

# Western Water Assessment

## Building Climate Resilience by Design



2020 - 2021 ANNUAL REPORT



**WESTERN WATER  
ASSESSMENT**  
A NOAA RISA TEAM



University of Colorado  
Boulder



# WESTERN WATER ASSESSMENT

A NOAA RISA TEAM

## WESTERN WATER ASSESSMENT

Cooperative Institute for Research in Environmental Sciences  
University of Colorado Boulder

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Cover photo: Easter Pasture Canyon, Colorado River, Glen Canyon National Recreation Area, Utah. Credit: Seth Arens.



University of Colorado **Boulder**



View of Green River from Range Creek, Utah. Credit: Seth Arens.

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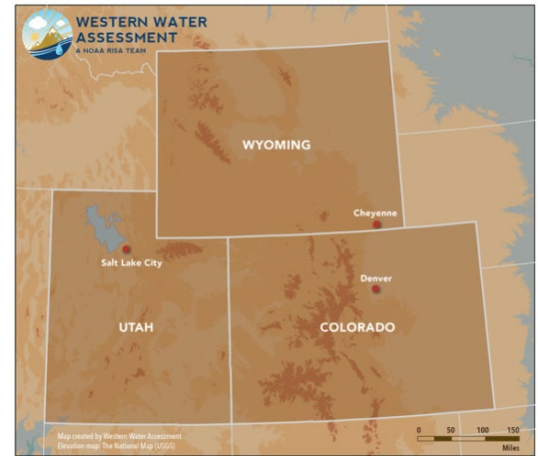
# INTRODUCTION: ABOUT WESTERN WATER ASSESSMENT

## MISSION AND THEMES

The mission of Western Water Assessment (WWA) is to conduct innovative research in partnership with decision makers in the Intermountain West, helping them make the best use of science to manage for climate impacts. Using multidisciplinary teams of experts in climate, hydrology, social sciences, and policy, WWA works with decision makers across Colorado, Utah, and Wyoming to produce policy-relevant information about climate variability and change. By building relationships with networks of decision makers, our team is able to develop practical research programs and useful information products.

WWA focuses its work on four overarching themes:

1. Climate vulnerability and adaptive capacity in the WWA region
2. Extremes and climate risk management
3. Designing organizations and networks for usable science
4. Understanding and monitoring drought in the WWA region



In 2020, WWA received supplemental RISA program funding that allowed us to expand our priorities to include engaging with small- to medium-sized communities, growing the capacity for adaptation in the state of Utah, and advancing adaptation science in the Intermountain West. We see each of these priorities as being critical pieces to building climate resilience in a way that considers the disproportionate impacts of climate change on frontline communities, is responsive to the context of each state in our region, and acknowledges the need for growing knowledge in adaptation science. Activities that were supported under this supplemental funding are denoted with “\*S” throughout this annual report.

## OUR PROGRAM STRUCTURE AND TEAM

WWA is formally part of the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado Boulder (CU Boulder), and our researchers and partners come from universities and government institutions across our region.

WWA has six core staff members who focus on program management, research development and synthesis, and coordination of stakeholder interactions. During the past year, **Dr. Lineke Woelders** received a promotion from a postdoctoral researcher to a research scientist, and **Ethan Knight** transitioned from an undergraduate student assistant to an associate scientist on the WWA team. In May 2021, CU Boulder graduate students **Aislyn Keyes** and **Ethan Burns** were awarded WWA Summer Graduate Fellowships. Aislyn is conducting a research project exploring flooding in manufactured housing communities, and Ethan is leading development of a series of fact sheets about critical hazards in the WWA region. We look forward to reporting on these projects in our next annual report.

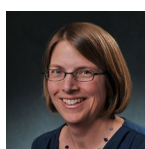


The Western Water Assessment Team and Network.

WWA's broader research team includes physical and social scientists at the University of Colorado, the University of Utah, NOAA, and the National Center for Atmospheric Research (NCAR). The WWA External Advisory Board consists of national experts from across the science-policy landscape, and provides programmatic guidance to the core staff and PIs. Taken together, this network represents a broad base of expertise that enables the program to successfully engage decision makers, building relationships that are critical for meeting stakeholder needs and advancing scientific understanding.

Photo to the left: South St. Vrain Creek near Long Lake, Colorado. Credit: Ethan Knight.

## Western Water Assessment Core Staff



**Lisa Dilling, Director**  
[ldilling@colorado.edu](mailto:ldilling@colorado.edu)  
 Expertise: Usable climate information;  
 Adaptation; Social Science



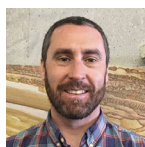
**Liz Payton, Colorado River Basin  
 Assessment Specialist**  
[elizabeth.payton@colorado.edu](mailto:elizabeth.payton@colorado.edu)  
 Expertise: Hydrology; Water system  
 modeling



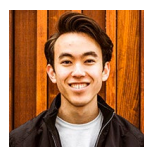
**Benét Duncan, Managing Director**  
[benet.duncan@colorado.edu](mailto:benet.duncan@colorado.edu)  
 Expertise: Assessments; Climate  
 indicators; Science policy



**Lineke Woelders, Water Resources  
 Specialist**  
[lineke.woelders@colorado.edu](mailto:lineke.woelders@colorado.edu)  
 Expertise: Hydrology; Climate change



**Seth Arens, Research Integration  
 Specialist, Utah**  
[www.arens@gmail.com](http://www.arens@gmail.com)  
 Expertise: Eco-hydrology; Air quality



**Ethan Knight, Associate Scientist**  
[ethan.knight@colorado.edu](mailto:ethan.knight@colorado.edu)  
 Expertise: Environmental science

## WWA PIs

Name	Title	Expertise
Lisa Dilling	Lead PI and Director, WWA; Professor, Environmental Studies, Univ. of Colorado; Fellow, CIRES	Climate information; Adaptation; Social Science
Joseph Barsugli	Research Scientist, CIRES, Univ. of Colorado	Climate dynamics
Ben Livneh	Assistant Professor, Civil, Environmental and Architectural Engineering, Univ. of Colorado; Fellow, CIRES	Physical hydrology; Land surface modeling; Climate impacts
Noah Molotch	Director, CWEST; Fellow, INSTAAR; Associate Professor, Geography, Univ. of Colorado	Snow hydrology
William Travis	Associate Professor and Department Chair, Geography, Univ. of Colorado	Natural hazards; Climate impacts; Adaptation

## WWA External Advisory Board

Name	Title	Expertise
Kathy Jacobs, Chair	Director, Center for Climate Adaptation Science and Solutions, University of Arizona	Climate adaptation; Climate assessment
Richard Moss	Visiting Researcher, Andlinger Center for Energy and the Environment, Princeton University; Senior Scientist, Joint Global Change Research Institute (on leave)	Climate assessment
Dannele Peck	Director, USDA Northern Plains Climate Hub	Agricultural economics
Mark Shafer	Director, Southern Climate Impacts Planning Program (SCIPP); Associate State Climatologist, Oklahoma	Climatology; Climate adaptation; Hazard preparedness
Amy Snover	Director, Climate Impacts Group; University Director, NW Climate Adaptation Science Center; Affiliate Associate Professor, Marine and Environmental Affairs, University of Washington	Climate adaptation and decision-making; Climate dynamics; Vulnerability assessment
Michelle Stokes	Hydrologist in Charge, NOAA Colorado Basin River Forecast Center; Co-Team Lead, NOAA Western Region Collaboration Team	Hydrology

