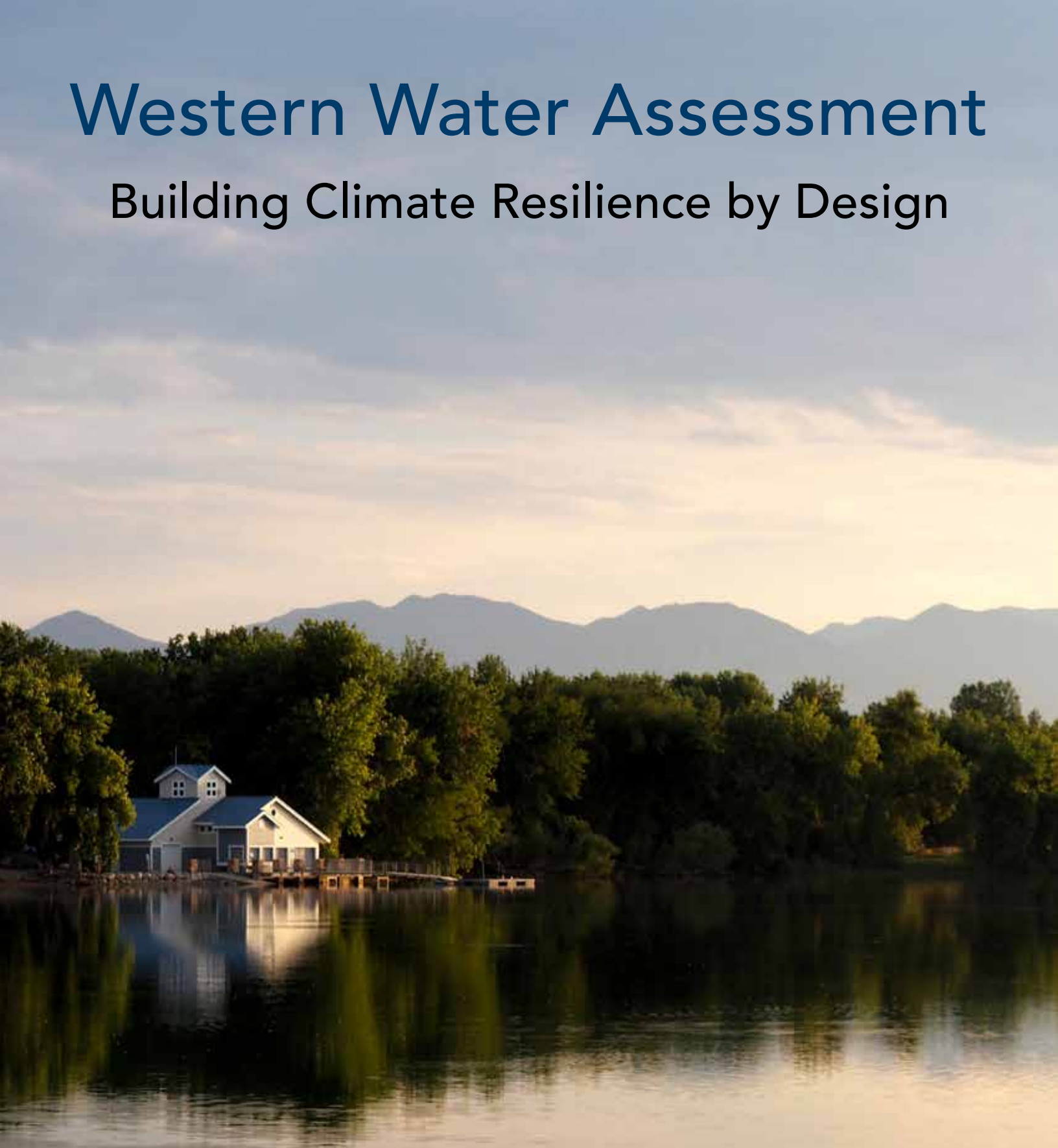
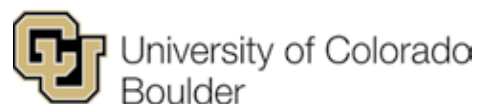


Western Water Assessment

Building Climate Resilience by Design



2017 - 2018 ANNUAL REPORT





WESTERN WATER ASSESSMENT

A NOAA RISA TEAM

WESTERN WATER ASSESSMENT

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Performance period covered in this report: June 1, 2017–May 31, 2018

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Cover photo: Waneka Lake, Lafayette, Colorado. Photo: Jeff Lukas.



University of Colorado **Boulder**



WWA ANNUAL REPORT

June 1, 2017 - May 31, 2018

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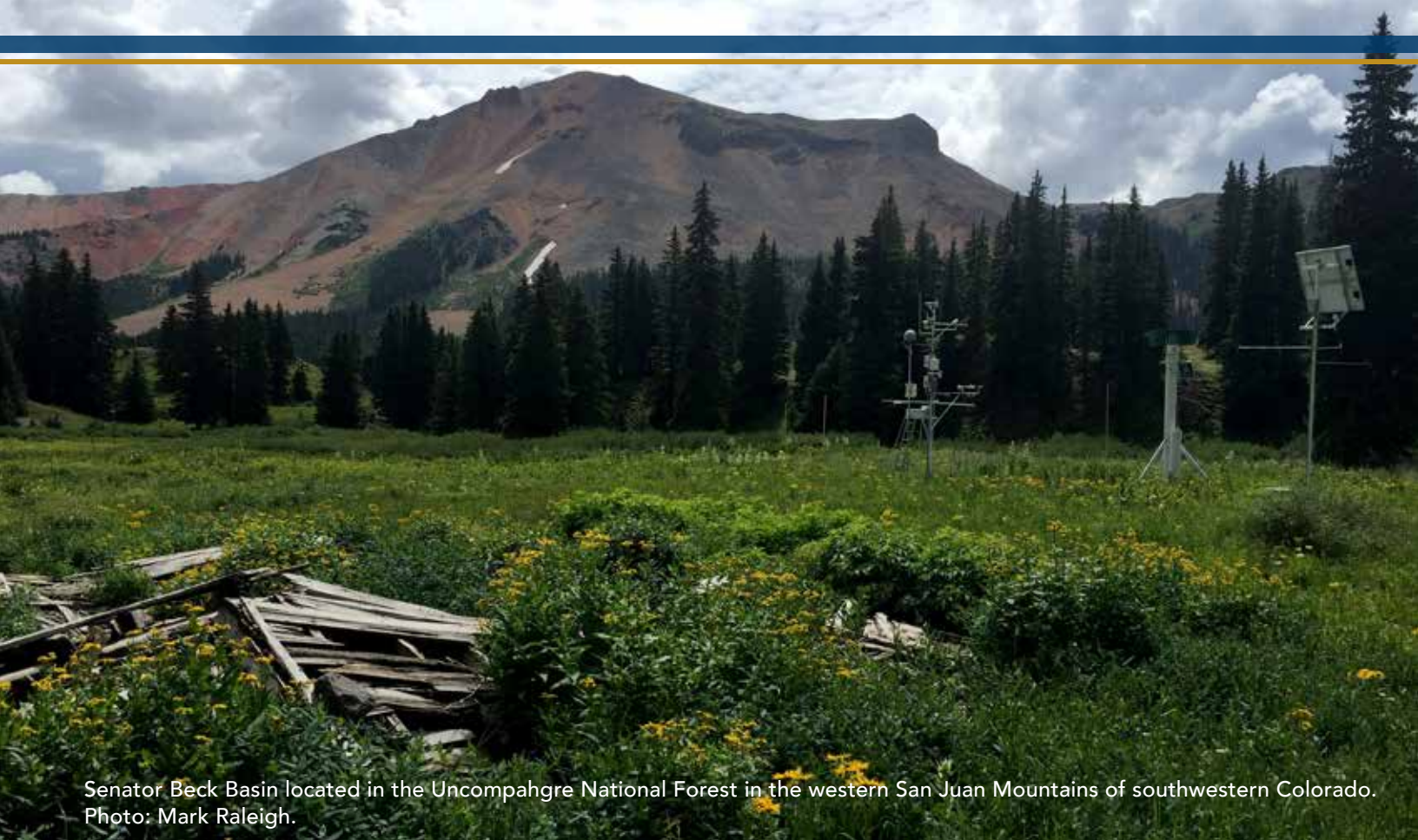
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Senator Beck Basin located in the Uncompahgre National Forest in the western San Juan Mountains of southwestern Colorado. Photo: Mark Raleigh.

INTRODUCTION

The mission of Western Water Assessment (WWA) is to conduct innovative research in partnership with decision makers in the Rocky Mountain West, helping them make the best use of science to manage for climate impacts. Using multidisciplinary teams of experts in climate, hydrology, ecology 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 and 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

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 STAFF AND RESEARCH TEAM

WWA is comprised of a core staff of five who focus on program management, research development and synthesis, and coordination of stakeholder interactions. WWA's research team (Table 1) includes physical and social scientists at the University of Colorado, NOAA, and the National Center for Atmospheric Research (NCAR).

