which are in the WWA region. Clifford has been participating in the Metro Denver Public Health working group on Climate and Equity, which connects and engages primarily with state, county, and municipal government staff as well as non-profit representatives focused on climate-related environmental health issues in the Front Range. She is also a member of the Colorado Sustainable Regional Systems (CO SRS-RN), a regional research collaboration aimed at producing integrated, applied, and actionable research that supports the health, equity, and vitality of communities across our region.

OUTREACH WITH SCIENTIFIC AND ADAPTATION PRACTITIONER COMMUNITIES

As a NOAA 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; such engagement helps us to identify opportunities to conduct research that both advances scientific understanding and meets stakeholder needs.



We are Water Exhibit at Atzac Public Library, NM.



We are Water Take and Make Kits.

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 virtual, national, public engagement workshop to introduce the proposed chapter outline and solicit comments from the public. **Corrie Knapp** has the same role with the NCA5 for the Northern Great Plains chapter. **Imtiaz Rangwala** is a Technical Contributor for 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** and **Lineke Woelders** 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 will travel to Aztec, New Mexico in June 2022 to host We are Water's upcoming Mini Film Festival 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.

WWA PIs, researchers, and staff also spoke at a number of virtual academic meetings and conferences. For example, Knapp attended

and led a panel on climate change impacts at the Yellowstone 150 conference in Cody, Wyoming. This conference had a diverse audience of community members, agencies, tribes, decision makers and scientists. Corrie's graduate student **Emily Peters** has taken a preliminary listening trip to Jackson to meet with underserved Latinx community members and organizations. She has also been reaching out across the state to understand where there is interest in climate change within underserved communities. **Court Strong** presented key hydroclimate results at American Geophysical Union and American Meteorological Society national meetings. **Noah Molotch** and graduate student **Eric Kennedy** presented the findings of their research at poster sessions at the American Geophysical Union Fall Meeting in New Orleans, LA in December 2021 and at the Western Snow Conference in Salt Lake City, UT in April 2022. Additionally, they presented these findings in research talks at the University of Colorado Hydrological Symposium and the Institute for Arctic and Alpine Research Seminar series, both in April 2022. They also incorporated the themes from their research into the "hands-on" portion of the curriculum for the Department of Geography's Snow Hydrology Research Internship.

Ben Livneh participated in an expert panel on the human side of climate solutions at a Fulbright Scholar meeting in Fort Collins, CO, in April 2022. He also participated in a virtual expert panel at the Yampa Basin Rendezvous, discussing drought, water availability, and conservation in September 2021. Livneh and **Katie Clifford** were invited to speak by the Colorado Water Conservation Board at the Colorado Water Congress about WWA's work on supporting resilient water systems and engaging frontline communities. **Seth Arens** presented at the Wyoming Rural Water Association annual meeting to water managers working in rural water systems across the state about climate and wildfire impacts to water quality.

WWA also has a close relationship with the USGS North Central Climate Adaptation Science Center (NC CASC) and the USDA Northern Plains Climate Hub. We 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 summer Three Centers Retreat was held virtually over multiple days in August 2021. Leveraging WWA's relationship with the NC CASC, Clifford also delivered a webinar about social dimensions of climate adaptation organized by the Science Director for the Bureau of Land Management.

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 a stand-alone webinar featuring WWA's **Seth Arens** called **What's up with the weather? A summer of extremes in the Intermountain West**, discussing the extreme weather events during the summer of 2021 and how they exemplify the concept of compound natural hazards. In January 2022, we presented a webinar on the **Snowtopography: Snowpack and Soil Moisture Monitoring Handbook**, covering the motivation for developing the handbook, the science supporting the snowtopography method, the structure and contents of the handbook, and on-the-ground experiences of handbook beta testers, followed by Q&A. The speaker list included collaborators **Marcos Robles** (The Nature Conservancy), **Joel Biederman** (USDA-ARS), **Danny Margoles** (Dolores Watershed Resilient Forest Collaborative), **Lindy Hutchinson** (Northern Arizona University), and WWA's **Liz Payton** and Arens. These webinars attracted attendees from academia, federal and state agencies, non-profits, the media, and the private sector. We plan to continue the WWA webinar series, highlighting climate impacts on water supply, natural hazards, community resilience, and more.

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 Associated Press News, ABC News, PBS NewsHour, Los Angeles Times, Chicago Tribune, NASA Earth Observatory, E&E News, The Guardian, Climate Central, The Salt Lake Tribune, Nevada Today, Montana Free Press, 9News KUSA, CBS Denver, The Denver Channel, The Conversation, InsideClimate 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.

