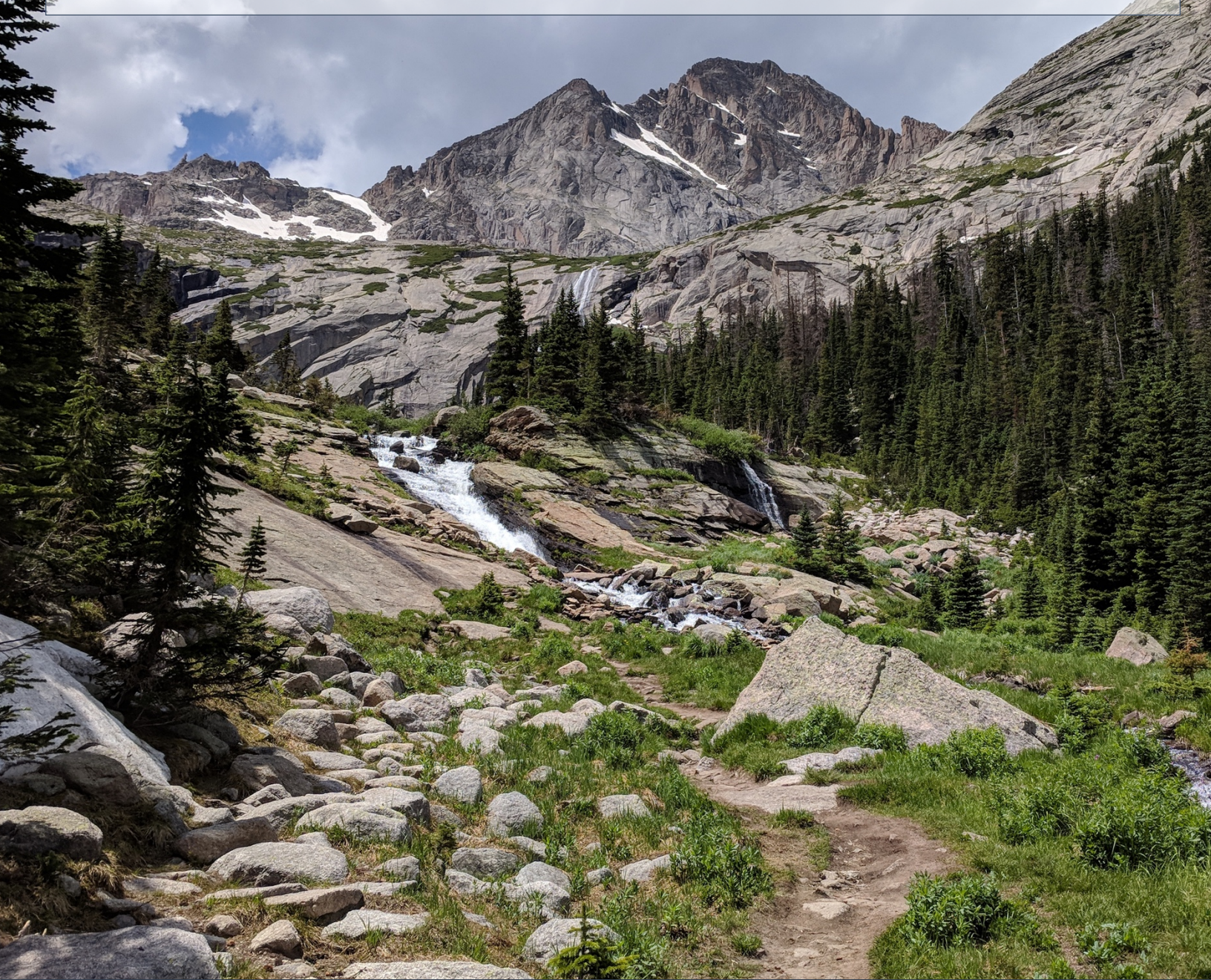


Western Water Assessment

Building Climate Resilience by Design



ANNUAL REPORT

JUNE 1, 2018 – MAY 31, 2019



**WESTERN WATER
ASSESSMENT**
A NOAA RISA TEAM



University of Colorado **Boulder**



WESTERN WATER ASSESSMENT

A NOAA RISA TEAM

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Cover photo: Rocky Mountain National Park. Photo: Brent Smith.



University of Colorado **Boulder**

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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 Rocky Mountain West, helping them make the best use of science to manage for climate impacts. Using multidisciplinary teams of experts in climate, hydrology, social sciences, 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 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.

Our Team

WWA is comprised of a core staff of five who focus on program management, research development and synthesis, and coordination of stakeholder interactions. During the past year, WWA's Managing Director left for a new position and Benét Duncan was hired to fill the role. Dr. Duncan previously served as the team's Climate Assessment Specialist, and she continues to work on climate assessment in her new role. WWA also hired Liz Payton as its Colorado River Basin Assessment Specialist, a new position that focuses on the State of the Colorado River Basin Report project. WWA also was fortunate to have a visiting intern, Samuel Ehret, who supported the WWA staff from summer 2018 through winter 2019.

WWA's 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 enable WWA to meet stakeholder needs and advance scientific understanding.