Western Water Assessment Core Staff



Lisa Dilling

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Expertise: Climate information, decision making



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Expertise: Science policy, glacial hydrology



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Benét Duncan

Climate Assessment Specialist
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Expertise: Climate indicators, oceanography

Western Water Assessment Research Team

Team Member	Title	Expertise
Joe Barsugli	Lead Researcher, Western Water Assessment Research Scientist, CIRES, Univ. of Colorado	Climate dynamics
John Berggren	Graduate Research Assistant, Univ. of Colorado	Colorado River water policy
Katie Clifford	Graduate Research Assistant, Univ. of Colorado	Conservation decision making
Jeff Deems	Research Scientist, CIRES, Univ. of Colorado	Climate and snow modeling
Jen Henderson	CIRES Postdoctoral Fellow	Weather and society
Joe Kasprzyk	Assistant Professor, Civil Engineering, Univ. of Colorado	Multi-objective analysis for water management
Ben Livneh	Assistant Professor, Civil Engineering, Univ. of Colorado	Hydrologic modeling
Kelly Mahoney	Research Scientist, NOAA ESRL Physical Sciences Division	Hydrometeorology, extreme precipitation
Noah Molotch	Lead Researcher, Western Water Assessment Assistant Professor, Dept. of Geography, Univ. of Colorado	Snow hydrology
Rebecca Morss	Scientist III, National Center for Atmospheric Research	Socioeconomic and policy impacts of weather
Ami Nacu-Schmidt	Graphic Designer and Communications	Social media, design
Rebecca Page	Graduate Research Assistant, Univ. of Colorado	Decisions in natural resources
Imtiaz Rangwala	Research Scientist, CIRES, Univ. of Colorado and NOAA ESRL	Regional climate change, high elevation climate
Andrea Ray	Scientist, NOAA ESRL Physical Sciences Division	Climate-society interactions, water management
Trisha Shrum	WWA and Earth Lab Post-Doctoral Fellow	Natural resource economics
Rebecca Smith	Graduate Research Assistant, Univ. of Colorado	Multi-objective analysis for water management
Bill Travis	Lead Researcher, Western Water Assessment Associate Professor, Geography, Univ. of Colorado	Natural hazards, climate impacts and adaptation
Olga Wilhelmi	Project Scientist III, National Center for Atmospheric Research	Vulnerability and adaptation to weather and climate
Klaus Wolter	Research Scientist, CIRES, Univ. of Colorado and NOAA ESRL	Climatology and meteorology
Heather Yocum	Research Scientist, CIRES, NOAA ESRL	Climate and social systems

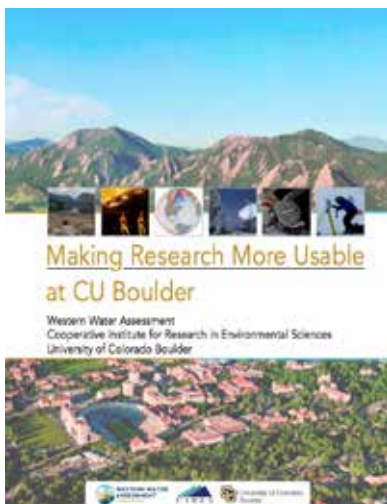


Cheesman reservoir on the South Platte River in upper Cheesman Canyon, Douglas County Colorado. Photo: Jeff Lukas.

WWA YEAR IN REVIEW

This year, WWA continued to have a positive impact across Colorado, Wyoming and Utah through various efforts such as workshops, webinars, decision tools and our climate dashboard. Our staff and researchers continue to be contacted for interpretation of new scientific papers, invitations to speak at various events, and to help put this year's very low snowpack in to context in terms of impacts and historical droughts. For example, WWA researchers were invited to present on topics as varied as best practices for climate assessment for the University of Connecticut, historical and new snowpack monitoring at a forum for water managers and engineers on the West Slope of Colorado, hydroclimatology for the Wind River Indian Reservation, and the impact of climate change on wetlands for the EPA. WWA staff served as technical advisors for the development of climate change training by the Water Utility Climate Alliance (WUCA), and they advised Boulder County's Department of Transportation in the development of a RFP and sat on the selection committee that evaluated proposals for a climate change planning effort. WWA continues to be seen as a valuable resource and partner to a wide variety of stakeholders in our region.

WWA has also been active within the University of Colorado Boulder (CU Boulder) community in promoting the production of usable science. As part of a seed grant from the Office of Vice Chancellor for Research and Innovation, we wrote Making Research More Usable at CU Boulder (<http://wwa.colorado.edu/publications/reports/>



[usable_research_guide.pdf](#)). The guide provides a spectrum of ways to conduct research with the goal of reducing the barriers to entry into projects creating information for stakeholders outside academia, and it includes example projects from across the university. The report received significant inter-campus media coverage and was shared across several departments throughout CU Boulder.

In addition to the many ongoing projects included in this annual report, we are pushing into new areas of research and engagement.

NEW AREAS OF FOCUS AND PARTNERSHIPS

This past year, WWA has begun working more with smaller municipalities in our region. Historically, we have worked a great deal in the large population centers of our region, Colorado's Front Range and Utah's Wasatch Front. Stakeholders in these areas tend to have higher capacity to partner with us and take up scientific information. While we have always strived to reach beyond these areas and have had many projects in smaller communities, particularly on Colorado's West Slope, we are making a concerted effort to reach smaller municipalities through our **VCAPS Project**. VCAPS (Vulnerability, Consequences, and Adaptation Planning Scenarios) was developed by CISA RISA and has been used in several communities across the East Coast to analyze climate vulnerability and actions to adapt. We are bringing this process to the mountain west, where climate impacts will be different from coastal towns. With the VCAPS project, we hope to build relationships with new stakeholders and test out the VCAPS methodology in another region of the United States.

WWA has made a significant change in Utah, moving the office of our Utah Research Integration Specialist from the NOAA Colorado Basin River Forecast Center (CBRFC) onto the campus of the **University of Utah**. WWA signed an MOU with the **Global Change and Sustainability**

Center to provide office space for WWA's **Seth Arens** where he will collaborate with a variety of researchers at the Center and across the University of Utah. This change in location fits with Arens' training and expertise and will set WWA up for possible new research partners in the next rebid. We are thankful for the many years of partnership with the CBRFC, and continue to maintain that relationship with CBRFC's director, Michelle Stokes, sitting on our External Advisory Board.

NEW CLIMATE SERVICES AND STAKEHOLDER PRODUCTS

In 2016, WWA's **Jeff Lukas**, **Bill Travis** and **Adam McCurdy** produced a set of maps of the monthly occurrence of ten types of significant weather events in Colorado, Utah,

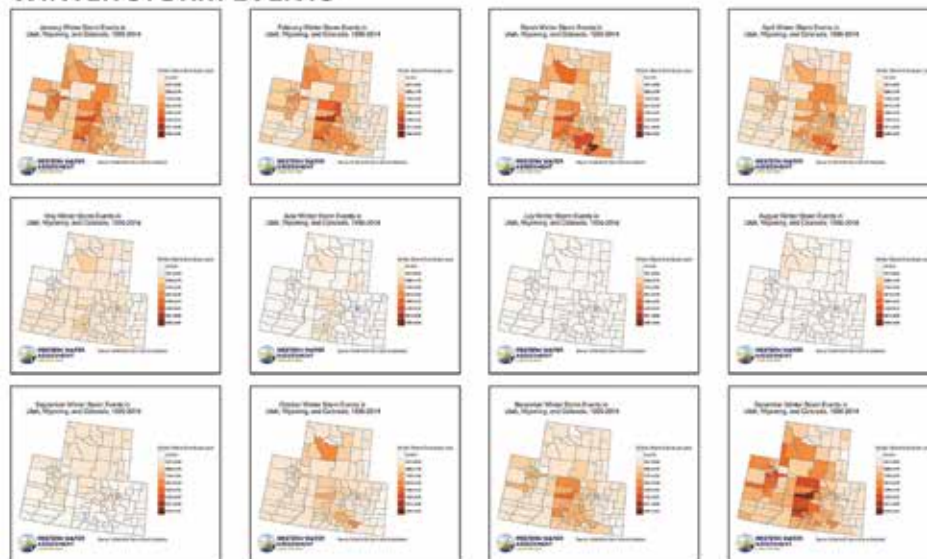
and Wyoming over the period of record, derived from the NOAA Storm Events Database. The Boulder, CO office of the engineering firm Wood (formerly Amec/Foster/Wheeler) has been updating the multi-hazard mitigation plans for five counties and their municipalities in the northeastern corner of **Wyoming**. In April 2018, we updated and re-formatted the maps for Wood to include in the **multi-hazard mitigation plans**, communicating the spatial and seasonal patterns of risk for those ten event types to hazard planners, emergency managers, and other local decision-makers.

