

# Western Water Assessment



2014 - 2015 ANNUAL REPORT



Western Water Assessment



University of Colorado **Boulder**





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<p><b>Principal Investigator</b>          Lisa Dilling, University of Colorado-Boulder</p>	<p><b>Co-Investigators</b>          Kristen Averyt, University of Colorado-Boulder          Nolan Doesken, Colorado State University          Robert Gillies, Utah State University          Douglas Kenney, University of Colorado-Boulder          Jeffrey Lukas, University of Colorado-Boulder          Jason Neff, University of Colorado-Boulder          Thomas Painter, California Institute of Technology          Balaji Rajagopalan, University of Colorado-Boulder          William Travis, University of Colorado-Boulder          Klaus Wolter, University of Colorado-Boulder</p>
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*Performance period covered in this report: June 1, 2014–May 30, 2015.*

Cover photograph: Barker Reservoir near Nederland, CO. Photo by Jeff Lukas, Western Water Assessment.



## Introduction

**The mission of the Western Water Assessment (WWA) is to identify and characterize regional vulnerabilities to and impacts of climate variability and change, and to develop information, products and processes to assist decision makers throughout the Intermountain West.** Using multidisciplinary teams of experts in climate, hydrology, ecology, law, and policy, WWA works with decision makers across the Intermountain West to produce policy-relevant information about climate variability and change. By building relationships and networks of decision makers, our team is able to develop practical research programs and useful information products. WWA is formally part of the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado in Boulder, and our researchers and partners come from universities and federal institutions in Colorado, Wyoming, and Utah.

### New Areas of Focus

Within the existing mission described above, WWA shifts its specific research foci from year to year to stay current with stakeholder needs and emerging research frontiers. New areas of focus and new partnerships developed in 2014-2015 are described in Table 1.

**Table 1. New partnerships and areas of focus developed in 2014-2015.**

New Area of Focus	Relevant Projects (see pp. 11-17)
Extreme events and collaboration with the emergency preparedness community	<ul style="list-style-type: none"> <li>Regional Extremes Database</li> </ul>
Climate and water literacy for the general public	<ul style="list-style-type: none"> <li>Water in the Western US Massive Open Online Course</li> </ul>
New Partnership	Relevant Projects (see pp. 11-17)
Utah Division of Water Resources Uinta-Wasatch-Cache and Ashley National Forests	<ul style="list-style-type: none"> <li>Informing the Integration of Climate Information into Water Supply Planning in Various Contexts in Utah</li> <li>Climate Change Vulnerability Assessment for the Uintah-Wasatch-Cache and Ashley National Forests</li> </ul>

### WWA Staff and Research Team

WWA is comprised of a core staff of four (Table 2) who focus on program management, research development and synthesis, and coordination of stakeholder interactions. In addition to the core staff shown below, WWA's graphic design/outreach specialist (Ami Nacu-Schmidt) is shared with the Center for Science and Technology Policy Research (CSTPR) at CU-Boulder in order to increase efficiency and leverage resources.

**Table 2. WWA Core Office Staff**

Lisa Dilling	Director	<a href="mailto:ldilling@colorado.edu">ldilling@colorado.edu</a>
Jeff Lukas	Senior Research Associate	<a href="mailto:lukas@colorado.edu">lukas@colorado.edu</a>
Eric Gordon	Managing Director	<a href="mailto:esgordon@colorado.edu">esgordon@colorado.edu</a>
Tim Bardsley	Utah Liaison	<a href="http://www.bardsley@gmail.com">www.bardsley@gmail.com</a>



WWA also works with a team of individual researchers at the University of Colorado and other institutions throughout the region. A full list of team members is provided in Table 3.

**Table 3. Western Water Assessment Research Team**

Team Member	Title	Expertise
Averyt, Kristen	Associate Director for Science, CIRES	Climatology, energy-water, assessment processes
Bardsley, Tim	Utah Liaison, Western Water Assessment	Snow hydrology, climate vulnerability in water utilities
Barsugli, Joseph	Research Scientist, CIRES, Univ. of Colorado	Climate dynamics
Berggren, John	Graduate Research Assistant, Univ. of Colorado	Climate adaptation, water policy
Clifford, Kate	Graduate Research Assistant, Univ. of Colorado	Conservation decision making
Deems, Jeff	Research Scientist, CIRES, Univ. of Colorado	Climate and snow modeling
Dilling, Lisa	Director, Western Water Assessment Assistant Professor, Environmental Studies, Univ. of Colorado	Climate information and decision making
Gordon, Eric	Managing Director, Western Water Assessment	Climate adaptation
Kasprzyk, Joseph	Assistant Professor, Civil Engineering, Univ. of Colorado	Multi-objective analysis for water management
Kenney, Douglas	Director, Western Water Policy Program, Getches-Wilkinson Center for Natural Resources, Energy, and the Environment, Univ. of Colorado School of Law	Western water policy and law
Klein, Roberta	Managing Director, Center for Science and Technology Policy Research, Univ. of Colorado	Environmental policy
Livneh, Ben	Research Scientist, CIRES, Univ. of Colorado	Hydrologic modeling
Lukas, Jeffrey	Senior Research Associate, Western Water Assessment	Paleohydrology, forest ecology
Mahoney, Kelly	Research Scientist, CIRES, Univ. of Colorado	Hydrometeorology, extreme precipitation
McCurdy, Adam	Graduate Research Assistant, Univ. of Colorado	Climate risk assessment
McNie, Elizabeth	Research Scientist, CIRES, Univ. of Colorado	Science policy, program evaluation
Molotch, Noah	Assistant Professor, Dept. of Geography, Univ. of Colorado	Snow hydrology
Rangwala, Imtiaz	Research Scientist, CIRES, Univ. of Colorado	Regional climate change, high elevation climate
Rajagopalan, Balaji	Professor, Civil Engineering, Univ. of Colorado	Water resources engineering
Ray, Andrea	Scientist, Climate Analysis Branch, NOAA ESRL Physical Sciences Division	Climate-society interactions, water management
Schneider, Dominik	Graduate Research Assistant, Univ. of Colorado	Snow hydrology
Smith, Rebecca	Graduate Research Assistant, Univ. of Colorado	Multi-objective analysis for water management
Travis, William	Associate Professor, Geography, Univ. of Colorado	Natural hazards, climate impacts and adaptation
Wessman, Carol	Professor, Ecology and Evolutionary Biology, Univ. of Colorado	Landscape ecology, remote sensing
Wolter, Klaus	Research Scientist, CIRES, Univ. of Colorado	Climatology and meteorology