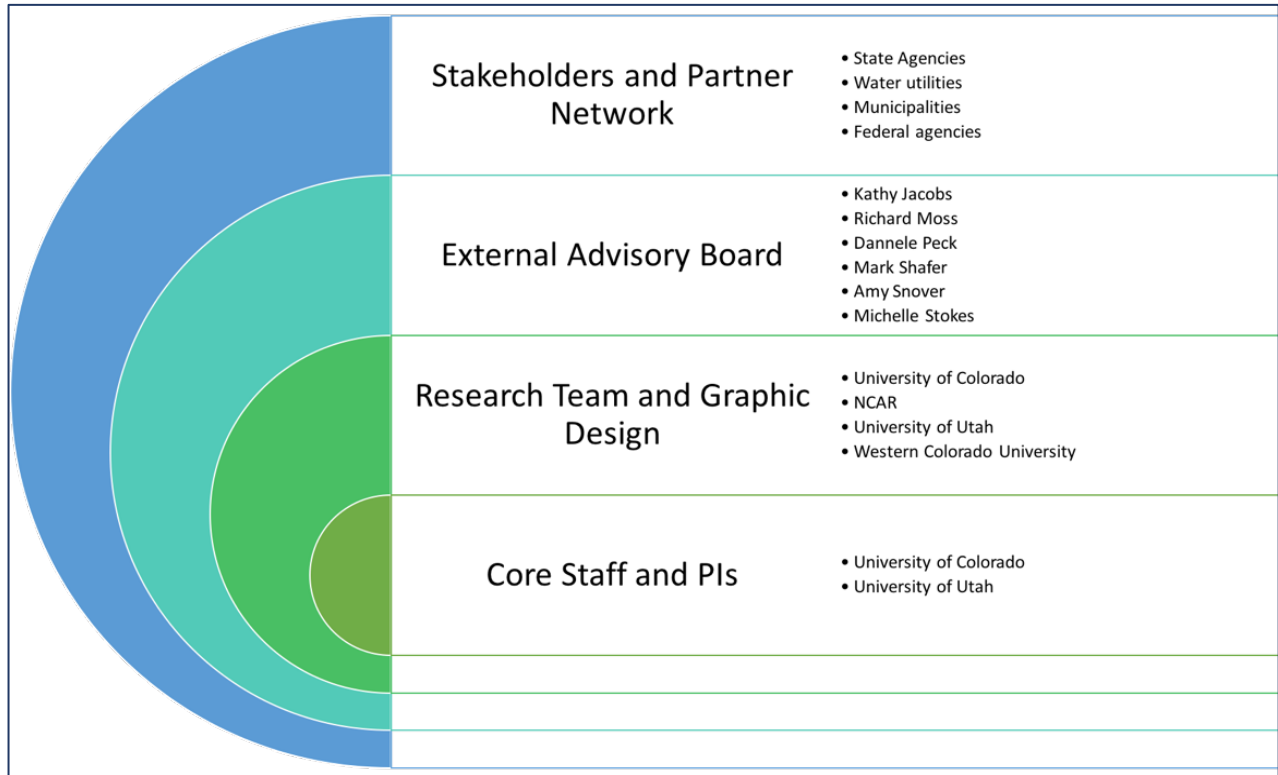


Figure 1: The Western Water Assessment Team and Network

WWA Core Staff

Name	Position	Expertise
Lisa Dilling	Director	Climate information; Decision-making
Benét Duncan	Managing Director	Assessments; Climate indicators; Science policy
Seth Arens	Research Integration Specialist, Utah	Eco-hydrology; Air quality
Jeff Lukas	Research Integration Specialist, Colorado	Climate variability and climate change; Paleoclimatology
Liz Payton	Colorado River Basin Assessment Specialist	Hydrology; Water system modeling

WWA PIs

Name	Title	Expertise
Lisa Dilling	Lead PI and Director, WWA Associate Professor, Environmental Studies, Univ. of Colorado Fellow, CIRES	Climate information; Decision-making
Joseph Barsugli	Research Scientist, CIRES, Univ. of Colorado	Climate dynamics
Ben Livneh	Assistant Professor, Civil Engineering, Univ. of Colorado Fellow, CIRES	Eco-hydrology; Air quality
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 Fellow, Policy Program, American Meteorological Society 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

Name	Affiliation	Expertise
John Berggren	Western Resource Advocates (Formerly Univ. of Colorado graduate student)	Colorado River water policy
Paul Brooks	University of Utah	
Katie Clifford	Univ. of Colorado (graduate student)	Conservation decision-making
Jeff Deems	Univ. of Colorado	Climate and snow modeling
Samuel Ehret	Western Water Assessment intern University of Bern	Climatology; Decision-making
Jen Henderson	Univ. of Colorado (Formerly CIRES/WWA postdoctoral fellow)	Weather and society
Joe Kasprzyk	Univ. of Colorado	Multi-objective analysis for water management
Corrie Knapp	Western Colorado University	Climate change adaptation
Leanne Lestak	Univ. of Colorado	GIS; Remote sensing
Kelly Mahoney	NOAA ESRL Physical Sciences Division	Hydrometeorology; Extreme precipitation
Toby Minear	Univ. of Colorado	Hydrology
Rebecca Morss	National Center for Atmospheric Research	Socioeconomic and policy impacts of weather
Ami Nacu-Schmidt	Univ. of Colorado	Social media; Design
Rebecca Page	Formerly Univ. of Colorado graduate student	Decisions in natural resources
Mark Raleigh	Univ. of Colorado	Snow and mountain hydrology
Imtiaz Rangwala	North Central Climate Adaptation Science Center, Univ. 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
Trisha Shrum	Formerly Postdoctoral Fellow, Univ. of Colorado	Natural resource economics
Court Strong	University of Utah	Climatology
Olga Wilhelmi	National Center for Atmospheric Research	Vulnerability and adaptation to weather and climate
Travis Williams	Univ. of Colorado (Formerly graduate student at Univ. of Colorado)	Climate risk management; Agriculture
Klaus Wolter	Univ. 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

Proudest Accomplishment

During the reporting period, WWA kicked off an effort to reach smaller municipalities in the mountain west through the VCAPS Pilot Project. VCAPS (Vulnerability, Consequences, and Adaptation Planning Scenarios) was developed by the Carolina Integrated Sciences and Assessments (CISA) RISA and has been used in several communities across the East Coast to analyze climate vulnerability and actions to adapt. WWA brought this process to our region, where climate impacts are often different from those in coastal towns.



WWA's Benét Duncan, Ursula Rick, and Rebecca Page lead diagramming exercises at a VCAPS workshop. Photo: Lisa Dilling.

