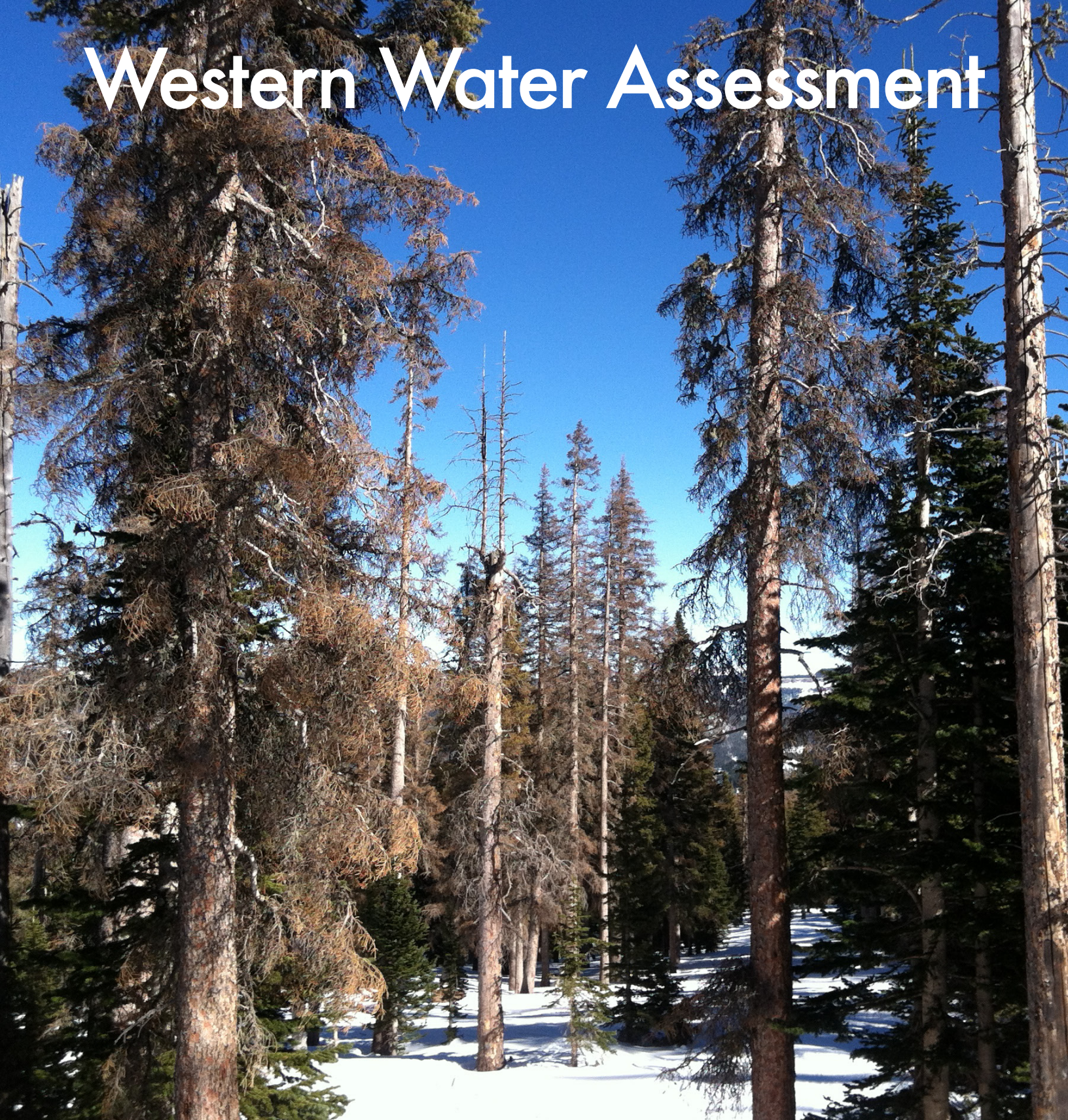


Western Water Assessment



2012 ANNUAL REPORT



Western Water Assessment



CIRES



University of Colorado **Boulder**



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<p>Principal Investigator Kristen Averyt, University of Colorado-Boulder</p>	<p>Co-Investigators Lisa Dilling, 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: January 1, 2012–December 31, 2012.



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 decisionmakers across the Intermountain West to produce policy-relevant information about climate variability and change. By building relationships and networks of decisionmakers, 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 is physically located in NOAA’s David Skaggs Research Center. Our researchers and affiliates 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 2012 are described in Table 1.

Table 1. New partnerships and areas of focus developed in 2012.

New Area of Focus	Relevant Projects (see pp. 10-20)
Missouri Basin (in partnership with NOAA Central Region Climate Services Director and USGS North Central Climate Science Center)	<ul style="list-style-type: none"> Assessment of Documented Needs for Climate Information in the Missouri River Basin Regional Technical Inputs for the National Climate Assessment
Modeling of Adaptation Decisionmaking	<ul style="list-style-type: none"> Decisionmaking Under Hydro-Climatic Uncertainty
New Partnership	Relevant Projects (see pp. 10-20)
The Nature Conservancy	<ul style="list-style-type: none"> Building Climate Science into Land and Water Conservation Planning and Decision-Making in the American Southwest
Wasatch Area Dendrochronology Research (WADR) Group, Utah State University	<ul style="list-style-type: none"> Project Evaluation for Stakeholder-Oriented Paleohydrology

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 early 2013, Brad Udall left WWA and Kristen Averyt became the program’s Director. Two Associate Director positions have also been named (Lisa Dilling, Noah Molotch) with the goal of improving ties to campus-based research. In addition to the core staff shown below, WWA now shares administrative support (Nancy Ollanik) and outreach staff (Amy Nacu-Schmidt) 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

Kristen Averyt	Director	kristen.averyt@colorado.edu
Jeff Lukas	Senior Research Associate	lukas@colorado.edu
Eric Gordon	Managing Director	esgordon@colorado.edu



Tim Bardsley Utah Liaison www.bardsley@gmail.com

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
Andersson, Krister	Assistant Professor, Political Science, Univ. of Colorado	Environmental governance
Archie, Kellie	Graduate Research Assistant, Univ. of Colorado	Climate adaptation
Averyt, Kristen	Director, Western Water Assessment Associate Director for Science, CIRES	Climatology, energy-water, assessment processes
Barsugli, Joseph	Research Scientist, CIRES, Univ. of Colorado	Climate dynamics
Berggren, John	Graduate Research Assistant, Univ. of Colorado	Climate adaptation, water policy
Buma, Brian	Graduate Research Assistant, Univ. of Colorado	Remote sensing, landscape ecology
Clifford, Kate	Graduate Research Assistant, Univ. of Colorado	Conservation decisionmaking
Cozzetto, Karen	Postdoctoral Research Associate, CIRES, Univ. of Colorado	Hydroclimatology, surface water hydrology and ecology
Deems, Jeff	Research Scientist, CIRES, Univ. of Colorado	Climate and snow modeling
Dilling, Lisa	WWA Associate Director; Assistant Professor, Environmental Studies, Univ. of Colorado	Climate information and decisionmaking
Endter-Wada, Joanna	Associate Professor, Environment & Society, Utah State Univ.	Human dimensions of ecosystem science and management
Gillies, Robert	Utah State Climatologist, Utah State Univ.	Climatology
Gordon, Eric	Managing Director, Western Water Assessment	Climate adaptation
Huisenga, Mary	Professional Research Assistant, Univ. of Colorado	Limnology, decision modeling
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	Visiting Fellow, Western Water Assessment and CIRES, Univ. of Colorado	Hydrologic modeling
Lukas, Jeffrey	Senior Research Associate, Western Water Assessment	Paleohydrology, forest ecology
McCutchan, James	Associate Director, Center for Limnology, CIRES, Univ. of Colorado	Limnology
Meldrum, James	Research Associate, Institute for Behavioral Studies, Univ. of Colorado	Applied environmental economics
Miller, Scott	Associate Professor, Renewable Resources, Univ. of Wyoming	Spatial processes in watershed hydrology
Molotch, Noah	WWA Associate Director; Assistant Professor, Dept. of Geography, Univ. of Colorado	Snow hydrology



Team Member	Title	Expertise
Nania, Julie	Research Assistant, Getches-Wilkinson Center for Energy, Natural Resources, and the Environment, Univ. of Colorado School of Law	Tribal law
Rajagopalan, Balaji	Associate 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
Rice, Janine	WWA Postdoctoral Research Associate, CIRES, Univ. of Colorado	Climate impacts and adaptation in National Forests
Schneider, Dominik	Graduate Research Assistant, Univ. of Colorado	Snow hydrology
Travis, William	Associate Professor, Geography; Director, CSTPR, Univ. of Colorado	Natural hazards, climate impacts and adaptation
Udall, Bradley	Director, Getches-Wilkinson Center for Natural Resources, Energy, and the Environment, Univ. of Colorado School of Law	Colorado River, hydrology, policy
Verdin, Andrew	Graduate Research Assistant, Univ. of Colorado	Water resources engineering
Wade, Lisa	Graduate Research Assistant, Univ. of Colorado	Water resources engineering
Wessman, Carol	Professor, CIRES, Univ. of Colorado	Landscape ecology, remote sensing
Wolter, Klaus	Research Scientist, CIRES, Univ. of Colorado	Climatology and meteorology
Zagona, Edith	Director, Center for Advanced Decision Support for Water and Environmental Systems, Univ. of Colorado	Water resources engineering

Major Stakeholders & Partners

WWA engages with stakeholders at multiple levels within federal and state agencies, municipalities, universities, and other organizations. Table 4 lists the members of WWA’s Stakeholder Advisory Board, a group of high-level decision makers and other partners who provide guidance on structuring our research agenda to best meet regional needs. The Advisory Board, along with other WWA stakeholders and partners, met in October 2012; WWA staff members frequently consult with stakeholders on an informal basis.