## WWA 2014-2015 Program Highlights

### Major Research Findings

- Water resources decision makers seeking to respond to climate variability and change need far more than additional information, according to a new paper authored by WWA's **Lisa Dilling** and **John Berggren** along with colleagues from the Carolinas Integrated Sciences and Assessments (CISA) and the Great Lakes Integrated Sciences and Assessments (GLISA). Governance arrangements and collaboration—so-called “enabling factors”—are often as important as the information itself, a finding with major implications for the provision of regional climate services.
- Under a high emissions scenario (RCP 8.5), Colorado is expected to warm 3.5-6.5°F by the middle of the 21<sup>st</sup> century, according to the updated *Climate Change in Colorado* report authored by WWA's **Jeff Lukas**, **Joe Barsugli**, **Imtiaz Rangwala**, and **Klaus Wolter**, along with affiliate Nolan Doesken from the Colorado Climate Center. Among the expected impacts of this warming are hotter summers and wetter winters.
- Colorado faces a number of key vulnerabilities in a warmer future, according to the *Colorado Climate Change Vulnerability Study* co-edited by WWA's **Eric Gordon**. Particularly vulnerable entities include water supply entities with junior water rights and little storage, residences and other buildings in floodplains, the wildland-urban interface, and those exposed to high daytime temperatures and West Nile Virus.
- WWA's **Lisa Dilling**, **Bill Travis**, and **Roberta Klein**, along with other colleagues, contend that addressing so-called “adaptation deficits” and focusing on the implementation of no-regrets strategies may be insufficient for climate change adaptation. Their review and synthesis of research from the climate adaptation and natural hazards fields indicates that the dynamics of vulnerability dictate that decision makers need to consider how choices in one part of a system can affect outcomes in another.
- A comprehensive high-resolution simulation of catchment-scale water yield changes from land cover disturbances indicates that annual water yield can increase between 8 and 13 percent from bark beetle infestations, according to results in a recently published paper by an interdisciplinary team of WWA researchers including **Ben Livneh**, **Jeff Deems**, **Brian Buma**, **Joe Barsugli**, **Dominik Schneider**, **Noah Molotch**, **Klaus Wolter**, and **Carol Wessman**. Desert dust deposition in the same catchments causes snowmelt to occur earlier, but the two disturbances appear to have little interactive effects. These findings that are being used in experimental adjustments to Colorado Basin River Forecast Center streamflow forecasts.



## Select Outreach Activities

### Outreach for *Climate Change in Colorado*



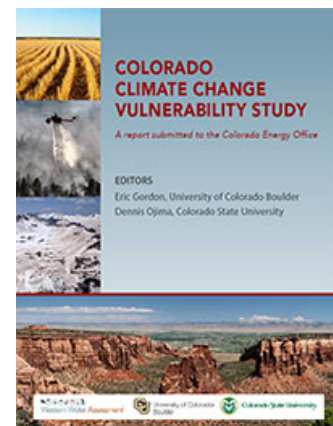
Figure 1. WWA's Jeff Lukas at the Colorado Water Congress Annual Meeting in Centennial, CO, January 2015.

Working directly with the Colorado Water Conservation Board, WWA comprehensively updated its 2008 [Climate Change in Colorado](#) report. This report is an authoritative assessment of the physical science regarding observed and projected changes in the state's climate and is being used to inform water supply planning. Since its publication in August 2014, WWA's **Jeff Lukas** has given over a dozen presentations on the report to stakeholder audiences, including the American Water Resources Association Colorado Section, the Colorado Water Congress, the Colorado Groundwater Conference, the Colorado Foundation for Water Education's Climate and Water Workshop, the Front Range Climate Change Group, and the Federal

Emergency Management Agency's Colorado Climate Change Preparedness and Resilience Workshop. In addition, Jeff was invited to speak at "NCAR Ignite" at the National Center for Atmospheric Research, and gave a 5-minute presentation on Colorado's water and climate in [Dr. Seuss-style rhyme](#).

### Media Response to the *Colorado Climate Change Vulnerability Study*

In early 2015, WWA, along with colleagues at Colorado State University, released the [Colorado Climate Change Vulnerability Study](#), an overview of key climate change vulnerabilities across the state. Drawing from existing data and peer-reviewed research, the study summarizes the key challenges facing seven sectors: ecosystems, water, agriculture, energy, transportation, outdoor recreation and tourism, and public health. Upon release of the report, WWA's **Eric Gordon** was featured on a variety of media outlets, including ClimateWire, Colorado Public Radio, the Denver Post, KOA Radio 850AM, and KGNU radio. In addition, Gordon presented findings from the study at venues including the American Water Resources Association Colorado Section meeting, the Colorado Homeland Security Advisory Committee, and the Denver Foundation's Environmental Affinity Group.



### Water in the Western US Massive Open Online Course



In April 2015, WWA's **Eric Gordon** and Anne Gold from CIRES Education and Outreach co-taught a Massive Open Online Course (MOOC) entitled "[Water in the Western United States](#)." Available on the Coursera platform and free to anyone with an Internet connection, the course was designed as an undergraduate-level survey and featured 17 expert guest lecturers, including WWA's **Jeff Lukas**, **Ben Livneh**, and **Kristen Averyt**. More than 6,000 students registered for the course, including a number of existing WWA stakeholders. The course was a novel opportunity for WWA and a foray into new education venues. The professionally edited video lectures on water and climate will also be useful in future WWA outreach activities.

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#### **Preparation for White House-FEMA Colorado Climate Preparedness and Resilience Workshop**

As part of a major climate-resilience initiative, the White House (CEQ, OSTP, and National Security Staff) and FEMA conducted three pilot workshops nationwide in fall 2014. One took place in Fort Collins, Colorado, gathering 80 local, state, and federal officials, resource and hazard managers, and content experts. WWA's **Jeff Lukas** assisted in the workshop preparation and execution by drafting text for the workshop brochure, reviewing the premises of the drought scenario for the 'tabletop exercise'; and presenting on projected climate impacts in Colorado at the workshop.

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#### **Business for Social Responsibility (BSR) Climate Science Initiative Webinar**

WWA's **Kristen Averyt** and **Eric Gordon** provided a webinar briefing in April 2014 to the BSR Climate Initiative. BSR is a nonprofit focused on promoting sustainability among some of the world's largest companies, and their Climate Science Initiative includes representatives from BNP Paribas S.A., The Gap Inc., Lockheed Martin Corporation, Standard Chartered PLC, and Unilever PLC. Kristen spoke about the effects of climate change on water resources globally and nationally, while Eric provided perspective on Colorado's efforts to prepare for climate impacts to water supplies based on the [Colorado Climate Change Vulnerability Study](#).

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### **Narrative Examples of Decision Contexts Informed by WWA Work**

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#### **State of Colorado: Informing Development of the Colorado State Climate Plan**

In early 2015, the State of Colorado began the process of developing a climate plan for state government. This process was intentionally timed to begin upon completion of two WWA reports developed with state support—[Climate Change in Colorado](#) (2014), which provided the physical science background of observed and projected climate in the state, and the [Colorado Climate Change Vulnerability Study](#) (2015), which incorporated literature and expert knowledge in seven sectors to





identify key vulnerabilities connected to future climate warming. WWA's **Jeff Lukas** and **Eric Gordon** were also asked to review an initial draft of the plan, which is still under development.

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### **Colorado Water Conservation Board: Technical Input into the State Water Plan**

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Colorado's Water Plan, which is expected to be released in final form in September 2015, was drafted by the Colorado Water Conservation Board (CWCB) with the intention of finding ways to meet the state's likely future supply-demand imbalances. Water supply analyses in the Plan relied heavily on a series of WWA engagements with CWCB, including the involvement since 2009 of multiple WWA team members in CWCB's Climate Change Technical Advisory Group (CCTAG), WWA's technical input into the CWCB's 2012 Colorado River Water Availability Study, and most recently, the [Climate Change in Colorado](#) report authored by **Jeff Lukas** and other WWA team members and co-produced with CWCB.

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### **State of Utah: Inclusion of Climate Change into State Water Plan**

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Interest in climate change in Utah—especially the impacts of rising temperatures on water resources—has grown significantly in recent years. As this was occurring, WWA's Utah Liaison **Tim Bardsley** was building relationships and establishing WWA as a trusted source of information on climate variability and change in relation to water resources. Thus, when the Utah Division of Water Resources (UTDWR) decided to include climate change for the first time in their update to the Utah State Water Plan, they sought assistance from WWA in conducting analyses of climate change impacts to hydrology and for an expert review. Tim and his WWA colleagues worked with UTDWR to redraft the climate change section of the Plan. When published, the new Utah Water Plan will broaden the discussion and consideration of climate change in water resources planning in Utah.