In the summer and fall of 2018, the entire WWA team helped to plan and facilitate VCAPS workshops in five smaller communities in Colorado and Utah that have limited resources and capacity to incorporate weather and climate information into their decision-making processes. The communities had a strong interest in increasing their resilience to extreme weather and climate change, and were all strongly motivated to engage by the severe drought in our region last year. The workshops each occurred over two half-days to allow ample time for discussion and synthesis by the WWA team overnight.

Each community-driven VCAPS workshop focused on key hazards that WWA staff identified in interviews with workshop participants. Due to the ongoing historic drought during 2018, all of the communities chose to focus on drought, and two communities also focused on extreme precipitation. WWA staff presented locally-relevant science talks about the impacts of climate change on drought and extreme precipitation at the workshops. The majority of the time at each workshop was spent exploring the impacts of a key hazard on the community and actions that they could take or were already taking to increase resilience and mitigate impacts, drawing on the local expertise of each participant. These impacts and actions were mapped onto a diagram for the community to use. Following each workshop, the WWA team developed a report summarizing the discussions and outcomes, including the detailed diagrams.

The VCAPS Pilot Project was exciting for the WWA team for a number of reasons. From a scientific perspective, it provided the opportunity to develop locally-relevant, hazard-specific resources for smaller municipalities in the region, and expanded our knowledge and understanding of a newer co-production methodology while testing its efficacy in a different context and location. Our relationships with each of the five communities that participated in the pilot project have continued to grow. Some of the communities have agriculturally-driven economies, while others rely more on recreation and tourism. The workshops helped us to gain a deeper understanding of the priorities and concerns each community faces, and this will help us to better reach more communities in the future.

Since the workshops, we have heard from many of the communities that participated in the VCAPS Pilot project about the value of these workshops and the impacts they had on municipal planning processes and decisions. We will be conducting a more formal evaluation of the impacts of the pilot project during the summer and fall of 2019, including interviews and an online survey of workshop participants.

New Areas of Focus or Partnership

Colorado River Basin State of the Science Report

The Colorado River Basin is a critical source of water for seven western US states (Colorado, Wyoming, Utah, New Mexico, Arizona, Nevada, and California), at least 22 federally recognized tribes, and the Republic of Mexico. Since 2000, the basin has experienced an extended dry period in which the average annual streamflow has been 18% lower than the historical average. This recent trend, as well as future projections, has led to concerns about the long-term reliability of basin water supplies.

Water resources practitioners in the Colorado River Basin rely on scientific information to support operational and planning activities. Recently, they have sought to strategically integrate into practice the large volume of research relating to the climate and hydrology of the basin. To support that goal, WWA's **Jeff Lukas** and **Liz Payton** are leading an effort to synthesize progress in climate and hydrology research in the basin in partnership with Climate Assessment for the Southwest (CLIMAS), another NOAA RISA program. This work is supported by the Bureau of Reclamation and a work group of state and local water management agencies including the Southern Nevada Water Authority, Arizona Department of Water Resources, Colorado Water Conservation Board, Colorado River District, Central Arizona Project, Colorado River Board of California, California Department of Water Resources, Metropolitan Water District, Utah Department of Water Resources, Wyoming State Engineer, Denver Water, and the New Mexico Office of the State Engineer. Several of these entities are new partners for WWA. The NOAA Colorado River Basin Forecast Center (CBRFC) is providing technical assistance to the effort.

Because so much of the Colorado River flow and allocation is managed by the Bureau of Reclamation, the report primarily focuses on the hydroclimatic inputs to that agency's short-, mid-, and long-term operations and planning tools. It describes research on the methods, models, concepts, and datasets that currently or may in the future contribute to the Bureau of Reclamation's and other stakeholders' activities. It also identifies remaining knowledge gaps, uncertainties, and opportunities. The report is expected to be available in fall 2019, in time to

support the start of renegotiation of the 2007 Interim Guidelines that currently govern the operations of the two largest reservoirs in the system and the sharing of water shortages among the basin states.

Cross-RISA Sustained Assessment Case Studies Project

WWA's **Benét Duncan** began a collaborative project with Sustained Assessment Specialists at the Pacific RISA and the Southern Climate Impacts Planning Program (SCIPP) RISA to build case studies that highlight practitioners that are producing and applying climate information across a range of geographic scales and sectors in each of the three RISA regions. Practitioners shared their experiences in interviews that guided the development of each case study. Further analysis of the case studies identified five themes that emerged, providing guidance and supporting learning in the climate planning and adaptation space. A report is currently in progress, expected to be available in early Fall 2019.

Expanding Relationships with Small-to-Midsize Communities

During the reporting period, WWA has expanded our work with smaller municipalities in our region that have less capacity and fewer resources to obtain and incorporate weather and climate information into their decision-making processes. This deliberate focus moves our impact beyond Colorado's Front Range and Utah's Wasatch Front, where stakeholders tend to have higher capacity to partner with us and take up scientific information. During the reporting period, the **VCAPS Pilot Project** (described above) provided the opportunity to build new relationships with smaller municipalities in the mountain west. In addition, WWA's **Benét Duncan** is collaborating with partners at Aspen Global Change Institute and the National Center for Atmospheric Research (NCAR) on a project to expand water sector climate preparedness in small-to-midsize communities in the Intermountain West region through network-based learning. The **Water Sector Preparedness Project**, which is funded through a NOAA SARP grant, seeks to leverage partnerships and strengthen networks to expand access to and reduce the cost of co-produce climate services for the water sector in this region. This project stems from the **Mountain West Climate Service Providers Partnership**, a network of researchers and local champions working to increase access to information, tools, and other resources to help small and medium-sized communities throughout the Mountain West region prepare for climate change. WWA's Benét Duncan and **Seth Arens** are members of the Partnership. Finally, PIs **Lisa Dilling** and **Ben Livneh** completed work with **Jeff Lukas** and graduate student **Rebecca Page** on the use of drought and climate information by small water system providers on the western slope of Colorado, funded by a NOAA SARP grant during this reporting period.