WWA also collaborates with a wide variety of research partners throughout the region. A list of selected WWA research partners is available at <http://wwa.colorado.edu/about/network.html>.

Table 4. WWA Stakeholder Advisory Board

Curtis Brown	Director, Research and Development, Science and Technology Division, US Bureau of Reclamation
Terrance Fulp	Regional Director, Lower Colorado Region, US Bureau of Reclamation
Jennifer Gimbel	Director, Colorado Water Conservation Board
Melinda Kassen	Independent environmental consultant
Eric Kuhn	General Manager, Colorado River District
Chuck Kutscher	Principal Engineer, National Renewable Energy Laboratory, Department of Energy
Patricia Mulroy	General Manager, Southern Nevada Water Authority
William Neff	Director, Physical Science Division, NOAA Earth System Research Laboratory



Michelle Stokes	Hydrologist-in-Charge, NOAA NWS Colorado Basin River Forecast Center
James Verdin	Deputy Director, National Integrated Drought Information System (NIDIS), USGS
Marc Waage	Manager, Water Resources Planning Division, Denver Water
Betsy Neely	Senior Conservation Planner, The Nature Conservancy

WWA 2012 Highlights

Major Research Findings in 2012

- A study led in part by WWA researcher **James McCutchan** found that bark beetle infestations in Colorado have not led to significant increases in nitrate concentrations in nearby surface waters, contrary to expectations (Rhoades et al. 2013).
- Although certain renewable generation technologies (such as water-cooled concentrating solar power) use large amounts of water, overall low carbon energy penetration scenarios show the most substantial savings in water withdrawals and consumption at a national level, according to WWA researcher **Kristen Averyt** and her colleagues from the National Renewable Energy Laboratory and the Union of Concerned Scientists (Macknick et al. 2012).
- Initial model results suggest that bark beetle infestations result in an increase in annual water yield on the order of approximately 3 to 15 percent over selected catchments across Colorado, according to sensitivity analyses by WWA's **Jeff Deems, Ben Livneh, Joe Barsugli, Noah Molotch, Carol Wessman, and Klaus Wolter** (paper in prep).
- WWA's **Lisa Dilling** and **Kristen Andersson** have found that although climate-related natural disasters can spur adaptation, there is often another explanation for a municipality undertaking adaptive action, such as the presence of a champion for the effort, the availability of additional financial resources, or opportunities for collaboration at other levels of government (paper in prep).



Select 2012 WWA Accomplishments

New Intermountain West Climate Dashboard

PIs: Jeff Lukas, Klaus Wolter, Eric Gordon, Tim Bardsley

Stakeholders/Partners: Water managers and others responsible for climate-sensitive resources

Leveraged Funding: In-kind contribution from NOAA ESRL Physical Sciences Division

For several years, Western Water Assessment produced the *Intermountain West Climate Summary* (IWCS), a semi-monthly update of climate and hydrology in Colorado, Wyoming, and Utah. In the interests of providing more up-to-date information in a clearer format for a variety of stakeholders, WWA’s Jeff Lukas led an effort to implement the Intermountain West Climate Dashboard (available at <http://www.colorado.edu/climate/dashboard.html>). Based on a prototype for the Missouri River Basin developed at the NOAA Earth System Research Laboratory’s Physical Sciences Division, the Dashboard contains an array of many of the same climate information graphics as in the IWCS, but directly feeds them from their original providers (such as NOAA CPC) to automatically update as often as those providers update them. Clicking on the thumbnail of each graphic brings up a full-sized version on the same page. In order to provide additional context and analysis, WWA staff also write and post bimonthly briefings on the Dashboard to provide additional context and analysis.

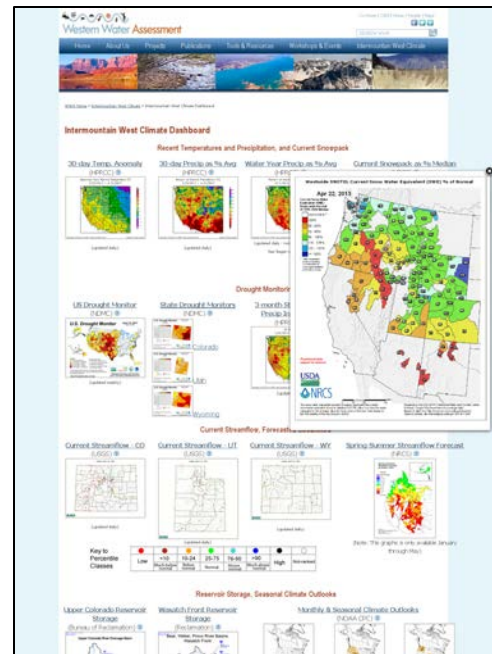


Figure 1. A portion of WWA’S Intermountain West Climate Dashboard, available at <http://www.colorado.edu/climate/dashboard.html>.

WWA Receives DOI’s “Partners in Conservation” Award

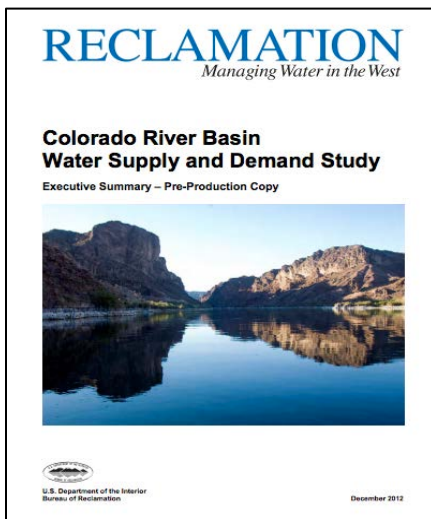


Figure 2. WWA shared in the DOI *Partners in Conservation* award for contributions to the Colorado River Basin Water Supply and Demand Study.

PIs: Joe Barsugli

Stakeholders/Partners: US DOI Bureau of Reclamation

On October 18, 2012, the Western Water Assessment was among the organizations awarded a Department of the Interior “Partners in Conservation” Award (see press release at <http://www.doi.gov/news/pressreleases/Interior-Department-Honors-2012-Partners-in-Conservation-Award-Winners.cfm>) for collaborative efforts on the Colorado River Basin Water Supply and Demand Study (<http://www.usbr.gov/lc/region/programs/crbstudy.html>), led by the Bureau of Reclamation. WWA’s Joe Barsugli, who helped Reclamation develop the future climate and hydrology scenarios for the Basin Study, accepted the award in Washington, D.C., on behalf of the program. This was the second “Partners in Conservation” award in four years that WWA has shared for its work with Reclamation and others on Colorado River climate and hydrology.



WWA and NIDIS Produce 2012 Drought Briefing

PIs: Jeff Lukas, Lisa Darby (NIDIS)

Stakeholders/Partners: NIDIS; various water and resource managers across the West

WWA worked in collaboration with the National Integrated Drought Information System (NIDIS) to develop a two-page briefing document focusing on the severe drought conditions that emerged in 2012 in Colorado, Utah, and Wyoming

(http://wwa.colorado.edu/climate/iwcs/docs/2012_July/WWA-NIDIS_July_2012_Drought_update.pdf). In

addition to reporting drought conditions, the special issue compared conditions in 2012 to 2002, considered a benchmark drought year throughout the Intermountain West. The briefing was intended for consumption by higher-level decisionmakers, along the lines of the west-wide “Quarterly Climate Impacts and Outlook” document crafted by NOAA, NIDIS, and the Western Governors’ Association. A special issue of the Intermountain West Climate Summary (http://wwa.colorado.edu/climate/iwcs/2012_July.html) supplemented the two-page briefing by providing additional analyses and information graphics for the 2012 drought.

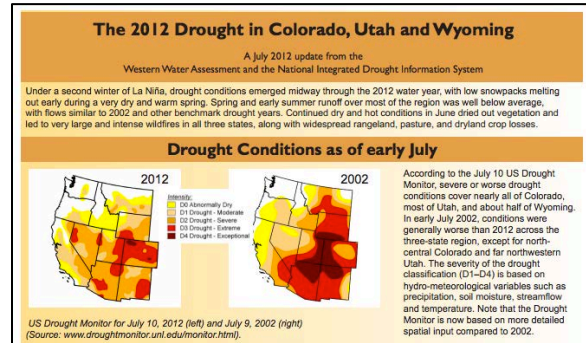


Figure 3. WWA and NIDIS co-produced a drought briefing comparing climate conditions in 2012 with 2002, another significant drought year for the Intermountain West.

Conceptual Model on Beetle Infestation Impacts to Hydrology

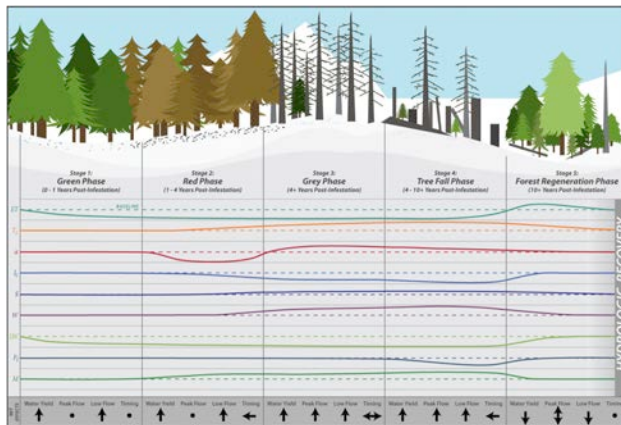


Figure 4. Conceptual model outlining impacts of bark beetle infestations on various hydrologic processes. Reproduced from Pugh and Gordon (2012).

