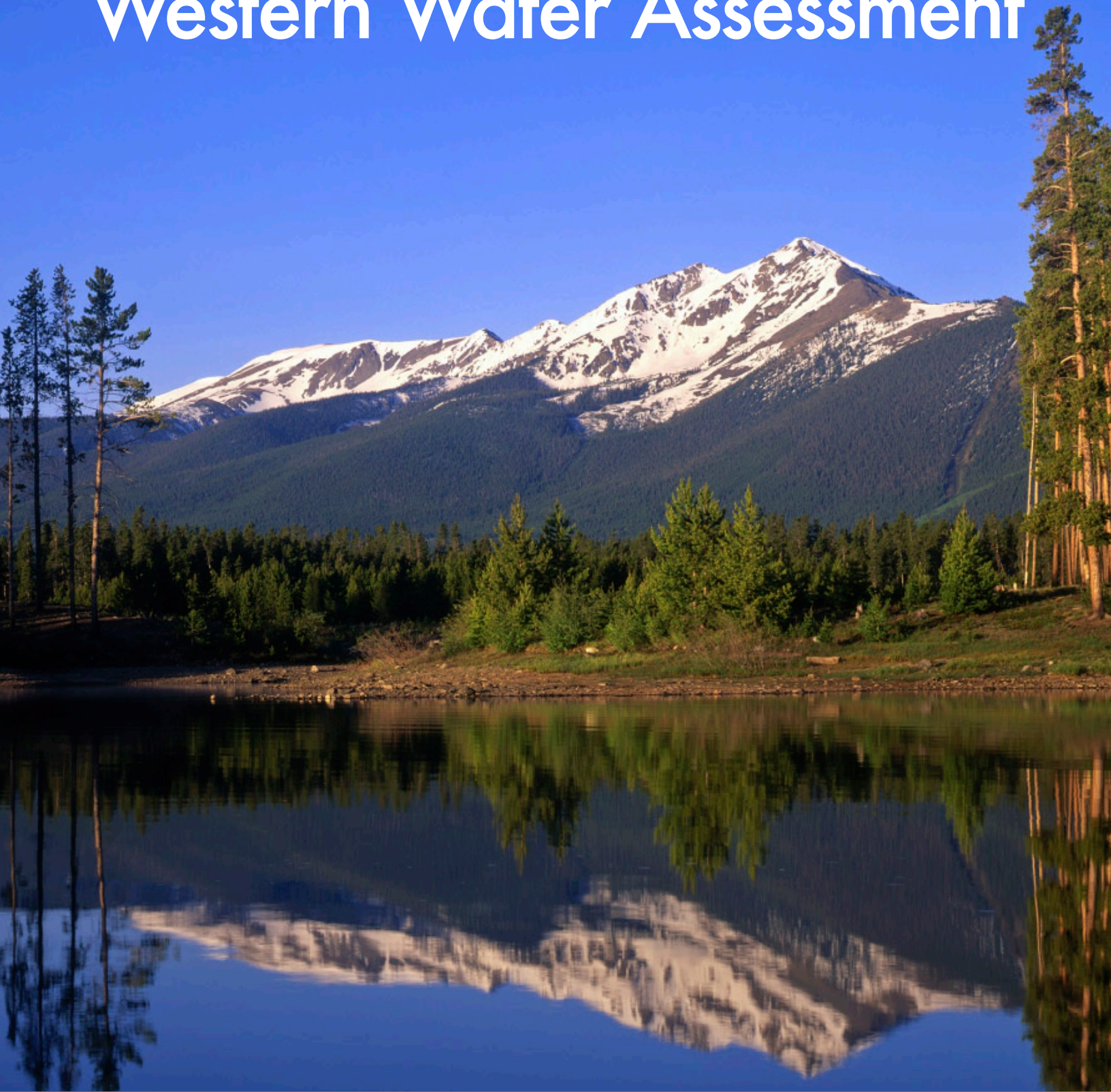


Western Water Assessment



2011 ANNUAL REPORT



Western Water Assessment



University of Colorado **Boulder**



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<p>Principal Investigators Bradley Udall (Lead), University of Colorado-Boulder Konrad Steffen, University of Colorado-Boulder 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, 2011–December 31, 2011.



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, and across the US.

Current Research Themes

WWA research and decision support products fall within one of three thematic categories:

- (1) Decision Support for the Colorado River Basin and Headwaters
Providing resource managers with the tools, data, and information about climate necessary to support management decisions in the Colorado River Basin and its headwaters region.
- (2) Ecological Vulnerabilities, Impacts, and Adaptation
Assessing the ecological impacts of climate change and variability in Western landscapes and the resulting effects on water quality and quantity and other ecosystem services.
- (3) Emerging Initiatives and Adaptation Strategies to Inform Climate Services
Responding to the needs of decisionmakers to find productive strategies to adapt to both climate change and natural climate variability.

In addition, WWA received funding in 2011 to engage in efforts to support the National Climate Assessment. A full list of research projects broken down by theme is available on pages 12-28.

New Areas of Focus

Within the existing themes 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 for 2011 are described in Table 1.

Table 1. New areas of research focus in 2011.

Area of Focus	Relevant Projects (see pp. 12-28)
Climate adaptation support for municipalities	<ul style="list-style-type: none"> • Boulder County (CO) Climate Change Preparedness Plan • Climate Adaptation Support for Salt Lake City Public Utilities • Drivers of Local Adaptation
Opportunities for improved water conservation among municipal and industrial (M&I) water providers	<ul style="list-style-type: none"> • Understanding Utility Disincentives to Urban Outdoor Water Conservation as a Means of Adapting to Climate Change Pressure • Motivating and Empowering Household Water Use Efficiency • Tools for Assessing Urban Landscape Water Use Efficiency
Lessons learned from international contexts	<ul style="list-style-type: none"> • Lessons Learned from Australia’s Drought Experiences



for drought planning in the Southwest US

Climate impacts and public land management	<ul style="list-style-type: none"> • Climate Change Impacts on Public Lands in the Upper Colorado River Basin • Climate Adaptation in Western National Forests • Climate-Related Decisionmaking on Public Lands in the Intermountain West • NEPA, Climate Change, and Public Lands Decisionmaking • Analysis of Policy Options for Mitigating Dust Production on the Colorado Plateau
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WWA Staff and Research Team

WWA is comprised of a core staff of five (Table 2) who focus on program management, research development and synthesis, and coordination of stakeholder interactions. Using an internal proposal and review process, WWA also funds 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 2. WWA Core Office Staff

Brad Udall	Director	bradley.udall@colorado.edu
Kristen Averyt	Deputy Director	kristen.averyt@colorado.edu
Jeff Lukas	Senior Research Associate	lukas@colorado.edu
Eric Gordon	Program Manager	esgordon@colorado.edu
Tim Bardsley	Utah Liaison	www.bardsley@gmail.com

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, federal land management
Averyt, Kristen	Deputy Director, Western Water Assessment	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
Bracken, Cameron	Graduate Research Assistant, Univ. of Colorado	Water resources engineering
Buma, Brian	Graduate Research Assistant, Univ. of Colorado	Remote sensing; landscape ecology
Cody, Kelsey	Graduate Research Assistant, Univ. of Colorado	Water policy
Cordalis, Daniel	Graduate Research Assistant, Univ. of Colorado	Tribal policy and law
Cozzetto, Karen	Postdoctoral Research Associate, Department of Environmental Studies, Univ. of Colorado	Hydroclimatology, surface water hydrology and ecology
Deems, Jeff	Research Scientist, CIRES, Univ. of Colorado	Climate and snow modeling
Dilling, Lisa	Assistant Professor, Environmental Studies, Univ. of Colorado	Climate information and decision-making
Duren, Sabre	Graduate Research Assistant, Univ. of Colorado	Tribal and environmental policy



Team Member	Title	Expertise
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	Program Manager, Western Water Assessment	Climate adaptation
Gray, Stephen	Wyoming State Climatologist, Univ. of Wyoming	Climatology and paleoclimatology
Kenney, Douglas	Director, Western Water Policy Program, NRLC, Univ. of Colorado	Western water policy and law
Klein, Roberta	Managing Director, Center for Science and Technology Policy Research, Univ. of Colorado	Environmental policy
Lukas, Jeffrey	Senior Research Associate, Western Water Assessment	Paleohydrology, forest ecology
Mahoney, Kelly	Postdoctoral Research Associate, UCAR, CLIVAR, PACE	Extreme precipitation, numerical modeling, warm season convection
McCutchan, James	Deputy Director, Center for Limnology, CIRES, Univ. of Colorado	Limnology
Miller, Scott	Associate Professor, Renewable Resources, Univ. of Wyoming	Spatial processes in watershed hydrology
Molotch, Noah	Assistant Professor, Dept. of Geography, Univ. of Colorado	Snow hydrology
Nania, Julie	Research Assistant, NRLC, Univ. of Colorado	Tribal law
Nowak, Kenneth	Graduate Research Assistant, Univ. of Colorado	Water resources engineering
Painter, Thomas	Research Scientist, NASA Jet Propulsion Laboratory, California Institute of Technology	Hydrology
Rajagopalan, Balaji	Associate Professor, Civil Engineering, Univ. of Colorado	Water resources engineering
Rangwala, Imtiaz	Post-doctoral Research Associate, UCAR, CLIVAR, PACE	High-elevation climatology
Ray, Andrea	Scientist, Climate Analysis Branch, NOAA ESRL Physical Sciences Division	Climate-society interactions, water management
Rice, Janine	Research Scientist, CIRES, Univ. of Colorado (located at US Forest Service Rocky Mountain Research Station)	Climate impacts and adaptation in National Forests
Rosenberg, David	Assistant Professor, Civil and Environmental Engineering, Utah State Univ.	Water resources engineering
Squillace, Mark	Director, NRLC, Univ. of Colorado	Natural resources and water law
Teel-Simmonds, Julie	Senior Research Associate, Center for Energy and Environmental Security, Univ. of Colorado	Energy law; climate policy; tribal climate adaptation
Travis, William	Associate Professor, Geography; Director, CSTPR, Univ. of Colorado	Natural hazards; climate impacts and adaptation
Udall, Bradley	Director, Western Water Assessment	Colorado River, hydrology, policy
van Drunick, Suzanne	Assistant Director for Science, CIRES, Univ. of Colorado	Hydrology and ecology
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



Team Member	Title	Expertise
West, Nicholas	Graduate Research Assistant, Univ. of Colorado	Tribal policy and law
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 a significant number of other stakeholders and partners, met in September 2011; WWA staff members also regularly consult with board members on an informal basis.

Although the Advisory Board represents a number of organizations in the Intermountain West, they represent a small subset of our overall stakeholder network. A more complete list of WWA stakeholders and partners is available at http://wwa.colorado.edu/about_us/docs/Stakeholders_2011.pdf.

Table 4. WWA Stakeholder Advisory Board

Curtis Brown	Director, Research and Development, Science and Technology Division, US Bureau of Reclamation
Terrance Fulp	Deputy 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 Water Conservation 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 Schmidt	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
Robert Wigington	Western Water Policy Counsel, The Nature Conservancy

WWA 2011 Highlights

Major Research Findings in 2011

- Shifting Colorado River water storage to increase levels in Lake Powell relative to Lake Mead can increase overall system reliability in the face of flow reductions due to climate change, but doing so is contrary to current policy, according to WWA researchers **Balaji Rajagopalan and Andrew Verdin** (paper in prep).