## WWA Research Team and Partners

Team Member	Title	Expertise
Natalie Bennett	University of Colorado graduate student	Climate adaptation
John Berggren	Western Resource Advocates (Formerly CU graduate student)	Colorado River water policy
Paul Brooks	University of Utah	Hydrology; Ecohydrology
Carli Brucker	University of Colorado graduate student	Hydrology; Wildfire
Steve Burian	University of Utah/Utah Water Center	Hydrology
Ethan Burns	2021 WWA Summer Graduate Fellow; University of Colorado graduate student	Hydrology; Ecohydrology
Katie Clifford	USGS North Central and National Climate Adaptation Science Centers (Formerly University of Colorado graduate student)	Conservation decision making
Jeff Deems	Research Scientist, CIRES, University of Colorado	Climate and snow modeling
Jen Henderson	Texas Tech University (Formerly CIRES/WWA postdoctoral fellow)	Weather and society
Joseph Kasprzyk	University of Colorado	Multi-objective analysis for water management
Eric Kennedy	University of Colorado graduate student	Snow hydrology
Aislyn Keyes	2021 WWA Summer Graduate Fellow; University of Colorado graduate student	Human-natural systems; Marine conservation
Corrie Knapp	University of Wyoming	Climate change adaptation
Leanne Lestak	University of Colorado	GIS; Remote sensing
Kelly Mahoney	NOAA ESRL Physical Sciences Division	Hydrometeorology; Extreme precipitation
Toby Minear	University of Colorado	Hydrology
Rebecca Morss	National Center for Atmospheric Research	Socioeconomic and policy impacts of weather
Ami Nacu-Schmidt	University of Colorado	Social media; Design
Rebecca Page	Formerly University of Colorado graduate student	Decisions in natural resources
Luca Palasti	University of Colorado graduate student	Environmental economics; Decision-making
Imtiaz Rangwala	North Central Climate Adaptation Science Center, University of Colorado	Regional climate change; High elevation climate
Andrea Ray	NOAA ESRL Physical Sciences Division	Climate-society interactions; Water management
David Rosenberg	Utah State University	Systems analysis for water and resource management
Danya Rumore	University of Utah	Decision-making
Court Strong	University of Utah	Climatology
Christa Torrens	2020 WWA Summer Graduate Fellow; University of Colorado graduate student	Hydroecology; Climate change
Olga Wilhelmi	National Center for Atmospheric Research	Vulnerability and adaptation to weather and climate
Travis Williams	National Renewable Energy Laboratory (Formerly CU graduate student)	Climate risk management; Agriculture
Klaus Wolter	University of Colorado and NOAA ESRL (Retired)	Climatology and meteorology
Heather Yocum	North Central Climate Adaptation Science Center, Univ. of Colorado	Climate and social systems





# YEAR IN REVIEW: WWA ACCOMPLISHMENTS

Due to the ongoing COVID-19 pandemic, our activities have relied on virtual modes of engagement, which has been a big change from our previous focus on in-person meetings and workshops prior to March 2020. While virtual engagement has its own challenges, it has provided unexpected opportunities to connect with a broader range of stakeholders. Many of the stakeholders in our region have limited resources and time to be able to engage in or travel to in-person events, which makes remote engagement a critical tool moving forward. Through our virtual events and remote stakeholder engagement over this past year, we are proud that WWA has remained a go-to entity for climate, drought, and resilience information in the Intermountain West. The WWA team's ability to increase engagement with regional stakeholders, including those from frontline communities, during the global COVID-19 pandemic is a major accomplishment.

In the summer and fall of 2020, **Liz Payton** and **Jeff Lukas** further engaged with stakeholders through a dozen different presentations and outreach efforts as an extension of the April 2020 release of the *Colorado River Basin Climate and Hydrology: State of the Science*. This remote engagement includes the Colorado River Basin State of the Science Webinar Series, which provided an overview of the entire report, and detailed and expanded upon a few key chapters. Liz and Jeff also coordinated with the Southern Nevada Water Authority and partners from the report work group to create the Colorado River Hydrology Research Symposium Webinar Series, another three-video series expanding upon opportunities listed in the report.

Similarly, in February and March 2021, **Liz Payton** and **Ethan Knight** engaged with stakeholders through a two-part webinar series highlighting the December 2020 release of *Snowpack Monitoring in the Rocky Mountain West: A User Guide*. In this webinar series, Liz and Ethan as well as guest speakers **Karl Wetlaufer** (NRCS), **Jeff Deems** (CIRES), **Gus Goodbody** (NRCS), and **Patrick Kormos** (CBRFC) expanded upon the guide by discussing observational methods of snowpack and applications of snowpack information. 206 individuals joined the first webinar, and 129 attended the second one, both significantly surpassing participation that in-person presentations or workshops have had in the past.

Lastly, in August 2020, **Lineke Woelders**, **Seth Arens**, and **Benét Duncan** organized, facilitated, and presented in the *Snowpack, Drought, and Water Supply in a Warming Mountain West* workshop, which included a series of presentations and discussions over several days. The workshop was sponsored by NOAA CPO in collaboration with the Water Research Foundation, and it was part of a series of workshops across the country that helped connect water managers and other stakeholders with tools like the NOAA Water Resources Dashboard. The workshop was initially planned as an in-person event. Hosting it online allowed us to reach additional stakeholders from across Colorado, Utah, and Wyoming due to its accessibility and helped us gain experience in organizing and facilitating such remote engagement.

Photo to the Left: Bald Mountain, located in Arapaho National Forest, southeast of Breckenridge, Colorado. Credit: Benét Duncan.

**Anatomy of a SNOTEL site**

United States Department of Agriculture  
Natural Resources Conservation Service

**USDA-NRCS Snow Survey and Water Supply Forecasting Program**

- Data Collection
- Water Supply Forecasting
- Product Generation
- Administered through National Water and Climate Center and 12 Western NRCS State Snow Survey Programs

Two-part webinar series highlighting the release of *Snowpack Monitoring in the Rocky Mountain West: A User Guide*.

**Making climate information usable:  
More than a field of dreams**

Seth Arens  
Western Water Assessment

**Recent Trends in Snowpack,  
Drought, and Water Supply**

Dr. Becky Bolinger  
Assistant State Climatologist

Western Water Assessment Workshop  
August 4, 2020

COLORADO CLIMATE CENTER

ATMOSPHERIC SCIENCE  
COLORADO STATE UNIVERSITY

A series of presentations in the *Snowpack, Drought, and Water Supply in a Warming Mountain West* workshop.



Photo: View of the mineral-covered swath of white, referred to as the “bathtub ring” at Lake Powell, Utah. Credit: Seth Arens.

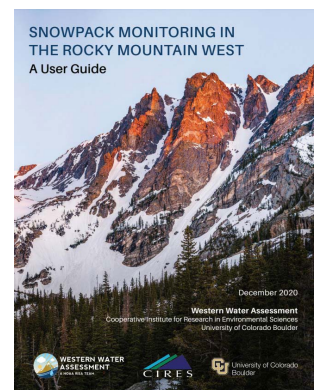
# NEW AREAS OF FOCUS OR PARTNERSHIPS

## COMMUNITY FLOODING RISK AND PREPAREDNESS (RISA Collaboration) (\*S)

In September 2020, WWA launched a new collaborative research effort with the Great Lakes RISA (GLISA) to explore changing flood risk in inland communities in the Intermountain West and the Great Lakes region, and to better understand the dynamics of community-level resilience to flooding. The GLISA team is leading development of a community-scale flood risk model that considers aspects like land use and population changes, and evaluating state-level flood planning resources and guidance in Colorado, Michigan, and New York. The WWA team is developing case studies of communities in Colorado and Michigan and planning workshops that will provide a more detailed look at the factors that affect a community’s resilience to flooding. Flooding is one of the most pressing issues that small and midsize communities face in the Intermountain West, and climate change is expected to exacerbate that. This project provides an important opportunity for WWA to better support community resilience to changing flood risk.

## DEVELOPING GUIDANCE ON A LOW-COST SNOW MONITORING TECHNIQUE

The release of WWA’s *Snowpack Monitoring in the Rocky Mountain West: A User Guide* highlighted the need for additional snow monitoring data across the Intermountain West, particularly in locations and at elevations where SNOTEL and Snow Course sites do not provide sufficient coverage. To help address that need, we are collaborating with The Nature Conservancy and the USDA - Agricultural Research Service to develop a handbook for a low-cost snow monitoring technique, called “snowtopography”. WWA’s **Liz Payton** is leading this effort, and **Seth Arens** is providing support to road test the handbook with water managers in the WWA region.