PIs: Eric Gordon, Evan Pugh (CU Geology), Jeff Lukas

Stakeholders/Partners: US Forest Service Rocky Mountain Research Station; various water and land managers across Intermountain West

Under the “Beetles, Forest Change, and Water” project, WWA has engaged with a diverse group of stakeholders and researchers dealing with the ongoing bark beetle epidemic, with the aim of developing integrated, decision-oriented information that can help stakeholders understand and plan for potential impacts on water resources. As part of that effort, WWA’s Eric Gordon worked with Evan Pugh of the University of Colorado Department of Geological

Sciences to develop a conceptual model that synthesizes research examining bark beetle impacts on individual ecohydrological processes (see Fig. 4). The model was published in *Hydrological Processes* in 2012 (Pugh and Gordon 2012) and has been used at multiple WWA workshops on beetle infestation impacts to water supplies.



New Website and Webinar Series

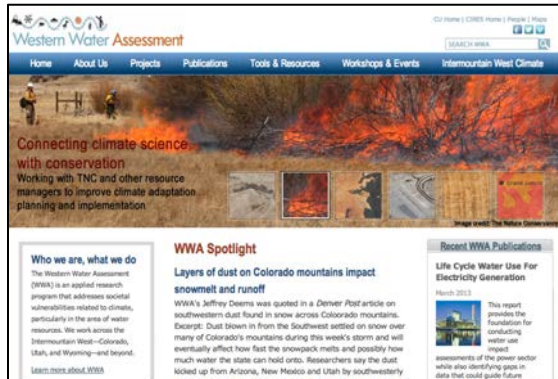


Figure 5. WWA's new website (<http://wwa.colorado.edu>).

PIs: Jeff Lukas and Eric Gordon

Stakeholders/Partners: All WWA stakeholders

In 2012, to bolster communication with stakeholders and research partners, WWA staff redesigned WWA's website, which is not only the primary method for articulating the mission of WWA and the RISA program but also a frequently consulted source of climate information. The WWA website

(<http://wwa.colorado.edu>) is now much simpler,

providing two-click navigation to virtually all site content. WWA also began a webinar series aimed at better communicating the goals and findings of various research projects to stakeholders, holding four

webinars in 2012. Archived webinar recordings are available at

<http://wwa.colorado.edu/events/webinars/>.



WWA 2012 Publication Highlights

Archie, K. M., L. Dilling, J. B. Milford and F. C. Pampel. (2012). Climate Change and Western Public Lands: A Survey of U.S. Federal Land Managers on the Status of Adaptation Efforts. *Ecology and Society* 17(4), 20.

Barsugli, J. J., J. Vogel, L. Kaatz, J. Smith, M. Waage, and C. Anderson. (2012). Two Faces of Uncertainty: Climate Science and Water Utility Planning. *Journal of Water Resources Planning and Management* 138(5).

Macknick, J., S. Sattler, **K. Averyt**, S. Clemmer, and J. Rogers. (2012). The water implications of generating electricity: water use across the United States based on different electricity pathways through 2050. *Environmental Research Letters* 7. [<http://iopscience.iop.org/1748-9326/7/4/045803/article>]

Pugh, E. and **E. Gordon.** (2012). A conceptual model of water yield impacts from beetle-induced tree death in snow-dominated lodgepole pine forests. *Hydrological Processes*. doi: 10.1002/hyp.9312.

Rice, J., A. Tredennick, and L. A. Joyce. (2012). Climate change on the Shoshone National Forest, Wyoming: a synthesis of past climate, climate projections, and ecosystem implications. Gen. Tech. Rep. RMRS-GTR-264. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 60 p. [http://www.fs.fed.us/rm/pubs/rmrs_gtr264.pdf]



WWA 2012 Project Reports

New Projects (Initiated in 2012)

Analysis of Use of Information by Stakeholders of the Colorado Basin River Forecast Center

Primary Investigator(s): L. Dilling, R. Klein

Effort to understand the flow of forecast information to stakeholders of the NOAA Colorado Basin River Forecast Center.

The Colorado Basin River Forecast Center (CBRFC) generates forecasts across the Colorado Basin and Utah, including daily streamflow forecasts, long lead peak flow forecasts and water supply forecasts. Decisionmakers such as Denver Water, the Bureau of Reclamation, the Central Arizona Project, and the Colorado River District are some of the CBRFC stakeholders who potentially might use these forecasts. Previous research has found, however, that unless reliability and/or quality are threatened, water management agencies have little incentive to use forecasts (especially ensemble forecasts), and that forecast use correlates more with perceived risk than with forecast skill and reliability. The WWA "Snowmelt Perturbations" project (described below) is working to improve tools such as CBRFC forecasts. PIs are augmenting this research by obtaining a better understanding of both the CBRFC stakeholder decision making process as well as how WWA research can feed into this process. PIs intend to provide basic data on the stakeholders of the CBRFC, their climate-related decision making contexts, and the role that forecast information does and could play. The PIs will also assess the potential for the WWA snowpack physical science research to be used by CBRFC and ultimately help stakeholders make better decisions.

Deliverables: WWA report or peer-reviewed publication in 2013

WWA Funding: July–December 2012

Cross-Jurisdictional Water Marketing

Primary Investigator(s): D. Kenney, J. Nania

Review of lessons learned from previous attempts at cross-jurisdictional (including interstate) water marketing for applicability to current contexts, including tribal water rights.

The growing water stresses in the Colorado River Basin are not solely a function of climate-related supply disruptions, but are also a function of growing demands and the presence of institutional barriers to many types of adaptive responses, including water reallocation. Over the past year, PIs have studied past efforts to establish water markets at large, cross-jurisdictional scales—specifically, interstate markets, and/or the marketing of tribal water off-reservation (which may or may not be interstate). The past proposals investigated include those offered by the Galloway Group (1984), the Resource Conservation Group (1990), the State of California (drought coping plan) (1991), the Ten Tribes Partnership (1992), Chevron's Roan Creek group (1993), Nevada's Proposed Lower Basin Water Bank (1994), the Bureau of Reclamation's draft regulations (1994), and the so-called California-Nevada "Dream Team" (1995). The evolution of Lower Basin water banking programs has also been reviewed, as well as the recent integration of Mexican water into parts of that evolving framework. These past efforts identified several legal and political barriers to cross-jurisdictional marketing, including constitutional law issues, compact compliance considerations, and in the case of tribal proposals, many issues related to Indian sovereignty. These legal issues provide a backdrop to ongoing conversations about new Upper Basin water banks and proposals by specific tribes (e.g., the Northern Utes) to develop new cross-jurisdictional markets. Findings will be summarized in a white paper to be completed in 2013.

Deliverables: WWA white paper expected in 2013

WWA Funding: July–December 2012

Decisionmaking Under Hydro-Climatic Uncertainty

Primary Investigator(s): W. Travis, M. Huisenga

Status: Ongoing

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

During a previous project, PIs set up a climate adaptation "testbed" using a set of software tools centered on the risk simulation software Analytica coupled with data management and visualization software. The goal of the testbed was to simulate impact and adaptation in realistic models of climate-sensitive systems like farming, storm-water management, and waste-water treatment, and to develop and test hypotheses about the adaptation process in an agent-centered, rules-based framework, with particular attention to signal-to-noise problems and pacing by extreme events. Work done in the initial pilot effort involved the development of a farm decision model, which was presented in 2012 at the Society for Risk Analysis Annual Conference and is available online at http://sciencepolicy.colorado.edu/research_areas/dm/index.html. Work in 2012 will build on another preexisting WWA project, the drought



dashboard, and coordinate with NIDIS to examine its utility as a means of understanding how decisionmaking during droughts results in traceable socioeconomic impacts (white paper on dashboard available at <http://www.colorado.edu/publications/reports/2013.01.pdf>). In addition, PIs will develop additional decisionmaking models, potentially including ranching and drought or wastewater and natural flows, using the adaptation testbed.

Deliverables: Working farm decision model available online at http://sciencepolicy.colorado.edu/research_areas/dm/index.html; WWA White Paper: Travis, W. R., and Z. Johnson. (2013). "Tracking Socioeconomic Impacts of Drought with Rapid Analytics and Dashboards," available at <http://www.colorado.edu/publications/reports/2013.01.pdf>.

WWA Funding: January–December 2012

Assessment of Documented Needs for Climate Information in the Missouri River Basin

Primary Investigator(s): K. Averyt, E. Gordon, J. Berggren, D. Kluck (NOAA Central Region Climate Services Director)

Partners: NOAA Regional Climate Services Central Region, DOI North Central Climate Science Center

Using document analysis to assess user needs for climate information across the Missouri River Basin.

This project delivered a report (available at <http://www.colorado.edu/publications/reports/2012.03.pdf>) forming a broad initial assessment of stakeholder needs for information regarding how climate variability and change could affect a wide variety of sectors. It leveraged an existing text analysis methodology developed by L. Dilling and J. Berggren in a previous WWA project. By providing a broad overview of needs that forms a blueprint for where services are needed the most, this effort can help guide federal investments in climate services for the basin. The examination of stakeholder needs also resulted in the development of a database providing a comprehensive list of documents where stakeholders have expressed the need for climate information within the Missouri River Basin.

Deliverables: Final report (<http://www.colorado.edu/publications/reports/2012.03.pdf>) delivered to NOAA Central Region Climate Services Director

WWA Funding: January–August 2012

Leveraged Funding: \$30,000 from NOAA Central Region Climate Services Director

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

Primary Investigator(s): W. Travis, J. Barsugli, G. Garfin (CLIMAS), E. Gordon

Partners: The Nature Conservancy

Project funded by intra-RISA competition will provide an opportunity to pilot new efforts to integrate climate science into conservation adaptation efforts developed by The Nature Conservancy in the Southwest.