- WWA researcher **Kristen Averyt** and her collaborators found that data on water withdrawals and consumption at power plants across the U.S. is significantly flawed, posing serious problems for water management (report available at http://www.ucsusa.org/assets/documents/clean_energy/ew3/ew3-freshwater-use-by-us-power-plants.pdf).
- Among other major reforms, the Australian system of prioritization among water uses (critical human needs, then the environment, then all other uses) demonstrates one of the more significant policy and cultural differences in water management when comparing southeastern Australia's Murray-Darling Basin to the Colorado River Basin, according to WWA researcher **Brad Udall** (presentation available at <http://www.youtube.com/watch?v=ULrwmukFt5I>).
- WWA researchers **Lisa Dilling and Kellie Archie** found that federal agency identification is more strongly correlated with public land managers' assessments of climate adaptation activities than are their individual beliefs or attitudes about climate change (paper in prep).
- An extensive assessment of user needs for modeled climate impacts on water quality by WWA researchers **Jimmy McCutchan and Mary Huisenga** indicates that stakeholders are concerned that regional climate and water quality models would be too complex and insensitive to site-specific factors to be used for making regulatory decisions (white paper in prep.)



Select 2011 WWA Accomplishments

Resource Manager Workshop on Bark Beetle Impacts to Water Supplies

PIs: Eric Gordon, Jeff Lukas, Tim Bardsley

Stakeholders/Partners: US Forest Service Rocky Mountain Research Station; US Forest Service Region 4; Colorado Basin River Forecast Center; water and forest managers in Utah

Leveraged Funding: In-kind contribution from US Forest Service

Bark beetles have impacted more than 4 million acres of forest in Colorado and more than 5 million acres across Utah. Water and forest managers alike are concerned about potential impacts on hydrology and water quality from such widespread

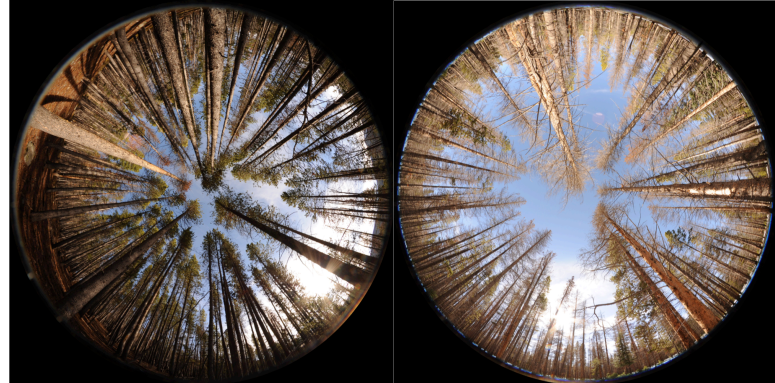


Figure 1. Hemispherical photos of living (left) and grey-phase beetle-killed lodgepole pine trees in northern Colorado. Grey-phase trees intercept significantly less snow, resulting in increased accumulation at the surface. Photos courtesy of Evan Pugh.

vegetation mortality in high-elevation watersheds. Building on the results of two previous WWA symposia organized to help researchers understand the state of the science on this issue, WWA held its first explicitly manager-oriented workshop on beetles and water on December 1st in Salt Lake City. Nearly 40 water and forest managers attended in person, with approximately 70 others watching via real-time webcast (webcast archive is accessible on the event webpage at <http://wwa.colorado.edu/ecology/beetle/mpbUTworkshopDec2011.html>). In addition, pre- and post-workshop surveys helped WWA researchers better understand how to successfully communicate complex and uncertain scientific information on the topic to different audiences.

Native Communities and Climate Change Database



Figure 2. Native Communities and Climate Change web portal available at <http://www.tribesandclimatechange.org>.

PIs: Karen Cozzetto, Julie Teel-Simmonds, Julie Nania
Stakeholders/Partners: Natural Resources Law Center, Navajo Nation, Ute Mountain Ute Tribe, other native communities

Leveraged Funding: \$45,000 from NIDIS

WWA researchers have developed an online database containing numerous resources on the impacts of climate change on American Indian tribes, on tribal adaptation activities and planning efforts, and on relevant federal laws and policies that support or inhibit these efforts. As part of the effort, the team developed outreach materials describing the

database and presented it at multiple forums, including the National Congress of American Indians 2011 Mid-Year Conference and the Northern Arizona University Institute for Tribal Environmental Professionals' Climate Change Training. In addition, a memo on the database was developed and submitted as a technical input the National Climate Assessment.



Modeling Climate-Driven Water Quality Changes on Colorado's Plains Rivers

PIs: James McCutchan, Suzanne van Drunick

Stakeholders/Partners: Colorado Department of Public Health and Environment; water utilities; wastewater treatment operators

In order to better understand drivers of pH variation and other water quality variables, WWA researchers conducted field measurements of algal biomass in rivers along Colorado's plains and built a neural network model to understand the relationships among multiple drivers of water quality, including climate change. Preliminary results indicated that continued warming could lead to higher pH levels and, in turn, greater levels of organic matter such as algae, posing challenges for wastewater treatment plant operators seeking to remove organic matter from effluent. However, hydrologic changes from drought water management were found to be more important drivers of periphyton biomass on streambeds and associated pH levels than water temperatures alone, demonstrating that impacts of climate warming are merely one in a set of multiple stressors on aquatic ecosystems and water supplies.



Figure 3. High biomass of attached algae typical of rivers on Colorado's plains after periods of extended low discharge. Photo courtesy James McCutchan.

Drought Adaptation Among Ranchers in the Intermountain West



Figure 4. Cows grazing on a ranch in Moffat County, Colorado. Photo courtesy Kristin Gangwer.

PIs: William Travis, Kristin Gangwer

Stakeholders/Partners: National Integrated Drought Information System (NIDIS); ranchers

Drought imposes physical, social, and economic impacts on ranching systems in the Rocky Mountains. To better understand how ranchers cope with drought, WWA Graduate Research Assistant Kristin Gangwer conducted interviews in the "Three Corners" region where Colorado, Wyoming, and Utah intersect. In this dry, sparsely populated region, ranchers use a range of strategies for buffering against, coping with, and adapting to the various impacts of drought. Gangwer's findings, documented in a completed master's thesis, demonstrate that ranchers' operations are comprised of varying quantities of

private, privately leased, state, and federal land – and with each of these forms of tenure come different levels of oversight on management during drought. For the ranchers interviewed, the complex land tenure system appears to support their drought coping and buffering strategies. It proves to be a constraint, though, in implementing long-term adaptation to drought and general aridity, particularly due to range improvement policies and tenure insecurity.



Ongoing Research Projects and Collaborations

Understanding Snowmelt Perturbations in the Upper Colorado River Basin

PIs: Jeff Deems, Noah Molotch, Carol Wessman, Joe Barsugli, Klaus Wolter
Partners/Stakeholders: NOAA Colorado Basin River Forecast Center, Colorado River Water Conservation District, NIDIS
Leveraged Funding: \$90,000 from NIDIS

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, and snow-water equivalent reconstructions in preparation for running a comprehensive land-and-snow-hydrology model. The ultimate goal of this multi-year effort is to provide usable information to improve streamflow forecasting at the NOAA Colorado River Basin Forecast Center (CBRFC).

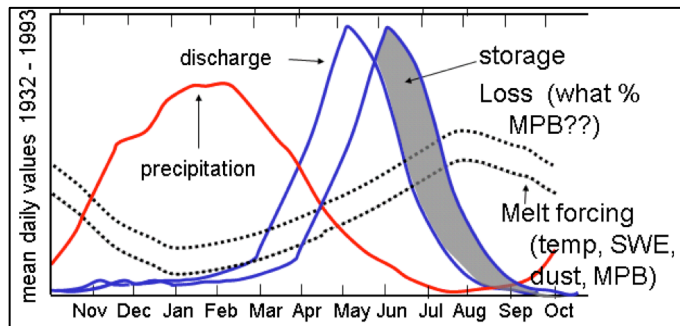


Figure 5. Conceptual diagram of theorized changes in melt forcings and streamflow due to multiple snowmelt perturbations. Courtesy Noah Molotch.

Drivers of Local Adaptation

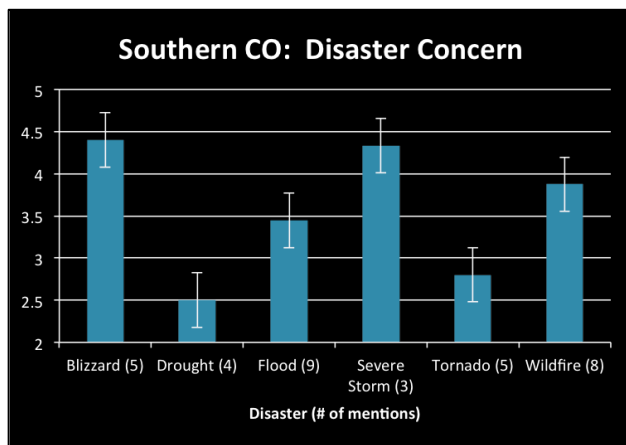


Figure 6. Level of concern regarding specific climate-related disasters as reported by representatives of municipalities in southern Colorado. Courtesy Lisa Dilling.

PIs: Lisa Dilling, Krister Andersson
Partners/Stakeholders: Municipalities across CO, WY, and UT

Why do some local decisionmakers choose to adapt to climate-related risks while others do not? WWA researchers Lisa Dilling and Krister Andersson are systematically investigating the conditions under which local decisionmakers in cities and large towns in Colorado, Utah, and Wyoming decide to adapt (or not) to climate-related risk and hazards, such as blizzards, tornadoes, and floods. Preliminary 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 to date show that municipalities that have experienced more disasters of greater magnitude tend to show greater adaptation to those hazards.



Climate Adaptation Support for Salt Lake City Public Utilities

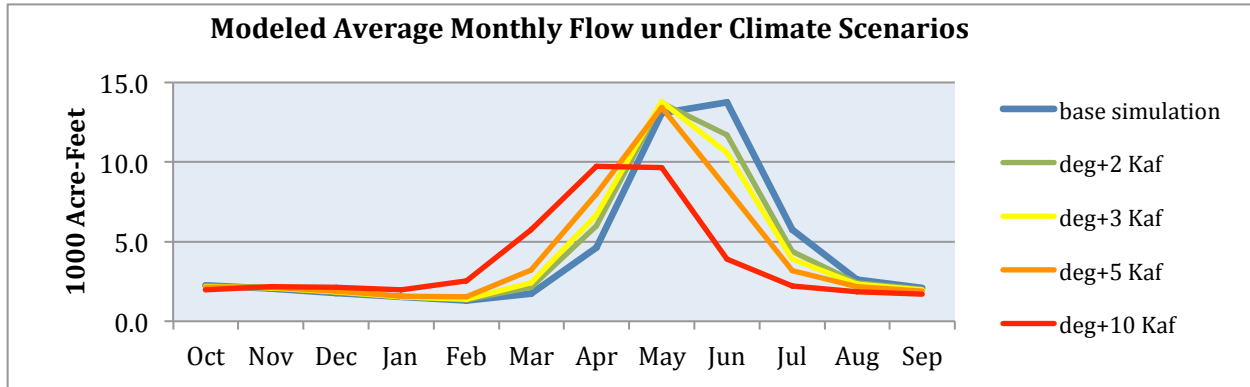


Figure 7. Modeled change in average monthly streamflow in the Big Cottonwood Creek under four scenarios of future warming. Colored lines represent warming in degrees Fahrenheit (see legend on right).