Training Video for Enterprise Risk Management for Water Utilities

During the summer of 2018, WWA's **Jeff Lukas** was asked by the American Association of Water Distribution and Management (AAWD&M) and Southern Nevada Water Authority (SNWA) to participate in a training video providing a scientific overview of climate change. The video is part of a series of three training modules about climate change, its impacts on public water systems, and how it impacts professionals in risk management, emergency management, and insurance/reinsurance. Working with AAWD&M, a nonprofit that provides educational support on risk-management issues for public water systems throughout the United States, represented a new partnership for WWA.

Significant Outputs

During the reporting period, WWA produced a wide range of outputs, including products, communications, tools, and other technical assistance. Our most significant outputs are listed below:

State:

- *Considering Climate Change in the Estimation of Extreme Precipitation for Dam Safety. Volume VI of the Colorado – New Mexico Regional Extreme Precipitation Study* is being used by the Colorado Dam Safety Office to guide planning efforts, including proposal of a new rule (Rule 7.2.4) that would create an atmospheric moisture factor to account for expected increases in temperature and atmospheric moisture availability from 2020 to 2070 (page 16).

Region & National:

- *Intermountain West Spatial Snow-Water Equivalent (SWE) Reports*, released on March 22, April 1, April 19, and May 3, were used by water managers, snow scientists, streamflow forecasters, and climate service providers as supplemental information to guide water resources planning (page 18).
- *Spring 2018 MODIS-Based Spatial SWE Product for the Intermountain West Region: Feedback from Beta Testers Report* was used by researchers to improve a MODIS-based spatial SWE product, and by managers to better understand how SWE data is used (page 19).
- *WWA Intermountain West Climate Dashboard* is used by WWA stakeholders to better understand climate conditions in the Intermountain West region. The dashboard has the highest traffic on the WWA website, with over 26,000 pageviews from 2015-2018.

Local:

- *Reports from Vulnerability, Consequences, and Adaptation Planning Scenarios (VCAPS) Community Workshops* were used by each of five municipalities in Colorado and Utah to document results of workshop discussions and diagrams; kickstart engagement with municipal leadership and citizens; inform budget discussions; and support municipal planning to increase resilience to drought and extreme precipitation (page 5).

Most Significant Publications

WWA researchers published a number of publications, which range from peer-reviewed research articles to grey literature and general reports. For a full list of publications from the reporting period, see Appendix A. Three significant publications are:

1. Mahoney, J., J. Lukas, and M. Mueller (2018). *Considering Climate Change in the Estimation of Extreme Precipitation for Dam Safety. Volume VI of the Colorado – New Mexico Regional Extreme Precipitation Study*, November, 57 pp.

This synthesis report reviewed the evidence for changes in extreme precipitation in Colorado and New Mexico due to climate change and approaches for incorporating that information in planning. The report recommended that implementation of probable maximum precipitation (PMP) in dam-safety rules by Colorado and New Mexico account for the climate change risk in which there is the most confidence: the increase in

precipitable water with warming temperatures, which would make more moisture available to storm systems.

2. Dilling, L., M.E. Daly, D.A. Kenney, R. Klein, K. Miller, A.J. Ray, W.R. Travis, and O. Wilhelmi (2018). Drought in urban water systems: Learning lessons for climate adaptive capacity. *Climate Risk Management*, doi: 10.1016/j.crm.2018.11.001.

In this paper, the authors conducted interviews with drought managers at urban water utilities across the U.S. to understand current drought policies and manager perceptions of drought responses. Better understanding of the experienced by these utilities can support innovations towards more sustainable water systems. Results show that managers perceive drought responses to be generally successful in reducing water demand and maintaining system reliability, but they can reduce flexibility in the system and cause other limitations. Other factors that play a dominant role in drought response include public perception, revenue structure, and expectations.

3. Smith, R., J. Kasprzyk, and L. Dilling (2019). Testing the potential of Multiobjective Evolutionary Algorithms (MOEAs) with Colorado water managers. *Environmental Modelling & Software*, Vol. 117, 149-163, doi: 10.1016/j.envsoft.2019.03.011.

Authors engaged with a group of Colorado water managers at a structured investigatory workshop to assess their perceptions of their system's potentially conflicting objectives (or tradeoffs) generated through Multiobjective Evolutionary Algorithms (MOEAs). Results show that managers' preferences diverged with increasing information about tradeoffs. Structured information about relationships between decision levers and performance would help managers interpret tradeoffs. This was the first study to formally engage with practitioners to investigate their perceptions of tradeoffs generated by MOEAs. The Bureau of Reclamation is now investigating the use of MOEAs.

Outreach: Engagement with Communities and Resource Managers

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:

Use of Snowpack Monitoring Data by Water Managers

On August 1, 2018, WWA convened a workshop with smaller system water managers in western Colorado, to share findings and continue a discussion about how water managers decide to incorporate new information in their decision-making processes, and the value of snowpack monitoring data in a changing climate. This workshop leveraged work on from an ongoing NOAA SARP project led by a team including WWA's **Ben Livneh**, **Lisa Dilling**, and **Jeff Lukas**, and including graduate student **Rebecca Page**, that focused on four key scientific questions:

1. How vulnerable are snowmelt dominated systems to warming and associated changes in snowpack/streamflow predictability?
2. Are higher elevation snow measurements more resilient to warming?
3. How do water managers currently use information?

4. Why do managers use and trust new information?

At the workshop, Page led a discussion about results from interviews she had conducted with Western Slope water managers regarding their use of information; Livneh shared modeling results about the use of snow as an indicator of water supply in a changing climate; and Lukas provided a short presentation about new perspectives in snowpack monitoring. The workshop was successful in sharing the latest scientific advances with water managers, encouraging peer learning among the managers in attendance and helped WWA learn about future useful projects.