This project is intended to connect the climate expertise of two RISA programs, the Western Water Assessment (WWA) and Climate Assessment for the Southwest (CLIMAS), with regional conservation planners and decision-makers through collaboration with The Nature Conservancy's (TNC) Southwest Climate Change Initiative (SWCCI) in order to improve climate adaptation planning and implementation by land managers in the American Southwest. A key challenge addressed in this effort is the need bring climate knowledge to bear on the many habitat and species conservation efforts underway in the region, and to move conservation projects beyond vulnerability assessments to adaptation planning and implementation. This project is intended to advance four goals: 1) expand translational science capacity in the region to support adaptation; 2) improve regional climate-sensitive conservation decision-making; 3) disseminate climate knowledge through conservation networks in the region; and 4) develop both a comprehensive evaluation of the project and a training curriculum for future personnel intending to engage in this type of work. The project as a whole is intended to prototype and develop a model for expanding the translational climate science capacity needed to move ecosystem management beyond vulnerability assessments and into on-the-ground decision-making for adaptation to climate variability and change. Due to a delay in processing funding at the University of Colorado, progress in 2012 was limited to identifying a research associate (I. Rangwala) to work on the project.

Deliverables: TBD

WWA Funding: \$200,000 in Intra-RISA FFO funding beginning in late 2012

Project Evaluation for Stakeholder-Oriented Paleohydrology

Primary Investigator(s): T. Bardsley, J. Lukas

Partners: Utah State University, Brigham Young University, US Forest Service

Real-time assessment of the development and use of stakeholder-oriented tree-ring paleohydrology research for water resource planning on the Wasatch Front.

In 2012 work began on tracking the development and use of stakeholder-oriented tree-ring paleohydrology research for water resource planning on the Wasatch Front. The paleohydrology project is being carried out by a research team led by the Wasatch Dendroclimatology



Research Group (WADR) at Utah State University, who are in the process of developing proxy hydrology records from tree rings for Wasatch Front creeks in order to provide water managers with a longer period of record to aid in planning. WWA's T. Bardsley has attended relevant WADR research and stakeholder events and interviewed stakeholders to begin the evaluation process. A total of nine interviews with water management stakeholders were conducted in the fall of 2012, as well as five interviews of research team members. Stakeholder interviews were summarized and shared with the WADR team to assist them in developing and communicating information that is most relevant to water managers' needs. WWA has also provided guidance to the WADR team on methodological issues such as development of naturalized flows needed to calibrate the paleohydrology records. The WADR group is expected to deliver streamflow reconstructions in 2013, and WWA will host a tree-ring stakeholder workshop to facilitate the delivery of streamflow reconstructions and conduct additional stakeholder interviews to help track the transfer and utilization of tree ring data.

Deliverables: Tree-ring workshop for Utah water managers, WWA Report or peer-reviewed publication expected by late 2013 or 2014
WWA Funding: July–December 2012

Intermountain West Climate Dashboard

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

Development of a new web resource providing updated regional climate information as soon as it is produced.

WWA has long produced the Intermountain West Climate Summary (IWCS), a semi-monthly web-based digest of recent climatic conditions that synthesized information from a variety of climate information providers. PIs recognized the need for this information to be updated more frequently than the IWCS production schedule allowed, and thus decided to create a web resource with 30 climate and water graphics in a "dashboard" format. The new format is capable of automatically updating with the most recent graphics from each climate information provider. Based on a prototype developed for another purpose by the NOAA ESRL Physical Sciences Division, the new Dashboard allows users to select from an array of thumbnail graphics and click to bring up a full-size image, which can be moved around the screen and compared with other graphics. To provide additional analysis and ensure that stakeholders continue to consult the Dashboard, short text summaries are posted on the Dashboard and emailed to the WWA listserv at regular intervals. The Intermountain West Climate Dashboard is at: <http://www.colorado.edu/climate/dashboard.html>.

Deliverables: New Intermountain West Climate Dashboard web resource (<http://www.colorado.edu/climate/dashboard.html>)

WWA Funding: January–December 2012

Leveraged Funding: In-kind contribution from NOAA ESRL Physical Sciences Division

Ongoing Projects (Initiated prior to 2012 and still in progress)

Snowmelt Perturbations and Water Supply Forecast Errors

Primary Investigator(s): J. Deems, B. Livneh, C. Wessman, N. Molotch, J. Barsugli, K. Wolter

Partners: NIDIS, NOAA NWS Colorado Basin River Forecast Center, Institute for Arctic and Alpine Research (Univ. of Colorado)

A collaborative effort among WWA hydrologists, ecologists, weather and climate experts, and operational forecasters at the NOAA Colorado Basin River Forecast Center in an effort to use a suite of modeling and observation techniques to better understand drivers of snow accumulation and melt in the Upper Colorado River Basin with the ultimate goal of improving CBRFC forecasts.

Over the past decade, the Upper Colorado River Basin has experienced unusual runoff patterns resulting in anomalously high errors in peak and daily streamflow forecasts. Water managers and hydrologic forecasters suspect that bark beetle infestations and/or increased dust deposition on snowpack might be causing these runoff anomalies, but to date there has been no concerted effort to understand the contributions of various snowmelt perturbations. A multidisciplinary team of WWA researchers with expertise in climatology, meteorology, snow hydrology, and landscape ecology is bringing a novel combination of methodologies to bear on this question. The team has assembled streamflow data, vegetation-change maps, snow albedo observations, and snow-water equivalent reconstructions in preparation for running a comprehensive land-and-snow-hydrology model. In 2012, Ben Livneh was awarded a CIRES Visiting Fellowship, bringing a hydrologic modeler to the project team. Subsequent to his hire, the project has focused on calibrating the DHSVM hydrology model to observed climate, streamflow, and snowpack information in the four project study basins (Uncompaghe River, Fish Creek, Snake River, and Boulder Creek). Multiple experiments were run within the calibrated model environment to assess runoff sensitivity to bark beetle (via MODIS-based LAI maps and aerial survey data) and dust scenarios (derived from "Impacts of Coupled Climate Change and Dust Deposition" project described below). Initial model results suggest that bark beetle infestations correspond with an increase in annual water yield on the order of approximately 3 to 15 percent over the selected basins. These results aim to improve process understanding and modeling of hydrologic disturbances such as MPB within the headwaters region. PIs have held multiple discussions with CBRFC streamflow forecasters about the implications of these findings and are expected to travel to Salt Lake City in 2013 to experiment with adjusting CBRFC's modeling framework to more explicitly incorporate research findings.



Deliverables: Peer-reviewed publication on remotely sensed trends in beetle outbreak in review at *International Journal of Remote Sensing*; peer-reviewed publication on runoff sensitivity to beetle and dust impacts expected in 2013

WWA Funding: January–December 2012

Leveraged Funding: \$90,000 from NIDIS; \$60,000 from Cooperative Institute for Research in Environmental Sciences Visiting Fellowship Program

Impacts of Coupled Climate Change and Dust Deposition on Water Resources in the Colorado River Basin

Primary Investigator(s): J. Deems, T. Painter

Partners: Center for Snow and Avalanche Studies, Jet Propulsion Laboratory

Using hydrologic modeling to examine the influence of dust deposition and climate change on snowmelt, runoff timing, and volume in the Colorado River Basin.

Previous WWA research suggested a 2-3 week earlier runoff and a 5 percent reduction in annual Colorado River flow due to anthropogenic dust loading on snowpack in the Rocky Mountains since the mid-19th century (Painter et al. 2010). In 2011, Pls began examining both the separate and the combined impacts of unusually high dust loads (as seen in 2009 and 2010) and projected climate warming on flow in the Colorado River. Modeling results show that even under the strongest projected warming, timing of runoff is highly sensitive to radiative forcing by dust. Under scenarios of extreme warming, however, dramatically reduced snow cover causes runoff volume to become less sensitive to dust deposition. A manuscript describing these results is currently in review at *Hydrology and Earth System Sciences*.

Deliverables: Deems, J., T. Painter, J. Barsugli, J. Belnap, and B. Udall. (2013, in review). Combined impacts of current and future dust deposition and regional warming on Colorado River Basin Hydrology. Submitted to *Hydrology and Earth System Sciences*.

WWA Funding: January–December 2012

Leveraged Funding: \$280,000 from NASA (2009–2011)

Drivers of Adaptation: A Comparative Analysis of Local Decision Making in the American West

Primary Investigator(s): L. Dilling, K. Andersson

Multi-year effort to systematically investigate the conditions under which local decisionmakers in cities and large towns in Colorado, Utah, and Wyoming decide to adapt (or not) to increased climate-related risk and hazards, such as blizzards, tornadoes, and floods.

Pls have administered a semi-formal survey instrument to over 140 individuals at the municipal level in 60 cities in Colorado, Utah and Wyoming. Survey findings indicate that while the acceptance of anthropogenic climate change widely varies among respondents, it does not appear to influence adaptation in any obvious way. In addition, results appear to show that municipalities that have experienced more disasters of greater magnitude tend to show greater adaptation. In-depth case studies of specific municipalities are underway.

Deliverables: Peer-reviewed publication in preparation for 2013 submission

WWA Funding: January–December 2012

Water, Energy, and Climate Change: Freshwater Use by Power Plants in the United States

Primary Investigator(s): K. Averyt, J. Meldrum

Partners: Union of Concerned Scientists, Western Resource Advocates, National Renewable Energy Laboratory, National Center for Atmospheric Research

Understanding the impacts of electricity generation on freshwater resources in a warming world.

Although the electricity sector accounts for a substantial portion of the total water withdrawn and consumed in the U.S., recent research led by WWA researchers demonstrates shortcomings in the current understanding of how much water is used for different technologies, life cycle stages, and fuel types within this sector. WWA researchers, in collaboration with scientists from numerous other organizations (including NCAR, NREL, and UCS), revisited the published literature to develop consistent estimates of water use for many aspects of the electricity sector and have been applying these factors to investigate current and future links between electricity generation and water supplies. This has led to numerous results in published articles, including that estimated power plant water use reported to the Energy Information Administration (EIA) deviates substantially from that calculated with literature-based estimates, although no single reason explains these discrepancies. Based on calculated values, recent research (currently under peer-review) indicates that water supplies are stressed in over 9% of watersheds in the US, and that even a single power plant has the potential to stress water supplies at the watershed scale. This analysis shows that the Western US is particularly sensitive to low flow events and projected long-term shifts driven by climate change. Other published analyses demonstrate that, from a life cycle perspective, power plant operations dominate the water use for most electricity generation technologies. When calculated per unit of electricity, water use in most cases is much lower for other processes, such as manufacturing wind turbines and photovoltaic equipment or developing unconventional natural gas deposits with hydraulic fracturing.