NATIONAL CLIMATE ASSESSMENT

Liz Payton's appointment as the lead author of the water chapter for the forthcoming Fifth National Climate Assessment is a recognition of her expertise in climate and water supply and the major impact of the [Colorado River Basin Climate and Hydrology: State of the Science report](#) that Payton and former WWA researcher **Jeff Lukas** published in 2020. **Imtiaz Rangwala** is also a contributor to the chapter. Through this role, WWA is helping to *build critical climate information assets* and *boost learning outcomes*. We anticipate that this chapter of the Fifth National Climate Assessment, and the Assessment as a whole, will *increase the flexibility* of our partners, *shift mindsets* in the region, and *elevate the sense of agency* for water managers and communities in the region.

WILDFIRE FACT SHEET

2021 WWA summer graduate fellow **Ethan Burns** developed fact sheets on [ecological drought](#) and [wildfire impacts on water systems and communities](#), in collaboration with WWA, the North Central Climate Adaptation Science Center, and the USDA Northern Plains Climate Hub (Burns 2021a,b). Since publication of the fact sheets, WWA has received direct requests for information and engagement from communities in Wyoming and Colorado, including the Colorado Mountain Town 2030 initiative and the Wyoming Association of Rural Water Systems. WWA's **Katie Clifford** and **Seth Arens** have since provided presentations on climate, wildfire, and water supply to these groups. Through the fact sheets and subsequent engagement, WWA has *built valuable assets* and *boosted learning outcomes*. As demonstrated by these new partners' desire for additional engagement, we have also elevated their *sense of agency* and nurtured their *ability to self-organize* to build climate resilience.

Mallory Cave Trail, Boulder, Colorado. Photo: Ethan Knight.

INTERMOUNTAIN WEST CLIMATE DASHBOARD AND HIGH-IMPACT EVENTS DATABASE

WWA developed and maintains the [Intermountain West Climate Dashboard](#) on our website, where **Seth Arens** also publishes monthly Intermountain West Climate Briefings {★}. **Ethan Knight** also led an effort to update the [High-Impact Events 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 even journalists to inform decisions and support outreach. WWA recently received a request from Ridgway, CO to share the dashboard on their website, and it is also featured online by partners with the Mountain West Climate Services Partnership. A reporter for the Denver CBS station recently used the database to explore the impacts of major flooding events in Colorado. Through this, WWA has **built and maintained valuable climate information assets** and **boosted learning outcomes**, helping to **shift mindsets**.

SUPPORTING COMMUNITY DECISION MAKING

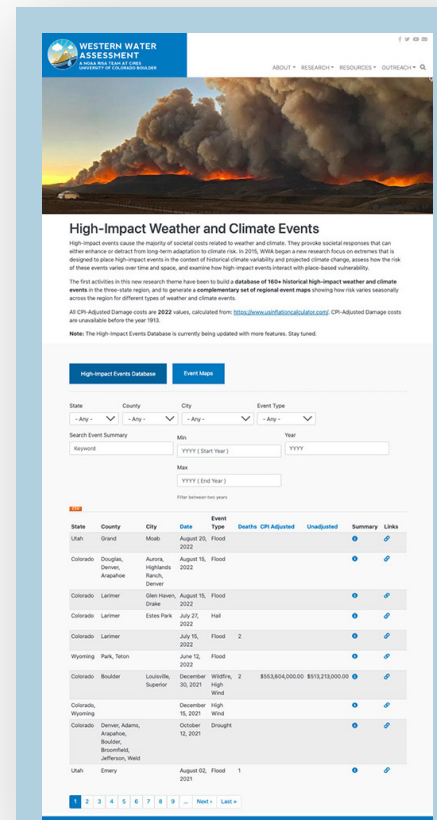
WWA staff and researchers frequently engage directly with communities, helping to **boost learning outcomes** and **shift mindsets**, and elevating their **sense of agency** to act to build climate resilience. For example, **Court Strong** and his team discovered that groundwater storage (reflected in midwinter baseflow) is a crucial control on water yield, enabling prediction of water yields as early as January. This is transforming how Salt Lake City Department of Public Utilities water managers approach seasonal-to-multi-year planning and public outreach, thereby increasing the resilience of the water supply for millions of residents. **Imtiaz Rangwala**, **Katie Clifford**, and **Bill Travis** engaged directly with staff at the City of Boulder to evaluate their ongoing efforts on building the climate resiliency of water, flooding, fire, and ecosystems in Boulder and other cities in the Colorado Front Range.