Restarting Drought Planning in Utah

WWA's **Seth Arens** continued to work with the NIDIS regional coordinator to improve awareness of NIDIS and other drought information for Utah. In July 2018, they convened a drought stakeholder meeting in collaboration with the Utah Division of Water Resources (UDWR). At the meeting, drought coordinators from Colorado, Arizona, and New Mexico shared their experiences with stakeholders in Utah. This meeting built on a workshop they planned and facilitated in November 2017 to introduce the IMW DEWS and to begin a conversation about drought planning in Utah. Following the July 2018 workshop, the state of Utah activated its Drought Response Plan and formally began drought planning efforts.

Connecting Communities with Climate Information

During the summer and fall of 2018, WWA led a pilot project of five participatory adaptation planning workshops in small- and medium-sized communities in Colorado and Utah (see page 5 for a detailed description). Building on those workshops, the WWA team has continued to engage with Colorado and Utah communities, with a focus on considering climate change in municipal decision-making. WWA's **Seth Arens** presented public science talks about locally-relevant impacts of climate change organized by the City of Cortez, CO and the Town of Carbondale, CO. WWA's **Lisa Dilling** participated as an invited panelist in the Yampa Basin Roundtable, sharing more about the VCAPS process and climate considerations with residents of the Yampa Basin region of Colorado. WWA's **Benét Duncan** will convene and lead a session at the Colorado Municipal League's Annual Conference in June 2019 focused on connecting Colorado's communities with weather and climate information.

Research Integration Specialist Ongoing Outreach

As Research Integration Specialists, WWA's **Seth Arens** and **Jeff Lukas** have cultivated strong relationships with resource managers at federal, state, and regional agencies, utilities, municipalities, and other entities. They delivered over 15 presentations during the reporting period, including at the Colorado Water Congress Climate Workshop (Lukas), the Colorado Environmental Health Association Annual Education Conference (Lukas), the Council of State Governments Annual Meeting (Arens), and the American Water Resources Association Conference (Arens).

Engaging with the Academic Community

WWA continued its commitment to share with and learn from the broader academic community, with a particular focus on hydrology, snowpack monitoring, agricultural applications, weather and climate science, and social science. To that end, we presented research at a number of academic conferences: WWA's **Ursula Rick**, **Seth Arens**, **Lisa Dilling**, and **Benét Duncan**

presented research at the American Geophysical Union (AGU) Fall Meeting in December 2018. Duncan and Rick also helped to convene a session focused on sharing research around building and leveraging networks to better meet stakeholder information needs. Duncan also participated as a panelist and organized a session at the National Adaptation Forum in April 2019 about improving climate resilience through research and practitioner networks. Duncan was a member of the planning committee and also participated as an invited panelist speaking about sustained climate assessment at the Southwest Adaptation Forum in October 2018.

The WWA team also planned and led the Usable Science Lecture and Workshop in March 2019 at the request of CIRES at CU Boulder, as part of the CIRES Engaged Scientist Series. The lecture and workshop were grounded in the Usable Science Guide, which WWA published in March 2018. At the lecture, WWA's **Lisa Dilling** shared the principles of co-production to better help campus research scientists, postdocs, and graduate students understand how to create usable science. Dilling then participated in a panel with three CU Boulder researchers who are conducting usable science in their own work: Lise St. Denis, Jeff



Early career scientists participate in the Usable Science Workshop in March 2019. Photo: Benét Duncan.

Deems, and Arnaud Chulliat. Following the panel discussion, WWA's **Ursula Rick** and **Benét Duncan** led a workshop with graduate students to practice applying the principles of co-production to help their own work to be more usable.

WWA's **Lisa Dilling** is collaborating with **Corrie Knapp** (Western Colorado University) to develop a database of regional vulnerability, adaptation, and resilience (VAR) researchers in the mountain west. They built a survey for researchers to share their current work, research interests, and interest in forming an online network. The survey was distributed to 874 people in Spring 2019, and it is currently open for responses. Knapp presented initial results at the National Adaptation Forum in April 2019, which indicate strong interest in creating a network to support increased collaboration and knowledge of research. Initial survey results also show that many VAR researchers identify a need for more knowledge on how to adapt to climate change, and the need to better identify those who are likely to be resilient to the impacts of climate change. The hope is that this network will be a catalyst to identify and connect regional researchers beyond WWA's immediate collaborative connections to the needs of users in our region.

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:

Engaging with Small- and Medium-Size Communities and Utilities

WWA will advance its efforts to build and strengthen relationships with small- and medium-sized communities and water utilities, which we initiated during this reporting period through the VCAPS pilot project (page 5) and Snowpack Monitoring Project (page 9). We will continue this engagement work through an additional VCAPS workshop in Moab, UT, planned for July 2019; a planned session at the Colorado Municipal League Annual Conference in June 2019; and continued participation in the Mountain West Climate Service Providers Partnership (page 7). WWA will also grow the body of scientific knowledge about the impacts of collaborative climate planning processes through analysis of the VCAPS process, experience, and outcomes during summer and fall 2019. This analysis will include a written evaluation survey and in-depth interviews with participants from the five pilot VCAPS workshops.

Colorado River Basin State of the Science Report

WWA will continue its leadership in developing the Colorado River Basin State of the Science Report, which will be finalized in fall 2019. Development of this report has both drawn from and helped to strengthen a collaborative network of researchers and managers that represents a deep resource of scientific knowledge and management experience for the Colorado River Basin. The report will be an important reference supporting operating guideline renegotiations among the basin states that is due to begin in 2020. Beyond this, the report will provide a benchmark of understanding the current state of knowledge in the Basin.

Weber Basin Climate Vulnerability Assessment

WWA's **Seth Arens** is engaging in a collaborative project to support the Weber Basin Water Conservancy District (WCD) in developing a climate vulnerability assessment for the Weber Basin. Weber Basin WCD is a wholesale water provider in northern Utah with over 600,000 customers, and it is the first water provider in Utah to address climate change in this manner. Arens has built a collaborative team with researchers from the University of Utah, Utah State University, and Utah Division of Water Resources to conduct the climate vulnerability assessment, which is expected to be complete in late 2019.