PIs: Tim Bardsley, Andy Wood (CBRFC)

Partners/Stakeholders: NOAA Colorado Basin River Forecast Center; Salt Lake City Department of Public Utilities

Leveraged Funding: In-kind effort from CBRFC

WWA’s Utah Liaison Tim Bardsley has been working with staff at NOAA’s Colorado Basin River Forecast Center (CBRFC) and the Salt Lake City Department of Public Utilities (SLCPU) to examine how projected increases in temperature and changes in precipitation may impact the timing and volume of SLCPU’s surface water supplies. This project is WWA’s effort to support broader climate adaptation work recently initiated by SLCPU and bolstered by the passage of a city council resolution recognizing the importance of adaptation. Bardsley and Wood evaluated the observed sensitivity of watershed creeks to past variability of temperature and precipitation and examined projected changes in average timing and volume as well as changes to a single extreme low flow year and a multi-year drought sequence. They also conducted initial analysis of the past 25 years of SLCPU demand data for correlations with climate variables to aid in projecting future demand under a changing climate. Future work will focus on the development of climate model-driven temperature and precipitation scenarios and incorporate a dynamical representation of potential evapotranspiration into the CBRFC hydrology model.

Boulder County (CO) Climate Change Preparedness Plan

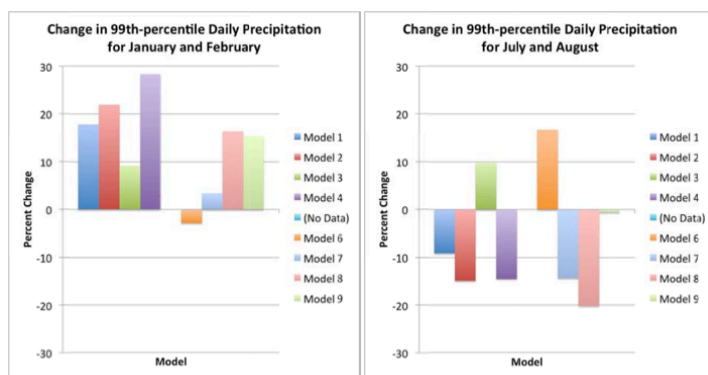


Figure 6. NARCCAP regional climate models show greater agreement on direction of changes to extreme precipitation for Boulder County in January and February (left) compared to July and August. One model was unavailable for this analysis (labeled “No Data”). Courtesy Joe Barsugli.

PIs: Eric Gordon, Joe Barsugli

Partners/Stakeholders: Stratus Consulting, AMEC Earth and Environmental, Boulder County, City of Boulder

Leveraged Funding: \$8500 from Boulder County and City of Boulder

WWA researchers Eric Gordon and Joe Barsugli joined a diverse team to assess the state of the science regarding climate change as it could affect Boulder County, Colorado, where WWA is located. The



county faces a number of challenges that could potentially be exacerbated by climate change including droughts, flash flooding, West Nile virus, heat waves, wildfire, and increased road maintenance, among others. In addition to the scientific assessment, the plan includes policy-oriented analyses of opportunities for the county and municipal governments to incorporate climate change concerns into planning and operations. This project provides a needed service to the city and county where WWA is physically located as well as an opportunity for WWA to engage in on-the-ground adaptation planning efforts, which will feed back into WWA efforts to understand and improve adaptation practices across the Intermountain West region.



WWA 2011 Project Reports

Decision Support for the Colorado River Basin and Headwaters

Stochastic Streamflow Simulation at Interannual and Interdecadal Time Scales and Implications to Water Resources Management in the Colorado River Basin

Primary Investigator(s): B. Rajagopalan, E. Zagona, K. Nowak, C. Bracken

Partners: Center for Advanced Decision Support for Water and Environmental Systems (Univ. of Colorado), US Bureau of Reclamation

Analysis of streamflow variability at short (interannual) and long (interdecadal) time scales to support Bureau of Reclamation management activities on the Colorado River.

This multi-year effort ended in 2011, with the Bureau of Reclamation ultimately benefiting from the integration of stochastic simulation techniques into planning and the development of the new Midterm Operations Model for the Colorado River Basin. In seeking to understand how streamflow has varied at interannual and interdecadal time scales, WWA researchers Rajagopalan, Nowak, Zagona, and Bracken worked to develop novel methodologies. At the interdecadal time scale, wavelet analysis was used to demonstrate the climatic drivers of streamflow variability, and a stochastic simulation of multisite streamflow with nonstationary spectral features was developed. At the interannual time scale, hidden Markov models were used to demonstrate that short-term changes in streamflow are greater than indicated by standard time-series analysis. In addition, development of a new probabilistic Midterm Operations Model was completed and has been in use by the Bureau of Reclamation. This project resulted in the completion of a Ph.D. thesis (Nowak), a M.S. thesis (Bracken), and one peer-reviewed publication in 2011, with additional publications in review for 2012.

Deliverables: Ph.D. Thesis (Nowak), M.S. Thesis (Bracken), peer-reviewed paper on wavelet autoregressive methodology, summary report.

WWA Funding: January–July 2011

Leveraged Funding: \$253,000 from Bureau of Reclamation (2009–2011)

Regional Integration Among Municipal and Industrial (M&I) Water Providers

Primary Investigator(s): D. Kenney, K. Cody

Case-based analysis of regional integration among M&I water providers in the West as a means of improving resiliency in the face of climate change.

Across the West, coalitions of municipal and industrial (M&I) water providers have increasingly looked to regional integration of both their physical and institutional systems as a means of dealing with common pressures associated with population growth and climate variability and change. In order to better understand the forces that can stimulate these efforts, the possible forms of the resulting integration, and the overall efficacy of this management strategy, this project reviewed three cases where regional integration is a prominent feature of policy: southern Nevada, California, and the Front Range of Colorado. The cases demonstrate that infrastructural integration and institutional connectedness go hand in hand, and can emerge together, or evolve from either point. Once established, these relationships can be useful in illuminating drawbacks to competition and benefits of cooperative action. In the case study regions, the resiliency of water systems appears to have improved (or the rate of decline has slowed), as evidenced by decreases in per capita demand, increased infrastructure connectivity and efficiency, and increased available resources. Regional integration, however, is not without drawbacks and trials. Breaking the bond between water scarcity and competitive behavior at any given regional scale is difficult to do without merely shifting the point of competition to other scales.

Deliverables: M.S. Thesis (K. Cody), WWA White Paper (draft completed)

WWA Funding: January–July 2011

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

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

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

Hydrologic modeling to understand the influence of dust deposition and climate change on snowmelt and runoff timing and volume in the Colorado River Basin.

Previous WWA research indicated a five percent reduction in annual Colorado River flow due to dust loading on snowpack in the Rocky Mountains (Painter et al. 2010). In 2011, PIs began examining the impacts of unusually high dust loads (as seen in 2009 and 2010) and climate warming on flow in the Colorado River. Initial modeling results show that even under the strongest warming, timing of runoff is strongly sensitive to radiative forcing by dust. Under scenarios of extreme warming, however, volume of runoff becomes less sensitive to dust deposition. These results are expected to be published in a peer-reviewed journal in 2012.



Deliverables: Peer-reviewed publication expected in 2012

WWA Funding: January–December 2011

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

Reconciling Projections of Future Flow in the Colorado River Basin

Primary Investigator(s): B. Udall, D. Cayan (CNAP), J. Overpeck (CLIMAS), D. Lettenmaier (Univ. of Washington)

Partners: CNAP, CLIMAS, NIDIS, NOAA Physical Sciences Division, US Bureau of Reclamation, Univ. of Washington

Reconciliation of climate data, scenarios, runoff sensitivities, and other information used by multiple groups projecting future flow in the Colorado River Basin with the intention of providing more useful outputs to water managers in the Southwest.

A number of studies including Seager et al. (2007), Christensen and Lettenmaier (2007), and Milly et al. (2005) suggest that substantial changes in runoff may occur over the next century in the Colorado River Basin. However, the range of estimated impacts on Colorado River discharge (all based on IPCC 2007 model runs) is large – from a low at 2050 of about 6% (Christensen and Lettenmaier 2007) to over 18% (Seager et al. 2007). Not surprisingly, the region’s water managers view with great concern the potential for large changes in the flow of the Colorado River. Of even greater concern, though, has been the wide range of projections – as large as 45% in Hoerling and Eischeid (2007) by mid-century. To reduce that range, this multi-RISA, multi-agency effort to reconcile multiple approaches and datasets. This entailed a significant amount of coordination and collaboration usually not found in academic research. Efforts in 2011 included evaluating alternative data sets, extending the datasets to the current year and conducting quality control, diagnosing reasons for differences in temperature sensitivities among climate models, reconciling climate scenarios, and evaluating Colorado River discharge sensitivities in regional climate models. A number of papers from this project have been accepted for publication and are either in press or in preparation: Vano, Lettenmaier, and Das, “Hydrologic Sensitivities of Colorado River Runoff to Changes in Precipitation and Temperature” (*Journal of Hydrometeorology*); Das, Lettenmaier, Cayan, Vano, and Pierce, “The Importance of Warm Season Warming to Western U.S. Streamflow,” (*Geophysical Research Letters*), and a proposal for an overarching paper on the entire project has been accepted by *Bulletin of the American Meteorology Society*.

Deliverables: Publication of three peer-reviewed articles expected in 2012.

WWA Funding: January–December 2011

TreeFlow: A Drought Planning Resource for Water Management in the Western U.S.

Primary Investigator(s): J. Lukas, S. Gray

Partners: Utah State University, Brigham Young University, University of Wyoming, CLIMAS

Further development of a comprehensive web-based tree-ring paleohydrology resource (<http://treeflow.info>) that addresses regional needs and interests and is expandable to cover additional regions and data in the future.

WWA researcher J. Lukas completed another round of maintenance on the multi-RISA [TreeFlow.info](http://treeflow.info) web resource in 2011, with many pages updated to reflect new references and applications of the data. New pages and data files were also added to provide access to three new reconstructions for the Snake River in Idaho and Wyoming developed by researchers with the University of Arizona, demonstrating the flexibility of the TreeFlow architecture in accommodating new data. A research team at Utah State University and Brigham Young University continued to engage WWA researchers J. Lukas and S. Gray to provide that team with guidance on conducting applied paleohydrologic work in the Wasatch Front in Utah, following the model of past WWA work in applied paleohydrology. Both Lukas and Gray participated in a workshop in Logan, UT, in March 2011 to convey to water managers in northern Utah the value of paleohydrology to a water resource planning.

Deliverables: Updated treeflow.info website

WWA Funding: January–December 2011

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

Building on previous efforts to understand the natural long-term variability of the upper Colorado River basin through generation of paleohydrologic reconstructions of annual flows between Lees Ferry and Imperial Dam and the Gila River at its mouth.