Looking toward the future, national water withdrawals for electricity generation are expected to drop across a variety of future scenarios for the national mix of generation technologies, whereas whether consumption will increase or decrease depends on which technologies will dominate that mix in the future. Other work under review investigates the potential impacts of changing water demands, following changes in electricity generation mix, on regional hydrology and water users. This analysis demonstrates that although thermoelectric cooling water consumption is small relative to other uses in the SW U.S., the region's physical, legal, and institutional context means that small differences between water use across electricity mix scenarios produce sometimes substantial impacts upon individual basins and water use sectors. This body of research emphasizes the importance of regional context for understanding the water implications of electricity generation, and it lays the groundwork for further investigations.

Deliverables: Paper on EIA reporting of freshwater use by power plants (Macknick et al. 2012) published in *Earth Research Letters*, numerous other publications expected in early 2013

WWA Funding: January–December 2012

Leveraged Funding: \$100,000 from Union of Concerned Scientists

Beetles, Forest Change, and Water

Primary Investigator(s): E. Gordon, J. Lukas

Partners: US Forest Service Rocky Mountain Research Station, US Forest Service Region 2, Univ. of Colorado Geological Sciences

Engaging with a diverse set of stakeholders and researchers dealing with the ongoing bark beetle infestation and developing integrated, decision-oriented information that can help stakeholders understand and plan for the current epidemic, with a particular focus on water quality and hydrologic impacts.

PIs have and are continuing to develop science seminars, outreach workshops, and synthesis papers and documents intended to communicate such information to forest and water managers. In 2012, this project produced a peer-reviewed manuscript reviewing existing science on beetle-related impacts to hydrologic processes and developing a relevant conceptual model that was published in *Hydrological Processes* (Pugh and Gordon 2012; see “Accomplishments” above). In addition, PIs surveyed attendees at a 2011 workshop in Salt Lake City and found that most were capable of making the uncertain information presented useful in their work; findings were presented at the 2012 Climate Predictions and Applications Science Workshop. Overall, the PIs have found broad interest among stakeholders for the synthesis effort and for products developed through this project. Some of what may be the least interesting aspects of this project from a research standpoint (writing a synthesis article and conducting a stakeholder workshop) have been very well received by stakeholders eager for coherent, contextualized information. An additional stakeholder workshop is scheduled for spring 2013 in southwestern Colorado.

Deliverables: Peer-reviewed article published in *Hydrological Processes* in 2012; additional stakeholder workshop to be held in 2013

WWA Funding: January–December 2012

Climate Change Preparedness Among Tribal Communities in the American West

Primary Investigator(s): K. Cozzetto, J. Nania

Partners: NIDIS, CLIMAS

Delivering climate guidance for the Navajo Nation as part of an effort to build stakeholder relationships with native communities and understanding tribes' needs for relevant climate information to prepare for climate change.

Many tribes in the Southwest face pressing challenges that would be exacerbated by a warming climate, including persistent drought and land-cover change, while socioeconomic and historical factors may limit their adaptive capacity. PIs are seeking to understand tribal efforts towards climate adaptation while bringing university-based resources to bear on those efforts. In 2012, WWA researchers joined with CLIMAS to help update the Navajo Nation's Drought Contingency Plan and produced a technical review (available at http://www.colorado.edu/projects/current/Navajo_Nation_Drought_Plan_Technical_Review.pdf). PIs have also begun to provide guidance to the Navajo on climate change adaptation planning and are expected to produce a report on climate change for the Navajo Nation in 2013 along with a project completion report aimed at elucidating the best processes for future interactions with tribes in the Southwest.

Deliverables: Technical Review of Navajo Nation Drought Plan; Climate Change Adaptation Report for Navajo Nation; project completion report to be prepared in 2013

WWA Funding: January–December 2012

Leveraged Funding: \$45,000 from NIDIS

Climate Adaptation for Salt Lake City Public Utilities

Primary Investigator(s): T. Bardsley, A. Wood (CBRFC), L. Briefer (SLCPUD), J. Niermeyer (SLCPUD), M. Hobbins (NOAA ESRL PSD), S. Burian (University of Utah), E. Goharian (University of Utah)



Partners: NOAA NWS Colorado Basin River Forecast Center, Salt Lake City Department of Public Utilities, University of Utah, NOAA ESRL PSD

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

Collaborative work aimed at advancing climate change assessment and adaption planning for Salt Lake City Department of Public Utilities continued in 2012. The results of a water supply climate sensitivity analysis along with water supply and demand scenarios, entitled: "Planning for an Uncertain Future: Climate Change Sensitivity Assessment towards Adaptation Planning for Public Water Supply" is in review for a special edition on climate change and infrastructure in the journal *Earth Interactions*. New work in collaboration with the University of Utah involves a pilot study on one of Salt Lake City's watershed creeks, where a reservoir systems planning model has been developed. Climate change scenarios have been run through the hydrology model at the Colorado Basin River Forecast Center, and the resulting hydrologies are used as input to the systems model. In combination with future water demand scenarios, assessments of changes in system reliability are being evaluated. Continued work will integrate soon-to-be-available statistically downscaled and high-resolution dynamically downscaled climate projections, test an expanded systems model, and develop more advanced water supply and demand scenarios to evaluate a range of possible future impacts to water supply to assist in defining low regrets management strategies.

Deliverables: Manuscript in review at *Earth Interactions*; multiple stakeholder presentations

WWA Funding: January–December 2012

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

Pilot Climate Extension Services in Utah

Primary Investigator(s): R. Gillies

Partners: Utah State University Cooperative Extension Program

Pilot project to develop small-scale experimental climate services in Utah as part of the broader development of a climate extension network for the state.

This project entails the development of multiple small-scale experimental climate services relevant to a potential new network of stakeholders for climate services Utah, leveraging existing networks from other extension programs. For example, PI developed forecasts of first freeze dates that were based on climatology, rather than extended weather forecasts, in response to a request from corn growers at the Utah State University agricultural experiment station. These forecasts proved more reliable and helped boost productivity as growers at the station were able to leave their crop growing longer before harvesting. WWA funding was also used to help the Utah Climate Center take over and improve an existing set of agricultural weather stations installed across Utah to measure evapotranspiration. These and other efforts are part of a broader idea of developing a climate services network that would allow WWA to help demonstrate the potential utility of establishing a formal Extension Climatologist position at Utah State University.

Deliverables: WWA white paper on pilot climate extension services for Utah in preparation

WWA Funding: January–December 2012

WWA Webinar Series

Primary Investigator(s): E. Gordon, J. Lukas

Development of a webinar series aimed at better connecting WWA research efforts with stakeholders and partners.

In April 2012, WWA initiated a webinar series aimed at better communicating the results of WWA research to stakeholder needs and to help identify potential research partners. The first webinar, entitled "Stimulating Colorado River Streamflow at Interannual and Interdecadal Time Scales and Implications for Water Resources Management," attracted more than 50 attendees. Subsequent webinars covered WWA's partnership with the US Forest Service Rocky Mountain Research Station on climate adaptation in western national forests; a WWA-Utah State University effort on landscape water use software; and an overview of research into the water-energy nexus. Additional webinars will be held in 2013.

Deliverables: Four WWA webinars conducted in 2012 (available at <http://wwa.colorado.edu/events/webinars/>)

WWA Funding: January–December 2012

Leveraged Funding: In-kind support from CIRES staff

Participating in the Evolution of Climate Science Centers (CSCs) and Landscape Conservation Cooperatives (LCCs)

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



Membership in networks of universities developing implementing Department of Interior-supported CSCs; providing guidance on the development of LCCs in the WWA region.

WWA, through its home institution (Univ. of Colorado), is part of two Department of Interior-funded CSCs—the Southwest CSC, based at the University of Arizona, and the North Central CSC, based at Colorado State University. WWA researchers help provide science direction for the CSCs, participate in the development of RFPs, and have helped set agendas and find directors for both of the CSCs. WWA's Lukas serves on the Science Working group for the Southern Rockies LCC and has reviewed funding proposals and helped prioritize the LCC's science needs.

Deliverables: Peer-reviewed paper on lessons learned at WWA RISA applicable to CSCs to be prepared in 2013

WWA Funding: January–December 2012

WWA Speakers Bureau

Primary Investigator(s): K. Averyt, J. Lukas, J. Barsugli, E. Gordon, T. Bardsley, B. Udall

Responding to stakeholder requests for WWA team members to speak on climate-related topics at events throughout the WWA region.

WWA researchers receive dozens of requests every year to speak at events throughout our region, as evidenced by many of the presentations listed in Appendix B. Examples of speaking engagements in 2012 include a presentation to the Colorado Chapter of the American Water Resources Association Luncheon on bark beetle infestations and water resources (Lukas), a presentation on climate impacts to water resources in Boulder County at a symposium for volunteers with Boulder Open Space and Mountain Parks (Gordon), a talk on uncertainties in climate science for a municipal adaptation group (Udall), a discussion of climate change impacts to Salt Lake City's water supply at a watershed symposium (Bardsley), a webinar on the energy-water nexus for the American Water Resources Association (Averyt), and a presentation on projected climate change effects on Colorado River supply for water managers in Wyoming (Lukas).