Making an Impact

WWA Evaluation and Metrics

In Spring 2019, WWA kicked off a formal program evaluation process with Susan Lynds, a Senior Program Evaluator and Associate Scientist at the University of Colorado Boulder. Lynds has over 15 years of experience in qualitative and quantitative methods of program evaluation. This summative evaluation will incorporate 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. The evaluation is scheduled to be complete in Fall 2019. It will include an online survey and interviews with stakeholders and RISA network members, and an in-depth analysis of WWA's progress towards our goals and metrics (detailed below). 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.

In addition to the formal evaluation currently underway, in November 2018, WWA held its bi-annual stakeholder workshop with stakeholders from across the region. The stakeholder workshop provided an important mechanism for sharing our recent research findings, understanding the impact that our work has on stakeholders, and updating our understanding of stakeholder priorities in ways that can shape future research projects.

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 are 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.

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 and the RISA Network report

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

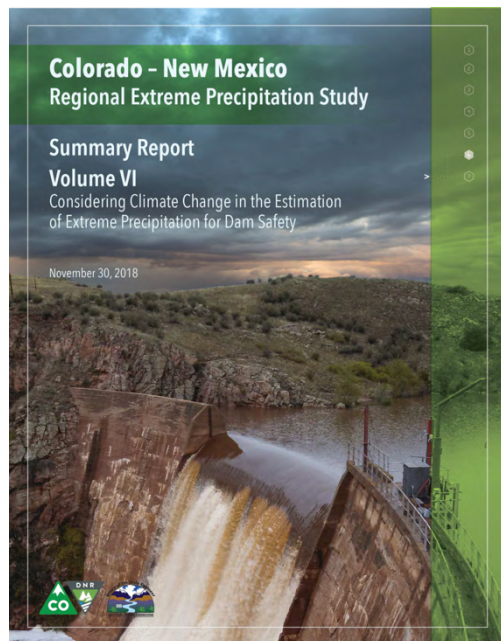
Impacting Stakeholders

Through our wide range of stakeholder-driven projects, WWA has made a positive impact on decision makers in the region. In addition to the case studies detailed below, we have become a go-to entity for climate, drought, and resilience information in our region. At the request of the State of Colorado, WWA's **Jen Henderson** conducted a survey of ranchers and farmers on how they have been impacted by drought. In September 2018, WWA's **Lisa Dilling** and **Ursula Rick** convened a workshop with six experts in modeling, economics, attribution, and scenarios to help Colorado identify methods for estimating the value of adaptation across the state. The workshop informed the state's research planning and conversations with FEMA. In Utah, WWA's **Seth Arens** co-convened a drought stakeholder workshop that informed the State of Utah's decision to formally begin its drought planning process (see page 10). Arens also provided content and input for Utah's Hazard Mitigation Climate Plan.

Beyond state agencies, WWA's work has impacted business communities in our region. WWA's **William Travis**, **Trisha Shrum**, and **Travis Williams** are conducting research about the complex decision-making and risk management that ranchers must conduct in the face of uncertainty about drought and climate change. As part of this work, Williams and Travis developed web-based drought index and drought insurance analysis tools that attracted interest of the USDA Risk Management Agency, which offers a popular rainfall index insurance to ranchers, and commercial firms that provide agricultural insurance and advice. For example, one tool compares rainfall insurance triggers to drought as depicted by the U.S. Drought Monitor to help ranchers and insurance providers better interpret what the USDM indicates for insurance payments (see: <https://www.earthlab-riskappone.org/>). Path to Positive Utah, a group of business

and community leaders in Utah focused on climate resilience, interviewed WWA's Seth Arens about climate change for an article to be released in late June 2019. WWA's **Jeff Lukas** and **Ursula Rick** also delivered a presentation about climate change at the invitation of an oil and gas company in Denver, CO during early 2019.

Case Study: Considering Climate Change in Dam Safety Planning



During the previous reporting period, WWA initiated an effort to provide a roadmap for incorporating climate change influences into Probable Maximum Precipitation (PMP) estimates used in the evaluation of spillway adequacy for dams in Colorado and New Mexico. Nearly all state dam safety offices use PMP estimates in regulating dams, and many other state and federal agencies use PMP estimates in building and regulating other high-hazard infrastructure.

This effort was part of a larger project sponsored by the Colorado Division of Water Resources and the New Mexico Office of the State Engineer to update decades-old PMP estimates used in these states using modern technical methods and current scientific understanding. But those methods did not explicitly address the additional risk from climate change. WWA's **Jeff Lukas** collaborated with NOAA ESRL physical

scientist **Kelly Mahoney** and CIRES Research Scientist **Michael Mueller**, to take stock of the state of the science and practice in PMP estimation with respect to climate change. The resulting synthesis report, *Considering Climate Change in the Estimation of Extreme Precipitation for Dam Safety*, was released in December 2018 and is included as Volume VI of the final *Colorado-New Mexico Regional Extreme Precipitation Study* report. The report recommended that the states' implementation of the updated PMP values in dam-safety rules account for the increase in precipitable water with warming temperatures, which is the climate-change risk for which there is the most confidence.

In January 2019, the Colorado Dam Safety Office proposed Rule 7.2.4, which would apply an atmospheric moisture factor (multiplier) of 1.07 to PMP values to account for the expected future warming and associated increases in atmospheric moisture availability from 2020 to 2070. The proposed rule will be open for public comment until June 1, 2019.

Case Study: Incorporating Climate Information into Municipal Planning

As part of the VCAPS Pilot Project (page 5), the entire WWA team planned and led a series of five community-driven climate scenario planning workshops in smaller municipalities in Colorado and Utah during the summer and fall of 2018. At the workshops, participants explored the impacts of severe drought and extreme precipitation on their communities and identified actions that they could take or were already taking to increase their resilience either by preventing negative impacts from occurring or by reducing the effect of those impacts. These impacts and actions were captured in real-time through diagrams. WWA provided a full report to

each of the five communities, summarizing workshop discussions and sharing the diagrams that were produced.