This project was initiated at the direction of a WWA stakeholder: Eric Kuhn from the Colorado River Water Conservation District, which has supported the project with District funds and also motivated the Colorado Water Institute’s support of the project. In 2011, datasets from 66 tree-ring chronologies were compiled and a naturalized annual flow for the Gila at its mouth was generated based on the chronologies and other sources. These efforts so far have allowed WWA researchers to identify key hydroclimatic drivers and management influences in the



Lower Colorado River Basin. Perhaps the most interesting discovery, part of the untangling of the complex hydrology of the Gila River basin, has been identifying the incredible variation in the historic natural flows at the mouth—some 50-fold from under 0.1 MAF (million acre-feet) to over 5 MAF. The tree-ring reconstructions are largely able to capture this historic-period variation, and they also estimate yet higher extreme annual flows prior to 1900.

Deliverables: Poster presented at 2011 AGU Fall Meeting; Two peer-reviewed manuscripts and one M.S. thesis expected in 2012

WWA Funding: January–December 2011

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

Snowmelt Perturbations and Water Supply Forecast Errors

Primary Investigator(s): J. Deems, 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 snow hydrologists, an ecologist, weather and climate experts, and hydrologists at the NOAA Colorado Basin River Forecast Center in an effort to use a suite of modeling and field work techniques to better understand drivers of snow accumulation and melt in the Upper Colorado River Basin with the ultimate goal of improving CBRFC forecasts, if possible.

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, and snow-water equivalent reconstructions in preparation for running a comprehensive land-and-snow-hydrology model. After work in 2011, snow-water equivalent reconstructions are complete for Upper Colorado domain for sample year 2010; data generation for 2000-2009 is ongoing as are data quality assessments. Time series of MODIS forest phenology metrics are complete and an assessment is proceeding. Four test basins were selected based on dust and beetle impacts: low dust/high beetle (Fish Creek, Snake), intermediate dust/incipient beetle (Boulder) and high dust/very low beetle (Uncompahgre). Spatial inputs for a hydrology model (DHVSM) are being prepped, with one of the four basins complete and two others nearing completion. Compilation and analysis of meteorologic data and streamflow records for each basin have begun. Daily USGS streamgage and NRCS SNOTEL data are being processed and analyzed for all four watersheds. Phenologic maps have been created for Colorado and parts of WY, NM, and AZ (250,000km²) for input into DHVSM. MODIS NDVI-based growing season metrics include the observed start-of-season, end-of-season, and length-of-season since 2000 at 250m resolution. Pls are currently analyzing and mapping changes in these metrics through the record. MODIS-based LAI (1 km) has been compiled for years 2002-2010 and processed for both mean and max summer LAI values. All of these metrics, representing vegetative water usage related to growth/death and evapotranspiration, will improve modeling of the influence of vegetation and the impact of disturbances such as the MPB on the hydrology of the region. The ultimate goal of this multi-year effort is to provide usable information to improve streamflow forecasting at the NOAA Colorado River Basin Forecast Center (CBRFC).

Deliverables: Stand-alone SWE data products; peer-reviewed publication on remotely sensed trends in beetle outbreak to be submitted in 2012

WWA Funding: July–December 2011

Leveraged Funding: \$90,000 from NIDIS

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

Investigation of storage reliability in the Colorado River Basin under multiple scenarios of flow reduction due to climate change.

Rajagopalan et al. (2009) found that under a climate change scenario of 20% reduced annual flow in the Colorado River by 2057 there is a nearly ten-fold increase in the probability of reservoirs being depleted annually by 2057. That study also suggested that flexibility in current management practices could mitigate some of the increased risk from climate change-induced reductions in flows. To further investigate this possibility, current work is examining the amount of water available in the basin and the associated reliability for a given amount of storage. Preliminary research findings in 2011 show that reliability of the Colorado River Basin water management system drops dramatically with even small increases in the amount of water yield needed. For example, under natural variability of streamflow, the reliability is quite high (~97%) for a yield of 12.67 million acre-free (MAF) but it drops to 80-85% for 13.5 MAF and substantially lower for 15MAF. In addition, storage in the upper reservoir (Lake Powell) appears to be higher than the lower reservoir (Lake Mead) when the equalization condition is relaxed, which is especially striking for flow scenarios under climate change. Furthermore, total yield is higher when equalization is relaxed, indicating the benefits of storing more water in Lake Powell due to a lower evaporation rate. Doing so, however, is not permitted under the current policy of equalization.



Deliverables: Peer-reviewed manuscript expected in 2012

WWA Funding: July–December 2011

Lessons Learned from Australia's Drought Experiences

Primary Investigator(s): B. Udall

Partners: State of South Australia, Commonwealth Scientific and Industrial Research Organization (Australia)

Communicating lessons learned applicable to the Colorado River Basin from an investigation of water management in South Australia.

Australian water management issues provide a unique opportunity to compare impacts and adaptations in portions of Australia, including the Murray-Darling Basin, with the Colorado River Basin. While both areas frequently face severe droughts as well as myriad sources of significant water demand, the severity of drought in portions of Australia exceeds most recent experiences in the CRB. Observing and analyzing the Australian response can provide lessons about governance structures, behavior of political institutions, and use of physical infrastructure to combat drought. WWA Director Udall has developed an extensive presentation on southeastern Australia's recent experiences with drought and subsequent management and planning responses. In his talks, he describes the history of 20 years of aggressive water reform in Australia, dramatic drought, and federalization of the Murray-Darling Basin in 2007 and 2008 that led to severe political fallout. He has shared his observations on water management and drought planning with water managers, planners, and researchers in the Colorado River Basin during at least five presentations and one radio interview and continues to do so in 2012.

Deliverables: Presentations to water managers and other stakeholders (see Appendix A)

WWA Funding: July–December 2011

Climate Training for Water Managers

Primary Investigator(s): E. Gordon, B. Udall, J. Barsugli

Partners: Bureau of Reclamation, UCAR COMET Program

Work in conjunction with the Bureau of Reclamation to engage the UCAR COMET program in establishing a training curriculum that will increase the ability of technical practitioners to incorporate climate change information in the studies they conduct that inform water and water related resource management decisions.

Based on the multi-agency report "Addressing Climate Change in Long-Term Water Resources Planning and Management – User Needs for Improving Tools and Information," WWA, the Bureau of Reclamation, and others identified the need to develop rigorous technical training aimed at helping water resource managers use climate information to study future water availability issues. After the creation a core team including experts from the Bureau of Reclamation, WWA, US Army Corps of Engineers, EPA, and Denver Water, the UCAR COMET program was engaged to develop online curriculum modules and training workshops as part of overall professional curriculum units. Additional work in 2011 involved the development of learning objectives for curricula on surface water hydrology and agricultural demand modeling. Training modules and workshops are expected to be completed in 2012.

Deliverables: Completed climate training modules and workshop preparations expected in 2012

WWA Funding: July–December 2011

Leveraged Funding: \$150,000 from Bureau of Reclamation

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

Primary Investigator(s): D. Kenney

Assessment of outdoor water conservation through an investigation of whether 1) outdoor conservation could be incentivized through the application of alternative revenue models from other industries, including the electricity sector; and 2) hardening demand by reducing "slack" in residential water systems is a threat to supply reliability.

For both halves of this project (i.e., the revenue model and the demand hardening focus areas), literature has been compiled and the review is in progress. Informal interviews on these subjects have occurred in several settings, but given the lack of tangible data or experience on either issue, most water managers have had relatively little to say to augment the findings already documented in the literature. The most interesting finding is that the electricity sector has roughly 30 years of experimentation and research on alternative revenue models, yet these models remain completely foreign to most individuals in the water sector. Thus, there is a tremendous opportunity for transferring lessons. On the demand hardening side, the biggest insight is that Front Range water providers seem more concerned with this phenomenon than water managers in other regions of the country.

Deliverables: Two WWA white papers expected in 2012

WWA Funding: July–December 2011



Tools for Assessing Urban Landscape Water Use Efficiency

Primary Investigator(s): J. Endter-Wada

Partners: Utah State University Agriculture Extension, Utah State University Dept. of Engineering

Spatial and temporal analyses of urban landscape water use patterns to provide municipalities and water suppliers with a better understanding of how landscape water use and conservation fit into the management of urban water supplies.

This project produces a seasonal site-specific landscape irrigation ratio that compares estimated landscape water use (total metered use minus estimated indoor use over an irrigation season) to estimated landscape water need. This ratio is derived from the classification of remotely sensed airborne multispectral imagery and localized reference evapotranspiration rates modified by relevant landscape factors. Work conducted in 2011 focused on refining software that automates this analysis and graphically displays ratios by locations (color coded by ranges the user can define) across an entire city or service area. In addition, the system is being tested with the Weber Basin Water Conservancy District. As water use data has been better incorporated into the software, assumptions (indoor water use, inclusion of parking strip) used in calculating the landscape irrigation ratio (LIR) have improved. The availability of monthly and/or hourly water consumption data enables more accurate definition of indoor water use utilizing winter consumption as a basis instead of an assumption based on average occupancy and water use. Inclusion of the parking strips in calculating landscape irrigation ratios has provided more accurate assessments of landscape water use, particularly in relation to small and/or corner lots. Current methodology for calculating water budgets is generally based upon landscaped area within a site's parcel boundaries, excluding the landscaped area in the parking strip, which residents nevertheless are required to maintain.

Deliverables: Peer-reviewed publication expected in 2012

WWA Funding: July–December 2011

Leveraged Funding: \$41,000 from U.S. Bureau of Reclamation and Weber Basin Water Conservancy District

Motivating and Empowering Household Water Use Efficiency

Primary Investigator(s): J. Endter-Wada, D. Rosenberg

Partners: Weber Basin Water Conservancy District, Utah State Univ. Dept. of Applied Economics

Pilot testing an approach for conducting a large, multi-year experimental intervention panel study on the effectiveness of various urban water conservation programs.

This project is aimed at addressing research design challenges and testing methodological procedures for conducting a real-world human experiment on the effectiveness of urban water conservation programs. Conducting this experiment would be scientifically innovative but requires determining how best to: select, recruit and retain participants; deliver conservation programs; collect, organize and analyze data; assess the influences of conservation programs in households subject to many sources of change; and, manage research design and budgetary trade-offs. In 2011, the PIs designed and administered a follow-up mail survey with 40 pilot-test households. The follow-up survey has enabled further testing of issues related to participant retention and attrition and to learn about changes, due to participation in the pilot study, which households may have made that affected their water use. PIs are now conducting further analysis of the 2010 and 2011 data collected from these 40 households. To date, project insights include concerns about high degree of variability between urban households in terms of their characteristics, knowledge, preferences, abilities, and constraints and that it is possible, maybe even necessary, to conduct a human experiment through a participatory action research (PAR) approach, and that experimenting *with* research participants instead of *on* research participants can retain scientific objectivity. Continued efforts in 2012 are expected to lead to an NSF proposal for funding to conduct a large (1000 households) panel study.

Deliverables: Peer-reviewed publication expected in 2012, NSF proposal in 2012

WWA Funding: July–December 2011

Leveraged Funding: \$35,000 from Utah State Univ. SPARC grant

Assessment of Policy Options for Mitigating Dust Production on the Colorado Plateau

Primary Investigator(s): E. Gordon

Partners: University of Colorado Natural Resources Law Center

Policy-based analysis of options to reduce dust production the impacts streamflow in the Colorado River Basin.