In 2018, WWA worked with the Colorado Department of Agriculture and the Colorado Water Conservation Board to develop a survey of the agriculture sector in the state asking about drought impacts, planning, and response. The results of this survey were included in the 2018

FLOOD EVENTS



WINTER STORM EVENTS



Monthly maps of significant weather events in Colorado, Utah, and Wyoming for flood events and winter storm events. Other extreme event maps are available at: <http://wwa.colorado.edu/climate/extremes/maps>.



Folsom Lake in the Sierra Nevada foothills of California. Photo: Steenaire, Flickr.

update of the **Colorado Drought Plan**. The goal was to better understand the water and drought challenges farmers and ranchers face across the state, including their past experiences and future concerns about water availability for their operations. A geographically broad sample of the agricultural community participated, giving us a snapshot of these producers and their previous and current experiences with drought. Fifty-five percent of respondents believe their operations are located in a geographical area that frequently experiences prolonged drought, and the majority (89%) reported that they had made changes to their operations to better prepare for the next drought. The types of changes they made to their operations included mostly technological changes, such as installing drip irrigation or more center pivots, and management practices, such as changing crop types or less intensive tillage practices.

In a November 2017 Utah drought meeting sponsored by WWA and NIDIS we learned that there has not been much recent work on the topic of drought planning. This was surprising because Utah is the second driest state

in the nation and because there has been significant work done in Utah on future water supply planning. An assumption going into the drought meeting was that water supply planning and drought planning were similar enough that work done on water supply planning would translate easily into drought planning. However, this was not the case, and there is a great and somewhat urgent need for drought planning in Utah. To that end, Seth Arens of WWA and Elizabeth Weight of NIDIS have actively worked with the Utah Drought Coordinator and the Utah Division of Water Resources to provide assistance with drought planning and help the Division move forward with a major update to their State Drought Plan, which is largely inactive at the present time. Work in spring of 2018 focused on planning a state drought planning meeting to begin a discussion with important stakeholder about a state drought plan and to provide information from other states and organizations about their experience with drought planning. A second Utah drought meeting sponsored by the Utah Division of Water Resources is planned for July 2018.



Niwot Ridge Trail located near Nederland, Colorado. Photo: Mark Raleigh.

WWA GOALS AND METRICS

WWA goals make progress toward the outcomes of building adaptive capacity in our region and increasing the use of new science and tools in decision making. Below are a list of those goals and how we measure progress toward them. Some of the goals are larger than what WWA can accomplish on our own, given limited resources and our organizational situation, but with these particular goals, we look outside WWA for indicators of progress and measure what effort WWA can contribute to the goal.

BUILDING RELATIONSHIPS AND ENHANCING NETWORKS

Building relationships is key to WWA achieving its mission, and literature and practice show strong relationships are necessary for producing usable science. We are interested in various aspects of relationships: new relationships, ongoing relationships, what types of organizations, and what activities. Enhancing networks shows how WWA convenes researchers and science users. Here we want to measure the connections WWA helps to foster among others, in addition to the relationships between WWA and its stakeholders.

Related Projects:

- Sustained Climate Assessment (p. 26)
- Climate Service Providers (p. 25)

Metrics:

- Stakeholder interaction tracking: with whom and what organizations, referrals to and from WWA, one-on-one conversations, attendees at WWA events
- Reports on how relationship building and maintenance lead to bigger, formal projects

INFLUENCE IN OUR REGION

WWA is seen as a **trusted** (non-partisan, non-advocacy) voice for information that helps stakeholders do their job and make decisions. We provide valuable services in our region.

Metrics:

- Stakeholder interaction tracking: number of people and organizations that attend WWA events, types and diversity of entities with which we work, requests for presentations, training, and inclusion on boards, type of information people seek from WWA and its use
- Track media mentions
- Survey of our stakeholders and request anecdotes/stories

BUILDING RESILIENCE IN OUR REGION

This goal is explicitly stated in our proposal, but it is very hard to measure. WWA can provide information and activities that help decision makers in their effort to increase resilience, but WWA does not have the expertise or position to take actions or implement policies that will result in actual resilience in our region. WWA can convene groups to work through what resilience means in their region or sector given what we know (and don't know) about current and future climate.

There are also some 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.



WWA's Jeff Lukas being interviewed by the Kyrgyz Public Radio and Television Corporation. Photo: George Santulli.

Metrics:

- Survey of stakeholders and RISA network to ask about conceptual use, justification use, instrumental use of WWA- provided information
- Identify cases in which scientific information is added to policies or referenced in justification for adaptation actions

Another example of a regional change is the **growth of capacity to incorporate climate knowledge** in other organizations. WWA cannot claim all the credit for this, 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.

Metrics:

- Analyze climate capacity change in Utah and compare to the changes already seen in Colorado
- Track where WWA personnel go next in their careers

- Analyze the capacity of our stakeholders through time (not just positions but also their use of climate information)

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 at various stages, so progress on this goal can be documented on a project basis.

Related Projects:

- MODIS SWE data (p. 22)
- Ranching insurance model (p. 28)
- EDDI usability
- Extremes Database (p. 5)
- Intermountain West Climate Dashboard (p. 23)

PROVIDING FEEDBACK TO NOAA

Providing Feedback about the use of their information/operational products. We can track what we send to back to NOAA (NWS, NIDIS, Climate Program Office), but it will be harder to measure whether NOAA takes up any lessons learned or changes anything due to WWA's findings. We submit annual reports to the RISA, Assessments, and NIDIS programs within NOAA CPO, and separately send specific items such as the R2O in the RISA Network report.

Methods of Transfer to NOAA:

- Annual reports to CPO
- Organize and lead sessions at RISA annual meetings
- Present project findings on RISA monthly calls
- Deliverables to NIDIS each year

CONTRIBUTING TO THE LITERATURE AND PROVIDING LESSONS LEARNED

Contributing to the literature and providing lessons learned across organizations that are aiming 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, building the capacity of the network beyond our region, including to other academics and groups like the USGS Climate Adaptation Science Centers and the USDA Climate Hubs.

Related Projects:

- VCAPS (p. 27)

Metrics:

- Papers, reports, presentations
- Retreats with North Central CASC and USDA Northern Plains Climate Hub



Las Cruces and the Organ Mountains. Photo: Abraham Sanogo, Wikimedia Commons.

SUSTAINED CLIMATE ASSESSMENT FOR THE U.S. SOUTHWEST

WWA's Sustained Climate Assessment in the Southwest project is led by **Benét Duncan**, WWA's Climate Assessment Specialist. In this project – a collaboration with CLIMAS and CNAP – WWA is investigating opportunities for sustained assessment in the US Southwest National Climate Assessment (NCA) region, which includes Arizona, California, Colorado, Nevada, New Mexico, and Utah. The project will produce recommendations for a regional sustained assessment process that draws on the broad existing capacity for climate assessment in the region with the goal of connecting climate service providers and users to increase access to information and understanding of climate impacts in decision-making contexts. This will form a foundation of knowledge and relationships that better meets ongoing information needs and can be drawn on when developing future national climate assessments and in other assessment processes.

During this reporting period, WWA had conversations and conducted informal interviews with producers of current and previous NCA reports to better understand the national assessment landscape and initial vision for sustained assessment. WWA also conducted a review of existing literature on climate service provision and developed a typology of the range of weather and climate information producers in the region. The typology informed selection of case studies that have successfully produced usable climate and weather information on a sustained basis, including assessments

at a range of scales. WWA is currently conducting interviews to build the case studies and will then identify characteristics they share. The case studies will be used in building recommendations for a sustained assessment process in the region.

Benét gave talks about this work as an invited speaker at the CU Boulder Center for Science and Technology Policy Research (CSTPR) Lunchtime Seminar Series in October 2017, and at the American Geophysical Union's Fall Meeting in December 2017 in New Orleans, LA. She also provided a summary of this work during a meeting of the interagency Sustained Assessment Working Group in August 2017.

Benét Duncan giving a talk at the Center for Science and Technology Policy Research on October 18, 2017. Photo: Ami Nacu-Schmidt





Big Horn Mountains of Johnson County, Wyoming. Photo: Sam Beebe, Wikimedia Commons.

CONTRIBUTIONS TO THE NIDIS INTERMOUNTAIN WEST DEWS

During this reporting period, WWA contributed to the Intermountain West Drought Early Warning System (IMW DEWS) through several activities, some of which are highlighted below and in other sections of this report. WWA's **Jeff Lukas, Heather Yocum, Seth Arens** and **Ursula Rick** planned and facilitated a meeting of IMW DEWS Information Providers in June 2017. The purpose of the meeting was to promote coordination, leverage information, connect networks to improve dissemination of drought information across the five-state IMW DEWS region. The meeting convened representatives from most of the key providers of drought-related information serving the region, including the state climate offices for Colorado, Arizona, and Wyoming, the two RISAs (WWA and CLIMAS) and the two Regional Climate Centers serving the IMW region (WRCC and HPRCC), NOAA CBRFC, the NRCS Snow Survey (Utah), NDMC, NIDIS, and state drought task forces/water agencies in Colorado, New Mexico, and Utah. The following summary statements synthesize the meeting presentations and discussions:

1. There is a healthy "crop" of new drought information resources, tools, and services for the IMW DEWS region, reflecting a strong collaborative network.
2. Engagement with users is highly important, though also challenging to balance with operational mandates.
3. What constitutes useful drought monitoring and early warning in the IMW DEWS (and elsewhere) largely depends on the user.
4. Some concrete next steps were identified, but questions about how to effectively leverage and coordinate efforts under the IMW DEWS banner need to be revisited in future dialogues.