In the months after the workshops, WWA staff was invited to return to some of the communities to share more about the workshops and deliver technical science talks about climate change to a broad public audience. WWA's **Seth Arens** provided public talks about the local impacts of climate change on drought and extreme precipitation in Cortez and Carbondale, CO in April 2019. WWA's **Lisa Dilling** was invited to participate as a panelist to share more about the VCAPS process at the Yampa Basin Rendezvous in Routt County, CO in June 2019.

One elected official reported that the VCAPS workshop was “life-changing” for her community in Carbondale, CO. Since the workshop, Carbondale has developed an action plan and spreadsheet to identify key areas where severe drought may impact their community and action items to reduce those risks. The community has already undertaken some action items, including incorporating key drought issue areas into their budgeting process, upgrading the technology for their wastewater treatment facility, and increasing the resilience of their public landscaping to drought. The same elected official emphasized that municipalities cannot conduct resilience planning and adaptation activities alone – partners are key to success.

The Director of Public Works in Cortez, CO shared that the VCAPS workshop was “a game-changer” for the city, because the city staff and leadership are now collectively working to increase the community’s resilience to drought. The workshop participants have been meeting twice monthly, and they have worked closely with the city’s marketing department to create public-facing resources using the report that WWA produced as a springboard. Water use in Cortez is primarily devoted to outdoor watering in the summer, and the community is now engaged in an effort to reduce this water use. The city has increased their budget for marketing to reduce water use, and they have partnered with local businesses to reduce water use at restaurants and in hotels. In addition to holding five public workshops to introduce concepts like water-wise landscaping, the city is developing a smart phone app that will allow customers to identify water leaks; contracting with experts to expand the city’s xeric landscaping; and installing a demonstration garden to remove grass at the local police department.

A leader in Routt County expressed that one of the values of the VCAPS workshop for them was bringing many of the actors together in one space, sharing what was already happening and connecting people with valuable opportunities underway to respond to extreme events. He realized from the VCAPS workshop that the missing link for his organization and beyond was communication, and the table of actions created from the workshop has now formed the basis of a more extensive “living” document online with information and contacts that can be updated and shared.

Taken together, the VCAPS workshops have given these smaller municipalities the information needed and convened conversations that have helped them to advance their own efforts to increase resilience to severe drought. While the economic benefits have not yet been quantified, the VCAPS workshop discussions, reports, and diagrams have informed budgeting conversations within these communities, and could help to reduce municipal costs and decrease spending by community members and businesses.

Coping with Drought in Colorado and Utah

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 **Seth Arens** continued to work with the National Integrated Drought Information System (NIDIS) regional coordinator to improve understanding of drought and available planning tools and increase preparedness in Utah. Building on a November 2017 meeting they held to introduce the IMW DEWS and engage with important drought stakeholders in Utah, Arens planned a July 2018 drought stakeholder meeting with Utah Division of Water Resources. Following this meeting, the state of Utah re-started their drought planning process. In September 2018, Arens gave a joint presentation, together with NIDIS and the Utah state government, at the Council of State Governments West Annual Meeting in Utah. Arens was also invited to present at a USDA Southwest Climate Hub-sponsored meeting in Ogden, UT about drought. At this meeting, he presented information about WWA's drought-related research and outreach activities in Utah. Meeting participants included the Utah Farm Service Agency, Utah Department of Agriculture, Utah Division of Water Resources, and other USDA staff. After the meeting, Arens was approached by a participant that was interested in WWA's help in drought and climate change planning in Moab, UT. As a result of this interaction, Arens will be leading a VCAPS drought and climate workshop in Moab, Utah in late July 2019.

Over the past three years, WWA has worked to promote the usability and effective application of snowpack monitoring information, including development of spatial snow data products that add appreciable value at low cost to users. In the spring of 2018, WWA pilot-tested a MODIS-based spatial SWE product developed by WWA's **Noah Molotch** and his group for the WWA Intermountain West region (Utah, Colorado, and Wyoming). The product and an accompanying report were released a total of five times from late March to late May 2018 to a small group of approximately 15 water managers, snow scientists, streamflow forecasters, and climate service providers. WWA's **Heather Yocum** then conducted phone interviews to collect feedback on the pilot project. During the reporting period, Yocum transcribed and analyzed the interviews to inform an evaluation of the MODIS-based spatial SWE product and general lessons learned about spatial snow products and their potential added value. This report was finalized and released in August 2018. It included identification of the most useful and/or compelling information in the product (particularly maps, the product report summary, and tabular information) and suggested improvements (particularly updates to presentation of data, frequency of the report, creation of an online archive and interactive website, and inclusion of more analysis of lower elevation snowpack). WWA produced the MODIS-based SWE product for the spring 2019 season as well (Molotch et al., 2019a,b,c,d), with enhancements as indicated by the pilot-test feedback. incorporated many of these user suggestions into the product.

WWA also advanced understanding of drought decision analyses for adaptation in the agricultural sector. This work by WWA's **William Travis**, **Trisha Shrum**, **Travis Williams**, and several undergraduate interns began by combining a drought decision model for ranching with drought impact calculators developed by the USDA Agricultural Research Service (ARS) and an insurance model simulating USDA's Pasture, Rangeland, and Forage (PRF) drought insurance based on a NOAA gridded precipitation product. Given concerns by ranchers about which climate indicators provided the best trigger for payment by the PRF insurance program,

Williams and Travis analyzed a wide range of drought indices and deployed a webtool for users to evaluate the application of such drought indicators to insurance. The webtool is now available online at <https://www.earthlab-riskapptwo.org/>. A peer-reviewed article comparing drought indices as insurance triggers has been accepted by the journal *Weather, Climate and Society*, and is in early online release at: <https://journals.ametsoc.org/doi/abs/10.1175/WCAS-D-18-0107.1>.

Williams and Travis expanded on this work to provide a new tool for evaluating drought using multiple drought measures for the contiguous US for both research and applications, and the “Drought Index Comparison Portal” is now online at: <https://climate-scatterplot.space/>.