## WWA 2014-2015 Publication Highlights

Dilling, L., M. E. Daly, W. R. Travis, O. V. Wilhelmi, and R. A. Klein (2015). [The dynamics of vulnerability: Why adapting to climate variability will not always prepare us for climate change](#). WIREs Climate Change, doi: 10.1002/wcc.341.

Dilling, L., K. Lackstrom, B. Haywood, K. Dow, M. C. Lemos, J. Berggren, and S. Kalafatis (2015). [What stakeholder needs tell us about enabling adaptive capacity: The intersection of context and information provision across regions in the United States](#). Weather, Climate, and Society 7:(1) 5-17.

Gordon, E., and D. Ojima, eds. (2015). [Colorado Climate Change Vulnerability Study](#). A report submitted to the Colorado Energy Office. Western Water Assessment and Colorado State University.

Lukas, J., Barsugli, J., Doesken, N., Rangwala, I., and K. Wolter (2014). [Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation](#). A Report for the Colorado Water Conservation Board, Western Water Assessment, 114 pp.

McNie, E., A. Parris, and D. Sarewitz (2015). [A Typology for Assessing the Role of Users in Scientific Research](#). User Engagement and Scientific Research, *Consortium for Science, Policy & Outcomes*.

## WWA Metrics of Success

As a RISA, WWA continually adjusts our research and outreach portfolio to the needs of regional stakeholders in order to remain innovative and relevant to both our stakeholders and the shifting landscape of decision support institutions and infrastructure. After significant discussion in preparing our recent renewal proposal, we have identified the following principles that will represent the foundation of all of our projects going forward:

- 1) Begin with the decision context;
- 2) Prioritize use-inspired science (i.e., science that is responsive to and inspired by user needs for decision making);
- 3) Follow the principles of co-production by directly interacting with stakeholders in the development and execution of projects whenever possible; and
- 4) Work in interdisciplinary teams.

Our next task is to develop metrics that align with these principles. A simple first pass, currently under implementation for projects that are concluding in 2015, is a binary self-evaluation by project leads—in other words, each project lead is being asked whether or not their project began with decision context, prioritized use-inspired science, was co-produced, and involved an interdisciplinary team. Following on this initial evaluation, we intend to next consider projects from the stakeholder point of view. Selected stakeholders identified by project leads (or reasonably considered to be involved in a project) will be contacted and asked for their input on the project process, whether they felt it was relevant to their decision context and was co-produced, and how results may inform decision contexts.



On a broader basis, however, WWA is concerned with its impact in the region. Over the course of the next several years, we will attempt to summarize our impact in terms of whether we have achieved the following:

- **Amplifying** the efficiency and effectiveness of climate engagement strategies regionally and nationally by applying a common framework to study co-production efforts across scales, sectors, capacity levels, and types of decision support needed
- **Catalyzing** regional resilience to weather and climate extremes by developing new place-based, multi-faceted datasets and syntheses informed by needs of local decision makers
- **Building** adaptive capacity for a changing climate through the incorporation of climate scenarios and 21<sup>st</sup>-century observational and modeling techniques into planning and operational decision making
- **Developing** an empirically-based, practical understanding of the limits and opportunities for implementing adaptive actions related to water and climate in the Intermountain West through a combination of participatory adaptation planning tools and targeted case studies

Work to develop tools for assessing that impact is ongoing.

## WWA Contributions to NIDIS Drought Early Warning Systems

During this reporting period, WWA's primary contribution to the National Integrated Drought Information System's (NIDIS) Drought Early Warning Systems was the preparation for a series of workshops intended to increase stakeholder awareness and knowledge of new approaches for snowpack monitoring, and the potential for integrating those approaches into streamflow forecasting.

In the Intermountain West, 60-80% of the region's surface water supply is derived from snowmelt. Thus real-time monitoring of the snowpack is essential to forecasting runoff amount and timing and preparing for both drought and flooding. The long-time backbone of the snowpack monitoring capability is the NRCS Snow Survey network of SNOTEL and snow course sites, which provides point-based estimates of snow-water equivalent available for runoff. New spatially-explicit snowpack monitoring data products are being developed by WWA researchers and others (e.g., LIDAR-based SWE estimates from the Airborne Snow Observatory and satellite-based SWE estimates incorporating real-time MODIS data, historic SWE patterns, and real-time in-situ SWE data). These products could usefully complement the NRCS network and existing NOAA spatially-explicit snow products, and facilitate new streamflow forecasting approaches. But it is not clear how best to deploy these products to enhance the overall utility of snowpack information, given funding constraints and differences in stakeholder capacity to ingest and use the information.

NIDIS considers snowpack monitoring to be a critical component of the integrated drought monitoring and forecasting system it is implementing through the regional Drought Early Warning Systems (DEWS). In June 2014, NOAA and the Western Governors Association (WGA) signed an MOU, in part to "ensure that collection and sharing of crucial drought, flooding, and extreme weather-related data...and information are improved and sustained," including "...snowpack monitoring...in the Mountain West."



In August and September 2015, WWA will be conducting three one-day user workshops, with one in each of the three WWA states (Colorado, Utah, and Wyoming; note that this spatial domain largely overlaps with the NIDIS Upper Colorado DEWS). The target participants are local, state, and federal water managers, major water users (agriculture, recreation), hydrologic forecasters, and others who directly or indirectly use real-time snowpack monitoring products to prepare for drought and other hydroclimatic variability.

In advance of the workshops, the investigators are developing a set of demonstration (retrospective, non-real-time) products relevant to the Rocky Mountain region to help workshop participants visualize the use, potential benefits, and limitations of the new spatially explicit snowpack datasets. These demonstration products will draw on ongoing efforts in California to develop applications for the new spatially-explicit snowpack products. Also, we will develop pre- and post-workshop survey instruments to assess participant use of existing products and unmet needs for snowpack monitoring data, and also participant responses to the information provided in the workshops.





## WWA 2014-2015 Project Reports

### Balancing Severe Decision Conflicts under Climate Extremes in Water Resource Management

*Primary Investigator(s):* L. Dilling, J. Kasprzyk, L. Kaatz (Denver Water)

*Other Investigator(s):* R. Smith, E. Gordon, K. Averyt, I. Rangwala, L. Basdekas (Colorado Springs Utilities)

*Stakeholders:* Denver Water, Colorado Springs Utilities, Northern Water Conservancy District, Aurora Water, City of Boulder Utilities, City of Fort Collins Utilities (collectively known as the Front Range Climate Change Group)

#### Exploring the utility of multi-objective evolutionary algorithms for improving the ability of water utilities to identify viable adaptation strategies under climate extremes.

Over the past several years there have been increasing calls for decision support tools in the area of climate (e.g. NRC 2009a, NRC 2009b) and acknowledgement that changing extremes add to an already challenging decision environment for water managers (e.g. IPCC 2012). Recurring droughts, flood events, and concerns over extreme events in the future have created a strong interest among water managers in the Front Range of Colorado about how to plan in the face of these extremes (Lowrey et al. 2009, Woodbury et al. 2012). Traditional methods of identifying alternatives for water supply management may not fully capture the range of existing preferred alternatives, meaning that utilities may miss some of the solutions that appropriately balance among tradeoffs. In this project we seek to co-produce and test a newly developed multi-objective decision tool as a Testbed to aid this process, balancing conflicting management objectives for water planning under climate extremes and determining how policy alternatives perform under severe climate uncertainty. By combining innovative search algorithms, simulation models, and interactive visualizations, the proposed decision tool helps generate and evaluate new alternatives, as well as promotes managers' learning about the tradeoffs and vulnerabilities of their systems. This Testbed approach will result in a visualization of the decision space that, we argue, may in fact expand the alternatives that still meet managers' decision criteria and allow managers to be able to visualize these more clearly than traditional tools. In our final step we will query managers about the tool, its results, and the process involved in incorporating such a tool into practice for helping to make decisions in anticipation of future extreme events. We will analyze these results and make some inferences about the viability of MOEAs and the larger issue of incorporating new tools into practice for urban water utilities.