WWA also hosted a meeting with NIDIS and the Colorado Climate Center (CCC) in February 2018 to improve coordination among the drought information provided respective websites of the three organizations: the NIDIS IMW DEWS page, the WWA Intermountain West Climate Dashboard, and the CCC's Drought Webinars and webpage. The information provided at these sites is not redundant, but there is some overlap. The audiences for these sites, while broad in all cases, have different concentrations of sectors with the NIDIS IMWS DEWS page facing the general public, the WWA dashboard visited by many water managers, and



the CCC serving many in the agricultural sector and general public. Staff at all three organizations go to each other's sites for information to share with stakeholders and to create information for their respective sites. No large changes to any of the sites were proposed, however the group agreed to keep monitoring usage and communicating with each other in the future to ensure resources are best used and stakeholder needs are met.

Seth Arens continued to work with the NIDIS regional coordinator to improve awareness of NIDIS and other drought information for Utah. They planned and facilitated a meeting in West Jordan, UT in November 2017 to introduce the IMW DEWS and to begin a conversation about drought planning in Utah with important drought stakeholder within the state. NIDIS had not previously engaged stakeholders in Utah on the topic of drought planning and this meeting was designed to begin to engage important drought stakeholders in Utah. Attendees included representatives from the Utah Division of Water Resources, the Utah Division of Emergency Management, Utah Climate Center, Bureau of Reclamation, US Forest Service, Colorado Basin River Forecast Center, NOAA National Weather Service, NRCS Utah Snow Survey and four local water conservancy districts. Arens of WWA acted as facilitator for this one-day and gave a presentation on the history of drought and drought planning in Utah.



Brainard Lake in Ward, Colorado. Photo: Jeff Lukas.

WWA 2017-2018 PROGRAM HIGHLIGHTS

MAJOR RESEARCH FINDINGS AND PUBLICATIONS

Testing a MODIS-based Spatial SWE Product

Over the past three years, WWA has worked to promote the usability and effective application of snowpack monitoring information through workshops, interviews with information users, and assessments of both in-situ (e.g., SNOTEL) and spatial snow data (e.g., SNODAS, ASO). In particular, we have been looking to augment the ubiquitous use of in-situ data with spatial products, in a manner that adds appreciable value at low cost to users. In the spring of 2018, in an effort to kickstart broader awareness and use of spatial snow data, WWA pilot-tested a MODIS-based spatial SWE product developed by **Noah Molotch** and his group for the WWA Intermountain West region (UT, WY, CO). From late March to late May, five times, a spatial SWE product and accompanying report were distributed to a small group (~15) of water managers, snow scientists, streamflow forecasters, and climate service providers, followed by phone interviews by **Heather Yocum** to systematically collect feedback on the pilot product. The pilot test has indicated benefits, and also limitations, of the MODIS-based SWE product. Currently (early June 2018), we are partway through the analysis of the interviews about the MODIS-based spatial SWE product. We expect that this feedback, along with interaction at the upcoming September workshop in western Colorado, will indicate priorities for follow-on work in this thematic area in FY2019.

Successful Collaboration Among Federal Regional Climate Centers

Federal investments by U.S. agencies to enhance climate resilience at regional scales grew over the past decade (2010s). To maximize efficiency and effectiveness in serving multiple sectors and scales, it has become critical to leverage existing agency-specific research,

infrastructure, and capacity while avoiding redundancy. The paper below discusses lessons learned from a multi-institutional “regional climate response collaborative” that comprises three different federally supported climate service entities in the Rocky Mountain west and northern plains region. These lessons include leveraging different strengths of each partner, creating deliberate mechanisms to increase cross-entity communication and joint ownership of projects, and placing a common priority on stakeholder-relevant research and outcomes. Averyt and co-authors share the conditions that fostered successful collaboration, which can be transferred elsewhere, and suggest mechanisms for overcoming potential barriers. Synergies are essential for producing actionable research that informs climate-related decisions for stakeholders and ultimately enhances climate resilience at regional scales.

- ◆ Averyt, K., J.D. Derner, L. Dilling, R. Guerrero, L. Joyce, S. McNeeley, E. McNie, J. Morissette, D. Ojima, R. O’Malley, D. Peck, A.J. Ray, M. Reeves, and W. Travis (2018). Regional Climate Response Collaboratives: Multi-Institutional Support for Climate Resilience. *Bulletin of the American Meteorological Society*, 891-898.

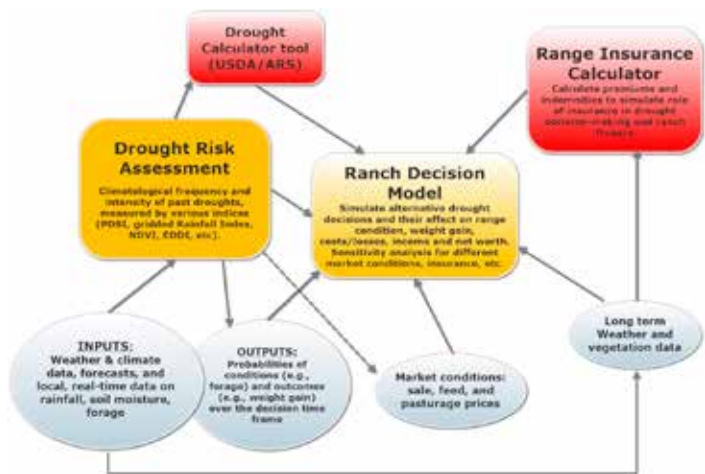
Managing Drought Risks on the Ranch

Ranching involves complex decision-making and risk management in the face of uncertainty about climate conditions. The profitability and sustainability of ranching depend heavily on sufficient and timely rainfall for rangeland forage production. As a result, ranchers may either adopt conservative long-term stocking strategies as a hedge against drought or practice a more dynamic approach in which they vary stocking rates and supplemental feed in response to drought. WWA’s Trisha Shrum, William Travis and their co-authors reviewed the literature to learn the drought management options as well as the tools and products for drought monitoring and early warning that are available to ranchers. They found

a large gap remains between the information needs of ranchers seeking to adapt dynamically to drought and the information that is available. Moreover, even when actionable information is available, it is unclear whether ranchers are optimally incorporating that information into their risk management decisions.

◆ Shrum, T. R., W. R., Travis, T. M. Williams, and E. Lih (2018). Managing climate risks on the ranch with limited drought information. *Climate Risk Management*, doi: 10.1016/j.crm.2018.01.002, February 22.

In related work, **T. Shrum** and **W. Travis** have run experiments with the Drought, Ranching and Insurance Response (DRIR) model testing whether the USDA PRF rain-index insurance affected investment in drought adaptation and intensity of grazing. We found that participants with insurance tended to increase their grazing intensity (measured as herd size) compared to those without insurance. While the results on drought adaptation through hay purchases was not statistically significant with the small sample of participants, they detected a trend that during early years the insured participants purchased less supplemental hay in response to low rainfall while in later years, as their incomes rose relative to the uninsured participants due to insurance indemnities, the insured participants purchased more supplemental hay. (See related outreach activity below.)



Knowing Climate: Limits of climate literacy tests and improved engagement with stakeholders

Climate perception can include interpretations of experienced climate, beliefs about how climate works or changes, attitudes about climate issues such as the human role in climate change, and even climate preferences. This study focused on how people come to “know” climate, not just climate change science, in a more fundamental way. WWA’s **K. Clifford** conducted semi-structured interviews of residents of the Gunnison Basin in Colorado whose livelihoods and activities bring them in routine contact with weather, climate, and landscape. Analysis

of their climate knowledge in three categories, features, processes, and benchmarks, yielded three findings.

1. People often focus on climate-related proxies that might be disregarded as tangential within narrow definitions of climate science.
2. People use rubrics to structure climate knowledge, they understand climate as relational and connected.
3. Climate knowledge does not isolate individual climate elements but accentuates the complex way that many processes together constitute climate.

These findings reveal that, for the interviewees, climate is a social-ecological-atmospheric construct. This research can provide new interpretations of results from previous research on attitudes about climate change, especially skepticism. Surveys of attitudes toward climate change often fail to address the underlying question of how people understand climate, much less why and how it changes. A focus on climate skepticism assumes that climate change beliefs are based on ignorance, politics and socio-economic motivations, when differences in climate experiences and climate knowledges could lead to some of these differences in attitude. A better understanding of climate knowledge can, and should, shape how we work to mitigate and adapt to climate change. Yet, some climate perception studies may be misleading. People might “fail” climate literacy tests because of jargon or technical language while still having robust knowledge. By understanding more about how people know climate, we may be able to better interpret climate attitudes and beliefs, diagnose why past efforts to encourage climate adaptation and mitigation have been unsuccessful, and provide insights into limits on the effective application of climate information.