Deliverables: Presentations as listed in Appendix B

WWA Funding: January–December 2012

Completed Projects (Completed in 2012)

Paleohydrology of the Lower Colorado River Basin

Primary Investigator(s): B. Rajagopalan, J. Lukas, L. Wade, C. Woodhouse (U. of Arizona/CLIMAS)

Partners: Univ. of Colorado Civil Engineering Dept., Colorado Water Institute, Colorado River Water Conservation District

Investigating the natural long-term variability of the Lower Colorado River basin using tree-ring estimates of past flows, and incorporating that paleo-variability into risk modeling for the entire Colorado River Basin.

This project was completed in 2012, meeting its objectives of (1) reconstructing the long-term hydrologic variability of the Lower Colorado River Basin back to at least 1600 using multiple statistical methods, including two novel approaches, and (2) incorporating that variability into Colorado River Basin system risk modeling. PIs deployed two new reconstruction methods, one of which for the first time allowed paleo-reconstruction of the highly intermittent gaged flows of the Gila River. They found that the pre-1900 streamflows in the Lower Colorado Basin were generally lower than those of the past century, but with more extreme low *and* high flows occurring before 1900. They also found that the Gila River's periodic and significant discharges into the mainstem of the Colorado do have a measurable impact on modeled system risk (e.g., of reservoir drying), pointing to the potential benefits of managing these inflows in a more coordinated manner. In addition to a master's thesis (L. Wade), the project produced an article published in the stakeholder-oriented *Colorado Water*, a completion report, and two manuscripts in preparation.

Deliverables: M.S. Thesis (L. Wade) completed in 2012; article published in *Colorado Water* November 2012; completion report (available at <http://cwi.colostate.edu/publications/cr/223.pdf>); two peer-reviewed manuscripts in preparation

WWA Funding: January–July 2012

Leveraged Funding: \$30,000 from Colorado Water Institute at Colorado State University

Framework for Colorado River Water Availability Assessment

Primary Investigator(s): B. Rajagopalan, A. Verdin

Partners: Center for Advanced Decision Support for Water and Environmental Systems (University of Colorado Boulder), Bureau of Reclamation



Examination of range of potential supply capacity in the Colorado River system given the existing storage capacity, variability, and possible flow reductions due to climate change.

Building on the findings in Rajagopalan (2009), PIs developed a representation of the Colorado River system with the two storage “tubs” representing Lakes Powell and Mead. The study examined ways to maximize yield with existing the water balance constraints. PIs also set a minimum storage constraint so the system does not go below a certain level. Optimization was driven by stochastic inputs of streamflow under natural and climate change variability, using scenarios from Rajagopalan et al. (2009). Each simulation was then driven through the optimization and the optimal yield obtained. From this PIs were able to compute the probability density function of the optimal yields and look at yields for different risk levels. Results showed that reliability at the current level of consumption (~12.7MAF) is > 95% under natural variability and approximately 87% under a climate change-induced reduction of 20% in flow. These numbers dropped to 89% and 57%, respectively, when a condition to keep the system at 40% capacity was imposed. Furthermore, the reliability drops significantly for even modest increases in consumption. The PDFs of the yields and the associated reliability provides a complete picture to policy makers and other stakeholders interested in how management alternatives might improve system reliability in the future. A peer-reviewed manuscript summarizing these findings will be submitted in 2013.

Deliverables: Peer-reviewed manuscript to be submitted in 2013.

WWA Funding: January–July 2012

Understanding Utility Disincentives to Urban Outdoor Water Conservation as a Means of Adapting to Climate Change Pressures

Primary Investigator(s): D. Kenney

Investigation of how institutional incentives may affect the use of outdoor water conservation by water utilities as a climate adaptation strategy.

Water conservation is an obvious strategy for utilities to minimize their exposure to shortages associated with climate variability and change. But while this risk-management argument may be intuitive, the reality is that many powerful institutional incentives encourage an accelerated expansion in water systems and consumption. In this investigation, the PI focused on two types of factors that discourage conservation: the notion that a system favoring high levels of non-essential uses is “adaptive” in that it maintains a cushion of uses that can easily be curtailed; and the desire to maintain revenue streams associated with high levels of water sales. Overcoming this first type of disincentive likely entails challenging long-standing norms about “smart management,” but also implicates the inability of water agencies to control the land-use decisions that shape municipal water demands. Overcoming the fiscal disincentives to conservation also involves changing rules outside the control of most water utilities, in this case those rules associated with the design of revenue models. In sum, the path toward using water conservation as a tool for minimizing the risks of climate variability and change hinges on the ability and willingness of actors largely outside the water community to reshape the incentive structure guiding water utility behavior. Experimentation with improved management approaches is in its infancy, with the most insightful lessons emerging from other sectors—namely the electricity sector. A white paper describing this project and its findings will be released in 2013.

Deliverables: WWA white paper in 2013

WWA Funding: January–July 2012

Climate Adaptation in Western National Forests

Primary Investigator(s): J. Rice, L. Joyce (USFS), J. Lukas

Partners: US Forest Service Rocky Mountain Research Station

Completing a pilot climate vulnerability assessment for the Shoshone National Forest as part of a broader effort by the US Forest Service to support climate adaptation by western National Forests.

WWA post-doctoral fellow Rice worked with Joyce and other researchers at the Forest Service’s Rocky Mountain Research Station in Fort Collins, CO and staff on Wyoming’s Shoshone National Forest to conduct a pilot vulnerability assessment. The first component of this project was a synthesis report that identified past and current climate changes as well as the potential for climate change to affect natural disturbances and many ecosystem services produced in the Shoshone National Forest. This report, published by the USFS in 2012, is now being used as a resource in the Shoshone’s forest planning process. The second component was the development of an assessment to identify potential vulnerabilities of the Shoshone NF to climate change. The Shoshone staff identified water availability, the Yellowstone cutthroat trout, and vegetation as key resources to consider in the assessment. The PIs spatially categorized vulnerability for these resources using several projected climate futures, and hydrologic and vegetation models to assess sensitivity and exposure. Results from this assessment have already been used to assist the Forest in directions for monitoring, and an evaluation of potential locations for restoration projects for Yellowstone cutthroat trout habitat. The funding provided in 2012 was used for completion and review of the climate vulnerability assessment and publication of technical reports on vulnerability assessment of vegetation, water availability, and coldwater fish habitat.

Deliverables: Peer-reviewed US Forest Service technical report published in 2012; peer-reviewed publications on the vulnerability assessments expected in 2013

WWA Funding: January–July 2012



Leveraged Funding: \$37,000 from US Forest Service through Research Joint Venture agreement

Assessing the Utility of Regional Climate-Driven Water Quality Modeling in the Intermountain West

Primary Investigator(s): J. McCutchan, M. Huisenga

Determining stakeholders' needs for climate-driven water quality modeling at regional and other scales and developing a database of existing water quality parameters useful for monitoring climate impacts on water quality.

Due to the complex interactions among factors affecting many aspects of water quality, the effects of climate change on water quality can sometimes be counterintuitive and are best evaluated through modeling. Before beginning modeling work, however, PIs sought to better understand what dischargers, government agencies, and other groups would find most useful in water quality modeling. A survey of 105 stakeholders working in water supply, water treatment and water quality regulation showed that respondents were most interested in nutrients, algae, pH, and temperature. Respondents also expressed general interest in water quality and in some specific water-quality variables that may be affected by climate, but many respondents also requested information on expectations for climate variability and hydrologic responses to climate change (e.g., how much change in timing or amount of discharge can be expected). Thus, enhanced climate literacy will likely make it easier to explain and understand the potential effects of climate variation on water quality. Aside from site-specific interests, there was considerable interest in headwaters (i.e., source areas) and transitional streams (i.e., foothills-plains transition). PIs then completed assembling a database of variables including discharge, temperature, nutrients, chlorophyll, dissolved oxygen, pH, conductivity to support modeling the effects of climate on water-quality in Colorado, Utah, and Wyoming. This work helps indicate that complex, mechanistic and semi-mechanistic models are well suited to some purposes, but that stakeholders prefer site-specific mass balance models when model results will be used to support regulatory decisions. A summary of the survey, model assessment, and database efforts will be compiled into a white paper in 2013, providing overall insight into the utility of water quality modeling under climate change.

Deliverables: WWA White Paper in preparation

WWA Funding: January–July 2012

Monitoring Network for the North Platte Headwaters at the Little Laramie River

Primary Investigator(s): S. Miller

Design and installation of a monitoring network that will monitor a number of critical variables to understand the conversion of snow and rain to soil water, groundwater, and runoff.

In 2012, the University of Wyoming completed instrumentation of the headwater streams of the Little Laramie River and instituted a data sharing policy with cooperators. A graduate student assistant (Alan Klatt) was recruited onto the project, with leveraged funding provided by the State of Wyoming to support the monitoring, outreach and modeling efforts. Additional significant funding was provided by the Wyoming Center for Environmental Hydrology and Geophysics, an NSF-sponsored research initiative, and Dr. Noriaki Ohara, a recent addition to the hydrology faculty at University of Wyoming. This resulted in the additional installation of groundwater wells and supplemental runoff, climate and snow observational networks. In support of understanding the fate and transport of water in the research area, the University installed seven new runoff observation stations to supplement the existing observation network and an additional 9 in-situ temperature stations in a nested watershed design for a total of 19 temperature flux sites. PIs will institute an isotope sampling protocol in spring 2013 at 10 runoff sites, multiple snow surveys and rainfall stations to investigate whether the streams are receiving waters from rainfall, snow, or groundwater. Statistical analyses of climate and runoff data have allowed us to develop fundamental relationships to predict total annual runoff and peak discharge based on climatological observations, which is of importance to stakeholders. PIs also established relationships with local stakeholders including the state engineer, USFS and research scientists and are developing a data sharing and information exchange program.