*Deliverables:* Initial workshop completed February 2015 with workshop report provided to participants April 2015. Additional workshop anticipated Spring 2016, peer-reviewed publications and conference presentations to follow.

*Leveraged Funding:* \$261,000 from NOAA SARP competitive grant (L. Dilling, PI)

### Regional Extremes Database

*Primary Investigator(s):* W. Travis, J. Lukas

*Other Investigators(s):* A. McCurdy

*Stakeholders:* To be determined (from emergency preparedness community)

#### Developing a database of extreme events to assist hazard planners and emergency managers.

Extreme events cause the majority of societal costs related to weather and climate and can provoke adaptive responses. WWA is beginning a new focus on extremes that is designed to place extreme events in the context of historical climate variability and projected climate change, assess how risk varies over time and space, and examine how extreme conditions interact with place-based vulnerability. The first activity in this new research theme is to build a definitive database of extreme weather and climate events in the three-state region. This regional extremes database is intended to be useful to hazard planners and emergency managers trying to identify where and when the risk for different types of extreme events is greatest. It will also serve as a foundation for further research on what leads to the variation in risk over time and space. The first concrete WWA effort on extremes is the development of a comprehensive roster of the major weather and climate extremes in recent history, as defined by their effects on society. Two sub-databases have been compiled: a more comprehensive dataset from multiple sources (chiefly NOAA-NCDC, FEMA, and state agencies) focused on the post-1950 period that includes over 20,000 floods, windstorms, tornadoes, winter storms, and other extreme events, and a smaller, much more selective roster of some 200 of the highest-impact events in the three-state region back to the late 1800s. The two databases are in spreadsheet form, and the next step is to make them accessible to our stakeholder group to get feedback on the structure and usefulness of the roster, and to make the high-impact roster available on the WWA website. The immediate future goal of the extremes project is to have the High Impact Events roster reviewed by a small set of key stakeholders, and then to distribute a beta version for further review, and make it available on the WWA website. Next we will work on the more exhaustive "Big List," and create statistics and maps detailing the pattern of extremes in the three-state WWA region. This will require decisions on the structure and usability of the roster. As we develop the Extremes theme over the next five years we will identify additional dimensions (e.g., cascading and secondary extremes like landslides) and decision-making contexts (e.g., stormwater management) that can be evaluated in the framework of climate risk management, which analyzes the decision context, risks, choices, options and decision criteria, as part of the process of working with decision makers to build adaptive capacity to weather and climate extremes.

*Deliverables:* Preliminary extremes database in spreadsheet form (completed); beta-tested and web-ready database



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**Informing the Integration of Climate Information into Water Supply Planning in Various Contexts in Utah**

*Primary Investigator(s):* T. Bardsley

*Other Investigators:* J. Lukas

*Stakeholders:* Utah Division of Water Resources, Weber Basin Water Conservancy District, Jordan Valley Water Conservancy District

*Partners:* D. Rosenberg (Utah State University), S. McGettigan and D. Cole (Utah Division of Water Resources), A. Wood (National Center for Atmospheric Research)

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**Exploring climate change impacts and adaptation opportunities in various water management contexts in Utah.**

This project description encompasses a number of smaller efforts aimed at helping water managers in Utah understand the potential impacts of climate change to water resources and consider climate change impacts and adaptation when planning for the future. Building off of previous work with early adopters like Salt Lake City Public Utilities, WWA has developed or brought into a number of additional opportunities to interact other major water management groups in Utah. Notably, the Utah Division of Water Resources (UTDWR) requested that WWA (via T. Bardsley) serve as an expert reviewer for the forthcoming Utah Water Plan, in addition to generating text and graphics for the climate change section of the plan. WWA has also engaged with the Weber Basin Water Conservancy District (in partnership with UTDWR) on a project evaluating both climate change and paleohydrology scenarios for the reliability of water deliveries on the Weber Basin. Future work will include refining systems modeling analysis and scenarios for testing with the Weber Basin Water Conservancy District in addition to Exploring partnerships with the Jordan Valley Water Conservancy District to assist them in understanding and integrating climate change into their water resources planning.

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*Deliverables:* Presentation and panel discussion at Utah climate variability and health symposium June 2015; Presentation at University Council on Water Resources Conference June 2015; Educational presentations for Jordan Valley Water Conservancy District Board to be conducted July and August 2015; review of climate section of Utah Water Plan; others TBD.

*Leveraged Funding:* \$5,000 from UTDWR to A. Wood for modeling; in-kind analysis from UTDWR

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**Snowpack monitoring for streamflow forecasting and drought planning in the Rocky Mountain West**

*Primary Investigator(s):* J. Lukas, N. Molotch, J. Deems

*Other Investigator(s):* T. Bardsley, E. McNie, D. Schneider, L. Lestak

*Stakeholders:* National Integrated Drought Information System (NIDIS), Wyoming State Engineer's Office, Natural Resources Conservation Service (NRCS) Snow Survey, various water managers across WWA region

*Partners:* A. Marrs (NIDIS), M. Hoobler (Wyoming State Engineer's Office), M. Stokes (Colorado River Basin Forecast Center), B. Domonkos and R. Julander, NRCS Snow Survey

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**Workshops aimed at introducing stakeholders to newer techniques of snowpack monitoring.**

Real-time monitoring of the snowpack is essential to forecasting runoff amount and timing and preparing for both drought and flooding. New spatially-explicit snowpack monitoring data products based on remote sensing are being developed by WWA researchers and others. These products could usefully complement the backbone NRCS SNOTEL network and facilitate new streamflow forecasting approaches, but it is not currently clear how best to deploy these products to enhance the overall utility from snowpack information. Thus WWA investigators are developing and conducting three one-day user workshops, in late summer 2015, in Colorado, Utah, and Wyoming. We will provide participants with a brief overview of snow hydrology informed by the latest science on snowpack processes, describe the current status of snowpack monitoring capacity and products, and solicit feedback on how participants are using them. Finally, we will introduce the spatially-explicit snowpack monitoring products and solicit feedback on their present utility and potential future utility. We will summarize the findings from the workshop in a report to NIDIS and our other partners. The primary future task is to carry out the workshops in August and September 2015, and then write up the findings and recommendations in a workshop report. We anticipate that the workshops will serve to guide further work by PIs Molotch and Deems in refining and deploying their respective snowpack-monitoring products, by informing them about user needs and capacities to ingest new data, and by connecting them with users who may become partners in supporting that work.

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*Deliverables:* Three one-day workshops, one each in CO, UT, and WY

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**Drought Planning on the Wind River Reservation**

*Primary Investigator(s):* S. McNeeley (North Central Climate Science Center), C. Knutson (National Drought Mitigation Center), E. McNie

*Stakeholders:* Eastern Shoshone and Northern Arapahoe Tribes

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**Providing support for tribal drought planning efforts on the Wind River Reservation.**

In collaboration with the Eastern Shoshone and Northern Arapahoe tribes, this project encompasses the development a comprehensive drought plan for the Wind River Indian Reservation in Wyoming (which is jointly managed by the two tribes). The research team will develop analytical tools and provide analysis to inform the drought plan. WWA investigator McNie's involvement in the research project is to provide

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evaluation support and to help inform the research design. She will use a typology of research approaches to guide the design and analysis of research goals, objectives and processes in order to ensure that the project meets its goals of producing useful drought information to inform future policy decisions.