IMPACT CASE STUDY 1

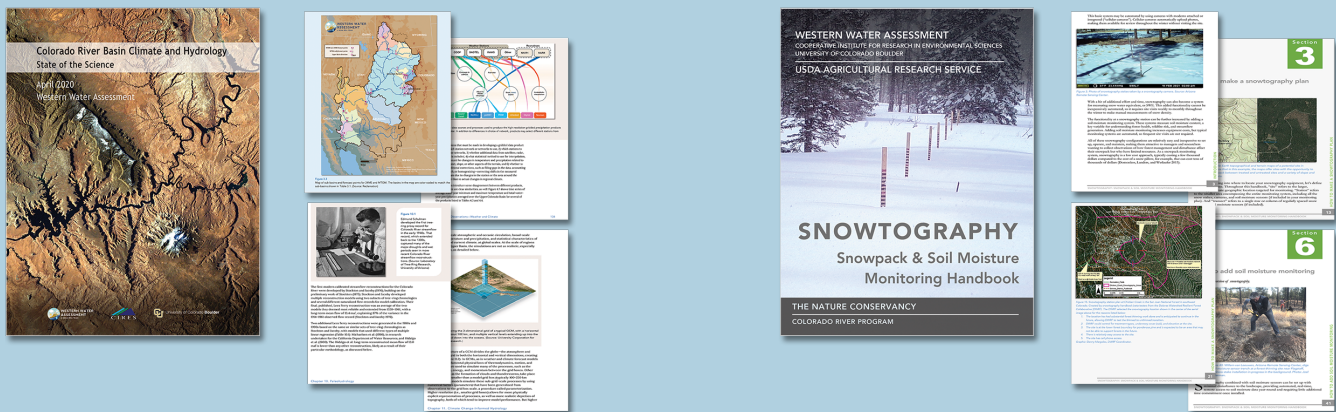
CLIMATE-INFORMED WATER MANAGEMENT IN THE COLORADO RIVER BASIN

Released in April 2020, the [Colorado River Basin Climate and Hydrology: State of the Science report](#) 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 WWA's **Liz Payton** and former WWA researcher **Jeff Lukas**, and a 17-member author team, with support and guidance from over a dozen federal, state, and local water agencies. In identifying both challenges and opportunities, the report is a **critical asset** that has **boosted learning outcomes**, **increased partner flexibility**, **shifted mindsets**, and elevated a **sense of agency** for water managers in the region. Over the past year, it has guided 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. This is articulated best by Southern Nevada Water Authority's **Seth Shanahan**, who coordinates the Colorado River Climate and Hydrology Workgroup that sponsored the report:

“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. Specifically in 2021, the Work Group met to consider new project implementation priorities. We amended our procedures to specifically consider the opportunities described in the SOS report and 4 of 6 projects that we agreed to pursue were SOS opportunities. 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



WWA's High-Impact Events Database.



The Colorado River Basin Climate and Hydrology: State of the Science report and the Snowtopography: Snowpack and Soil Moisture Monitoring Handbook.

biggest challenges (needs) in the Basin and, specifically, the tools that are in use. This latter item is particularly relevant because it minimizes the development of alternative tools that likely have major hurdles for adoption and builds a larger community of practice for 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. Building more awareness of it is an important priority of ours.”

IMPACT CASE STUDY 2

LOW-COST SNOW MONITORING TECHNIQUES

WWA’s **Liz Payton** led a new partnership with **Marcos Robles** from The Nature Conservancy and **Joel Biederman** with the USDA Agricultural Research Service (ARS) to develop a handbook describing a new, low-cost method for monitoring snowpack. The **Snowtopography: Snowpack and Soil Moisture Monitoring Handbook** has proved to be a **valuable information asset** for our partners and stakeholders as they pursue increased snowpack monitoring to help guide climate-informed water management decisions. With the help of the handbook, TNC is setting up a project with ARS for the next two years that will expand snowtopography in the Dolores Watershed in 2022 and then in Wyoming in 2023. The handbook itself has been very popular on the WWA website and beyond, with over 180 downloads from the website, and over 625 views of an associated webinar. Partners have received information inquiries from forest collaboratives in southwest Colorado that bring together many different stakeholder groups. Taken together, the handbook has **boosted learning outcomes** and increased the ability of partners and stakeholders to **self-organize**. It has also **shifted mindsets** and **increased flexibility** to expand snowpack monitoring in areas with limited resources and a lack of existing traditional snowpack monitoring infrastructure.