Deliverables: In-kind contributions from University of Wyoming Center for Environmental Hydrology and Geophysics

WWA Funding: January–July 2012

Leveraged Funding: \$45,000 in State of Wyoming funds

Towards Frameworks for Climate Services: Meeting the Needs of Different Users with Different Information Requirements

Primary Investigator(s): K. Averyt, T. Bardsley, K. Werner (CBRFC) G. Owen (CLIMAS)

Partners: CLIMAS, NOAA NWS Colorado Basin River Forecast Center



Presenting the RFC Water Resources Outlook tool at user workshops to help identify differences in the user populations and determine changes in the Water Resources Outlook product that might be necessary for a different suite of users.

WWA researchers Kristen Averyt and Tim Bardsley worked with the NOAA Colorado Basin River Forecast Center (CBRFC) to better understand how water managers interpret and use streamflow forecast information through a series of interactive workshops. Workshops were held in 2010 and 2011 in numerous locations. During these workshops the PIs introduced a gaming exercise that involved forecasted flows and reservoir schedules. These engagements have improved managers' understanding of available products and user driven improvements to CBRFC web based tools. In addition, scenario-based exercises indicate that most participants tend to use the median forecasts rather than worst-case scenario predicted at the tails of forecast ranges, and many use a wait-and-see approach to planning. These efforts are feeding into continued adjustment of decision support forecasts based on improved understanding of decision-making constraints and processes. A publication entitled "River Forecast Application for Management: Oil and Water?" is in press for *Weather, Climate, and Society* (Werner et al., in press). Future work by L. Dilling (see "Analysis of Use of Information by Stakeholders of the Colorado Basin River Forecast Center" below) will build on this effort.

Deliverables: Peer-reviewed article in press at *Weather, Climate, and Society*

WWA Funding: January–July 2012

Leveraged Funding: In-kind support from NOAA CBRFC

National Climate Assessment Energy-Water-Land Sectoral Chapter Technical Input

Primary Investigator(s): K. Averyt

WWA researcher serving as a lead author on a sectoral technical input for the National Climate Assessment's 2013 report.

WWA researcher Averyt is an author of the technical input for the energy-water-land chapter of the National Climate Assessment. This report provides an overview of climate interactions with energy-water-land systems, assesses the state of scientific understanding, and identifies gaps and challenges. A final version of the technical input is available at http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-21185.pdf.

Deliverables: Final version of energy-water-land technical input report completed in 2012; NCA chapter expected in 2013; presentation at regional NCA town hall in 2013

WWA Funding: January–December 2012

A Socioeconomic Impacts and Adaptation Strategies Clearinghouse

Primary Investigator(s): R. Klein, W. Travis

Development of an online, searchable database to provide stakeholders with resources regarding socioeconomic impacts of climate change in the Western Water Assessment region.

In 2012, the online, searchable database structure was completed. It has been populated with peer- and non-peer-reviewed articles, reports, websites, and presentations addressing the socioeconomic impacts of various climate phenomena. The items can be sorted by sector (e.g., agriculture, outdoor recreation—which can further be broken down by type of activity—and water), phenomenon (climate variability, climate change, drought, floods, fire, heat waves, extreme events), and geographical location. In general, more literature about the socioeconomic impacts of climate variability and change on outdoor recreation was found than initially expected. PIs wrote and published two WWA White Papers describing results: "Socioeconomic Impacts and Adaptation Strategies: Assessing Research on Quantification of Drought Impacts" (<http://www.colorado.edu/publications/reports/2012.01.pdf>) and "Assessing Measurements of Drought Impact and Vulnerability in the Intermountain West" (<http://www.colorado.edu/publications/reports/2009.01.pdf>). Research findings have been shared directly with stakeholders, including the Western Governors' Association and the National Integrated Drought Information System.

Deliverables: Database (<http://www.socioeconimpacts.org>) and WWA White Papers completed in 2012

WWA Funding: January–July 2012

Update of WWA Website

Primary Investigator(s): J. Lukas, E. Gordon

WWA's website, critical to effective communication with stakeholders, was updated to better meet stakeholder needs and appropriately reflect WWA's mission and activities.

In October 2012, coincident with WWA's annual Stakeholder Meeting, WWA launched a completely updated website (see <http://www.colorado.edu>). The website was rebuilt from scratch, reflecting comments from WWA stakeholders and partners that the previous



site was cumbersome and difficult to use. All content on the website is now reachable through no more than two clicks by using drop-down menus. The site has been well-received by stakeholders as it serves two critical functions: 1) clearly explaining to stakeholders and partners what WWA does and 2) acting as a user-friendly portal for accessing climate and other information relevant to resource management in the Intermountain West.

Deliverables: Updated WWA website (<http://wwa.colorado.edu>)

WWA Funding: January–December 2012

Leveraged Funding: In-kind support from CIRES and CSTPR staff



APPENDIX A: List of 2012 WWA Publications

Archie, K. M., L. Dilling, J. B. Milford and F. C. Pampel. (2012). Climate Change and Western Public Lands: A Survey of U.S. Federal Land Managers on the Status of Adaptation Efforts. *Ecology and Society* 17(4).

Averyt, K. (2012). Freshwater Use by U.S. Power Plants: Initial insights into the energy-water nexus. *Intermountain West Climate Summary* 8(2).

Averyt, K. (2012). The Coal Conundrum. In: *The Water-Energy Nexus in the Western United States*, D. Kenney and R. Wilkinson, Eds. Cheltenham: Edward Elgar Publishing.

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APPENDIX B: List of 2012 WWA Presentations

January 23, 2012

K. Averyt

“Does Climate Attribution of Extreme Climate Events Matter?”

American Meteorological Society Annual Meeting, New Orleans, LA

January 27, 2012

J. Lukas

“Wyoming climate: Past variability and trends, future projections, and implications for wildlife and habitats”

Presentation to Wyoming Fish & Game Commission, Cheyenne, WY

January 31, 2012

K. Averyt

“An Introduction to the Energy-Water Nexus”

American Water Resources Association, Webinar

January 31, 2012

J. Lukas

“Bark beetle impacts on Colorado water supplies: Still waiting for the shoe to drop?”

American Water Resources Association (AWRA) Colorado Chapter Luncheon, Denver Water, Denver, CO

March 1, 2012

K. Averyt

“The Energy-Water Nexus: Challenges for the Southeastern United States”

Duke Energy, Board Meeting, South Carolina

March 9, 2012

J. Lukas

“Drought, climate change, the water cycle, and ecosystems: Linkages and feedbacks in Colorado”

Climate Change and Water Resources Workshop, Colorado Foundation for Water Education, Lakewood, CO

March 13, 2012

E. Gordon

“Understanding the Utility of Uncertain Scientific Information Regarding Bark Beetle Infestations, Water Resources, and Climate for Natural Resource Managers”

10th Annual Climate Prediction Applications Science Workshop, Miami, FL

March 15, 2012

K. Averyt

“Use-Inspired Social Science”

Climate Prediction Applications Science Workshop. Miami, FL

March 19, 2012



E. Gordon

“The Secondary Impacts of Climate Change on the Western Adaptation Alliance Region”

Western Adaptation Alliance Regional Leadership Academy, Denver, CO

March 20, 2012

E. Gordon

“Colorado Climate Preparedness Project”

Western Adaptation Alliance Regional Leadership Academy, Denver, CO

March 22, 2012

K. Averyt

“Perspectives in Information Needs to Support Water Resource Planning”

Presentation to Department of Energy, Energy Information Administration, Washington, DC

March 27, 2012

K. Averyt

“Power Generation and Water Stress in the US: Science to Inform Choices about Our Energy, Water and Climate Future”

Planet Under Pressure Meeting, London, UK

March 29, 2012

L. Dilling

“Climate Adaptation Barriers and Opportunities in the United States: A Focus on Policy and Decision Making at the Sub-National Scale”

Planet Under Pressure Meeting, London, UK

April 3, 2012

T. Bardsley

“Climate Change Sensitivity and Water Demand Analysis for Public Water Supply”

Utah State University Spring Runoff Conference, Logan, UT

April 3, 2012

J. Lukas

“TreeFlow: Tree-ring paleohydrology across the western U.S. and its application to water management”

Utah State University Spring Runoff Conference, Logan, UT

May 1, 2012

E. Gordon and J. Lukas

“The Western Water Assessment: Using Climate and Water Expertise to Support Stakeholders in the Intermountain West”

Wyoming State Water Forum, Cheyenne, WY

May 1, 2012

J. Lukas

“Assessing the Future Climate Risk to Upper Colorado River Basin Water Supply: Results from the Most Recent Studies”

Wyoming State Water Forum, Cheyenne, WY



May 2, 2012

B. Udall

“Science Water Policy Challenges and Solutions in the American West: Lessons from the Klamath, Sacramento-San Joaquin, and Colorado Rivers”

American Geophysical Union Science Policy Conference, Washington, DC

May 15, 2012

J. Lukas

“The long view: What tree rings tell us about climate and water in Colorado”

Denver Museum of Nature and Science, Denver, CO

May 30, 2012

L. Dilling

“Defining Adaptation Success in Natural Resource Management”

Adaptation Futures: 2012 International Conference on Climate Adaptation, Tucson, AZ

May 31, 2012

W. Travis

“Extreme Events: Pacemakers of Adaptation?”

Adaptation Futures: 2012 International Conference on Climate Adaptation, Tucson, AZ

May 31, 2012

B. Udall

Panelist on “Perspectives from Ground Zero: Adapting to Climate Change in the Southwest—Key Themes from the U.S. National Climate Assessment Southwest Region Technical Report”

Adaptation Futures: 2012 International Conference on Climate Adaptation, Tucson, AZ

June 7, 2012

K. Averyt

“Low Carbon Electricity: Implications for Water Resources”

University of Colorado Natural Resources Law Center 2012 Clyde Martz Summer Conference, Boulder, CO

June 12, 2012

K. Averyt

The Water Energy Nexus: Will We Have Enough Water?

Western Public Utilities Commissioners, Annual Meeting, Bend, OR.

July 15, 2012

B. Udall

“Detection and Attribution of Extreme Events: Is the Scientific Community Providing a Service or a Disservice?”