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*Deliverables:* Drought and climate technical assessment followed by Wind River Reservation Drought Plan.

#### **Climate Adaptation Support for the National Renewable Energy Laboratory (NREL)**

*Primary Investigator(s):* J. Vogel and M. O'Grady (Stratus Consulting); E. Gordon, I. Rangwala, J. Barsugli

*Stakeholders:* National Renewable Energy Laboratory in Golden, CO

*Partners:* L. Meyers, NREL

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#### **Developing location-specific climate analysis for a climate adaptation plan at a federal research facility.**

This project was motivated by a request from Stratus Consulting that WWA provide climate science expertise for a climate adaptation planning effort being undertaken for the National Renewable Energy Laboratory. The overall process attempted to ascertain from NREL what major climate-related areas of concern were at the facility and provide guidance on how to potentially meet those challenges. WWA's contribution was to provide, both in person and in writing, guidance on the general observed and projected climate of the area as well as specific potential impacts. The NREL project was intended to be a pilot effort informing other site-specific adaptation planning at DOE facilities across the country. The outcome here was climate adaptation planning by a single stakeholder. However, we also hope that we advanced the overall concept and practice of site-specific climate adaptation, which will likely become more common as federal requirements proceed.

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*Deliverables:* Climate analysis provided to report authors (October 2014); final report completed May 2015

*Leveraged Funding:* \$10,000 from National Renewable Energy Laboratory through Stratus Consulting

#### **Water in the Western United States Massive Open Online Course**

*Primary Investigator(s):* E. Gordon, A. Gold (CIRES Education and Outreach Group)

*Stakeholders:* General public

*Partners:* University of Colorado Office of Information Technology; various contributors to guest lectures

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#### **Developing and teaching a massive open online course about Water in the Western United States.**

In April 2015, WWA's **Eric Gordon** and Anne Gold from CIRES Education and Outreach co-taught a Massive Open Online Course (MOOC) entitled "[Water in the Western United States](#)." Available on the Coursera platform and free to anyone with an Internet connection, the course was designed as an undergraduate-level survey course and featured 17 expert guest lecturers, including WWA's **Jeff Lukas**, **Ben Livneh**, and **Kristen Averyt**. More than 6,000 students registered for the course, representing 175 countries. Informal conversations indicated that a number of existing WWA stakeholders and researchers either took the course directly or recommended it to others to expand general understanding of water issues in the region. The course was a novel opportunity for WWA and a foray into new education venues. In addition, the professionally edited video lectures on water and climate will also be useful in future WWA outreach activities.

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*Deliverables:* Completed online course (April 2015)

*Leveraged Funding:* \$10,000 in NASA grant funding from CIRES Education and Outreach; in-kind support from Univ. of Colorado Academic Technology Design Team

#### **Climate Change Vulnerability Assessment for the Uinta-Wasatch-Cache and Ashley National Forests**

*Primary Investigator(s):* J. Rice (Janine Rice Consulting, T. Bardsley, L. Joyce (USFS Rocky Mountain Research Station)

*Stakeholders:* Uintah-Wasatch-Cache National Forest, Ashley National Forest

*Partners:* P. Gomben (Uintah-Wasatch-Cache National Forest), D. Bambrough (Ashley National Forest)

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#### **Developing Vulnerability Assessments for National Forests in Utah.**

The Uinta-Wasatch-Cache and Ashley National Forests are faced with the challenge of incorporating climate change into their land management planning. To meet this challenge, the forests have begun to synthesize scientific information about how climate change may affect resources and conduct vulnerability assessments. These vulnerability assessments can provide information to help guide climate adaptation planning and are one element of the US Forest Service's Climate Change Scorecard. The assessments, developed by former WWA postdoctoral researcher J. Rice along with T. Bardsley and L. Joyce (USFS RMRS and USDA Northern Plains Climate Hub) will provide information to help land managers integrate climate change information into their planning, identify information gaps, and set a foundation for future assessments that may be conducted. Accomplishments to date include two introductory workshops to introduce basic climate change information while also seeking input from the forests to help address their information needs. A draft USFS General Technical Report

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on the Watershed Vulnerability Assessment has undergone Forest Service, and external expert review. Final publication of the Watershed Vulnerability Assessment for the Uinta-Wasatch-Cache and Ashley National Forest, Utah General Technical Report is expected in summer or fall of 2015. A separate USFS and outside expert review of the Assessment of Aspen Ecosystem Vulnerability to climate change for the Uinta-Wasatch-Cache and Ashley National Forests will also take place summer and fall of 2015, with final publication of GTR winter/spring of 2015/2016.

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*Deliverables:* Vulnerability workshops (completed) final USFS General Technical Reports on climate change vulnerability (2015/2016)

*Leveraged Funding:* \$6,500 from US Forest Service

### Update of Climate Change in Colorado

*Primary Investigator(s):* J. Lukas

*Other Investigator(s):* J. Barsugli, I. Rangwala, K. Wolter, N. Doesken (Colo. State Univ.)

*Stakeholders:* Colorado Water Conservation Board; water managers and planners across the state of Colorado

*Partners:* T. Finessey (Colorado Water Conservation Board), L. Kaatz (Denver Water)

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### Comprehensive synthesis of observed and projected climate co-produced directly with the Colorado Water Conservation Board.

WWA updated and expanded its 2008 *Climate Change in Colorado* report with a 2014 version that synthesizes the best available climate science relevant to the state's water resources. Like the original, the updated report covers the observed climate patterns and trends in Colorado, a primer on climate models, linking observed state trends with global changes, projections of future climate and hydrology, and guidance on using this information in planning and management. Several dozen stakeholders at the local, state, and federal levels reviewed or contributed to the updated report. One key area of updating was using the new CMIP5 global climate model output; for Colorado, CMIP5 shows a modest shift towards wetter projected precipitation outcomes compared to the previous CMIP3 models. Subsequent to the release of the report, lead author J. Lukas gave numerous media interviews and presentations on the findings of the report. In addition, this study has been used to inform the Colorado Climate Plan, which is currently under development by the state of Colorado.

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*Deliverables:* [Final report](#) released in summer 2014

*Leveraged Funding:* \$45,000 from Colorado Water Conservation Board

### Colorado Climate Change Vulnerability Study

*Primary Investigator(s):* E. Gordon, D. Ojima (Colorado State University)

*Other Investigator(s):* R. Klein, K. Averyt, J. Lukas

*Stakeholders:* Colorado Energy Office, Colorado Water Conservation Board, numerous other entities concerned with climate impacts in the state

*Partners:* Numerous from CU-Boulder, Colo. State Univ., National Center for Atmospheric Research

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### Overview of key climate-related vulnerabilities facing several sectors in the State of Colorado.

The goal of this project was to develop an overview of key climate-related vulnerabilities facing several sectors in the State of Colorado. During its 2013 session, the Colorado Legislature passed HB 13-1293, which declared that "climate change presents serious, diverse, and ongoing issues for the state's people, economy, and environment. Among other provisions, the bill required a person appointed by the Governor to submit an annual report to a number of committees within the legislature "on climate change issues generally, the current climate action plan...and the specific ways in which climate change affects the state." Multiple state agencies, including the Colorado Energy Office, the Colorado Department of Public Health and the Environment, and the Colorado Water Conservation Board are leading efforts to respond to this legislation and to meet the challenges of climate change in the state. To help meet this requirement, the Colorado Energy Office commissioned the University of Colorado Boulder (through the Western Water Assessment) and Colorado State University to complete a study providing an overview of the key vulnerabilities that climate change and climate vulnerability will pose for Colorado's economy and resources. The primary outcome of this project was to engage a number of state agencies and others in thinking about climate vulnerability, which will aid in future preparedness planning. The study also informed the ongoing development of the Colorado Climate Plan, showing a direct link to policy. Finally, it created a reference and a resource for groups making use of this type of information, such as The Nature Conservancy. To date, the main future direction is providing guidance to Taryn Finessey at CWCB in the development of the Colorado Climate Plan.