The restoration of rangelands on the Navajo Nation has been proposed as a potential “win-win” climate adaptation strategy designed to, in effect, increase storage in the Colorado River Basin by reducing dust deposition on snowpack. Numerous researchers, including Jayne Belnap and Margaret Hiza Redsteer of USGS, are investigating the technical questions involved in reducing dust generation from the Colorado Plateau. But even if such technical questions can be solved, is there sufficient stakeholder support for the implementation of solutions? What are the political and policy realities faced by decisionmakers from the Four Corners to the Front Range who want to deal with this issue? To



date, this project has focused on gathering scientific literature about both dust impacts to snowpack and dust generation from disturbed lands, including preliminary efforts to understand grazing policies on the Navajo Reservation.

Deliverables: WWA White Paper expected in 2012

WWA Funding: July–December 2011

Ecological Vulnerabilities, Impacts, and Adaptation

Climate Change Impacts on Public Lands in the Upper Colorado River Basin

Primary Investigator(s): J. Neff, K. Cozzetto, D. Fernandez

Partners: San Juan Public Lands Center (US Forest Service & Bureau of Land Management)

Work in conjunction with managers at the BLM/USFS San Juan Public Lands Center to develop a model to understand the vulnerability of public lands to drought based on a variety of ecological and physical factors.

This project entailed the development of a simple ecophysiological model to produce initial drought vulnerability mapping that could be used by land managers in climate change analysis and planning efforts. A model incorporating climate, soil, and vegetation was run with precipitation data from 1948–1998 to produce a vulnerability map representing plant communities, soil textures and depth, and precipitation gradients. In the model used, transpiration and precipitation were very strong predictors of drought vulnerability. However, for the model to be of greater value to land managers, it needs a second soil depth layer in order to capture the true difference between summer and winter precipitation.

Deliverables: Summary for San Juan Public Lands Center, final project report

WWA Funding: January–July 2011

Downscaled Precipitation Projections for Southwestern Colorado

Primary Investigator(s): I. Rangwala, K. Cozzetto, J. Neff

Partners: San Juan Public Lands Center (US Forest Service & Bureau of Land Management)

Analysis of downscaled precipitation projections for the San Juan Mountains to understand their accuracy at simulating precipitation patterns in the region.

PIs have examined in detail the dynamically downscaled temperature and precipitation projections available from the NARCCAP for southwestern Colorado for two 30-year periods: a historic period (1971–2000) and a future period (2041–2070). The area of investigation was centered on the San Juan Mountains. Overall, the results show at least 4°F warming in all seasons, with summer having the highest warming in maximum (daytime) temperatures (>6°F) and greater increases at higher elevations (>8,000'). By the mid-21st century, the normal daytime summer temperatures are projected to be similar to those observed in 2002, the year with the highest observed summer temperatures in the San Juans. The consensus among six RCM runs is that southwestern Colorado can expect near-average precipitation or a slight increase during December and January, near-average precipitation or a decrease from April to June, and a decrease in precipitation in July and August. However, none of the RCM simulations captured the monthly precipitation climatology of the region. In particular, all of the models had trouble reproducing various features of the North American Monsoon from July through September. In most cases, no monsoon was simulated, and in the remaining ones, the monsoon was not maintained for a long enough period. Additionally, a majority of the RCM simulations had problems reproducing the observed trend of increasing precipitation with elevation during the fall, winter, and spring months, the period during which the snowpack is accumulated. This analysis indicates that climate model projections of changes in precipitation have much greater uncertainty than temperature and, therefore, should be treated with greater caution.

Deliverables: Peer-reviewed article to be published in *Climate Dynamics* in 2012, WWA Intermountain West Climate Summary Feature Article (July 2011), white paper to San Juan Public Lands Center

WWA Funding: January–December 2011

Leveraged Funding: PACE Postdoc Program support for I. Rangwala; \$92,000 from Department of Interior/Bureau of Land Management

Controls on pH and Ammonia Toxicity in Rivers of the Colorado Plains

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

Development of a modeling framework to predict changes in water quality in response to climate variation or changes in water



management.

Temperature directly affects the numeric standards for ammonia in warm-water streams of Colorado, but temperature also can affect ammonia standards indirectly through interactions that link climate, metabolic processes, and pH. Recent monitoring data for rivers on the plains of Colorado, in combination with results of studies of oxygen metabolism, suggest that the balance between photosynthesis and respiration favors high pH when temperature is high. Samples and field measurements were collected between July 2010 and May 2011 at four stations, in order to determine the relative importance of temperature, hydrologic variables, and biomass of benthic algae in controlling pH in Plains streams and rivers. Across the sampling stations, biomass of benthic algae remained low when depth was greater than ~0.35 m; below this depth threshold, algal biomass was able to accumulate when other factors were not limiting to growth. For a given location, the depth threshold of ~0.35 m can be translated into a discharge threshold for removal of algal biomass, thus providing a basis for analysis of historical records or for modeling. The potential for metabolic control of pH is highest at low discharge and especially after extended periods of low discharge. Neural-network modeling showed, for a given location, a strong relationship between discharge and pH. Temperature, time of day, and recovery (time since a critical flow for removal of periphyton biomass) affect pH at low discharge, but not when discharge is high. Although additional field studies are needed to improve modeling accuracy, these relationships demonstrate strong potential for predictions of the effects of climate variation or changes in water management on pH in Plains rivers. Preliminary modeling suggests that climate warming may lead to a modest increase in pH for Plains rivers. The most important factors affecting pH, however, are related to hydrologic variation and changes in water management, both of which can affect the patterns of accumulation for periphyton biomass.

Deliverables: WWA Technical Report; peer-reviewed publication expected in 2012

WWA Funding: January–July 2011

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 mountain pine beetle (MPB) epidemic and developing integrated, decision-oriented information that can help stakeholders understand and plan for the current MPB epidemic, with a particular focus on water quality and hydrologic impacts.

In 2011, this project produced three major accomplishments. First, in April WWA convened its second annual research symposium on water-related impacts of beetle infestations, allowing researchers to exchange knowledge and methodological insights while also allowing the PIs to understand the state of relevant science. Second, on December 1 WWA convened an all-day stakeholder workshop in Salt Lake City aimed at providing a synthesis of research on water-related impacts of bark beetle infestations in Utah and the Rocky Mountain West. Over 40 forest and water resource managers and researchers participated on-site, with several dozen others participating via live streaming videoconference (this was the first WWA-sponsored event that has offered this option). Third, a peer-reviewed manuscript reviewing existing science on beetle-related impacts to hydrologic processes and developing a relevant conceptual model was submitted to *Hydrological Processes*. Overall, the PIs have found significant desire among stakeholders for the sort of synthesis work involved in 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 tremendously well received by stakeholders eager for coherent, contextualized information.

Deliverables: Research Symposium in Boulder, CO; Stakeholder workshop in Salt Lake City, UT; peer-reviewed article to be published in *Hydrological Processes* in 2012

WWA Funding: January–December 2011

Climate Adaptation in Western National Forests

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

Partners: US Forest Service Rocky Mountain Research Station

Conducting a pilot climate vulnerability assessment for the Shoshone National Forest as part of a broader effort by the US Forest Service to develop a climate adaptation toolkit.

As part of a broader US Forest Service effort entitled “A Toolkit for Adapting to Climate Change on Western National Forests: Incorporating Climate into Resource Management and Planning,” WWA post-doctoral fellow Rice has been worked with others at the Forest Service’s Rocky Mountain Research Station in Fort Collins, CO to complete a technical report covering climate impacts in Wyoming’s Shoshone National Forest. Rice is now working on a climate vulnerability assessment for the forest, which will focus on whitebark pine and aspen range shifts, along with streamflow changes that would affect Yellowstone cutthroat trout and water supply. In 2011, the PIs completed a Forest Service General Technical Report entitled “Climate Change on the Shoshone National Forest, Wyoming: A Synthesis of Past Climate, Climate Projections, and Ecosystem Implications,” which synthesizing current scientific information about climate and its effects on ecosystem components of the Shoshone NF. Additional funding provided in 2012 will be 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 to be published in 2012; Natural Resources Climate Change Conference in Cody, WY

WWA Funding: January–December 2011

Leveraged Funding: \$120,000 from US Forest Service through Research Joint Venture agreement

Climate Science Support for Vulnerability Assessment of the Gunnison Basin

Primary Investigator(s): J. Barsugli

Partners: The Nature Conservancy

Providing climate science support and guidance for a multi-stakeholder effort to assess climate change vulnerability in the Gunnison River Basin.

Throughout 2011, WWA researcher J. Barsugli provided climate science support and guidance to a landscape-scale climate change vulnerability assessment effort led by The Nature Conservancy. This assessment was developed explicitly for the Gunnison Climate Working Group, a collaboration among public and private stakeholders interested in building ecosystem resilience in the basin. Barsugli's efforts focused in particular on guiding the selection and use of climate models and relevant climate and hydrologic data used to determine the relative future vulnerability of 24 ecosystems in the Gunnison Basin. These efforts were compiled into a report (Neely et al. 2011) that will serve as the basis for future collaborative resilience management efforts and as a pilot for other landscape-scale assessments initiated by The Nature Conservancy.

Deliverables: Gunnison Basin Climate Change Vulnerability Assessment report (Neely et al. 2011)

WWA Funding: January–December 2011

Reconstructing Environmental Flows on the Yampa River

Primary Investigator(s): J. Barsugli

Partners: The Nature Conservancy

Developing a pilot effort to reconstruct natural flows in order to understand ecological responses to alterations of natural flow patterns.

Regional assessment of the trade-offs between environmental flows and human demands on river flows requires a hydrological framework which enables the consistent examination of the ecological response to more or less alteration of daily and other natural flow patterns. This framework is a comprehensive regional water management tool for integrating the flow needs of river ecosystems with human water needs. In 2011, the PI developed an improved calibration strategy (the sequence of steps that one goes through in order to calibrate the model) and improved meteorological forcing data for the Variable Infiltration Capacity (VIC) hydrologic model to provide a more robust and extensive set of natural flows for assessing the ecological response to water management actions across the Colorado River Basin. The underlying data was then assessed the Yampa-White Basin to determine how the calibration can be extended to the rest of the Colorado River Basin. Streamflow data will soon be made available on a server. The PI plans to submit a proposal to a) further develop the meteorological forcing data to better represent smaller scale variations in precipitation, b) gather and assess the quality of naturalized streamflows, including the CBRFC daily quasi-natural flows, c) extend the calibration of VIC to the Upper Colorado basin.

Deliverables: WWA White Paper (completed in 2012), peer-reviewed publication expected in 2012

WWA Funding: July–December 2011

Leveraged Funding: \$35,000 from The Nature Conservancy

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

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

Understanding stakeholders' needs for climate-driven water quality modeling at regional and other scales and assessing the utility of existing regional water quality and climate models.

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 focused on understanding 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). Ongoing work involves 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. Efforts to date 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 2012, providing overall insight into the utility of water quality modeling under climate change.

Deliverables: WWA White Paper in 2012

WWA Funding: July–December 2011

Building a Monitoring Network for the North Platte Headwaters at the Little Laramie River (Formerly Green River Headwaters Network)

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.

Note: This project was originally entitled “Green River Headwaters” in previous WWA reports, but the original PI (S. Gray) left U. of Wyoming prior to funding being in place. Funds were transferred to new WWA team member Scott Miller, who moved the geographic location of the project and changed some of the scope in light of his expertise.