◆ Clifford, K.R. and W.R. Travis (2018). Knowing climate as a social-ecological-atmospheric construct. *Global Environmental Change*, Volume 49, pp. 1–9, doi: 10.1016/j.gloenvcha.2017.12.007.

Incorporating Climate Change into Probable Maximum Precipitation Estimates for Dam Safety

The Colorado Division of Water Resources and the New Mexico Office of the State Engineer have identified and set as a priority the need to update the decades-old extreme precipitation estimates used in the evaluation of spillway adequacy for dams in these states, based on the most modern methods and scientific understanding available. Due to similarities in geography and meteorology between Colorado and New Mexico, a cooperative, regional study (Colorado-New Mexico Regional Extreme Precipitation Study; CO-NM REPS) has been undertaken, the first instance of states combining resources and



Dam Safety Meeting. Photo: Kelly Mahoney.

working collaboratively toward a solution to the problem. The project began in June 2016 and is scheduled to be completed in August 2018. Of particular concern in both states are questions about the physical limits on high-elevation rainfall amounts and the annual exceedance probability (AEP) of the extreme rainfall amounts used for spillway design. This has led to an ensemble approach deploying three different methods to update extreme precipitation estimates. The initial study plan for CO-NM REPS did not seek to explicitly incorporate climate change influences in Probable Maximum Precipitation (PMP) estimates in any of the three approaches. Recognizing future risk from extreme precipitation may be different in a changing climate, the study's sponsors asked WWA to take stock of the state of the science and practice in PMP estimation with respect to climate change in a white paper that has become a volume in the study final report. An initial literature search and review was completed in spring 2017, followed by a web-based survey of CO-NM REPS sponsors, researchers, and technical advisory board members and other stakeholders in summer 2017 to scope additional questions and issues of interest. An initial draft volume was completed in March 2018; the revised draft is currently under review again with the final volume to be submitted at the end of June 2018.

SELECT OUTREACH ACTIVITIES

Wildfire Data Use Workshop

WWA was awarded a grant to work with a



University of Colorado Grand Challenge program, Earth Lab, to ensure their research is connected to Colorado stakeholders and to train people across campus in the production of usable science. In June 2017, we held a workshop for wildfire practitioners and researchers to improve the usability of a wildfire database created by Earth Lab's **Lise St. Denis**. The goals of the workshop were to 1) understand the capabilities of the dataset, 2) identify ways the dataset can be useful 3) identify opportunities for collaboration, and 4) understand practitioner needs for data. There were fifteen attendees, including physical and social scientists, journalists, and wildfire practitioners. The practitioners provided guidance on the source of the wildfire data used in the database, and how they might use the various combinations of data. They also expressed a desire to keep working with scientists as they do their research so that it might better inform their work.

Wetlands Talk for EPA

In October 2017, **Jeff Lukas** was invited to present on "Future Challenges for Aquatic Resource Resiliency" at the **EPA Region 8 Wetlands Conference** in Boulder, CO, a gathering of about 150 resource managers, researchers, and consultants from Federal, state, and local entities in the Rockies and Northern Plains states. Lukas summarized recent climatic and hydrologic trends for Region 8, the mid-century climate projections from GCMs, and the likely consequences of climate change for wetlands, concluding with a synthesis of recent wetlands vulnerability assessments. This indicates that EPA's staff and stakeholders are committed—despite pressures to the contrary—to informing their discussions and management with the latest climate science.



June 2017 Retreat hosted by the USDA Northern Plains Climate Hub at the USDA experimental Range Station in Nunn, CO. Photo Bill Travis.

Intermountain Sustainability Summit

Seth Arens was invited to speak at Weber State University's annual Intermountain Sustainability Summit in March of 2018. The conference had an urban water and climate change track and Arens gave a presentation entitled "Is it too hot for my lawn? Outdoor water use and climate change on the Wasatch Front." The talk gave a broad introduction into climate change, urban outdoor water use and how the two topics interact. Specifically, Arens discussed original research conducted with Jordan Valley Water Conservancy District about the impact of climate change on outdoor water use. The Intermountain Sustainability Summit has a wide audience that includes natural, physical and social scientists, sustainability professionals and students from the entire Wasatch Front. The talk given by Arens was attended by approximately 50 people.

Zion Regional Collaborative

Seth Arens of WWA has participated in a regional planning collaborative in the Zion National Park area of southern Utah at the request of the planning collaborative's lead

investigator, Danya Rumomre of the University of Utah. While climate change is not the dominant topic of the Zion Regional Collaborative (ZRC), Arens was asked to participate as a scientist and climate expert relevant information on regional planning. In July 2017, Arens was invited to give a presentation about specific climate concerns in the Zion National Park region. Based on information from previous meetings, Arens developed an analysis of future climate risks related to extreme precipitation and extreme heat in the region. Arens presented information from this analysis to the planning group, which in comprised of approximately 25 people representing organizations including the National Park Service, local city and county planning officials, Utah Department of Transportation, Utah Department of Tourism, Bureau of Land Management, US Forest Service and others.

Methodologies and Engagement for State Level Climate Assessment

Anji Seth and Christine Kirchoff, a former CU postdoctoral researcher, at the University of Connecticut

were asked to conduct a climate assessment for the state of Connecticut. The main purpose of the workshop was to learn from those who have experience in assessments at these scales to inform their assessment. The invitees were largely those who had produced state (CO, VT, MA) and city (Boston) scale assessments to share their expertise, as well as partners in Connecticut that were co-producing their assessment. Because of his involvement through the WWA RISA in assessments for Colorado, **Joe Barsugli** was invited and presented on the 2008 and 2014 iterations of the Climate Change in Colorado Report, the Colorado Climate Preparedness Project, and the Boulder City and County Climate Preparedness Report. State and local climate assessment is emerging as an important requirement for adaptation planning, and the intention is to write a manuscript on best practices as an outcome of this workshop.

Ranching Drought Tool Testing USDA Northern Plains Hub and NC CSC

In June 2017, the USDA Northern Plains Climate Hub hosted a retreat at the USDA experimental Range Station in Nunn, CO for WWA and the USGS North Central Climate Science Center. A key activity at this retreat was an experiment involving the Ranching Drought Decision Tool with producers (rather than scientists or the general public). The tool tests the impact of the USDA Pasture Rangeland and Forage insurance on cow-calf ranching operations. This session provided key feedback to the model developers, **William Travis** and **Trisha Shrum**, in a debriefing session after the experiment. There were a number of helpful suggestions that improved our simulation, and there was a great deal of positive feedback on the usefulness of the tool.



Barr Lake State Park in Brighton, Colorado. Photo: Jeff Lukas.

WWA 2017-2018 PROJECT REPORTS

ASSESSING THE FEASIBILITY AND USABILITY OF SPATIAL SNOWPACK INFORMATION

Primary Investigator(s): J. Lukas, N. Molotch, U. Rick, H. Yocum

Other Investigator(s): L. Lestak, J. Berggren

Stakeholders: National Integrated Drought Information System (NIDIS), Colorado Basin River Forecast Center and other snow/water information providers, water resource managers and other users of snowpack information

Pilot test of a new spatial snow-water equivalent (SWE) product for the Intermountain West

A key indicator of water availability and drought, and the primary input to streamflow models, is snow-water equivalent (SWE), which is monitored from a network of in-situ SNOTEL observing sites across the West. However, conditions at SNOTEL sites (e.g., percent of normal SWE) may not be representative of conditions in the large areas between these point measurements, and at elevations above and below the range of the SNOTEL sites. Over the past three years, WWA has worked to promote the usability and effective application of snowpack monitoring information, through workshops, interviews with information users, and assessments of both in-situ (e.g., SNOTEL) and spatial snow data (e.g., SNODAS, ASO). In particular, we have been looking to augment the ubiquitous use of in-situ data with spatial products, in a manner that adds appreciable value at low cost to users. In the spring of 2018, in an effort to kickstart broader awareness and use of spatial snow data, WWA pilot-tested a MODIS-based spatial SWE product developed by N. Molotch and his group for the WWA Intermountain West region (UT, WY, CO). From late March to late May, a spatial SWE product and accompanying report were distributed to a small group (~15) of water

managers, snow scientists, streamflow forecasters, and climate service providers, followed by phone interviews by H. Yocum to systematically collect feedback on the pilot product. The pilot test has indicated benefits, and also limitations, of the MODIS-based SWE product. Currently (early June 2018), we are partway through the analysis of the interviews about the MODIS-based spatial SWE product. We expect that this feedback, along with interaction at the upcoming September workshop in western Colorado (below), will indicate priorities for follow-on work in this thematic area in FY2019.