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*Deliverables:* [Final report](#) released February 2015

*Leveraged Funding:* \$73,500 from Colorado Energy Office



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**Evaporation, Drought, and the Water Cycle Across Timescales: Climate Foundational Sciences for the North Central Climate Science Center**

*Primary Investigator(s):* I. Rangwala, J. Barsugli, B. Livneh, M. Hobbins (NIDIS)

*Other Investigator(s):* J. Lukas, A. Ray

*Stakeholders:* The Nature Conservancy, US Forest Service, other conservation agencies

*Partners:* J. Morissette, D. Ojima, and S. McNeely (NCCSC); R. Rondeau, CO Natural Heritage Program; J. Rice (Southern Rockies LCC); L. Joyce (USFS Rocky Mountain Research Station); D. Llewellyn (Bureau of Reclamation); M. Friggens (US Forest Service)

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**Providing climate science support for the DOI North Central Climate Science Center, particularly for water cycle issues.**

The goals of this project are twofold: First, we aim to co-produce relevant climate information and integrate that into the socio-ecological decision making context—this includes helping with the development of future climate scenarios for specific projects; application of existing and emerging climate products and tools; interpretation of emerging and relevant physical science research; and continuous engagement with stakeholders and boundary organizations in exploring appropriate tools and datasets. Second, we are conducting primary research into drivers of hydro-climatic trends and extremes in the North Central Great Plains and Intermountain West Regions (Missouri River Basin and Upper Colorado River Basin) across multiple timescales. These include understanding drivers of droughts and developing better indicators for short and long-term trends. In meeting the project goals mentioned above, we expect to: (a) Help the NCCSC funded projects as well as any relevant NCCSC stakeholder (e.g., DOI Land Managers, LCCs) in navigating through the process of better incorporating our current climate understanding and use appropriate methodology (approach, datasets, and other tools) to represent the effect of climate change to their specific system. (b) Produce research output (papers and datasets) relevant to drivers and indicators of hydroclimatic trends and extremes in the region, in particular, focus on drought and evapotranspiration.

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*Deliverables:* Peer reviewed papers (TBD); stakeholder-oriented reports and materials (some already in circulation and some under development), databases (some already completed), workshops (One planned for Sep. 24-25, 2015), various presentations.

*Leveraged Funding:* \$450,777 from the NCCSC.

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**Climate Adaptation Guidance for Salt Lake City Public Utilities**

*Primary Investigator(s):* T. Bardsley, S. Burian (Univ. of Utah), C. Strong (Univ. of Utah)

*Stakeholder:* Salt Lake City Department of Public Utilities

*Partners:* A. Wood (NCAR); L. Briefer, J. Niermeyer, and T. Kirkham (SLCPUD); M. Hobbins (NOAA ESRL PSD); E. Goharian (University of Utah); J. Lhotak (NOAA CBRFC)

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**Continued work with the Salt Lake City Department of Public Utilities (SLCPUD) to help them assess and adapt to the challenges that climate change presents to their water supply system.**

This project was intended to be a co-production with SLCDPU senior staff aimed at understanding the potential impacts of climate change to their water supply system and to explore adaptation options to help the utility maintain a reliable system under a variety of potential future conditions. Since the inception of this effort, WWA has established a collaborative team including experts from the University of Utah, the Colorado Basin River Forecast Center, NOAA and the National Center for Atmospheric Research. Regular meetings with SLCDPU helped focus research efforts to best address their challenges and information needs. Since publication of an article in *Earth Interactions* in 2013, T. Bardsley has presented at several conferences as well as to boards of local water districts, and the project has raised awareness and interest in understanding the impacts of climate change to water resources and acted as a catalyst for discussions of adaptation planning among a variety of water managers in northern Utah (see "Informing the Integration of Climate Information into Water Supply Planning in Various Contexts in Utah" project description above.) Ongoing work will include testing the recently completed system-wide integrated water planning model under several climate change, water demand, and infrastructure scenarios. Additional work is required to better define future water demand scenarios. We plan to also incorporate recently completed 4km resolution dynamically downscaled climate projections for the Wasatch into hydrologic modeling and the integrated water resources model.

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*Deliverables:* Journal of Water Resources Planning and Management peer reviewed paper, in press; multiple stakeholder presentations; information directly transferred to SLCPUD

*Leveraged Funding:* In-kind staff efforts from NOAA Colorado Basin River Forecast Center, University of Utah, National Center for Atmospheric Research, and NOAA Earth Systems Research Laboratory Physical Sciences Division

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**Decision Analysis for Climate Adaptation**

*Primary Investigator(s):* W. Travis

*Other Investigator(s):* A. McCurdy

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**Development of models and other tools capable of understanding how decision makers deal with hydro-climatic uncertainty in climate adaptation, including response to droughts.**

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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. We are focusing on three sectors: dryland agriculture; water, flood and stormwater management; and ranching. The goal is to provide decision aids to those sectors while also conducting research to better understand the processes underlying people's adaptation decisions. Underlying this work is a basic question: When is it time to change strategies and practices in a changing climate? In this year we completed and made available the Wastewater Temperature Model, which simulates exceedance of stream temperature standards below wastewater treatment plants based on scenarios of up-stream temperature and flow. We also developed the prototypes of the next generation of farm adaptation models, a suite that simulates crop switching choices by farmers based on expected value, and the role of risk management tools like insurance. The immediate future goal of the climate adaptation decision analysis project is to get the crop switching analysis and models into the peer reviewed literature. Following that, the project will take on development of a joint project with the DOI North-Central Climate Science Center and the USDA Northern Plains Climate Hub to develop and deploy a drought decision model for the region's livestock ranching industry. WWA's role will be to integrate its adaptation decision modeling with the agricultural production expertise of the Climate Hub and the Climate Science Center's ecosystem modeling. WWA will also prepare a research proposal to NSF that extends the drought decision modeling into a more experimental direction to ask basic questions about the role of risk aversion, insurance, and seasonal climate forecasts in ranch decision-making.

*Deliverables:* Peer-reviewed papers (Huisenga and Travis 2015; Travis 2014; Travis and Bryce 2014); NSF proposal "Are extreme events efficient pacemakers of adaptation?"; enlarged decision models web resource

### Building Climate Science into Land and Water Conservation Planning and Decisionmaking in the American Southwest

*Primary Investigator(s):* W. Travis, I. Rangwala, J. Barsugli, G. Garfin and J. Brugger (CLIMAS), E. Gordon

*Stakeholders:* The Nature Conservancy and other agencies participating in conservation and climate adaptation efforts in southwestern Colorado

*Partners:* The Nature Conservancy, DOI/USGS North Central Climate Science Center (NCCSC), CLIMAS RISA, Mountain Studies Institute, National Center for Atmospheric Research, Colorado Natural Heritage Program, Univ. of Montana

### Project funded by intra-RISA competition provided an opportunity to pilot new efforts to integrate climate science into conservation and adaptation efforts.