## HAZARD PLANNING IN UTAH AND THE SOUTH (RISA Collaboration) (\*S)

WWA also launched a new collaborative research effort with the Southern Climate Impacts Planning Program (SCIPP) RISA in September 2020, to apply their award-winning Simple Planning Tool (SPT) for Utah emergency managers. Utah is poised to continue making strides in building resilience to climate impacts, and emergency managers can play a critical role in that process. WWA's **Seth Arens** is working with SCIPP's **Rachel Riley** to develop an updated version of the SPT that incorporates additional climate data. In March 2021, Arens hosted a virtual workshop to solicit feedback on the draft Utah Hazard Planning Tool with 37 Utah emergency managers and other decision makers. Following release of the tool in late 2021, Arens and Riley plan to host parallel workshops that will use each RISA's version of the tool to explore the adaptation decision space -- that is, the gap between identifying a hazard and taking action -- in each region.

## EXPLORING THE IMPACTS OF CHANGING LAKE POWELL LEVELS

During the past year, **Seth Arens** continued working on a broad collaborative research project to address the impacts of very low Lake Powell levels on ecology, hydrology, and land management in Cataract Canyon. During an October 2020 research trip down Cataract Canyon, Seth continued work to document ecological changes, continued collaboration with the USGS and the Returning Rapids project, and formed new relationships with the Grand Canyon Monitoring Center, the Center for Colorado River Studies, and the Glen Canyon Institute. Seth published a short article about ecological changes in Cataract Canyon in the Glen Canyon Institute's annual publication, *Hidden Passage*. Seth also participated in a short field excursion to Lake Powell in April 2021 to survey ecological changes happening due to near-record low Lake Powell levels in the Escalante Arm. During spring 2021, Seth was interviewed for several news articles in regional papers about the ecological impacts of a low Lake Powell.

## ADVANCING FUTURE STREAMFLOW PREDICTABILITY

In Fall 2020, WWA PI **Ben Livneh** began a new area of focus to advance future streamflow predictability by investigating alternatives to snow-based streamflow prediction methods. This expansion represented an evolution from earlier work supported by the NOAA Sectoral Applications Research Program (SARP) that focused on advancing drought early-warning systems in the Colorado River Basin. Both the previous and new areas of work were inspired by stakeholder interests in building resilient water systems given the consensus that a warmer future is likely to have less snow than the past. Activities in this focus area include a project supported by the NOAA Modeling, Analysis, Predictions, and Projections (MAPP) program that uses machine learning, hydrologic modeling, and social science methods to explore alternative streamflow prediction techniques, in collaboration with **Benét Duncan** and **Joe Kasprzyk**. Ben is also working with graduate student **Nels Bjarke** to identify hot-spots of increased drought risk under climate change and to characterize the uncertainty associated with those risks.

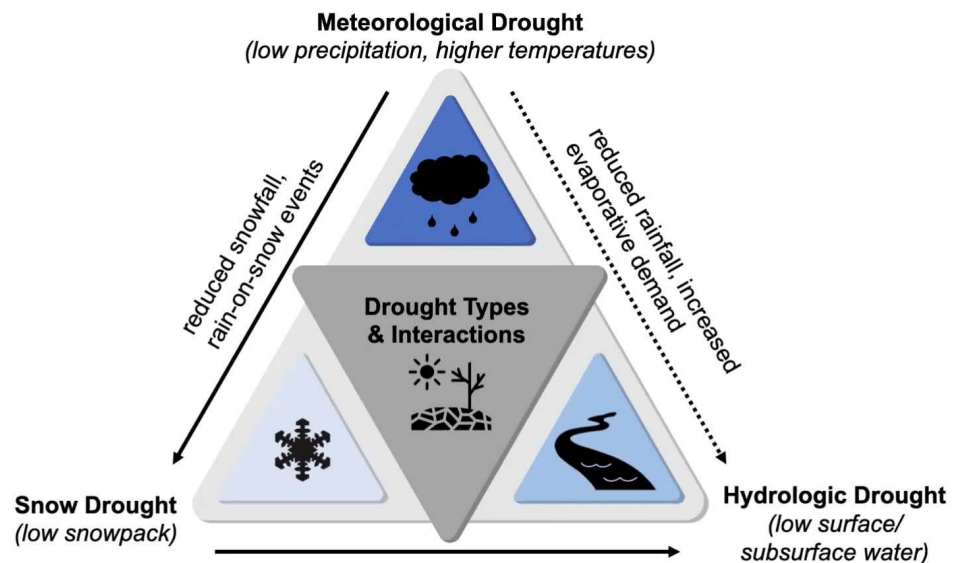


Figure from: Heldmyer, A.J., N.R. Bjarke, and B. Livneh, 2021: A 21st century perspective on snow drought in the Upper Colorado River Basin, *Journal of the American Water Resources Association*, (in review).

## MULTI-YEAR AND DECADEAL ADAPTATION IN AGRICULTURAL DECISION-MAKING

Co-PI **William Travis** and graduate student **Luca Palasti** expanded their decision modeling of short-term, weather and climate sensitive decisions to consider multi-year and decadal adaptation to climate change in a forthcoming, summer 2021 project. The main question to be addressed is whether and how the short-term (weekly to seasonal) decision models developed to assess the economic value of a USDA forage production forecast ("Grass-Cast") can be modified to simulate decisions to adapt to climate change on multi-year and even decadal time-scales.



# RESEARCH HIGHLIGHTS

As a university-based program, WWA researchers, staff, and partners are committed to advancing scientific understanding of climate impacts and adaptation. Our team includes leaders in hydrology, climate science, adaptation and decision-making, and other areas of scholarship in physical and social sciences. In the past year, WWA researchers have conducted a wide range of research activities related to our core research themes and supplemental priorities. Activities include investigating how snowpack is changing in the region and the impacts of those changes on water resources; exploring community resilience to drought and flooding; and evaluating metrics and drivers of aridification in the Colorado River Basin.

WWA PI **Lisa Dilling** is finishing a project to evaluate drought management and adaptive capacity across three major metropolitan areas in the US. Former WWA graduate student (and current USGS postdoctoral researcher) **Katie Clifford** is collaborating with Lisa, **Benét Duncan** and others to share results from our VCAPS pilot project with the broader research community. WWA graduate student **Natalie Bennett** is conducting research on how communities prepare for wildland fire in Colorado with Lisa. This study is investigating how public officials at the local level plan and implement actions to minimize the risks to their communities from wildfire. Natalie aims to understand the role of stakeholder and community participation in wildfire mitigation planning and building community adaptive capacity. This study will explore the participatory processes involved in the creation of Community Wildfire Protection Plans (CWPPs) in the state of Colorado, specifically how these processes enabled transparency, community representativeness, inclusivity throughout the development process, and information exchange across stakeholder groups. Natalie will also explore the outcomes of community participation, such as what recommended actions and next steps were included in the final plans and what actions and next steps were implemented after plan completion.

Researcher **Imtiaz Rangwala** is part of a collaborative research effort to identify and quantify the changing character of aridification in the Colorado River Basin, particularly due to climate change. Changes in recent decades are being referred to as “early warming” and represent an important gap in our understanding of climate impacts in the region. This research represents a collaboration with partners that include NOAA’s Physical Sciences Laboratory, Desert Research Institute, and experts such as **Brad Udall**, former Director of WWA. This work will bolster our understanding of the changing nature of climate and climate extremes in the Intermountain West, and help to validate climate model projections.