37th Annual Natural Hazards Research and Applications Workshop, Boulder, CO

July 16, 2012

J. Lukas, L. Wade, and B. Rajagopalan



“Paleohydrology Reconstructions for the Lower Colorado River Basin and Implications for Water Supply Reliability”

Presentation to Colorado River Water Conservation District, Glenwood Springs, CO

July 23–27, 2012

K. Averyt

“The Intergovernmental Panel on Climate Change: Then and Now”

“The USGCRP National Climate Assessment”

“Communicating Climate Science: You are the 1%”

International Arctic Research Center Summer School, Climate System Modeling: Downscaling techniques and practical applications, University of Alaska Fairbanks

August 7, 2012

K. Averyt

“The Energy-Water Nexus: Low Carbon Electricity and Implications for Water Resources”

ASME Nanotechnology Institute Energy-Water Nexus Webinar Series

August 27, 2012

B. Udall

“Making Projections Useful to Researchers and Users”

Methods of Projecting Hydrologic Impacts of Climate Change Workshop, Muskegon, Michigan

August 28, 2012

E. Gordon

“Climate Variability and Change: How do they Impact Colorado’s Water?”

Climate Change Symposium with Boulder Open Space and Mountain Parks, Boulder, CO

September 25, 2012

K. Averyt

“Climate Mitigation & Adaptation Nexus: How Might Future Electricity Generation Choices Impact Water Resources?”

Dept. of Energy Workshop On Community Modeling And Long-Term Predictions Of The Integrated Water Cycle, Washington D.C.

September 26, 2012

T. Bardsley

“Climate Change and Salt Lake City’s Water Supply”

2012 Salt Lake Countywide Watershed Symposium, Salt Lake City, CO

October 2, 2012

J. Rice

“A vulnerability assessment tool for adapting Yellowstone cutthroat trout to climate change on the Shoshone National Forest”

Poster presented at MTNCLIM 2012, Estes Park, CO

October 8, 2012

J. Lukas



“Drought and climate change in Colorado: What can we expect?”
Natural Resources Seminar Series, Colorado Mesa University, Grand Junction, CO

October 18, 2012

B. Udall
“Fundamental Uncertainties in Climate Science”
Arizona Municipal Climate Planning Workshop, Tucson, AZ

October 19, 2012

K. Averyt
“Squeezing Blood from a Desert: Western Water Management”
Society of Environmental Journalists, Lubbock, TX.

October 25, 2012

J. Lukas
“We’ve been here before: A multi-century tree-ring perspective on drought in the South Platte Basin”
23rd Annual South Platte Forum, Longmont, CO

November 8, 2012

E. Gordon
“A Conceptual Model of Water-Related Impacts from Bark Beetle Infestations”
Colorado Mesa University Upper Colorado River Basin Water Conference, Grand Junction, CO

November 8, 2012

B. Livneh
“Hydrologic Impacts of the Mountain Pine Beetle on Tributary Catchments of the Upper Colorado River Basin”
Colorado Mesa University Upper Colorado River Basin Water Conference, Grand Junction, CO

December 4, 2012

J. Barsugli
“A critical evaluation of bias and uncertainty in the use of downscaled climate projections in water resources impacts modeling”
2012 American Geophysical Union Fall Meeting, San Francisco, CA

December 5, 2012

J. Deems
“Integration of ground-based and airborne LIDAR data for improved model terrain generation”
2012 American Geophysical Union Fall Meeting, San Francisco, CA

December 5, 2012

B. Livneh
“Interpreting changes to Upper Colorado River Basin hydrologic response via alternate climatic and land-cover scenarios”
2012 American Geophysical Union Fall Meeting, San Francisco, CA

December 5, 2012



D. Schneider

“A regression-based approach for blending remotely sensed and in-situ snow-water equivalent estimates in the Colorado River Basin”

2012 American Geophysical Union Fall Meeting, San Francisco, CA

December 6, 2012

J. Deems

“Multiscale hydrologic impacts of dust deposition and climate warming in the Upper Colorado River Basin”

2012 American Geophysical Union Fall Meeting, San Francisco, CA

December 6, 2012

J. Meldrum and K. Averyt

“Sectoral Vulnerabilities to Changing Water Resources: Current and Future Tradeoffs between Supply and Demand in the Conterminous U.S.”

Poster presented at 2012 American Geophysical Union Fall Meeting, San Francisco, CA

December 10, 2012

M. Huisenga, K. Clifford, and W. Travis

“An Agent-Centered Decision-Analytic Approach to Climate Change Adaptation”

Society for Risk Analysis Annual Meeting, San Francisco, CA

December 11, 2012

J. Barsugli

“Future Climate of Colorado and the Southwest”

Colorado Climate Network Third Annual Conference, Aurora, CO

December 11, 2012

B. Udall

“Climate Change Impacts on Water”

Colorado Climate Network Third Annual Conference, Aurora, CO

December 11, 2012

E. Gordon

“Colorado Climate Preparedness Project”

Colorado Climate Network Third Annual Conference, Aurora, CO



APPENDIX C: WWA Appearances in Media

January 9, 2102

“A warmer future could make Colo. mountain hail disappear”

E & E ClimateWire

Kelly Mahoney

<http://www.eenews.net/climatewire/2012/01/09/7>

“Boulder study: Hail could vanish from Front Range by 2070”

Daily Camera (Boulder, CO)

Kelly Mahoney

http://www.dailycamera.com/boulder-county-news/ci_19707732

January 17, 2012

“Review of *A Great Aridness: Climate Change and the Future of the American Southwest*”

Climate Progress Blog

Brad Udall

<http://thinkprogress.org/romm/2012/01/17/392184/review-a-great-aridness-climate-change-and-the-future-of-the-american-southwest/?mobile=nc>

January 22, 2012

“Draft of Boulder County ‘Climate Change Preparedness Plan’ finished”

Daily Camera (Boulder, CO)

Western Water Assessment mentioned (work by Eric Gordon and Joe Barsugli)

http://www.dailycamera.com/boulder-county-news/ci_19786666

February 2012

“Climate science: A future Colorado without Hail”

Nature Climate Change: News and Views

Kelly Mahoney

http://www.nature.com/nclimate/journal/v2/n2/full/nclimate1396.html?WT.ec_id=NCLIMATE-201202

February 7, 2012

“Climate change to be key in Shoshone Forest plan”

Billings Gazette

Reference to climate vulnerability assessment authored by Janine Rice et al.

http://billingsgazette.com/news/state-and-regional/wyoming/climate-change-to-be-key-in-shoshone-forest-plan/article_89554eb0-bde6-5c7d-8b05-dee5f75b560b.html

February 16, 2012

“Recent extreme weather affected 80% of Americans”

USA Today

Kristen Averyt

<http://www.usatoday.com/weather/news/extremes/story/2012-02-16/extreme-weather-climate-change-global-warming/53116220/1>



March 13, 2012

“Duke: Catawba River ‘stress’ study unfair”

Lake Wylie (SC) Pilot

Kristen Averyt

<http://www.lakewyliepilot.com/2012/03/13/1461827/duke-catawba-river-stress-studies.html>

March 15, 2012

“Climate study warns of possible changes to Shoshone Forest”

Billings (MT) Gazette

Janine Rice

http://billingsgazette.com/news/state-and-regional/wyoming/climate-study-warns-of-possible-changes-to-shoshone-forest/article_a51f7771-8f6c-53ed-a4ba-161523f6888b.html

March 18, 2012

“Boulder water managers, scientists mull impacts of pine beetles on water supply”

Boulder Daily Camera

James McCutchan

http://www.dailycamera.com/boulder-county-news/ci_20197754/boulder-water-managers-scientists-mull-impacts-pine-beetles

June 6, 2012

“Warmer average temperatures may reduce summer output of power plans – study”

E&E News Climatewire

Kristen Averyt

www.eenews.net/climatewire/print/2012/06/04/2 (subscription required)

June 13, 2012

“Is drought a side effect of Southwest warming?”

Arizona Daily Star

Brad Udall and Jeff Lukas

http://azstarnet.com/news/science/environment/is-drought-a-side-effect-of-southwest-warming/article_e8d91f20-13dd-5aec-bd0e-9c9242c6cc2b.html

June 29, 2012

“Death Valley heat in Kansas? How the end of June got so hot.”

Christian Science Monitor

Klaus Wolter

www.csmonitor.com/layout/set/print/content/view/print/535868

July 3, 2012

“Dear monsoon, please materialize”

High Country News

Klaus Wolter

www.hcn.org/blogs/goat/dear-monsoon-please-materialize?utm_source=wcn1&utm_medium=email

July 5, 2012

“Boulder, Front Range can hold out hope for wet second half of 2012”



Boulder Daily Camera

Klaus Wolter

http://www.dailycamera.com/weather/ci_21003048/boulder-front-range-can-hold-out-hope-wet?source=most_viewed

October 10, 2012

“Climate models show long-range reduction in West Slope water supply”

Grand Junction (CO) Sentinel

Jeff Lukas

<http://www.gjsentinel.com/news/articles/hot-dry-future-in-the-forecast> (subscription required)

October 11, 2012

“WATER LINES: Climate change likely to heat up Western Colorado” (Column by Hannah Holm)

Grand Junction (CO) Sentinel

Jeff Lukas

http://www.gjfreepress.com/article/20121012/COMMUNITY_NEWS/121019995

November 16, 2012

“The future is now for the Colorado River Basin”

Denver Post

Op-ed by Doug Kenney

<http://blogs.denverpost.com/opinion/2012/11/16/future--colorado--river--basin/29151/>

December 4, 2012

“Disappearing Act: James Balog’s Quest to Capture Climate Change in Action”

Outside Magazine

Jeff Deems

<http://www.outsideonline.com/outdoor-adventure/science/Disappearing-Act-Balog.html?page=all>