The project, now completed, also engendered new efforts to expand the work in Colorado via support from the Department of Interior's North Central Climate Science Center, in which I. Rangwala has now become the lead climatologist, and which entailed a collaboration among the Nature Conservancy (TNC) and its partners, including the U.S. Forest Service, Bureau of Land Management, and National Park Service, in the Gunnison Basin, San Juan Mountains and the Four Corners regions. Rangwala developed landscape-scale climate scenarios from the CMIP5 global climate models for the region, and these were used by an ecologist and a social scientist, in conjunction with Rangwala, to develop narrative scenarios of future climate and its impacts. The scenarios were then used to develop the ecological and social-ecological response models for selected landscape targets: sagebrush, subalpine spruce-fir forests, piñon-juniper forests, and seeps and springs. Rangwala was an integral part of the interdisciplinary and multi-agency team in developing these models. Lastly, based on these models, the project scientists in a collaborative process with land managers, are now in the process of developing robust adaptation strategies that could work across these climate futures for a particular time horizon. Rangwala has been working with WWA team members J. Barsugli, W. Travis, K. Clifford, B. Neely (TNC), R. Rondeau (Colorado Natural Heritage), E. Towler (NCAR), T. Chapman (TNC), and C. Wyborn (U. Montana), among others, to evaluate and improve the approach for developing more effective and actionable climate scenarios for resource management and conservation. This addendum to the project is being pursued now as a white paper on scenarios in collaboration with the NCCSC. Finally, the CLIMAS team at University of Arizona conducted an evaluation of the climate science outreach project, building a data-base of outreach experience by the two key climate scientists involved in the project, Rangwala and Barsugli, and the first product of this evaluation: "Lessons from First Generation Climate Science Integrators" by Julie Brugger, Alison Meadow and Alexandra Horangic has been accepted for publication in the *Bulletin of the American Meteorological Society*.

*Deliverables:* Direct guidance to TNC and its partners; publication in press (Brugger et al.)

*Leveraged Funding:* \$10,000 in travel and other support from TNC

### Intermountain West Climate Dashboard

*Primary Investigator(s):* J. Lukas, T. Bardsley, K. Wolter, E. Gordon

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

### Maintenance of the widely used climate information web resource and production of monthly text briefings.

The Intermountain West Climate Dashboard, which debuted in October 2012, is a grid of 30 weather, climate and water information graphics that are automatically updated on the Dashboard as their providers update them. Feedback from WWA stakeholders has indicated that the Dashboard is a very useful 'one-stop shop' for up-to-date climate and water information for WWA's three-state region. The creation of similar dashboards by other climate-service entities (e.g., Great Basin Climate Dashboard by WRCC and DRI/CNAP) is further confirmation of the effectiveness of this format. Work during the past year on the Dashboard has mainly consisted of producing the monthly text briefings (~1500 words) that summarize and interpret current conditions, as well as minor web maintenance to ensure consistent loading of all graphics. The





Intermountain West Climate Dashboard is at: <http://wwa.colorado.edu/climate/dashboard.html>. In the coming year, WWA plans to further develop and officially debut a second, similar, dashboard covering the combined eight-state region of WWA, the North Central Climate Science Center, and the Northern Plains Regional Climate Hub, in collaboration with those two entities. A prototype “Rocky Mountains and High Plains” Dashboard was created in May 2015.

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*Deliverables:* Intermountain West Climate Dashboard web resource (<http://wwa.colorado.edu/climate/dashboard.html>); operational “Rocky Mountains and High Plains Dashboard”



## APPENDIX A: List of 2014-2015 WWA Publications

- Archie, K. M., L. Dilling, J. B. Milford, and F. C. Pampel (2014). [Unpacking the “information barrier”: Comparing perspectives on information as a barrier to climate change adaptation in the interior mountain West](#). *Journal of Environmental Management* 133:397-410.
- Averyt, K., et al. (2014). [Chapter 10: Energy, Water and Land Use](#). In: Third National Climate Assessment (NCA), *Climate Change Impacts in the United States*, U.S. Global Change Research Program.
- Chen, F., M. Barlage, M. Tewari, R. Rasmussen, J. M. Jin, D. Lettenmaier, B. Livneh, C. Y. Lin, G. Miguez-Macho, G. Y. Niu, L. J. Wen, and Z. L. Yang (2014). [Modeling seasonal snowpack evolution in the complex terrain and forested Colorado Headwaters region: A model intercomparison study](#). *Journal of Geophysical Research-Atmospheres*, 119 (24) 13795-13819, [doi: 10.1002/2014JD022167](#), December 27.
- Chen, Y., C. Naud, I. Rangwala, C. Landry, and J. Miller (2014). [Comparison of the sensitivity of surface downward longwave radiation to changes in water vapor at two high elevation sites](#). *Environmental Research Letters*. 9(11): 114015.
- Cozzetto, K., J. Nania, et al. (2014). [Considerations for Climate Change and Variability, Adaptation on the Navajo Nation](#). University of Colorado Boulder. 212 pp.
- Dilling, L., and J. Berggren (2014). [What do stakeholders need to manage for climate change and vulnerability? A document-based analysis from the Intermountain West region of the U.S.](#) *Regional Environmental Change*.
- DeRose, R., M. Bekker, E. Allen, T. Bardsley, B. Buckley, R. Kjelgren, T. Rittnenour, and S. Wang (2015). [A millennium-length reconstruction of the Bear River steamflow](#). *Journal of Hydrology*, [doi: 10.1016/j.jhydrol.2015.01.014](#), June.
- Dilling, L. (2015). [Community involvement critical to adaptation, managing climate change risks](#). *Daily Camera*, May 3.
- Dilling, L., M. E. Daly, W. R. Travis, O. V. Wilhelmi, and R. A. Klein (2015). [The dynamics of vulnerability: Why adapting to climate variability will not always prepare us for climate change](#). *WIREs Climate Change*, [doi: 10.1002/wcc.341](#).
- Dilling, L., K. Lackstrom, B. Haywood, K. Dow, M. C. Lemos, J. Berggren, and S. Kalafatis (2015). [What stakeholder needs tell us about enabling adaptive capacity: The intersection of context and information provision across regions in the United States](#). *Weather, Climate, and Society* 7:(1) 5-17.
- Gordon, E., and D. Ojima, eds. (2015). [Colorado Climate Change Vulnerability Study](#). A report submitted to the Colorado Energy Office. Western Water Assessment and Colorado State University.
- Huisenga, M. T. and W. R. Travis (2015). [Climate variability and the sensitivity of downstream temperature to treated wastewater discharge: A simulation analysis](#). *Environment Systems and Decisions* 35: (1) 11-21.