IMPACT CASE STUDY 3

SNOW-WATER EQUIVALENT MAPPING IN THE INTERMOUNTAIN WEST

WWA PI **Noah Molotch** and his research team, led by **Leanne Lestak**, have been producing **spatial snow-water equivalent (SWE) maps** using satellite observations in the Intermountain West {★}. This effort builds on initial mapping work for California. This SWE mapping has built significant adaptive capacity in the region in that the SWE data is being used by stakeholders to evaluate real-time water supply conditions and to explore ways of integrating new SWE data into runoff forecasts produced by the Colorado Basin River Forecast Center (CBRFC).

WWA PROGRAM EVALUATION

In WWA's previous summative program evaluation, feedback from resource managers, community leaders, researchers, and other stakeholders demonstrated the impact of our integration and outreach activities from 2015-2019. Evaluation participants shared that engagement with WWA researchers and staff has helped to increase their scientific understanding of climate impacts, supported peer learning among decision makers, and provided information that has encouraged organizations and communities to take actions that build resilience (Gold et al. 2020). Results of this evaluation are detailed in WWA's 2020-2021 Annual Report, available on the [WWA website](#).

The 2021-2022 performance period marked the launch of WWA's RISA renewal projects and activities, including an updated approach to our program evaluation. Investigators **Anne Gold** and **Christine Okochi** are leading our evaluation design and implementation. Our updated evaluation approach will include ongoing tracking and evaluation of our impact, and it will incorporate resilience metrics being developed by **Lisa Dilling** and **Katie Clifford**.

WWA is committed to using a thoughtful and integrated evaluation approach 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. Gold and Okochi's evaluation activities will occur in three phases: 1) a needs assessment in 2022, 2) a mid-term evaluation of program activities and opportunities in 2023-2024, and 3) a summative evaluation of WWA's impact and progress in meeting program goals in 2026.

YEAR 1 EVALUATION ACTIVITIES

Throughout WWA's research projects, outreach and integration activities, and evaluation plan, the evaluation team aims to collect data to understand the program's impact and how its work is supporting adaptive capacity and resilience in the region. **Lisa Dilling** and **Katie Clifford** have made progress developing sets of actionable metrics that will help to track the impact of WWA's work on the resilience of water systems and communities. Resilience theory indicates that there are many potential 'resilience metrics,' and they aim to develop a small set of metrics that will take this from theory to practice. They convened a multidisciplinary conversation with WWA researchers to explore water system resilience metrics, and have done an extensive review of existing resilience metrics literature. In the summer of 2022, they will finalize an initial set of potential resilience metrics, and we will test and track a subset of those metrics through our research projects over the coming years.

During the summer of 2022, the evaluation team will be developing evaluation metrics that will be followed for the coming four years. These metrics will include the resilience tracking metrics described above, and metrics to track our progress with JEDI (Justice, Equity, Diversity, and Inclusion) priorities. The evaluation team will also be developing guiding evaluation questions and a short survey that will be disseminated to stakeholders and partners for each project to collect data on how well the project is reaching its research and resilience-building goals.

FUTURE EVALUATION ACTIVITIES

In the coming years, WWA will distribute a project-level survey to stakeholders and partners involved in many of our research projects. The evaluation team will also conduct a mid-point mini program evaluation in 2023-2024 that evaluates progress towards WWA's program goals and resilience metrics. This mid-point evaluation will also identify how well we are meeting stakeholder needs and opportunities, and whether new needs or opportunities have emerged. In 2026, the evaluation team will use the results of project-specific surveys, and an additional survey on the impact of WWA's work with the broad stakeholder community, to conduct a summative program evaluation. This will provide an assessment of WWA's success in meeting program goals, being responsive to stakeholder needs and opportunities, and documenting impact on understanding the state of resilience and adaptive capacity and resilience in action.



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 expand our connections with stakeholders in the region, with a particular emphasis on frontline communities that are disproportionately affected by climate impacts.