WWA PI **Ben Livneh** advanced stakeholder-centered research on changing snowpack in the region. He helped lead a virtual workshop in June 2020 titled *Projecting Rocky Mountain Snow Persistence and Depth Under Climate Change*. The workshop had the goals of bringing state, federal, and Tribal land and resource managers in Colorado, Wyoming, and Montana together with university researchers to identify snow modeling and snowpack tool needs to support habitat assessment and planning. Ben also published an important manuscript on snow-based drought predictability earlier in 2020 (Livneh and Badger 2020). Since then, he gave several talks to regional stakeholder audiences that facilitated a deeper understanding of regional water issues and needs. This work is helping to change the culture of hydrologic research by centering stakeholder information needs and interests in designing research activities and sharing results.

WWA PI **Bill Travis** worked with graduate student **Luca Palasti** to continue to develop a decision model for livestock ranching using bi-weekly “Grass-Cast” forage forecasts, to test whether these forecasts provide added economic value to range livestock operations in the Great Plains and Rocky Mountains at their current skill level. Initial results suggest that there are key aspects to forecast value for producers: skill, timing of decisions, risk aversion, and the weight of adaptation costs on forecast value. Value is especially derived when information reduces the likelihood of a producer taking an unnecessary adaptation. This work was conducted with support from the National Drought Mitigation Center, University of Nebraska-Lincoln, WWA, and the USDA Northern Plains Climate Hub.

WWA PI **Noah Molotch** and his research group have made three major research discoveries during the reporting period. First, they analyzed Snowpack Telemetry (SNOTEL) data and discovered an increasing trend in mid-winter snowmelt over the past 3+ decades (Musselman et al., 2021 - Nature Climate Change). Second, they used SNOTEL data to identify statistical relationships between snow cover duration and maximum snow water equivalent which has important implications for future work to improve estimates of snow water equivalent (Heldmeyer et al., 2021 - Water Resources Research). Third, using a series of hypothetical snowmelt model experiments they disentangled the influence of snowmelt rate and snowmelt timing on the magnitude of runoff. This result has important implications for water availability as climate warming continues to cause snow to melt earlier in the spring (Barnhart et al., 2020 - Water Resources Research). In addition to these findings, Noah’s group conducted analyses relating snowmelt metrics and forest productivity data as an important first step in upcoming work that will look at the impacts of changing forests due to stressors like wildfire on snowpack and snowmelt.

Photo to the Left: Colorado River near Moab, Utah. Credit: Imtiaz Rangwala.



Buckskin Gulch in southern Kane County, Utah, near the Arizona border. It is one of the main tributaries of the Paria River, and is a minor tributary of the Colorado River. Credit: Seth Arens.

# OUTREACH AND ENGAGEMENT

WWA has made effective communication and outreach a priority by developing and implementing a robust communications strategy to connect with our stakeholders, who span a wide range of sectors and interests. **Ethan Knight** developed an updated WWA communications plan, which lays out clear actions and guidance for efficiently and effectively engaging with stakeholders. It 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 will 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 made exciting progress in increasing our online presence. This has included developing a new program website; building a YouTube channel to archive all of our video content, including workshop and webinar recordings; and maintaining critical tools like our highly visited Intermountain West Climate Dashboard. Here, we release monthly briefings on the state of the climate for the WWA region and provide the latest regional climate information from partners like NIDIS, NOAA CBRFC, NRCS, and more. We have also increased our use of 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 **417** new followers, **370,400+** 'impressions' or tweet-views, **28,935** profile visits, **196** account mentions, and thousands of 'engagements' or tweet interactions (including clicks, likes, retweets, and replies). This is a significant increase over the previous reporting period (June 1, 2019 - May 31, 2020), when we gained 46 new followers, 31,400+ impressions, 149 profile visits, 30 mentions, and hundreds of engagements.

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. Following are highlights from this work:

## ENGAGING WITH COMMUNITIES AND RESOURCE MANAGERS

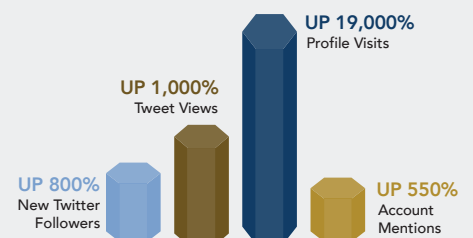
In addition to the *Snowpack, Drought, and Water Supply in a Warming Mountain West* workshop, our WWA researchers and staff worked with communities and resource managers within and beyond the Intermountain West to connect them with information about climate impacts to support planning and resilience-building efforts. **Seth Arens**, **Benét Duncan**, and PI **Lisa Dilling** have continued to engage with staff in the City of Cortez department of public works as they work to increase the resilience of their water system (see Case Study 2, below). This included exploring opportunities for supplemental funding to support drought planning activities in Cortez, applying for a (declined) grant with the NSF CIVIC call, and developing updated information about climate impacts on the city to inform development of a drought contingency plan. **Liz Payton** provided historical evapotranspiration and water use data and analysis, evapotranspiration and water supply projections, and other climate resources to the City of Golden water resources staff. The Moab Area Watershed Partnership (MAWP), a partner in a 2019 VCAPS workshop held in Moab, asked Seth Arens to present information about the impact of climate change on regional groundwater for a special MAWP meeting on regional groundwater supplies. MAWP also asked Seth to write a climate section for the revision of the Moab-area watershed management plan.

## OUTREACH BY THE NUMBERS

June 1, 2020 - May 31, 2021



**370,400+** Tweet Views  
**28,935** Profile Visits  
**417** New Followers  
**196** Account Mentions



**1,117** Webinar Attendees  
**6** Number of Webinars  
**1,023** Views on YouTube



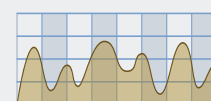
**32** Research Publications



**26** Media Mentions



**1,517** Subscribers to our mailing list



**16,394** Website Visitors

Building on his recent research about changing snowpack and streamflow predictability, PI **Ben Livneh** led a workshop with CU Boulder's Earth Lab, called *Projecting Rocky Mountain Snow Persistence and Depth Under Climate Change*, that brought state, federal and Tribal land and resource managers in the region together with university researchers to identify snow modeling and snowpack tool needs to support habitat assessment and planning. He also delivered presentations at the Niwot Ridge and City of Boulder Water and Climate Summit, Pacific Northwest Drought Early Warning System 2020 Drought and Climate Outlook, and the Oregon-Washington Water Year 2020 Recap & 2021 Outlook Meeting. PI **Noah Molotch** met with Denver Water and a group of water-related stakeholders to determine how spatial snowpack information may improve water resource management. This has involved a group of stakeholders engaged in the 'Colorado Airborne Snow Observatories' collective that is interested in utilizing airborne snow data to improve complementary approaches to snowpack estimation - such as those being developed by Noah's team.

## ENGAGING WITH OUR BROAD STAKEHOLDER COMMUNITY

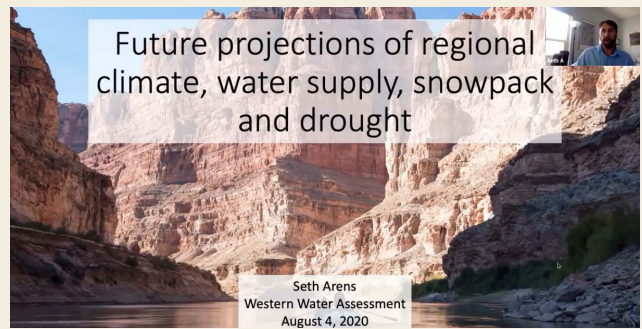
In 2020, we established the WWA webinar series to share research highlights and timely climate information with our broad stakeholder network. The first webinars highlighted our *Colorado River Basin Climate and Hydrology: State of the Science* report, followed by our two-part webinar on our *Snowpack Monitoring in the Rocky Mountain West: A User Guide* report and a stand-alone webinar called *The Impacts of Climate Change on Snowpack and Streamflow in the Western US*. These webinars attracted **over 1,100 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 *The Washington Post*, *The Guardian*, *Medium*, *The Salt Lake Tribune*, *The Denver Post*, *The Colorado Sun*, *CPR News*, *CBS Denver*, *InsideClimate News*, and *The Daily Camera*.