Deliverables: Spatial SWE product and reports (5); report summarizing findings from pilot test (forthcoming summer 2018)

PROVIDING GUIDANCE ON THE USE OF IN-SITU SNOWPACK INFORMATION

Primary Investigator(s): J. Lukas, J. Deems, M. Raleigh

Other Investigator(s): B. Livneh, A. Badger

Stakeholders: National Integrated Drought Information System (NIDIS), Colorado Basin River Forecast Center, water resource managers and other

Helping water managers and others make the best use of in-situ (i.e., SNOTEL) snow information

The use of snow information from the network of >800 in-situ SNOTEL observing sites across the West is ubiquitous. Virtually all water managers and other water users track SNOTEL data, and many also use the data to generate their own estimates of seasonal water availability, through regression modeling and similar methods, in addition to consulting operational streamflow forecasts from NRCS and NOAA based on the SNOTEL data. Recognizing that conditions at SNOTEL sites (e.g., percent of normal

SWE) may not be representative of conditions in the large areas between these point measurements, and at elevations above and below the range of the SNOTEL sites, our objective is to identify the most representative SNOTEL data in space and time, so that users can make more robust estimates of basin-wide SWE volumes given the limited point data. Deems and Raleigh have been analyzing and visualizing SNOTEL data, in order to make those judgements about the better SNOTEL data. They are also using Airborne Snow Observatory (ASO) data collected for western Colorado to ground-truth inferences about the robustness of SNOTEL data. We are also leveraging analyses of SNOTEL and observed and modeled streamflow data by Livneh and Badger for a related NOAA SARP project. The findings of the analyses will be distilled and presented at a half-day workshop for water managers and others planned for western Colorado in September 2018. At that workshop we will also distribute the first version of a general user's guide to snowpack monitoring information that will draw from several prior WWA projects.

Deliverables: Workshop on snowpack monitoring information for western Colorado (forthcoming, September 2018); User's guide to snowpack monitoring information (forthcoming, September 2018)

INTERMOUNTAIN WEST CLIMATE DASHBOARD

Primary Investigator(s): J. Lukas

Partners: NIDIS, CLIMAS

Stakeholders: Water resource managers; anyone needing to monitor evolving weather, climate, and hydrologic conditions

Surveying users to identify potential enhancements to the WWA Dashboard and the Intermountain West Drought Early Warning System

The WWA Intermountain West Climate Dashboard (<http://wwa.colorado.edu/climate/dashboard.html>) is a web resource with a grid of 30 weather, climate and water information graphics that are automatically updated on the Dashboard as their providers update them. The graphics are supplemented by monthly text briefing highlighting the most important conditions and trends. Feedback from WWA stakeholders has indicated that this Dashboard is a very useful 'one-stop shop' for up-to-date climate and water information for WWA's three-state region. Over the past few years, two other resources for drought monitoring in the IMW DEWS have functionally converged with the WWA Intermountain West Climate Dashboard: The Colorado Climate Center (CCC) IMW DEWS Drought Summary page, and NIDIS's own IMW DEWS Current Conditions page. We first conducted

discussions with CCC staff and the NIDIS Program Office to assess current usage of the respective resources and programmatic objectives in light of the IMW DEWS Strategic Plan; it was decided that the convergence itself did not indicate that the WWA Dashboard was redundant, as long as the usage of the Dashboard was sufficient to justify the continued investment in its production by WWA, with NIDIS support. In June 2018 we developed and posted a web-based instrument to survey current users of the WWA Dashboard. The responses, still being collected, will inform future changes to the WWA Dashboard, and the collective provision of information by the IMW DEWS more generally.

Deliverables: The Intermountain West Climate Dashboard web resource (monthly maintenance and updates); Dashboard user survey

EXTREME PRECIPITATION ESTIMATION UNDER CLIMATE CHANGE FOR DAM SAFETY

Primary Investigator(s): K. Mahoney, J. Lukas

Stakeholders: Colorado Division of Water Resources Dam Safety Program; New Mexico Office of the State Engineer, CO-NM REPS technical advisory board members and other stakeholders

Assessing the state of the science and practice in extreme precipitation estimation under climate change and making recommendations

The Colorado Division of Water Resources and the New Mexico Office of the State Engineer have identified and set as a priority the need to update the decades-old extreme precipitation estimates used in the evaluation of spillway adequacy for dams in these states, based on the most modern methods and scientific understanding available. Due to similarities in geography and meteorology between Colorado and New Mexico, a cooperative, regional study (Colorado-New Mexico Regional Extreme Precipitation Study; CO-NM REPS) has been undertaken, the first instance of states combining resources and working collaboratively toward a solution to the problem. The project began in June 2016 and is scheduled to be completed in August 2018. Of particular concern in both states are questions about the physical limits on high-elevation rainfall amounts and the annual exceedance probability (AEP) of the extreme rainfall amounts used for spillway design. This has led to an ensemble approach deploying three different methods to update extreme precipitation estimates. The initial study plan for CO-NM REPS did not seek to explicitly incorporate climate change influences in Probable Maximum Precipitation (PMP) estimates in any of the three approaches. Recognizing future risk from extreme precipitation may be different



Granby Dam in Grand County, Colorado. Photo: Jeffrey Beall, Wikimedia Commons.

in a changing climate, the study's sponsors asked WWA to take stock of the state of the science and practice in PMP estimation with respect to climate change in a white paper that has become a volume in the study final report. An initial literature search and review was completed in spring 2017, followed by a web-based survey of CO-NM REPS sponsors, researchers, and technical advisory board members and other stakeholders in summer 2017 to scope additional questions and issues of interest. An initial draft volume was completed in March 2018; the revised draft is currently under review again with the final volume to be submitted at the end of June 2018.

Deliverables: Volume to be published in the CO-NM REPS final report in August 2018; potential for peer-reviewed paper based on the volume

DROUGHT PLANNING ON THE WASATCH FRONT USING PALEO-DROUGHT INFORMATION AND FUTURE CLIMATE PROJECTIONS

Primary Investigator(s): S. Arens

Stakeholders: Weber Basin Water Conservancy District, Utah Division of Water Resources and Utah State University

Partners: D. Johnson and D. Hess (Weber Basin Water Conservancy District), D. Rosenberg and J. Stagge (Utah State University), S. McGettigan, C. Hasenyager and A. Nay (Utah Division of Water Resources)

Drought contingency plan development for Weber Basin Water Conservancy District

Weber Basin Water Conservancy District (WBWCD) was awarded a grant in June 2016 from the US Bureau of Reclamation to develop a drought contingency plan. Arens received one month of salary from the grant award to develop future projections of Weber River streamflow. The project uses a RiverWare systems model of the Weber River Basin to explore how past and future droughts may impact water availability and reservoir storage in the Weber River Basin. WBWCD is a relatively junior water rights holder, despite providing water to several hundred thousand residents of the northern Wasatch Front. The project will use information derived from paleo-reconstructions of Weber River streamflow using tree rings to understand how droughts of the past could impact water availability in the Weber River Basin. Future Weber River streamflows were projected using the NOAA Colorado Basin River Forecast Center operational models. Information about past and future drought conditions in the Weber River Basin will be used to develop a drought contingency plan to help WBWCD prepare for future variability in Weber River water availability.

Deliverables: Future projections of Weber River streamflow based on projected changes in temperature and precipitation derived from Global Climate Models. A report on this project will be completed by WBWCD in Fall 2018.

Leveraged funding: \$150,000 each from US Bureau of Reclamation and WBWCD

DYNAMICS OF VULNERABILITY BETWEEN URBAN AND RURAL COMMUNITIES IN DROUGHT PLANNING AND MITIGATION

Primary Investigator(s): J. Henderson, L. Dilling, U. Rick, R. Morss (NCAR), O. Wilhelmi (NCAR)

Stakeholders: Water utilities, municipalities, and agricultural community along Arkansas River Basin

Understanding the temporal and spatial dynamics of drought

As municipalities implement adaptation or mitigation plans based on past drought experience that improve their resilience, emergent and unexpected vulnerabilities can arise in response to these changes. They can happen immediately in response to water strategies or may be displaced in time or space (e.g. in rural communities months later). The goals of this project are threefold: 1) To understand the types of vulnerabilities to drought that water utilities, industries, agricultural producers, and municipal leaders are concerned about and plan for; 2) To trace the dynamic nature of vulnerabilities to drought that emerge between urban and adjacent rural communities as the implement drought plans; 3) To identify the triggers for emergent vulnerabilities that may be displaced across time and space in drought contexts. To meet these goals, the PI is interviewing representatives from each stakeholder group in two locations, along the Arkansas River Basin and in Ogden UT along the Weber River Basin. Initial results suggest that stakeholders are well versed in the common vulnerabilities their sector faces, and even new resilient strategies that have emerged based on experiences with recent droughts (e.g. 2002 and 2012). However, many expressed surprise at some of the unanticipated outcomes in adjacent communities. A survey of the agricultural community in Colorado was completed in Spring 2018, and a similar survey may be deployed in Utah pending input from state agencies and other stakeholders there.