Since March 2020, the COVID-19 pandemic has limited our ability to conduct in-person stakeholder meetings and engagement activities. We pivoted to conduct as many meetings and workshops virtually as possible, and this has helped us to build our virtual meeting facilitation skills. For example, **Seth Arens** led virtual workshops in 2021 and 2022 to advance the Utah Hazards Project, and we now host a regular WWA webinar series that enables attendance across Colorado, Utah, and Wyoming – and beyond. During the coming year, we plan to complete those activities that we were unable to host virtually, including extending our original **Vulnerability, Consequences, and Adaptation Planning Scenarios (VCAPS) pilot project** to conduct VCAPS workshops in one to two Wyoming communities. First developed by the Carolinas Integrated Sciences and Assessments (CISA) RISA, the VCAPS process provides a framework for community-based adaptation planning workshops that also draws on the expertise of community members. In 2018 and 2019, WWA conducted the VCAPS pilot project in 6 communities in Colorado and Utah. We are excited to expand this effort to conduct VCAPS workshops in one to two Wyoming communities in 2023. Two additional initiatives are highlighted below:

DEVELOPING METRICS TO TRACK PROGRAM IMPACTS ON RESILIENCE

Existing social science research suggests that the resilience of systems in our region clearly depends not only on relevant, skillful information, but also on trusted networks of actors and institutions that can act to adjust and maintain function, or possibly transform systems, even as the region encounters shocks and stresses. Over the coming year, **Lisa Dilling** and **Katie Clifford** will complete development of an initial set of “resilience metrics” to help track our program impacts on the community and water system resilience. The metrics are being developed with an extensive review of existing literature and deep engagement with community and water system managers, and with the input of WWA PIs. WWA will test these metrics by tracking them over the next four years as part of our program evaluation activities.

NEEDS ASSESSMENT IN UNDERSERVED WYOMING COMMUNITIES

WWA’s **Corrie Knapp** will complete a needs assessment of current and future research needs among underserved communities in Wyoming, in collaboration with **Katie Clifford** and graduate student **Emily Peters**. This will result in a more robust understanding of current research gaps and priority areas in Wyoming and a list of potential stakeholders and actors across the state who are interested in compound hazards. These results will serve as the basis for outreach related to a future call for supplemental small-grant funding for planning and implementation efforts across the state. This needs assessment is part of a larger research project that, together with additional research activities and a future supplemental small-grant funding program, will help advance from assessment and synthesis of existing efforts to co-production of tangible and actionable projects to allow rural communities to plan to address compound hazards and tribal communities to implement adaptation actions.

Photo above: Caribou Ranch Open Space, Nederland, Colorado. Credit: Brent Smith.



APPENDIX A

WWA PUBLICATIONS

Following are publications written by, or in collaboration with, WWA researchers from June 1, 2021 through May 31, 2022.

Badger, Andrew M., Nels Bjarke, Noah P. Molotch, and Ben Livneh. 2021. “The Sensitivity of Runoff Generation to Spatial Snowpack Uniformity in an Alpine Watershed: Green Lakes Valley, Niwot Ridge Long-Term Ecological Research Station.” *Hydrological Processes* 35 (9). <https://doi.org/10.1002/hyp.14331>.

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, Theodore B., Jelena Vukomanovic, Patrick Bourgeron, and Noah P. Molotch. 2021. “Future Land Cover and Climate May Drive Decreases in Snow Wind-Scour and Transpiration, Increasing Streamflow at a Colorado, USA Headwater Catchment.” *Hydrological Processes* 35 (11). <https://doi.org/10.1002/hyp.14416>.

Bjarke, Nels R., Ben Livneh, Sarah C. Elmendorf, Noah P. Molotch, Eve-Lyn S. Hinckley, Nancy C. Emery, Pieter T. J. Johnson, Jennifer F. Morse, and Katherine N. Suding. 2021. “Catchment-Scale Observations at the Niwot Ridge Long-Term Ecological Research Site.” *Hydrological Processes* 35 (9). <https://doi.org/10.1002/hyp.14320>.

Photo above: South Mesa Trail, Boulder, Colorado. Credit: Ethan Knight.



Photo above: Indian Peaks Wilderness, Colorado. Credit: Katie Clifford.

Brooks, Paul D., Andrew Gelderloos, Margaret A. Wolf, Logan R. Jamison, Courtenay Strong, D. Kip Solomon, Gabriel J. Bowen, et al. 2021. “Groundwater-Mediated Memory of Past Climate Controls Water Yield in Snowmelt-Dominated Catchments.” *Water Resources Research* 57 (10). <https://doi.org/10.1029/2021WR030605>.