In 2011, PI began the process of instrumenting the Little Laramie River from its headwaters to its confluence with the Laramie River below the town of Laramie. The headwaters has been instrumented off and on over the past several decades by several scientists from University of Wyoming, the USFS in Fort Collins and others, making it an ideal location to carry out longer term research. The new network is an extension of an ongoing collaborative hydrologic monitoring and modeling effort in the Snowy Range facilitated by the PI. Sites were identified in fall 2011 and equipment has been ordered for installation in Fall 2012. An MS-level Graduate Research Assistant has been leveraged from state funds for this grant, and the student will assist in data management, database development and outreach / data dissemination. Continuing work entails setting up observation stations longitudinally down the river to continuously monitor stream discharge and temperature and partnering with other scientists collecting rainfall and climate data in order to better understand the fate and timing of snowmelt and rainfall with respect to its conversion to soil water, groundwater and ultimately runoff.

Deliverables: Project completion report and presentation to stakeholders expected in 2012

WWA Funding: July–December 2012

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

Emerging Initiatives and Adaptation Strategies to Inform Climate Services

Climate-Related Decisionmaking on Public Lands in the Intermountain West

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

Partners: US Forest Service, Bureau of Land Management, National Park Service, and Fish and Wildlife Service

Assessment of 1) the awareness of climate variability and change and 2) willingness to incorporate climate information into planning among public land managers in the west.

Despite agency-level efforts to promote climate adaptation on federal public lands, it is unclear how widespread adaptation efforts are on a regional or office basis. Previous research has showed that though there is strong climate change awareness among land managers, direct action addressing climate change is more limited. In order to obtain data about individual land manager and agency-level adaptation barriers and plans, PIs surveyed approximately 3,100 land managers employed by the Bureau of Land Management, the US Forest Service, the National Park Service, and the US Fish and Wildlife Service in CO, UT, and WY. Results suggest that adaptation planning by public lands agencies in CO, UT and WY is occurring but that implementation of these plans remains relatively rare. In addition, individual beliefs and attitudes about climate change do not appear to influence responses about adaptation planning, although the agency for which a respondent works is a statistically significant predictor of respondents' assessments of current adaptation planning. Complete results will be reported in a peer-reviewed publication expected to be published in 2012.

Deliverables: Peer-reviewed publication expected in 2012

WWA Funding: January–July 2011

Analyzing Expressed Stakeholder Needs in the Western Water Assessment Region



Primary Investigator(s): L. Dilling, J. Berggren

Partners: GLISA, CISA

Systematic examination of stakeholder needs for climate information through previous documentation, in order to avoid replicating previous efforts and exacerbating stakeholder fatigue.

Through web-based searches and querying a network of key informants and collaborators, PIs were able to develop a list of documents to include in a database of expressed stakeholder needs for climate information. Documents were ultimately included if they identified any type of stakeholder need in regards to climate information, and were within the WWA geographic scope. Prominent findings include monitoring needs such as additional USGS stream gauges and NRCS SNOTEL sites, better communication and collaboration between scientists/researchers and the stakeholders themselves, and a ‘clearinghouse’ or ‘portal’ where stakeholders could easily obtain climate related information. The documents also suggested that current management and research are addressing the appropriate issues, but could be better coordinated and communicated to improve decision-making. Additional climate and hydrologic monitoring and modeling would better assist managers and planners, but only if the data is readily available and in a useful form. PIs are currently in the process of producing a white paper and writing an article for submission in a peer-review journal. Two other RISAs (Great Lakes Integrated Sciences and Assessments, and Carolinas Integrated Sciences and Assessments) conducted similar stakeholder needs analyses, and the resulting comparative framework will be published in 2012.

Deliverables: WWA White Paper and peer-reviewed publication expected in 2012.

WWA Funding: January–July 2011

NEPA, Climate Change, and Public Lands Decisionmaking

Primary Investigator(s): M. Squillace

Providing legally relevant guidance on how public land management agencies can address climate change in decision documents.

One of the most difficult challenges facing public land managers today is how to address climate change in a meaningful way when making decisions affecting public lands. This problem is largely the product of the high levels of uncertainty surrounding climate change and the potential consequences of climate change for the large and complex landscapes and ecosystems that public land agencies manage. In February 2010, the Council on Environmental Quality (CEQ) issued draft guidance to federal agencies describing how these agencies should address climate change in their decision documents. Recognizing the difficulty of the task, however, the CEQ’s draft guidance expressly disclaimed any intention of affording assistance to public land management agencies making complex land use decisions. The PIs sought to expressly fill that gap with an analysis of three case studies that illustrate the complex challenges facing managers and recommendations for CEQ and land management agencies. In a legal studies working paper, the PIs recommended that CEQ write regulations to hold agencies accountable for commitments to adaptive management and that agencies make better use of programmatic analyses and tiering to better address climate change impacts.

Deliverables: Law review working paper (Squillace and Hood 2011)

WWA Funding: January–July 2011

Drought Adaptation among Ranchers in the Intermountain West

Primary Investigator(s): W. Travis, K. Gangwer

Identification and measurement of the effects of adaptations among agriculturalists in the “Three Corners” region of CO, WY, and UT via detailed surveys of their decision-making and by building a typology of responses that reflect the direct and indirect outcomes of both impacts and adaptations.

Drought imposes physical, social, and economic impacts on the ranching system in the Rocky Mountains, and ranchers interviewed for this project exhibit a range of strategies for buffering against and coping with these impacts, and for adapting to dry conditions. Ranchers’ operations are comprised of varying quantities of private, privately leased, state, and federal ground – and with each of these forms of tenure come different levels of oversight on management during drought. However, for the ranchers interviewed, the complex land tenure system appears to support their drought coping and buffering strategies. It proves limiting, though, in terms of long-term adaptation to drought and/or general aridity, particularly due to range improvement policies and tenure insecurity. In addition to these system-level implications of the land tenure system, certain elements of an individual’s land holdings – including length, spatial distribution, size, composition, and perceived and real security – play an important role during drought and help explain the unequal impacts ranchers experience. This information has been compiled into a master’s thesis completed in 2011 and will be distilled into a WWA white paper.

Deliverables: M.S. Thesis (Gangwer), WWA White Paper expected in 2012

WWA Funding: January–July 2012

**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 January 2011 at the AMS Meeting in Seattle, WA in conjunction with a short course on water resources and in June 2011 in Salt Lake City. 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 NOAA SARP proposal intended to expand these efforts through a cross-regional comparison was not funded, but PIs are currently seeking other sources of support.

Deliverables: Workshops at AMS Annual Meeting and in Salt Lake City, SARP proposal (not funded), workshop report

WWA Funding: January–December 2011

Leveraged Funding: In-kind support from NOAA CBRFC

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

Primary Investigator(s): K. Averyt

Partners: Union of Concerned Scientists, Western Resource Advocates, National Renewable Energy Laboratory

Outlining the national water footprint of electricity generation, and then to address regional vulnerabilities to climatically driven changes in water and energy resources both in the present and in the near future.

In November 2011, the first of two major reports (*Freshwater Use by US Power Plants: Electricity's Thirst for a Precious Resource*) was released on November 15 2011. (The report is available at http://www.ucsusa.org/assets/documents/clean_energy/ew3/ew3-freshwater-use-by-us-power-plants.pdf). Beyond the originally proposed work the project expanded significantly in 2011 to include a water stress analysis, which took significant effort. Two major insights came from the report: 1) Data collected and disseminated by the Energy Information Administration about water withdrawals and consumption is significantly flawed. Given that 41% of national water withdrawals are by power plants, these data gaps can create significant problems for those managing and planning for water resources. 2) Stress imposed on water systems by power plants is both a water quality and quantity issue. The manifestation of stress is different in different parts of the US. Research results have been communicated directly to stakeholders through meetings, dissemination of the report, and other methods.

Deliverables: Report on freshwater use by power plants (Averyt et al. 2011), two peer-reviewed publications expected in 2012

WWA Funding: January–December 2011

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

Water-Energy-Climate Change Nexus

Primary Investigator(s): D. Kenney, K. Averyt

Publication of a book providing an overview of the nexus among water, energy, and climate issues in the western United States.

In 2011, Edward Elger Publishing produced *The Water-Energy Nexus in the Western United States*, edited by Kenney (WWA) and Robert Wilkinson. It features contributions from authors drawn from a network of researchers and decisionmakers working on energy-water issues, including WWA's K. Averyt. The research and analyses presented in the book demonstrate that the choices that must be made in order to continue the sustainable development and management of water and energy systems to meet public needs in under future scenarios of climate and other changes.

Deliverables: Published book (Kenney and Wilkinson, 2011)

WWA Funding: January–July 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.

In 2011, the PIs developed and administered a semi-formal survey instrument to over 140 individuals at the municipal level in 60 cities in Colorado, Utah and Wyoming. Interviews included three individuals for each city covering both elected and appointed positions. Survey questions asked about top priority areas, what natural hazards were seen as important, how municipalities have allocated resources to a given hazard, what types of plans exist and how they relate to implementation, impressions of memorable extreme events, where communities obtain information, how collaborations occur, how citizen groups are involved, and beliefs about climate change. In addition, researchers collected city policy documents and reviewed city websites for additional information. Preliminary 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.

Deliverables: WWA White Paper and peer-reviewed publication expected in 2012

WWA Funding: July–December 2011

Climate Change Preparedness Among Tribal Communities in the American West

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

Partners: NIDIS, CLIMAS

Building new stakeholder relationships with native communities and understanding tribes' needs for relevant climate information and assistance 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. For *Part 1* of this project, PIs completed the "Native Communities and Climate Change" database available at <http://www.tribesandclimatechange.org> and sent it directly to the National Climate Assessment along with a descriptive memo. For *Part 2* they completed the culturally appropriate Tribal Energy Action and Climate Change Adaptation Reports in consultation with the Southern Ute Tribe and Navajo Nation in the Southwest. For *Part 3* they have worked to develop relationships with tribal managers interested in drought mitigation, water conservation planning, or climate change information. The Ute Mountain Ute have expressed interest in developing a water and climate section for their integrated resource management plan. WWA has joined with CLIMAS to help update the Navajo Nation's Drought Contingency Plan. Little progress has been made in developing a relationship with the Southern Ute.

Deliverables: Native Communities and Climate Change database, Climate Change Adaptation and Energy Action Reports for Navajo Nation and Southern Ute Tribe

WWA Funding: July–December 2011

Leveraged Funding: \$45,000 from NIDIS

Climate Adaptation Decision-Making: A Modeling Approach

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

Development and application of decision-making analysis to the study of climate adaptation through the use of a modeling testbed.

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 is 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. Uncertainty and decision analysis routines in Analytica allow a risk-based approach with the ability to manipulate distributions of inputs and outcomes rather than mean conditions, and to capture uncertainty via Monte Carlo sampling of those distributions. Analysis begins with development of an impact and adaptation storyline that incorporates the postulated variables and processes and is used to organize data collection, specification of variables in the model, and interpretation of results. For an initial pilot effort, the project tested hypotheses about the timing of adaptation in response to climate change signals on a simulated dryland wheat farm. Once climate change, expressed by a declining yield distribution, passed a threshold of negative net income, adaptation was paced by the rate of change, but was also slowed by larger noise-to-signal ratio. Extreme years evoked adaptation sooner than gradual change without extreme events and in some scenarios extremes induce premature adaptation, as hypothesized in the literature. PIs found an interesting pattern in which reducing input costs (and thus overall production) appeared to yield better net income than did trying to maintain or increase production in a worsening climate.