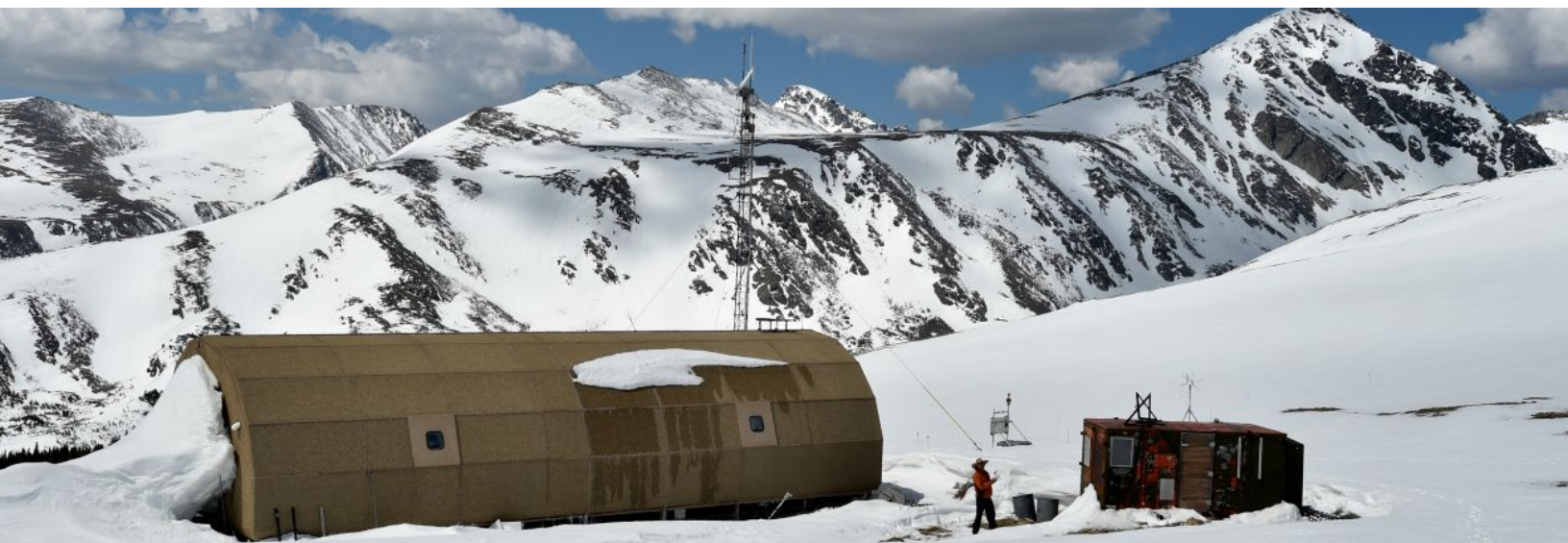
Photo below: CU Boulder's Niwot Ridge Long Term Ecological Research program Tundra Lab on Niwot Ridge. Credit: Jeremy Papasso.

## ENGAGEMENT HIGHLIGHT

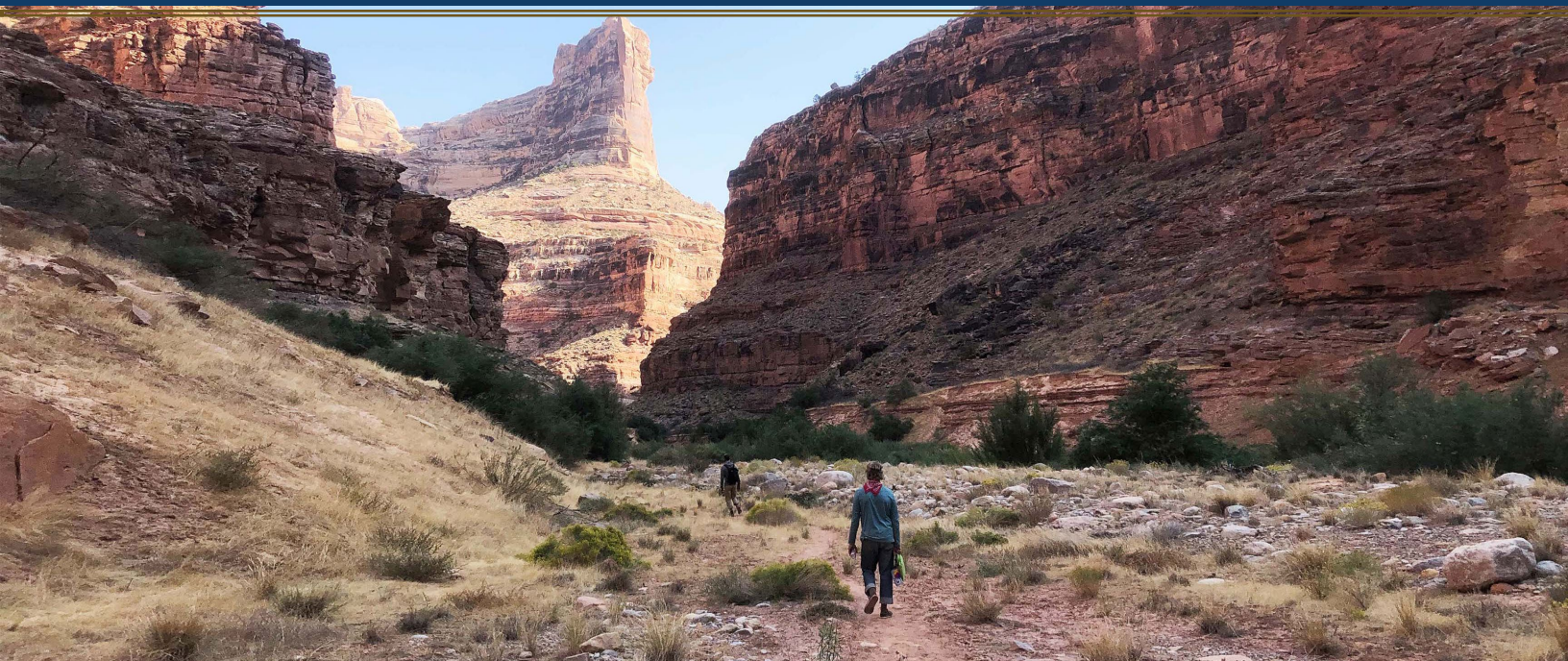
### Smaller Water Providers



NOAA and the Water Research Foundation organized a series of workshops across the country to connect with small- and medium-size water utilities around NOAA-produced and other tools and resources. WWA was part of this effort, through our *Snowpack, Drought, and Water Supply in a Warming Mountain West* workshop in August 2020 (see Year in Review). Organized in partnership with colleagues from Aspen Global Change Institute and the Water Research Foundation, the workshop connected over 60 participants, largely water professionals from small-medium providers in the Intermountain West, with the latest usable scientific information and tools about snowpack, drought, and water supply. It featured talks from scientists on the current water year, and on recent trends and future projections in snowpack, drought and water supply. Scientists also provided introductions to several tools and data sources tailored to the Intermountain West. Water managers shared their perspectives and experiences incorporating climate and snowpack information into decision-making processes in presentations and a panel discussion.







Field work in Dark Canyon, Cataract Canyon, Utah. Photo: Seth Arens.