Deliverables: Peer reviewed papers, drought survey of Colorado agriculture

Leveraged funding: \$110,000, 2-year CIRES Visiting Fellowship

INCREASING UNDERSTANDING OF CLIMATE SERVICE PROVISION

Primary Investigator(s): B. Duncan, B. McMahan (CLIMAS, University of Arizona)

Stakeholders: NOAA Western Regional Collaboration Team

Toward closing the gap between climate service providers and users

Development of a public, searchable database of climate-service organizations in the NOAA West Region was an important first step in bridging the gap between climate information producers and users. The resulting Climate Service Providers Database, which launched in May 2017, had over 700 monthly visits for its first two months, and then over 250 monthly views from July through November 2017. While the database has simplified the process of identifying climate service providers, our understanding of the network that these providers form continues to be limited. To fill this need and continue bridging the gap between providers and users, this project developed an online survey to better understand service provision from a provider's perspective, assess gaps in service coverage, learn how stakeholder needs are assessed and fulfilled by the network of providers, and map the network itself. This work is designed to better understand the landscape of climate service providers in the West, and to inform resource allocation and resource funding. Following the online survey, the project conducted follow up interviews with a subset of providers for a complementary case study approach. The finished product will be a report that summarizes survey results, shares case studies, and provides an initial network map, and it is currently in development.

Deliverables: Searchable database: <https://wrcc.dri.edu/ClimSvcProviders>; Final report (in progress)

DECISION ANALYSIS FOR CLIMATE ADAPTATION

Primary Investigator(s): W. Travis

Other Investigator(s): A. McCurdy, T. Shrum

Stakeholders: Ranchers and others associated with the range livestock industry (e.g., ag extension specialists)

Development of simulation models and decision tools for drought adaptation

The adaptation decision analysis project seeks to analyze decision processes in climate-sensitive sectors and to build decision models that act as both research tools and decision aids. In this year, we put all of our focus on the western range livestock industry, aka ranching, the most extensive agricultural system in the American West. With assistance from the USDA Northern Plains Climate Hub, the WWA team finished building, and distributed two versions of the Drought Ranch Insurance Response (DRIR) model. Both include modules that calculate ranch outcomes with and without the USDA's forage and range insurance, an index insurance product linked to NOAA's gridded precipitation product. The spreadsheet version,



Fish and Wildlife Service worker on boat checking gill net full of fish. Photo: Pedro Ramirez Jr., U.S. Fish and Wildlife Service.

which is easiest for producers to use, can be downloaded, along with instructions, from the WWA's "Understanding and Monitoring Drought" webpages. An on-line version, written in the R coding language, was demonstrated on a NIDIS-sponsored webinar in May which also provided the URL for running it online. Next steps are to invite producers and others to test the drought response model via agricultural conferences and publications. The next research steps are to submit a paper describing the model for peer-reviewed publication and to set-up experimental trials to gather sufficient run samples to test hypotheses about the role of drought forecasts, insurance, and market conditions in rancher decision-making in the face of drought.

Deliverables: Working spreadsheet version of the drought decision model (DRIR) demonstrated in webinar and published in downloadable from on the WWA website. Test version of the online "R" version (DRIR-R) demonstrated in a NIDIS webinar and URL published for testing.

SUSTAINED CLIMATE ASSESSMENT IN THE US SOUTHWEST

Primary Investigator(s): B. Duncan

Stakeholders: NOAA Climate Program Office, US Global Change Research program, Interagency Sustained Assessment Working Group

Building a process for sustained assessment in the US Southwest

The Sustained Assessment in the Southwest project, is investigating opportunities for sustained assessment in the US Southwest region – an area that includes Arizona, California, Colorado, Nevada, New Mexico, and Utah. This work draws on recommendations in the Third National Climate Assessment (NCA3), with the goal of developing best practices for a sustained assessment process in the US Southwest region. The resulting sustained assessment process will draw on the broad existing weather and climate capacity in the region to connect information producers and users and increase access to information and understanding of climate impacts in decision-making contexts. It will also build a foundation of relationships and knowledge that can be drawn on for future national climate assessments and other assessment activities. Following a review of existing literature about sustained assessment and informal interviews with producers of current and previous versions of the National Climate Assessment, this project identified existing climate service providers in the region. This project is now developing case studies of sustained programs that produce and share weather and climate information, including assessments. Case studies will be used to identify shared characteristics from across these programs. The resulting shared characteristics will form the foundation of a recommended approach to sustained assessment in the region. The finished

product will be a report that summarizes project results and shares recommendations for a regional sustained assessment process. Work will also include sharing the recommendations broadly with relevant agencies and information producers.

Deliverables: Final report (in progress)

TESTING VCAPS IN THE WWA REGION

Primary Investigator(s): L. Dilling, U. Rick, R. Page, B. Duncan, S. Arens, K. Clifford

Stakeholders: Two communities in the WWA region, CISA RISA, NOAA Climate Program Office

Providing climate vulnerability and adaptation discussions in communities across our region

CISA RISA developed the VCAPS (vulnerability, consequences and adaptation planning scenarios) process and used it to help several communities along the East Coast think about their exposure to various climate hazards and to identify potential actions that could be used to address their vulnerability. The communities were all coastal municipalities whose main concern was flooding and sea level rise. The climate hazards faced by communities in the WWA region are different and include things such as changing drought patterns, wildfires, intense precipitation events and heat health. We are testing the VCAPS process with at least two communities to determine if the process will work well for our region and to provide analysis of the versatility of VCAPS across the US.

Deliverables: VCAPS workshops and reports for two communities in our region

COMMUNICATING CLIMATE CHANGE FOR THE U.S. FOREST SERVICE INTERMOUNTAIN ADAPTATION PARTNERSHIP

Primary Investigator(s): D. Peterson, J. Halofsky (USFS/ University of Washington); L. Joyce (USFS), S. Arens

Stakeholders: U.S. Forest Service

Partners: L. Joyce (USFS); M. Talbert, J. Morissette (USGS North Central Climate Science Center)

Providing climate change and drought assessment to the USFS in Utah

The Intermountain region of the U.S. Forest Service began a formal planning process to consider the impacts of climate change on forest resource management called the Intermountain Adaptation Partnership. S. Arens was

asked by the U.S. Forest Service to present information about future climate projections at two Wasatch Front workshops about the Intermountain Adaptation Partnership. One meeting focused on the Wasatch and Uinta sub-region of the Intermountain West and the other workshop focused on the Plateaus region of central Utah. The goal of each meeting was to introduce information about climate change in the Intermountain West and to gather USFS resource managers to brainstorm about potential climate adaptation strategies. S. Arens was also asked to participate in reviewing the final Intermountain Adaptation Partnership report. S. Arens was also asked by the USFS to give a presentation at an Intermountain West drought workshop in March 2017 in Ogden, UT. Arens of WWA was invited to speak at the rollout workshop for the US Forest Service Region 4 Intermountain Adaptation Partnership Climate Assessment in Ogden, UT in May 2018. Arens was also asked to speak at the kickoff to this process in May 2016. Arens was asked to participate in a panel of climate scientists to discuss the results of the climate change chapter of the climate assessment report and gave a presentation on uncertainty in regional climate modeling.

Deliverables: Presented on future climate in the Intermountain West region for two workshops in June 2016. Presented on drought and climate change in the Intermountain West at a USFS drought workshop in March 2017. Present at the rollout workshop in May 2018.

RANCHING DROUGHT DECISION ANALYSIS

Primary Investigator(s): W. Travis, T. Shrum

Stakeholders: Ranchers and others associated with the range livestock industry (e.g., ag extension specialists)

Development of simulation models and decision tools for ranching drought adaptation

The adaptation decision analysis project seeks to analyze decision processes in climate-sensitive sectors and to build decision models that act as both research tools and decision aids. Over the past two years, we have focused on the western range livestock industry, aka ranching, the most extensive agricultural system in the American West. With assistance from the USDA Northern Plains Climate Hub, the WWA team finished building, and distributed two versions of the Drought Ranch Insurance Response (DRIR) model. Both include modules that calculate ranch outcomes with and without the USDA's forage and range insurance, an index insurance product linked to NOAA's gridded precipitation product. The spreadsheet version, which is easiest for producers to use, can be downloaded, along with instructions, from the WWA's "Understanding and Monitoring Drought" webpages. We translated the spreadsheet model to an on-line version, tested it at the

Three-Center retreat, and then deployed it for the first experiment with 540 subjects from the general population recruited online. Next, we developed methods to recruit ranchers per se, with help from the USDA Northern Plains Climate Hub staff, and will deploy it to them in the second experiment this summer of 2018. Both WWA and Earth Lab have invested in the effort and related efforts by Travis to compare the usefulness of drought indicators for risk management. While continuing experiments with recruited subjects like ranchers, we're maintaining a publicly-accessible version at <http://www.ranching.io>.