Burns, Ethan. 2021a. “Ecological Drought in the Intermountain West.” *Western Water Assessment*. https://www.colorado.edu/sites/default/files/2022-01/ecological_drought_fact_sheet_2021.pdf.

Burns, Ethan. 2021b. “The Impacts of Wildland Fire on Municipal Water Supply.” *Western Water Assessment*. https://www.colorado.edu/sites/default/files/2022-02/wildfire_fact_sheet_2021.pdf.

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>.

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>.

Dilling, Lisa, Maria Carmen Lemos, and Nuvodita Singh. 2021. “Commentary: First, Do No Harm: Scaling Usable Knowledge for Just and Equitable Outcomes.” *Global Environmental Change* 71 (November): 102404. <https://doi.org/10.1016/j.gloenvcha.2021.102404>.

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>.

Hale, Katherine E., Adam N. Wlostowski, Andrew M. Badger, Keith N. Musselman, Ben Livneh, and Noah 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>.

Henderson, Jen, Lisa Dilling, Rebecca Morss, Olga Wilhelmi, and Ursula Rick. 2021. “We Got in the Pilot Program to Learn from It:’ Features of Social Learning in Drought Contexts Along the Arkansas River in Colorado.” *Weather, Climate, and Society*, June. <https://doi.org/10.1175/WCAS-D-20-0120.1>.

Keyes, Aislyn. 2021. “Mobile Homes and Flood Risk: An Analysis of Flood Risk and Historical Flooding in the Intermountain West and Michigan.” *Western Water Assessment*. https://www.colorado.edu/sites/default/files/2021-11/Final_Report_Keyes_2021.pdf.

Kroepsch, Adrienne 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>.

Lukas, Jeff, and Elizabeth Payton, eds. 2020. “Colorado River Basin Climate and Hydrology: State of the Science.” *Western Water Assessment*, University of Colorado Boulder. <https://doi.org/10.25810/3hcv-w477>.

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>.

Payton, Elizabeth, Joel Biederman, and Marcos Robles. 2021. “Snowtography: Snowpack & Soil Moisture Monitoring Handbook,” November. <https://doi.org/10.25810/R9S7-4T28>.

Pierce, David W., Lu Su, Daniel R. Cayan, Mark D. Risser, Ben Livneh, and Dennis P. Lettenmaier. 2021. “An Extreme-Preserving Long-Term Gridded Daily Precipitation Data Set for the Conterminous United States.” *Journal of Hydrometeorology*, May. <https://doi.org/10.1175/JHM-D-20-0212.1>.

Rangwala, Imtiaz, Wynne Moss, Jane Wolken, Renee Rondeau, Karen Newlon, John Guinotte, and William Riebsame Travis. 2021. “Uncertainty, Complexity and Constraints: How Do We Robustly Assess Biological Responses under a Rapidly Changing Climate?” *Climate* 9 (12): 177. <https://doi.org/10.3390/cli9120177>.

Shrum, Trisha R. and William R. Travis (2022). “Experiments in ranching: Rain-index insurance and investment in production and drought risk management.” *Applied Economics Perspectives & Policy* 44: 1513–1533. <https://doi.org/10.1002/aep.13304>.

Su, Juhn-Yuan, Ramesh Goel, Steven Burian, Sarah J. Hinnners, Adam Kochanski, Courtenay Strong, and Michael E. Barber. 2021. “Water Quality Trading Framework with Uncertainty for River Systems Due to Climate and Population Characteristics.” *Water* 13 (13): 1738. <https://doi.org/10.3390/w13131738>.

Western Water Assessment. 2022. “Utah Hazard Planning Tool.” Edited by Seth Arens. *Western Water Assessment*. <https://www.colorado.edu/sites/default/files/2022-04/Utah%20Hazard%20Planning%20Tool%20011422.pdf>.

Williams, A. Park, Ben Livneh, Karen A. McKinnon, Winslow D. Hansen, Justin S. Mankin, Benjamin I. Cook, Jason E. Smerdon, et al. 2022. “Growing Impact of Wildfire on Western US Water Supply.” *Proceedings of the National Academy of Sciences* 119 (10): e2114069119. <https://doi.org/10.1073/pnas.2114069119>.

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>.



WESTERN WATER ASSESSMENT

A NOAA RISA TEAM

Western Water Assessment
Cooperative Institute for Research in Environmental Sciences
University of Colorado Boulder
University of Utah
University of Wyoming
<http://wwa.colorado.edu>