## 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.

During the performance period, WWA staff engaged with the academic and adaptation practitioner communities in a number of ways. **Seth Arens** continued to work with researchers from the University of Utah, USGS, and the National Park Service in investigating the impacts of low Lake Powell levels on Cataract Canyon and surrounding areas. He also delivered guest lectures at a graduate seminar at the University of Utah and mentored students who were assisting with the workshop for his Utah Hazard Planning Tool workshop (see *New Partnerships*, above). **Benét Duncan** and Seth also engaged with the Mountain West Climate Services Partnership, a group that brings together climate service practitioners from across the region to identify opportunities for collaboration. Benét Duncan is a Science Advisor on the NSF-funded *We Are Water* project led by CIRES E&O. 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. Benét 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 staff also spoke at a number of virtual academic meetings and conferences. For example, Benét Duncan gave an invited talk about WWA's work continuing to provide climate services during the COVID-19 era at the 2020 AGU Fall Meeting. PI **Lisa Dilling** delivered a presentation to the American Association of Geographers on drought and urban water management, and an invited seminar presentation about co-production processes with the Consortium for Climate Risk in the Urban Northeast (CCRUN) RISA. Researcher **Imtiaz Rangwala** delivered a guest lecture for a graduate-level course at the University of Wyoming about understanding and quantifying the impacts of regional climate change. PI **Noah Molotch** provided spatial snowpack data within the WWA region in response to requests from the US Bureau of Reclamation for historical snowpack data, Lawrence Livermore Laboratory, and the NOAA NIDIS program. PI **Bill Travis** and student **Luca Palasti** shared initial results from their analysis of the value of the Grass-Cast tool at the 2020 American Meteorological Society conference.

WWA also has a close relationship with the USGS North Central Climate Adaptation Science Center 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 2020 Three Centers Retreat was held virtually over multiple days, and the spring 2021 retreat was held as a virtual "mini-meeting". We are currently planning another virtual meeting for the summer 2021 Three Centers Retreat.



San Luis Valley in south-central Colorado. Credit: Imtiaz Rangwala.

# COVID-19 IMPACTS

The COVID-19 pandemic has had a major impact on all aspects of our program's activities, from internal program operations to external engagement with communities, agencies, and other partners. Our stakeholders have faced significant challenges. Community leaders that were already stretched thin across increasing responsibilities and uncertain budgets due to the pandemic also grappled with limited water supply due to historic drought and a record wildfire season in 2020. State and federal decision makers continued to advance climate planning efforts but needed to do so in a remote work environment. As a result, we faced increasing demand for climate services in the region, and needed to be nimble to adapt our approach to meet as many stakeholder needs as possible while protecting the health and safety of our team.

WWA shifted from in-person to virtual workshops whenever feasible. In situations when in-person stakeholder engagement could not be shifted to remote formats, we pivoted to identify other ways to engage and learn with our partners. For example, we are collaborating with the Great Lakes RISA program (GLISA) on a project to explore inland community flood risk and adaptation (\*S; see New Partnerships, above). The project includes plans for workshops with communities that face high flooding risk. While these workshops have been delayed to 2022, we have made progress identifying communities with high flood risk, so that we can quickly move forward with workshops when public health conditions improve.

Prior to the COVID-19 pandemic, we had planned to expand our Vulnerability, Consequences, and Adaptation Planning Scenarios (VCAPS) pilot project to convene 1-2 climate planning workshops in Wyoming communities (\*S; see Looking Forward, below, for more details). Because it was not safe to host an in-person workshop in 2020, WWA pivoted to host two summer student fellows from May-August 2020 who led Wyoming-focused projects. Christa Torrens, the WWA inaugural Summer Graduate Fellow, conducted interviews with climate service providers and other partners in Wyoming to explore the landscape of climate planning and opportunities. Ethan Petersen, a Stanford undergraduate Cardinal Quarter Fellow, analyzed existing adaptation planning and conducted additional interviews to identify Wyoming communities that might benefit from VCAPS workshops in the future. The results of their research will guide our future efforts in Wyoming.

# LOOKING FORWARD: NEXT STEPS

During the coming year, WWA will continue to advance scientific understanding in ways that decision makers need and can use, and to expand our connections with stakeholders in the region. Three of our initiatives are highlighted below:

## VCAPS IN WYOMING (\*S)

First developed by the Carolinas Integrated Sciences and Assessments (CISA) RISA, the VCAPS process provides a framework for community-based adaptation planning workshops that draw on the expertise of community members to explore the impacts of climate stressors and identify actions to build resilience. In 2018 and 2019, WWA conducted the VCAPS pilot project in 6 communities in Colorado and Utah. We plan to expand this effort to conduct VCAPS workshops in 1-2 Wyoming communities in 2022. Research conducted by the 2020 WWA Graduate Summer Fellow and the 2020 Stanford Cardinal Quarter Fellow will provide critical understanding to help identify communities for this effort. We will also leverage partnerships with researchers at University of Wyoming and the Northern Plains Climate Hub to ensure that our efforts are sensitive to the unique needs of communities in the state.



VCAPS meeting held in Cortez, Colorado in 2018. Credit: Seth Arens.

## ADVANCING CROSS-RISA COLLABORATIONS (\*S)

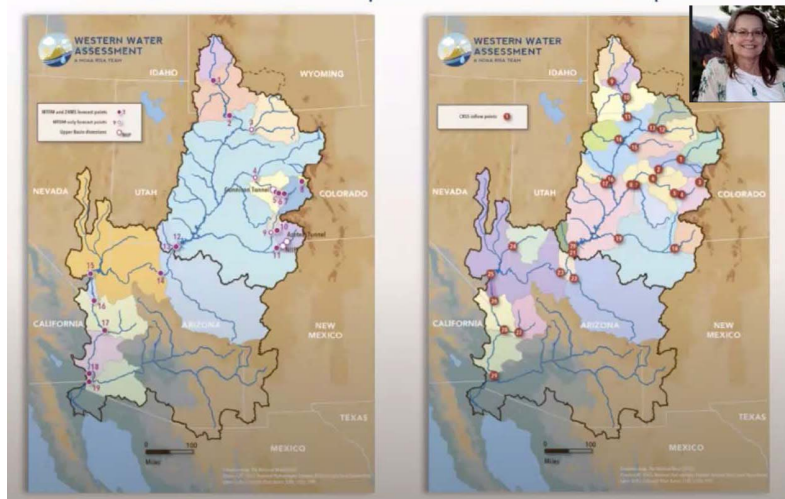
Supplemental RISA support has enabled us to collaborate with RISAs in the southern US (SCIPP) and the Great Lakes region (GLISA) to support adaptation planning with new stakeholder groups and communities. We will advance efforts with SCIPP to develop a version of their award-winning Simple Planning Tool for Utah emergency managers, incorporating additional climate information for the range of natural hazards that Utahns face. We will also advance efforts with GLISA to explore changing flood risk in inland communities, and how communities can build resilience as their risks change due to a range of factors including population growth and land use decisions. The project includes an investigation of the information resources and regulations in Colorado and Michigan, and will aim to connect communities with those resources.

## EXPANDING THE EXTREME EVENTS DATABASE

WWA PI **Bill Travis** and researcher **Jeff Lukas** developed a database of Historical High-Impact Weather and Climate Events that occurred in Colorado, Wyoming, and Utah from 1862–2017. Using best professional judgment, Travis and Lukas identified high-impact flooding, drought, wildfire, winter storm, and other events. The database was recently used by the local CBS station in Denver, CO to explore the impacts of major flooding events in Colorado. We plan to update the database to include high-impact events that occurred in 2018-2021, and to add new features to the database that will increase its utility to program staff, media, and communities.



### 24MS & MTOM forecast points and CRSS inflow points



WWA Colorado River Basin Climate and Hydrology: State of the Science Overview Webinar by Jeff Lukas and Liz Payton on June 23, 2020.



# MAKING AN IMPACT

## WWA EVALUATION AND METRICS

WWA's formal summative program evaluation was completed in December 2020 and covered the period from 2015 through 2019. The evaluation was conducted by the CIRES Education and Outreach Team, including **Anne Gold** (Director of Education and Outreach) and **Christine Okochi** (Professional Research Assistant and Program Evaluator).

The evaluation incorporates elements of the Meadow-Wall framework for project-level evaluation of co-production, and the WWA framework that uses customized metrics for a series of goals that assess our progress towards the outcomes of building adaptive capacity in our region and increasing the use of new science and tools in decision-making (detailed below). This thoughtful and integrative approach to evaluation tracks our alignment with stakeholder needs, and our effectiveness in meeting program goals and building resilience in the Intermountain West. While some of the goals WWA seeks to contribute to, such as building regional resilience, go well beyond what we can accomplish on our own, we still aim to evaluate how WWA is seen as a contributor to these larger goals through the eyes of our stakeholders.