Deliverables: Ranching insurance tool, peer-reviewed papers

Leveraged funding: T. Shrum is supported by both WWA and CU's Earth Lab

RELATIVE VALUE OF EARLY WARNING

Primary Investigator(s): W. Travis, P. Kamps

Stakeholders: NIDIS, any stakeholder relying on drought information

Providing comparisons of drought early warning to other warning systems

Finally, WWA started a two-year effort in 2018 aimed at improving our understanding of the economic effects of drought across multiple sectors, and the value that stems from drought information and early warning. There is a long history of research on the economic value of weather and climate information, especially for weather forecasts and warnings, but less on drought per se. In theory, similar

methods, like decision-trees, expected utility calculations, and value of additional information (VAI) analysis should apply to slower-onset hazards like drought. Our first step in this effort, completed last year was to conduct a full literature review to identify methods, findings and gaps in current knowledge, and to lay the groundwork for a set of sector-specific drought damage functions. The next step to be done this year is to evaluate the savings provided by timely drought information and early warning.

Deliverables: Literature review, peer-reviewed papers

EVALUATION OF VARIOUS INDICES FOR RANCHING INSURANCE

Primary Investigator(s): W. Travis, T. Williams

Stakeholders: NIDIS, USDA RMS Program, ranchers

Providing comparisons of drought early warning to other warning systems

In addition to continuing work on the ranching decision model and given concerns by ranchers about whether NOAA gridded precipitation is the best indicator for payment by the USDA PRF insurance program, we have been exploring various drought indicators in relation to the USDA rainfall insurance program. We have also begun looking at whether a single rain gage accurately predicts an insurance payout compared to drought indices. In FY19, we will further develop this analysis and deploy a webtool for users to evaluate the use of such indicators and expand upon and complete the rain gage work.

Deliverables: Literature review, peer-reviewed papers

Eastern Colorado ranchers during a workshop on drought this year, supported by the USDA Natural Resources Conservation Service, Colorado State University Extension, and the Yuma County Conservation District. Photo: Don Schoderbek, Colorado State University.





Mount Sherman, Colorado. Photo: Jeff Lukas.

APPENDIX A

2017-2018 WWA PUBLICATIONS

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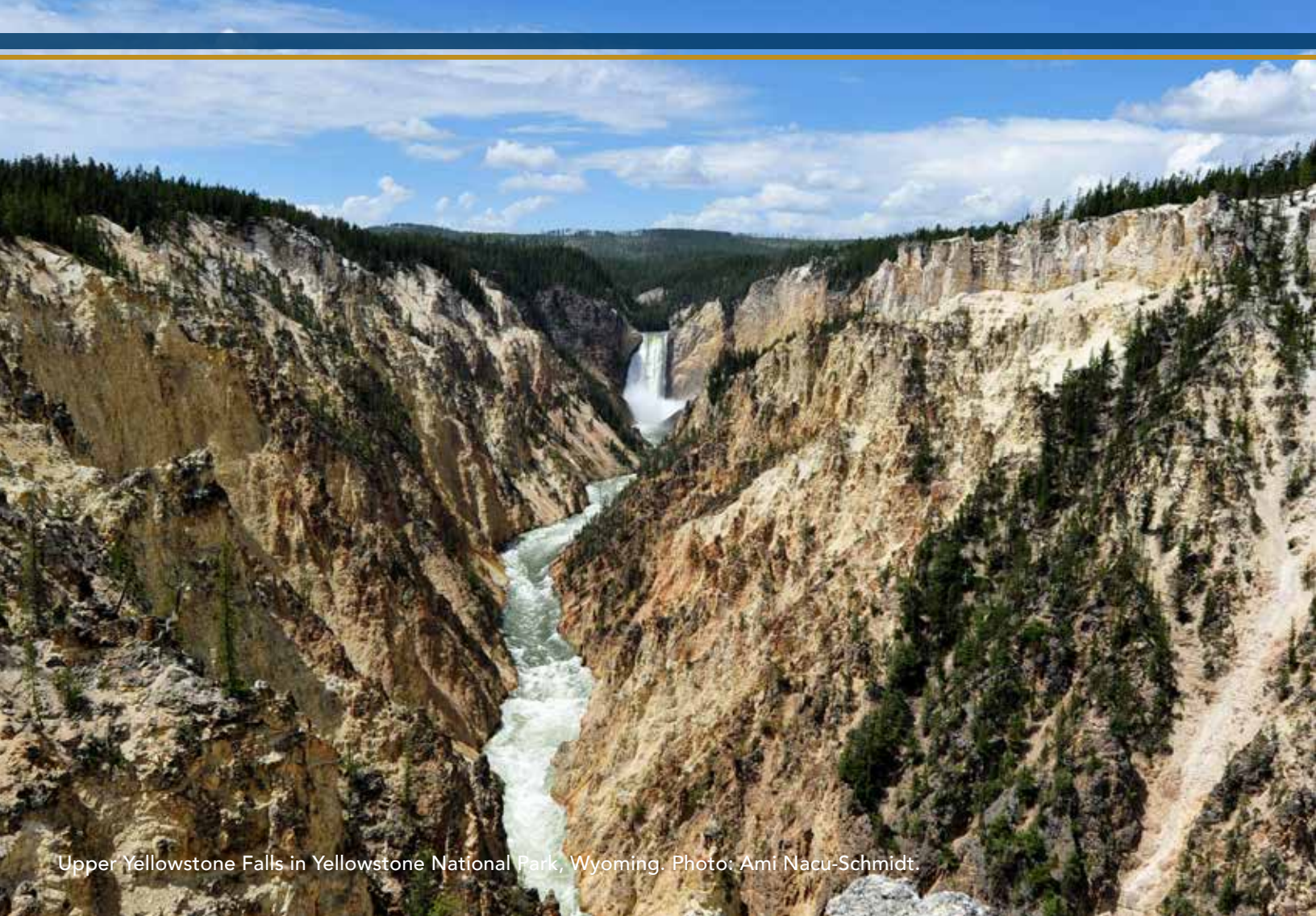
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Upper Yellowstone Falls in Yellowstone National Park, Wyoming. Photo: Ami Nacu-Schmidt.

APPENDIX B

WWA APPEARANCES IN MEDIA

2018

May 15, 2018

"Making your research relevant for decision-makers"
CU Boulder Today
<https://cires.colorado.edu/news/making-research-relevant-decision-makers>

April 17, 2018

Jeff Lukas was interviewed by journalists Aina Isakova and Salabat Erkitai with ELTR TV from Bishkek, Kyrgyzstan. The Kyrgyz team was in the US for two weeks to interview local experts on waste management and other resource issues, with the support of The

US Department of State. Lukas talked to Isakova and Erkitai about water resource management in Colorado, including impacts of climate change. Kyrgyzstan has topography and climate not unlike Colorado, with similar snowmelt-driven hydrology, but very little water storage.
ELTR TV from Bishkek, Kyrgyzstan

April 3, 2018

"Geoengineering the Climate"
KGNU How on Earth
<http://howonearthradio.org/archives/6504>

March 8, 2018

"Three American Cities That Could Be The Next Cape Town"
EcoWatch
<https://www.ecowatch.com/three-american-cities-cape-town-2544493744.html>

February 2, 2018

“Colorado snowpack is historically low, but Summit County is faring better than most”

The Aspen Times

<https://www.aspentimes.com/news/regional/colorado-snowpack-is-historically-low-but-summit-county-is-faring-better-than-most>

January 29, 2018

“Why Low Snowfall In The Rockies Is Concerning For Western Water Managers”

National Public Radio

<http://aspennpublicradio.org/post/low-snowfall-rockies-could-concerning-water-managers-out-west>

January 26, 2018

“Sun Valley’s snow guns boost base in lean winter”

Idaho Mountain Express

https://www.mtexpress.com/news/recreation/sun-valley-s-snow-guns-boost-base-in-lean-winter/article_624592d4-022d-11e8-8743-a7d710337dcb.html

January 19, 2018

“Colorado’s Wimpy Winter Has Skiers, Water Managers Grumbling”

Colorado Public Radio

<https://www.cpr.org/news/story/colorados-wimpy-winter-has-skiers-water-managers-grumbling>

January 18, 2018

“Western Snowpack Is Low. How Worried Should We Be?”

KUNC News

<http://www.kunc.org/post/western-snowpack-low-how-worried-should-we-be>

2017

November 6, 2017

“UNL shares the consequences of climate change in Nebraska”

The Daily Nebraskan

http://www.dailynebraskan.com/news/unl-shares-the-consequences-of-climate-change-in-nebraska/article_1d7dc04e-c2a5-11e7-86b5-17e34615c6e6.html

September 21, 2017

“Small Pests, Big Problems: The Global Spread of Bark Beetles”

Yale Environment 360

<https://e360.yale.edu/features/small-pests-big-problems-the-global-spread-of-bark-beetles>

August 25, 2017

“Storm Chaser: Firsthand Account”

Inside Science

<https://www.insidescience.org/video/storm-chaser-firsthand-account>

June 15, 2017

“Aspen leafing out early? Don’t trust your memory, but yes, this year is a peek into the future”

The Colorado Independent

<http://www.coloradoindependent.com/165894/aspen-leafing-out-early-dont-trust-your-memory-but-yes-this-year-is-a-peek-into-the-future>



WESTERN WATER ASSESSMENT

A NOAA RISA TEAM

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