Appendix A: WWA Publications

- Arens, S., K. Clifford and D. Rumore. 2018. *Final Workshop Report for Vulnerability Consequences and Adaptation Planning Scenarios (VCAPS) for the Cities of Springdale, Rockville and Hurricane*. Western Water Assessment: Salt Lake City, UT.
- Clifford, K., J. Henderson, S. Arens, S. Ehret, L. Dilling, B. Duncan. 2018. *Final Workshop Report for Vulnerability Consequences and Adaptation Planning Scenarios (VCAPS) for the City of Cortez*. Western Water Assessment: Boulder CO.
<https://www.cityofcortez.com/DocumentCenter/View/1418/VCAPS-FINAL-REPORT-MARCH-2019>
- Dilling, L., Berggren, J., Henderson, J. and Kenney, D. 2019. Savior of rural landscapes or Solomon's Choice? Colorado's experiment with Alternative Transfer Methods for water (ATMs). *Water Security* 6. <https://doi.10.1016/j.wasec.2019.100027>
- Dilling, L., M.E. Daly, D.A. Kenney, R. Klein, K. Miller, A.J. Ray, W.R. Travis, and O. Wilhelmi. 2018. Drought in urban water systems: Learning lessons for climate adaptive capacity. *Climate Risk Management*, doi: 10.1016/j.crm.2018.11.001.
- Ehret, S., J. Lukas, S. Arens, K. Clifford, L. Dilling, 2018. *Final Workshop Report for Vulnerability Consequences and Adaptation Planning Scenarios (VCAPS) for the Town of Carbondale*. Western Water Assessment: Boulder CO.
https://www.carbondalegov.org/Carbondale_VCAPS_Final_Draft_2019_21_01.pdf
- Jennings, K.S., T.G.F. Kittel, N.P. Molotch. 2018. Observations and simulations of the seasonal evolution of snowpack cold content and its relation to snowmelt and the snowpack energy budget. *The Cryosphere*, 12, 1595-1614, doi:10.5194/tc-12-1595-2018.
- Jennings K.S., T.S. Winchell, B. Livneh, N.P. Molotch. 2018. Spatial variation of the rain-snow temperature threshold across the Northern Hemisphere, *Nature Communications*, 9, Article number: 1148, doi:10.1038/s41467-018-03629-7.
- Jepsen, S.A., T.C Harmon; D.L Ficklin, N.P. Molotch, B. Guan. 2018. Evapotranspiration sensitivity to air temperature across a snow-influenced watershed: space-for-time substitution versus integrated watershed modeling, *Journal of Hydrology*, 556, Pgs 645-659, <https://doi.org/10.1016/j.jhydrol.2017.11.042>.
- Kirchhoff, C. J., J. J. Barsugli, G. L. Galford, A. V. Karmalkar, K. Lombardo, S. Stephenson, M. Barlow, A. Seth, G. Wang, A. Frank. 2019. Climate assessments for local action. *Bull. Amer. Meteorol. Soc.* (accepted)
- Knowles, J.K., N.P. Molotch, E. Trujillo, M. Litvak. 2018. Snowmelt-driven trade-offs between early and late season productivity negatively impact forest carbon uptake during drought, *Geophysical Research Letters*, 45(7), Pgs 3087-3096, doi/10.1002/2017GL076504.

Lemos, M.C., H. Eakin, L. Dilling, J. and Worl. 2019. Ch. 26. Social Sciences, Weather, and Climatic Change. Invited contribution to American Meteorological Society 100-year Anniversary Monograph. <https://doi.10.1175/amsmonographs-d-18-0011.1>

Mahoney, J., J. Lukas, and M. Mueller. 2018. Considering Climate Change in the Estimation of Extreme Precipitation for Dam Safety. *VI of the Colorado – New Mexico Regional Extreme Precipitation Study*, November, 57 pp. https://wwa.colorado.edu/publications/reports/co-nm-reps_summary.pdf

Molotch, N., D. Schneider, L. Lestak, U. Rick, J. Lukas. 2019a. *Spatial Estimates of Snow-Water Equivalent (SWE), Intermountain West Region, March 16, 2019*. Western Water Assessment Intermountain West SWE Series. 24 pp. https://wwa.colorado.edu/publications/reports/0RockyMtn_SWE_Report_20190316.pdf

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Molotch, N., D. Schneider, L. Lestak, U. Rick, J. Lukas. 2019c. *Spatial Estimates of Snow-Water Equivalent (SWE), Intermountain West Region, April 19, 2019*. Western Water Assessment Intermountain West SWE Series. 24 pp. https://wwa.colorado.edu/publications/swe_reports/20190419_RockyMtn_SWE_Report.pdf

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Page, R., L. Dilling, U. Rick, B. Duncan, I. Rangwala, J. Lukas. 2018. *Final Workshop Report for Vulnerability Consequences and Adaptation Planning Scenarios (VCAPS) for the City of Durango*. Western Water Assessment: Boulder CO.

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Rick, U., B. Duncan, K. Clifford, L. Dilling. 2018. *Final Workshop Report for Vulnerability Consequences and Adaptation Planning Scenarios (VCAPS) for Routt County*. Western Water Assessment: Boulder CO.

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Williams, T.M. and W.R. Travis. 2019. Evaluating alternative drought indicators in a weather index insurance instrument. *Wea. Climate Soc.*, 0, <https://doi.org/10.1175/WCAS-D-18-0107.1>.

Yocum, H., J. Lukas, and U. Rick. 2018. Spring 2018 MODIS-Based Spatial SWE Product for the Intermountain West Region: Feedback from Beta Testers. Western Water Assessment Report, August, 53 pp.
https://wwa.colorado.edu/publications/reports/MODIS_based_SWE_product.pdf.

Zheng, Z., N.P. Molotch, C.A. Oroza, M. Conklin, R.C. Bales. 2018. Spatial snow estimation for mountainous areas using wireless-sensor networks and remote-sensing products, *Remote Sensing of Environment*, 215, Pgs 44–56, doi: 10.1016/j.rse.2018.05.029.