### WWA Goals and Metrics

#### **Goal 1: Building Relationships and Enhancing Networks**

Building relationships is key to WWA achieving its mission, and literature and practice show strong relationships necessary for producing usable science. We are interested in tracking various aspects of relationships: the type of relationship (new or ongoing), the types of organizations involved, and what activities are occurring through the relationship. A key way that WWA acts to improve the usability of information for decision-making is to enhance networks by convening researchers and decision makers throughout the region. Here, WWA wants to measure the connections we help to foster among others, in addition to the relationships between WWA and its stakeholders.

##### Metrics:

- Track stakeholder interactions, including who we engage with and what organizations they are from; referrals to and from WWA; one-on-one conversations; and attendees at WWA events
- Track how relationship building and maintenance lead to bigger, formal projects, including through reports

#### **Goal 2: Having Influence in the Region**

WWA should be seen as a trusted (non-partisan, non-advocacy) voice for information that helps stakeholders do their job and make decisions, and that provides valuable services in the region.

##### Metrics:

- Track stakeholder interactions, including the number of people and organizations that attend WWA events; the types and diversity of entities with which we work; requests for presentations, training, and inclusion on boards; and the type of information people seek from WWA and its use
- Track media mentions
- Survey stakeholders to assess the impact of our work

#### **Goal 3: Building Resilience in our Region**

Building resilience in the Colorado, Utah, and Wyoming region is a core goal of WWA's work, but it is very difficult to measure. WWA provides information and activities that help decision makers in their effort to increase resilience. We can convene groups to work through what resilience means in their region or sector given what we know about current and future climate.

There are also overall changes in our region that point to progress on resilience. For example, increasing uptake of relevant science into decision-making can help decision makers more clearly see risks and vulnerability in their systems. Another example of regional change is the growth of capacity to incorporate climate knowledge in other organizations. WWA cannot claim sole credit when this occurs, but we should see increased capacity in partners as a sign that we are doing our job well. We can trace our interactions with organizations that helped to make the case that climate was important for them to consider.

Photo to the left: Boulder Flatirons. Credit Benét Duncan.

### Metrics:

- Survey stakeholders and the broader RISA network to learn about conceptual, justification, and instrumental use of WWA-provided information
- Identify cases in which scientific information is added to policies or referenced in justification for adaptation actions
- Track where WWA personnel go next in their careers
- Analyze the climate capacity of our stakeholders over time, both in terms of positions created and stakeholder use of climate information
- Analyze the change in climate capacity in Utah and Colorado, and compare those changes

### Goal 4: Piloting New or Underutilized Tools

RISAs are meant to be a place to try out new tools, datasets, and other experimental information. WWA has several examples of tools at various stages, so progress on this goal can be documented on a project basis.

### Metrics:

- Track tools that WWA pilots, and analyze each tool's status and use by stakeholders

### Goal 5: Providing Feedback to NOAA

One important goal of WWA is to provide feedback to NOAA about the use of their informational and operational products. In addition to organizing meetings with stakeholders to solicit feedback that can inform NOAA, we submit reports to the RISA, Assessments, and NIDIS programs within NOAA CPO, and separately send specific items in the RISA Network report. We also organize and lead sessions at RISA annual meetings and present project findings on RISA monthly calls.

### Metrics:

- Track workshops and other meetings with stakeholders regarding NOAA products
- Track contributions to NOAA regular reporting systems, including RISA monthly calls

### Goal 6: Contributing to the Literature and Providing Lessons Learned

WWA is committed to contributing to the literature and providing lessons learned across organizations that aim to do similar work. Activities under this goal include sharing best practices; writing papers and reports; participating in cross-RISA, regional, or national dialogues for connecting knowledge to decision-making; and building the capacity of the network beyond our region, including to other academics and groups like the USGS Climate Adaptation Science Centers (CASCs) and the USDA Climate Hubs.

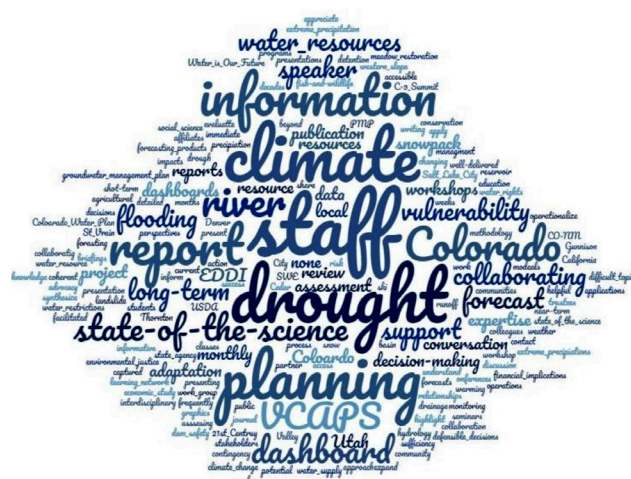
### Metrics:

- Track papers and reports published
- Track presentations delivered and participation on panels
- Track workshops organized
- Participate in semi-annual retreats with the North Central CASC and the USDA Northern Plains Climate Hub

## Results from the WWA Program Evaluation

Evaluation activities included a web analytics analysis of WWA's website, an online survey that received responses from 128 stakeholders, and interviews with a subset of five stakeholders who participated in the survey. Respondents work across a range of scales, including national, regional, state, and local levels, and over one third have worked with WWA for more than five years, a testament to our enduring relationships with stakeholders in the region. The program evaluators coded responses to five questions to better understand and categorize stakeholder perceptions of WWA, their institutional experiences working with WWA, and the impacts that WWA has on stakeholders.

Results from the WWA program evaluation demonstrate 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.



Word cloud from WWA evaluation.

Over 90% of respondents consider WWA to be trusted, valuable, accessible, and non-partisan. Respondents indicated that information resources and data from WWA has aided their planning, decision-making, and forecasting activities. They valued engaging with us through the VCAPS process, collaborating on projects, and working with WWA staff for support and expertise. 81% of respondents indicated that WWA has provided information that helped them to become better informed about an issue or changed their opinion about the issue, particularly related to climate and weather, the Colorado River, drought, adaptation planning, snowpack, and flooding. 59% of respondents have used information provided by WWA to help make a decision in their work, particularly related to operational and water management decisions. Respondents also used WWA information for background information on an issue, for public education and outreach, to assess risk, and to guide research priorities. 59% of respondents have also referred others, particularly professional colleagues and policymakers, to WWA team members and resources.

The evaluation survey and interviews provided insights that suggest we are helping to build resilience in the region. Respondents largely reported greater awareness, knowledge, and understanding of climate vulnerability and felt that WWA resources have contributed to this, particularly by increasing awareness or understanding, and providing data or information. 78% thought that the use of climate information in their organization has changed in the last five years, including increased awareness and acceptance of climate change, and more widespread consideration of climate impacts for future planning. 72% of respondents felt that their organization is incorporating more climate information now than it did five years ago. 54% of respondents indicated that there are more individuals in their organization working on climate topics today than there were five years ago - a nod to the slowly increasing capacity for climate planning in the region.

**Ways WWA information was used to make a decision (n=36)**



Looking to the future, WWA stakeholders feel that there is more to be done to build climate resilience in the region. They would like to see us continue to share scientific information that is relevant to their work and decisions; convene stakeholder groups at meetings and workshops; develop new tools to share information; and continue to serve as a resource for scientific information and a partner for conducting scientific research.