Deliverables: Working farm decision model available online; peer-reviewed publication expected in 2012.

WWA Funding: July–December 2011



Boulder County Climate Change Preparedness Plan

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

Partners: Stratus Consulting, AMEC Earth and Environmental

Development of policy-oriented climate change adaptation plan for Boulder County and the City of Boulder, Colorado.

Climate change has the potential to exacerbate many of the challenges faced by Boulder County and its municipalities. These challenges include droughts, flash flooding, West Nile virus, heat waves, fire mitigation and fire protection, and increased road maintenance, among others. In light of this, WWA, together with Stratus Consulting and AMEC Earth & Environmental, was awarded a contract to develop an adaptation plan for the County of Boulder, Colorado and the municipalities contained within its borders. In addition to providing a needed service to the city and county where WWA is physically located, this project provides an opportunity for WWA to engage in on-the-ground adaptation planning efforts, which will feed back into WWA efforts to understand and improve adaptation practices across the Intermountain West region. WWA's specific contributions included drafting of a review of relevant science on climate projections and hydrologic impacts (Barsugli), drafting of a chapter on adaptation options for the water sector (Gordon) and co-authoring of the report's introduction and conclusion (Gordon). The draft report was completed in December 2011 and a final version is expected to be approved by Boulder County Commissioners in 2012.

Deliverables: Final Boulder County Climate Change Preparedness Plan expected in 2012

Leveraged Funding: \$8,500 from Boulder County and City of Boulder

Climate Adaptation for Salt Lake City Public Utilities

Primary Investigator(s): T. Bardsley, A. Wood (CBRFC)

Partners: NOAA NWS Colorado Basin River Forecast Center, Salt Lake City Public Utilities

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

The primary goal of this project is to assist SLCPU in understanding how projected increases in temperature and changes in precipitation may impact the timing and volume they have historically expected from their surface water supplies in order to allow them to plan for a reliable and resilient system into the future. Work completed in 2011 evaluated the measured sensitivity of watershed creeks to past variability of temperature and precipitation. In addition, the CBRFC's hydrology model has been run with a variety of temperature and precipitation forcings over the calibration period of 1981-2010 for seven creeks and rivers currently used by the SLCPU system, as well as two neighboring creeks. Projected changes in average timing and volume have been evaluated as well as changes to a single extreme low flow year and a multi-year drought sequence. The past 25 years of SLCPU demand data has been analyzed for likely correlations with climate variables to aid in projecting future demand under a changing climate. Several meetings with SLCPU staff and leadership have guided the analysis to address their concerns. Future efforts will use climate model-driven temperature and precipitation scenarios and incorporate dynamic potential evapotranspiration into the CBRFC hydrology model. System demand will be evaluated in light of climate change, with the goal of modeling future demand. The collaboration will be expanded to leverage new research focused on urban water management being conducted at the University of Utah.

Deliverables: Presentation of results to Salt Lake City Public Utilities; WWA White Paper in 2012

WWA Funding: January–December 2011

Leveraged Funding: In-kind staff efforts from NOAA Colorado Basin River Forecast Center

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 2011, a beta version of an online, searchable database structure was created. It has been populated with 167 items so far, including peer- and non-peer-reviewed articles, reports, websites, presentations, etc. 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 any geographical location the item focuses on. In general, there is more literature about the socioeconomic impacts of climate variability and change on outdoor recreation than initially expected. In 2012 the database will be completed, a white paper will be written, and the database will be shared directly with stakeholders, including the Western Governors' Association, which requested this type of information.



Deliverables: Completed database and WWA White Paper expected in 2012

WWA Funding: July–December 2011

Developing Climate Extension Services in Utah

Primary Investigator(s): R. Gillies

Partners: Utah State University Cooperative Extension Program

Development of a preliminary network for climate extension work in Utah.

Note: This project was unable to begin in 2011 due to the delay in transferring funds from the University of Colorado to Utah State University. The funds transfer was completed in early 2012 and work will continue through 2012.

This project entails the development of a preliminary climate extension network for Utah, leveraging existing networks from other extension programs. Developing such a network would allow WWA to help demonstrate the potential utility of establishing a formal Extension Climatologist position at Utah State University. The project PI, who is faculty at Utah State University (USU) and director of the Utah Climate Center, will use WWA funding for the development of a Climate Extension Network and explore establishing an Extension Climatologist Position. WWA could benefit from both the expertise and services of the person in that position and from the information developed through a climate extension network. Personnel at the Utah Climate Center, led by Gillies, will begin developing a network for future climate-oriented extension outreach. This process will focus on individuals and associations of individuals—for example, reaching out to individual farmers as well as farmers' groups throughout the state, complementing the efforts to engage public agencies by the WWA Utah Liaison (Bardsley).

WWA Funding: Funding was not in place during 2011 due to the time involved in setting up a subcontract. Funds will be used during 2012.

Support of the National Climate Assessment

Colorado Climate Preparedness Project

Primary Investigator(s): R. Klein, E. Gordon, W. Travis, J. Lukas, K. Averyt, B. Udall

Partners: Governor's Energy Office, Colorado Water Conservation Board, Colorado Dept. of Agriculture

Preliminary analysis of climate impacts and adaptations relevant to state agencies in Colorado; development of an online adaptation database.

At the request of the state of Colorado, WWA researchers conducted a preliminary analysis of climate impacts and adaptation options in five sectors—water; electricity; wildlife, ecosystems, and forests; agriculture; and outdoor recreation. The results of this effort are compiled in a database of people, projects, products, and organizations relevant to adaptation in the state (<http://www.coloadaptationprofile.org>) and a final report (http://www.colorado.edu/CCPP_report.pdf). The report and the database are intended to help facilitate future vulnerability assessment and adaptation planning efforts across the state. The database code is being made available to other RISAs as needed and will be used in future WWA assessment work. The final report (Klein et al. 2011) was completed in March 2011 and presented to Governor Hickenlooper and his staff.

Deliverables: Final CCPP report (Klein et al. 2011), final CCPP database (<http://www.coloadaptationprofile.org>).

WWA Funding: January–March 2011

Leveraged Funding: \$161,000 from State of Colorado

Utah & Wyoming Climate Adaptation Databases

Primary Investigator(s): T. Bardsley, E. Gordon, K. Averyt, S. Miller

Creation and maintenance of two databases; each containing information related to the people, products, documents, and projects in the state of Utah, and the state of Wyoming, respectively, that support climate adaptation in each state.

Similar to the completed effort in Colorado, these proposed databases add “product maps” of existing science efforts and information about vulnerable sectors in Utah & Wyoming. In 2011, the Utah Liaison (Bardsley) crafted a database for Utah. Since WWA has been unable to hire a Wyoming Liaison due to a lack of qualified candidates, the project for constructing the Wyoming database became the responsibility of S. Miller, a member of the research team based at Univ. of Wyoming, and a graduate student, who completed the database for that state. Both databases were shared with teams crafting regional technical inputs for the National Climate Assessment.

Deliverables: Databases for each state along with narrative summaries



WWA Funding: January–December 2011

Colorado River Basin Workshop

Primary Investigator(s): G. Garfin (CLIMAS), J. Galayda (CLIMAS), T. Wall (CNAP), E. Gordon (WWA)

Partners: CLIMAS, CNAP

Cross-RISA effort to hold a workshop on evaluating capacity for climate change assessment in the Colorado River Basin.

The “Evaluating Our Capacity: A Discussion of Capability for Ongoing Climate Assessment in the Colorado River Basin” workshop was held in Boulder, CO, on June 6-8, 2011. Sponsored by CLIMAS, WWA, and CNAP, the workshop brought together a diverse group of professionals working in the Colorado River Basin. Participants tried to answer two main questions during the workshop: What is our capacity for conducting ongoing assessments of climate vulnerabilities, impacts, and adaptive capacity? What is our capacity to evaluate the efficacy of our efforts to adapt to regional climate changes and their impacts? Workshop participants assessed capacity by identifying current adaptation initiatives. They applied eight metrics to current assessment and adaptation efforts in the region: institutions; communication; attitudes, culture & framing; leadership; resources; monitoring; science capacity; and legal. Results from the workshop provide a roadmap for considering how to move forward with climate change assessment and adaptation efforts in the Colorado River Basin. The final workshop report, drafted by T. Wall (CNAP), is available at <http://www.climas.arizona.edu/publications/2375>.

Deliverables: Completed workshop and workshop report

WWA Funding: January–July 2011

Regional Technical Inputs for the National Climate Assessment

Primary Investigator(s): B. Udall, K. Averyt, J. Lukas, J. Barsugli, W. Travis, L. Dilling, E. Gordon, K. Wolter, R. Gillies

Partners: CLIMAS, CNAP, North Central Climate Science Center

Participation as lead authors and contributing authors of various sections of the Southwest Region Technical Input report for the National Climate Assessment.

The Southwest Climate Alliance, an affiliation of multiple research organizations in the Southwest (including WWA, CNAP, and CLIMAS) is working to develop a technical input report on the Southwest Region for the National Climate Assessment. This effort brought together a diverse set of authors to craft an IPCC-style peer-reviewed assessment of climate challenges and scientific findings related to climate variability and change in the six-state region. WWA researchers served as authors on many chapters, including Water (Udall–Lead), Uncertainty (Averyt–Lead), The Changing Southwest (Travis and Gordon–Contributing), Weather and Climate (Gillies–Contributing), Evolving Weather and Climate Conditions (Lukas and Wolter–Contributing), Projections of Mean Climate (Barsugli–Contributing), and Solutions for a Sustainable Southwest (Dilling–Lead, Gordon–Contributing). WWA researchers K. Cozzetto and K. Averyt also participated in the development of the Great Plains Region Technical Input report.

Deliverables: Final technical inputs expected in 2012

WWA Funding: January–December 2011

Support for the National Climate Assessment Sectoral Chapters

Primary Investigator(s): K. Averyt

WWA researchers are serving as lead authors on multiple sectoral chapters for the National Climate Assessment’s 2013 report.

In addition to regional chapters, the next National Climate Assessment report will include nationwide perspectives on a variety of sectors. WWA researcher Averyt is a lead author for the energy-water-land cross-sectoral chapter. Chapters were outlined and discussed in 2011 with completion expected in 2013.

Deliverables: Final versions of sectoral chapters expected in 2013

WWA Funding: July–December 2011

Core Activities

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



Primary Investigator(s): B. Udall, 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 (Averyt–North Central; Udall–Southwest) for the CSCs, participate in the development of RFPs, and have helped set agendas and find directors for both of the CSCs. In addition, WWA’s Lukas has served as a member of the science steering committee for the Southern Rockies LCC and helped that organization prioritize its most critical climate science needs.

WWA Funding: January–December 2011

Building a Network of Stakeholders for Future WWA Research

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

Participation in numerous stakeholder events and direct interactions with decision-makers to build trusted relationships in the region in order to further develop WWA’s stakeholder network and identify future research opportunities.

WWA staff, along with team members, spent a significant amount of time interacting with stakeholders throughout our three-state region. Examples of such interactions include attending water users’ conferences, meeting with key stakeholders at state and federal agencies, and participating in workshops. Although this work did not produce direct research results, it is both critical to ensuring that WWA work is relevant and accepted by the stakeholder community and extremely time-intensive.