- Kenney, D., and A. Kuranz. (2014). [Media Treatment of 'Climate Change' in Shaping Colorado River Problems and Solutions](#). Western Water Assessment White Paper.
- Kumar, S. V., C. D. Peters-Lidard, D. Mocko, R. Reichle, Y. Q. Liu, K. R. Arsenault, Y. L. Xia, M. Ek, G. Riggs, B. Livneh, and M. Cosh (2014). [Assimilation of Remotely Sensed Soil Moisture and Snow Depth Retrievals for Drought Estimation](#). Journal of Hydrometeorology, 15 (6) 2446-2469, [doi: 10.1175/JHM-D-13-0132.1](#), December.
- Livneh, B., J. S. Deems, B. Buma, J. J. Barsugli, D. Schneider, N. P. Molotch, K. Wolter, and C. A. Wessman (2015). [Catchment response to bark beetle outbreak and dust-on-snow in the Colorado Rocky Mountains](#). Journal of Hydrology, 523 196-210, [doi: 10.1016/j.jhydrol.2015.01.039](#), April.
- Livneh, B., J. S. Deems, D. Schneider, J. J. Barsugli, and N. P. Molotch (2014). [Filling in the gaps: Inferring spatially distributed precipitation from gauge observations over complex terrain](#). Water Resour. Res. 50 (11) 8589-8610, [doi: 10.1002/2014WR015442](#), November 10.
- Livneh, B., E. Marino and J. E. Ten Hoeve (2014). [Emerging Ideas and Interdisciplinary Perspectives on Climate Change](#). Eos Trans DISCCRS VIII Interdisciplinary Climate Change Research Symposium, 95 (7) , [doi: 10.1002/2014EO070006](#), February 18.
- Lukas, J., Barsugli, J., Doesken, N., Rangwala, I., and K. Wolter, (2014). [Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation](#). A Report for the Colorado Water Conservation Board, Western Water Assessment, 114 pp.
- Lundquist J., M. Hughes, B. Henn, E. D. Gutmann, B. Livneh, J. Dozier, and P. Neiman (2014). High-elevation precipitation patterns: using snow measurements to diagnose when and why gridded datasets succeed or fail across the Sierra Nevada. California Journal of Hydrometeorology, January.
- McNie, E. (2014). [The Utah Model Report](#). Western Water Assessment Report.
- McNie, E., A. Parris, and D. Sarewitz. (2015). [A Typology for Assessing the Role of Users in Scientific Research](#). User Engagement and Scientific Research, *Consortium for Science, Policy & Outcomes*.
- Mulvaney, K. K., C. J. Foley, T. O. Höök, E. C. McNie, and L. S. Prokopy (2014). [Identifying useful climate change information needs for Great Lakes Fisheries Managers](#). Journal of Great Lakes Research, 40 (3) 590-598, [doi: 10.1016/j.jglr.2014.06.002](#), September.
- Naud C., I. Rangwala, M. Xu and J.A. Miller (2014). [A satellite view of the radiative impact of clouds on surface downward fluxes in the Tibetan Plateau](#). Journal of Applied Meteorology and Climatology, [doi:10.1175/JAMC-D-1114-0183.1171](#).
- Pal, I., E. Towler, and B. Livneh (2015). [Advancing the Science of Low Flows in a Changing Climate](#). *EOS*, January.
- Pepin, N., R. S. Bradley, H. F. Diaz, M. Baraer, E. B. Caceres, N. Forsythe, H. Fowler, G. Greenwood, M. Z. Hashmi, X. D. Liu, J. R. Miller, L. Ning, A. Ohmura, E. Palazzi, I. Rangwala, W. Schönner, I. Severskiy, M.



Shahgedanova, M. B. Wang, S. N. Williamson, and D. Q. Yang (2015). [Elevation-dependent warming in mountain regions of the world](#). Nature Climate Change, 5: 424-430, doi: 10.1038/nclimate2563.

Rangwala I., E. Sinsky, and J. Miller (2015). [Variability in Projected Elevation Dependent Warming in Boreal Midlatitude Winter in CMIP5 Climate Models and its Potential Drivers Climate Dynamics](#). Journal of Climate, June.

Travis, W.R. (2014). [Weather and Climate Extremes: Pacemakers of Adaptation?](#) Weather and Climate Extremes 5-6: 29-39, doi:10.1016/j.wace.2014.08.001

Travis, W.R. and B. Bates (2014). [What is Climate Risk Management?](#) Climate Risk Management 1: 1-4, doi:10.1016/j.crm.2014.02.003



## APPENDIX B: WWA Appearances in Media

**May 22, 2015**

["California drought holds lessons for Colorado"](#)

*The Colorado Independent*

Jeff Lukas

**May 21, 2015**

["Adaptation Policy: Forget No Regrets"](#)

*Nature Climate Change*

Lisa Dilling

**May 6, 2015**

["Boulder ends up with above-average moisture after spring turnaround"](#)

*Daily Camera*

WWA

**April 27, 2015**

["Should Water Issues Be Included in Public Education?"](#)

*Outside Magazine*

Eric Gordon

**March 27, 2015**

["Free online course from CU-Boulder explores water issues in the West"](#)

*The Gazette*

Eric Gordon

**March 19, 2015**

["New study analyzes climate change impacts in Colorado"](#)

*Summit Daily*

Eric Gordon

**March 12, 2015**

["More water flowing from bark beetle infested watersheds"](#)

*Fondriest Environmental*

Ben Livneh

**March 11, 2015**

["CU-Boulder offering free online course on water scarcity in the West"](#)

*Daily Camera*

Eric Gordon

**March 9, 2015**

["How global warming makes flying more expensive"](#)

*Mountain Town News*

WWA





**March 7, 2015**

["Adapting to climate change will cost us plenty, too"](#)

*Denver Post*

Eric Gordon

**February 27, 2015**

["As the River Runs Dry: The Southwest's water crisis"](#)

*AZ Central*

Jeff Lukas

**February 9, 2015**

["Scientist says it's 'prudent' for Colorado to prepare for climate change"](#)

*Colorado Public Radio*

Eric Gordon

**February 6, 2015**

["Disease one danger in climate report"](#)

*Daily Camera*

Eric Gordon

**February 5, 2015**

["New Report on Colorado's Vulnerability to Climate Change"](#)

*KGNU Radio*

Eric Gordon

**February 5, 2015**

["Climate change may create a Wild West that cowboys wouldn't recognize, Colo. researchers report"](#)

*ClimateWire*

Eric Gordon

**February 4, 2015**

["Study: Climate change could bring more disease, crop damage, fires to Colorado"](#)

*Denver Post*

Eric Gordon

**February 4, 2015**

["Study: Colorado tourism industry may be hit hard by climate change"](#)

*Daily Camera*

Eric Gordon

**February 4, 2015**

["Report: Ag, water sectors show climate change vulnerabilities"](#)

*The Fence Post*

Eric Gordon



**February 4, 2015**

["Report: Four ways Colorado is vulnerable to climate change"](#)

*Colorado Public Radio*

Eric Gordon

**December 15, 2014**

["Purloining our groundwater savings accounts"](#)

*Mountain Town News*

Jeff Lukas

**November 27, 2014**

["Obama's climate pact with China a great first step, not a swindle"](#)

*Mountain Town News*

WWA

**November 3, 2014**

["Global warming takes bite out of Colorado ski season"](#)

*Colorado Independent*

Jeff Lukas

**October 7, 2014**

["Colorado climate change report looks into 'uncharted territory'"](#)

*Mountain Town News*

Jeff Lukas

**September 29, 2014**

["Working together with water issues"](#)

*Glenwood Springs Post Independent*

Jeff Lukas

**September 16, 2014**

["Climate paradox: More snow, less water?"](#)

*Colorado Independent*

Jeff Lukas

**September 9, 2014**

["Climate Change Forecast: More Rain Yet Less Water For Roaring Fork Valley"](#)

*Aspen Public Radio*

Jeff Lukas

**August 16, 2014**

["Hot times ahead for Colorado"](#)

*Summit County Citizens Voice*

Jeff Lukas



**August 12, 2014**

["What Climate Change in the Rockies Means for its Water"](#)

*Climate Central*

Jeff Lukas

**August 5, 2014**

["Climate change report projects future of Colorado's water supply, related industries"](#)

*The Denver Channel (7 News)*

Jeff Lukas

**August 5, 2014**

["Colorado's climate could be hotter, like New Mexico's, by 2050, study says"](#)

*Colorado Public Radio*

Jeff Lukas

**August 5, 2014**

["Researchers: Colo. faces warmer future, water supply challenges"](#)

*Boulder Daily Camera*

Jeff Lukas

**June 19, 2014**

["How Dust on Colorado's Snow Could Ruin Your Salad"](#)

*Climate Progress*

Jeffrey Deems

**June 17, 2014**

["Drought Parches the West, but Americans Shrug It Off"](#)

*NBC News*

Kristen Averyt