## ON-THE-GROUND IMPACTS

In addition to the results of our program evaluation, feedback and decisions from a range of stakeholders demonstrate the tangible, on-the-ground impact of our recent program activities. For example, water managers who participated in our *Snowpack, Drought, and Water Supply in a Warming Mountain West* workshop in August 2020 (see Engagement Highlight: Smaller Water Providers) shared feedback in a post-workshop survey. All respondents said that the two-day workshop was “mostly” or “definitely” a good use of their time. One respondent noted, “I continue to be impressed by the WWA offerings and feel like I am stealing very valuable time and information each time I attend. I look forward to continued engagement with the program!”

During spring and summer 2021, **Liz Payton** worked with the city of Golden, CO to explore the relationship between their water use and evapotranspiration, in preparation for development of a water resources master plan for the city. WWA provided historical evapotranspiration and water use data and analysis, evapotranspiration and water supply projections, and other climate resources to them. This information and analysis will be used in communications with city planners and decision makers.

**Seth Arens** delivered the final version of the *Weber Basin Climate Vulnerability Assessment* to the Weber Basin Water Conservancy District (WBWCD) in early 2021. WBWCD presented the report to their Board of Directors and plans to use the information from the report in their medium-term and long-term planning efforts. WBWCD asked WWA to provide a guidance document to summarize the key points of the research and highlight areas of greater certainty in climate projections. The guidance document will be completed during Fall 2021.

## Impact Case Study 1: Colorado River Basin Research Opportunities

In recent decades, increasing water demand, dry conditions, and warming temperatures have impacted the Colorado River, creating greater uncertainty about the future of the basin's water supply. With support and guidance from over a dozen federal, state, and local water agencies, WWA's **Liz Payton** and (formerly) **Jeff Lukas** teamed up with leading experts to integrate nearly 800 peer-reviewed studies, agency reports, and other sources to assess the state of the science and technical practice relevant to water resources in the Colorado River Basin.

Released in April 2020, *Colorado River Basin Climate and Hydrology: State of the Science* aims to create a shared understanding of the physical setting and the latest data, tools, and research underpinning the management of Colorado River water resources. In identifying both challenges and opportunities, the report is guiding 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 system.

The report summarizes the large and varied range of methods for developing long-term streamflow projections in the basin, and identifies that this is quite challenging for those not intimately involved in the engineering, statistics, and programming used in hydrologic modeling. Since the report's release, the Bureau of Reclamation has launched a study to understand the methods and their implications for large-scale planning purposes and to generate new hydrology ensembles to fill needed gaps in existing data. This project represents important progress to meet a need identified in the *Colorado River Basin Climate and Hydrology: State of the Science*, and it will support basin-wide planning and operations for a river system that supplies water to seven basin states, 29 Tribes, and Mexico, and that is under enormous stress due to aridification and over-allocation of water. Continued advances in planning are critical for improving the adaptive capacity of the Colorado River Basin system.

## Impact Case Study 2: Drought Planning in Cortez, CO

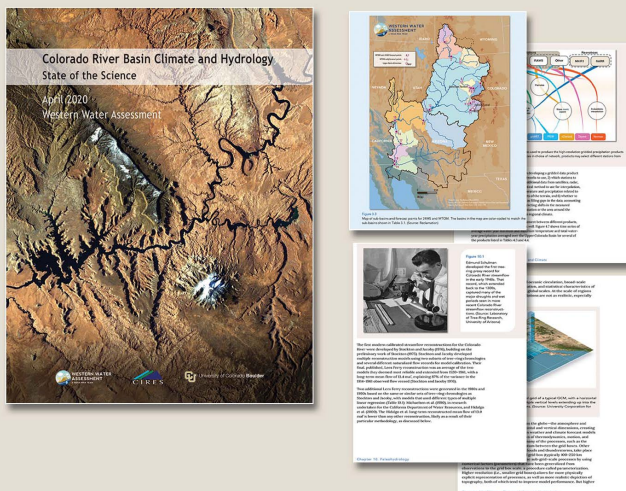
As part of our VCAPS pilot project, WWA organized and led a community-based participatory climate planning workshop in Cortez, CO during the summer of 2018. Located in the Four Corners region of Colorado, Cortez is a small municipality of 8,645 people, with large Tribal and Latino communities. Though the city holds senior water rights on the Dolores River, the region experiences regular droughts, including in 2018 and 2020. The economy in Cortez is heavily dependent on tourism, with Mesa Verde National Park being a significant draw, and Montezuma County is dependent on agriculture. Both industries are vulnerable to drought impacts.

During the VCAPS workshop, which consisted of two half-day meetings, WWA staff gave a brief presentation on the observed and projected impacts of climate change in Southwest Colorado and potential impacts on water supply. The WWA team then led the group in participatory diagramming exercises in which participants mapped the outcomes and consequences of drought, analyzed existing and anticipated community impacts of drought, identified gaps in knowledge, and brainstormed strategic short- and long-term solutions for mitigating and adapting to increasing drought risks.

Since the workshop, the City of Cortez has pursued a number of actions to increase their adaptive capacity. For example, the city has continued to convene cross-departmental meetings to discuss drought and water supply, and launched the Water is Our Future conservation initiative in 2019. Most recently, WWA has engaged with Cortez to provide updated information on local climate impacts. The city is kicking off development of a drought contingency plan, another action identified during the VCAPS workshop. It is exciting to see that the VCAPS process is continuing to have tangible impacts in support of a resilient water supply in Cortez.

Colorado River Basin Climate and Hydrology: State of the Science, J. Lukas and E. Payton, eds., 2020.

Weber River Basin Climate Vulnerability Assessment, S. Arens, L. Jamieson, P. Brooks et. al., 2021.







Balloons launching at the Erie Hot Air Balloon Festival, Erie Colorado 2021. Credit: Lisa Dilling.

# APPENDIX A

## 2020-2021 WWA PUBLICATIONS

Following are publications written by, or in collaboration with, WWA researchers from June 1, 2020 through May 31, 2021. The list also includes selected publications that were released prior to the performance period, but that are cited in this annual report.

Abolafia-Rosenzweig, R., A. M. Badger, E. E. Small, and B. Livneh, 2020. A continental-scale soil evaporation dataset derived from soil moisture active passive satellite drying rates. *Scientific Data* 7 (1): 406. <https://doi.org/10.1038/s41597-020-00748-z>.

Abolafia-Rosenzweig, R., M. Pan, J.L. Zeng, and B. Livneh, 2021. A remotely sensed ensemble to observe the terrestrial water budget over major global river basins. *Remote Sensing of Environment* 252, 112191. <https://doi.org/10.1016/j.rse.2020.112191>.

Arens, S., L. Jamieson, P. Brooks, A. Weech, C. Strong, J. Everitt, and D.E. Rosenbergs, 2021. *Weber River Basin Climate Vulnerability Assessment*. Western Water Assessment. [https://wwa.colorado.edu/publications/reports/weber\\_basin\\_report.pdf](https://wwa.colorado.edu/publications/reports/weber_basin_report.pdf).

Barsugli, J. J., A. J. Ray, B. Livneh, C. F. Dewes, A. Heldmyer, I. Rangwala, J. M. Guinotte, and S. Torbit, 2020. Projections of mountain snowpack loss for wolverine denning elevations in the Rocky Mountains. *Earth's Future* 8 (10). <https://doi.org/10.1029/2020EF001537>.

Bjarke, N., B. Livneh, S. Elmendorf, N. Molotch, E. L. Hinckley, N. Emery, P. Johnson, and K. Suding, 2020. Catchment scale observations at the Niwot Ridge long-term ecological research site. *Hydrological Processes*, July 21. <https://doi.org/10.1002/hyp.14320>.

Clifford, K. R., 2020. Problematic exclusions: Analysis of the Clean Air Act's exceptional event rule revisions. *Society & Natural Resources* 34 (2), 135-148. <https://doi.org/10.1080/08941920.2020.1780358>.

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- Culler, E., A. Badger, J. Minear, K. Tiampo, S. Zeigler, and B. Livneh, 2020. A multi-sensor evaluation of precipitation uncertainty for landslide-triggering storm events. *Hydrological Processes*. <https://doi.org/10.22541/au.160619798.86581537/v1>.
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