Deliverables: Continued efforts towards building a robust stakeholder network

WWA Funding: January–December 2011

WWA Speakers Bureau

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

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

WWA receives dozens of requests every year to speak at events throughout our region, as evidenced by many of the presentations listed in Appendix A. Examples of speaking engagements in 2011 include a presentation to the Colorado River Water Conservation District on drought planning in Australia (Udall), a presentation on climate impacts in Wyoming for the state’s Game and Fish Department (Lukas), and a presentation on projected climate change in the West for Forest Service resource managers (Lukas).

Deliverables: Presentations as outlined in Appendix A

WWA Funding: January–December 2011

Intermountain West Climate Summary (IWCS)

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

Publication of a bi-monthly summary of climate information for WWA’s three-state region, with in-depth articles communicating WWA research and related efforts.

In 2011, WWA continued on its schedule of producing six web-based issues of the IWCS, whose release is announced to a list of 400 stakeholders. All of the Feature and Focus articles in 2011 were written expressly for the IWCS, with the Feature articles highlighting WWA work including the Colorado Climate Preparedness Project and downscaled climate projections for the San Juans region while also providing other stakeholder-relevant information like background on the National Climate Assessment and expectations of an unusually high runoff season. The release of each issue of the IWCS continues to be emailed directly to approximately 400 recipients and be announced on the homepages of NOAA NWS forecast offices throughout the region and other partner organizations. IWCS issues are available at <http://wwa.colorado.edu/IWCS/index.html>.

Deliverables: Continued publication of Intermountain West Climate Summary during 2011

WWA Funding: January–December 2011

Update of WWA Website and Other Communication Materials



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

WWA's communication materials, critical to effective communication with stakeholders, are being revised to better meet stakeholder needs and appropriately reflect WWA's mission and activities.

In fall 2010, Program Manager Gordon carried out the first quarterly update of WWA research and outreach activities, which was produced as a PDF, emailed to the WWA stakeholder list, and posted on the WWA website. That precedent was followed in 2011 with an announcement of descriptions of upcoming projects, sent with the intention of allowing stakeholders to directly contact researchers whose projects may be of interest. In addition, during 2011 plans were drawn up for a revision of the WWA website (including the development of a new template) and a webinar series, all of which will be carried out in 2012.

Deliverables: WWA website template, project update reports, webinar series in 2012.

WWA Funding: July–December 2011

Leveraged Funding: In-kind support from CIRES staff

Best Practices for Observational Datasets

Primary Investigator(s): K. Wolter, R. Gillies, N. Doesken

Developing a publication of findings and recommendations on best practices for developing and interpreting historic records and time series.

The Utah Climate Center at Utah State University, in collaboration with the Colorado Climate Center at Colorado State University, the Western Water Assessment at the University of Colorado and the Cooperative Institute for Research in the Atmosphere in the CSU Department of Atmospheric Science, is developing a publication of findings and recommendations on best practices for developing and interpreting historic records and time series, specifically for temperature and precipitation records. This paper will document the process of selecting the best station records in Colorado and Utah. The goal is to make climate data from the instrumental record (late 1800s until the present) accessible to public audiences, decision makers and educators in a manner that the seasonality, interannual variability and long term trends can be easily visualized and accurately portrayed. A publication has been drafted in 2011 and is expected to be submitted for publication in 2012.

Deliverables: Peer-reviewed publication expected in 2012

WWA Funding: None (no-cost extension)

WWA 2011 Publications

Averyt, K., J. Fisher, A. Huber-Lee, A. Lewis, J. Macknick, N. Madden, J. Rogers, and S. Tellinghuisen. 2011. Freshwater use by U.S. power plants: Electricity's thirst for a precious resource. A report of the Energy and Water in a Warming World initiative. Cambridge, MA: Union of Concerned Scientists. Available at http://www.ucsusa.org/clean_energy/technology_and_impacts/impacts/freshwater-use-by-us-power-plants.html.

Information communicated by K. Averyt directly to elected officials and other stakeholders in areas with high water consumption by power plants.

Averyt, K. 2011. The Coal Conundrum. In: *The Water-Energy Nexus in the Western United States*, D. Kenney and R. Wilkinson, Eds. Cheltenham: Edward Elgar Publishing.

Bracken, C. 2011. Seasonal to Inter-Annual Streamflow Simulation and Forecasting on the Upper Colorado River Basin and Implications for Water Resources Management. M.S. Thesis, Department of Civil, Environmental, and Architectural Engineering, University of Colorado Boulder. Available at http://cadswes.colorado.edu/PDF/Theses-PhD/Bracken-MS_thesis-2011.pdf.

Information directly communicated to Bureau of Reclamation through testing of streamflow simulations in Bureau of Reclamation's Midterm Operations Model.



Cozzetto, K., I. Rangwala, and J. Lukas. 2011. Examining Regional Climate Model (RCM) Projections: What Do They Add to our Picture of Future Climate in the Region? *Intermountain West Climate Summary* 7(4).

Information communicated to various stakeholders throughout the region via distribution of Intermountain West Climate Summary to approximately 400 subscribers.

Deems, J. and J. Lukas. 2011. Dust-on-Snow and Hydrologic Impacts in the Colorado River Basin. *Intermountain West Climate Summary* 7(1).

Information communicated to various stakeholders throughout the region via distribution of Intermountain West Climate Summary to approximately 400 subscribers.

Gangwer, K. 2011. Dryness and Desperate Measures: The Implications of Land Tenure on Rocky Mountain Ranchers' Drought Experiences and Behaviors. M.S. Thesis, Department of Geography, University of Colorado Boulder.

Gray, S.T., Lukas, J.J., and Woodhouse, C.A. 2011. Millennial-Length Records of Streamflow from Three Major Upper Colorado River Tributaries. *Journal of the American Water Resources Association* 47(4): 702-712.

Kenney, D.S., and R. Wilkinson (editors). 2011. *The Water-Energy Nexus in the Western United States*. Cheltenham: Edward Elgar Publishing.

Klein, R., E.S. Gordon, W.R. Travis, J.J. Lukas, B. Udall, K. Averyt, J. Vogel, and J. Smith. 2011. Colorado Climate Preparedness Project Final Report. 108 pp. Available online at http://wwa.colorado.edu/CCPP_report.pdf.

Information directly communicated to Colorado state agencies that funded the project (Colorado Water Conservation Board; Governor's Energy Office; Colorado Department of Agriculture).

Lukas, J., R. Klein, E. Gordon, and W. Travis. 2011. The Colorado Climate Preparedness Project – Capturing the State of Climate Adaptation in Colorado. *Intermountain West Climate Summary* 7(2).

Information communicated to various stakeholders throughout the region via distribution of Intermountain West Climate Summary to approximately 400 subscribers.

Lukas, J. 2011. The Spring Runoff Roundup: Another Look at ENSO, Dust-on-Snow, Beetles, and Lake Mead. *Intermountain West Climate Summary* 7(3).

Information communicated to various stakeholders throughout the region via distribution of Intermountain West Climate Summary to approximately 400 subscribers.

Lukas, J. 2011. The National Climate Assessment – Available and Forthcoming Resources for the Intermountain West and Beyond. *Intermountain West Climate Summary* 7(5).

Information communicated to various stakeholders throughout the region via distribution of Intermountain West Climate Summary to approximately 400 subscribers.

Neely, B., R. Rondeau, J. Sanderson, C. Pague, B. Kuhn, J. Siemers, L. Grunau, J. Robertson, P. McCarthy, **J. Barsugli,** T. Schulz, and C. Knapp, Eds. 2011. Gunnison Basin: Vulnerability Assessment for the Gunnison Climate Working Group by The Nature Conservancy, Colorado Natural Heritage Program,



Western Water Assessment at the University of Colorado-Boulder, and University of Alaska-Fairbanks. Project of the Southwest Climate Change Initiative. Available online at http://www.cnhp.colostate.edu/download/documents/2011/Gunnison-CC-Vulnerability-Assessment_and_Appendices-FULL_REPORT-Jan_9_2012.pdf.

Nowak, K. 2011. Stochastic Streamflow Simulation at Interdecadal Times Scales and Implications for Water Resources Management in the Colorado River Basin. Ph.D. Thesis, Department of Civil, Environmental, and Architectural Engineering, University of Colorado Boulder. Available at <http://cadswes.colorado.edu/PDF/Theses-PhD/Nowak-PhD.pdf>.

Information directly communicated with Bureau of Reclamation. Primary author is now an employee of the Bureau.

Nowak, K., B. Rajagopalan, and E. Zagona. 2011. Wavelet Auto-Regressive Method (WARM) for multi-site streamflow simulation of data with non-stationary spectra. *Journal of Hydrology*, 410 (1-2): 1-12. *Information directly communicated with Bureau of Reclamation. Primary author is now an employee of the Bureau.*

Squillace, M.S., and A.N. Hood. 2011. NEPA, Climate Change, and Public Lands Decision-Making. U of Colorado Law Legal Studies Research Paper No. 11-13.

Links with Other NOAA Programs

- WWA collaborated and shared costs with the **National Integrated Drought Information System (NIDIS)** on two research projects: 1) Snowmelt Perturbations and Forecast Runoff Errors in the Upper Colorado River Basin and 2) Climate Change Preparedness Among Tribal Communities in the American West. Jim Verdin from NIDIS is a member of the WWA Advisory Board.
- WWA team members work extensively with staff at the **NOAA Colorado Basin River Forecast Center (CBRFC)** in Salt Lake City (see “Towards Frameworks for Climate Services” above). WWA Utah Liaison Tim Bardsley is located in the CBRFC office, and CBRFC Hydrologist-in-Charge Michelle Schmidt is a member of the WWA Advisory Board. In addition, the “Snowmelt Perturbations and Forecast Errors in the Upper Colorado River Basin” project was developed largely to improve CBRFC forecasting.
- WWA is physically housed in the **Physical Sciences Division (PSD)** of the NOAA Earth Systems Research Laboratory at the David Skaggs Research Center in Boulder, CO. This co-location provides frequent opportunities to interact with PSD researchers. PSD Director William Neff is a member of the WWA Advisory Board.
- WWA staff coordinates activities with **NOAA Central Region Climate Services Director** Doug Kluck and are participating in the development of the Missouri River Basin Climate Consortium.



APPENDIX A: List of 2011 WWA Presentations

January 18, 2011

K. Cozzetto

“Downscaled temperature and precipitation projections for the San Juan Mountains region”
San Juan Public Lands Center Workshop: Climate Change Adaptation Strategies for Vegetation Management, Durango, CO

January 18, 2011

J. Neff

“A new approach to evaluating drought vulnerability across the landscape”
San Juan Public Lands Center Workshop: Climate Change Adaptation Strategies for Vegetation Management, Durango, CO

January 18, 2011

B. Udall

“The Colorado Climate Preparedness Project”
Colorado Water Quality Forum, Denver, CO

January 23, 2011

K. Averyt

“Decision Gaming Using Reservoir Inflow Forecasts”
American Meteorological Society Annual Meeting, Seattle, WA

January 26, 2011

B. Udall

“Water in Our Corner of the World: A Comparative Look at Water Management in Colorado and Australia”
Colorado Water Congress Annual Convention, Denver, CO

January 27, 2011

B. Udall

Opening Panel Presentation
Colorado Water Congress Annual Convention, Denver, CO

January 27, 2011

J. Deems

“Snowmelt and runoff impacts of desert dust deposition on mountain snowpacks in the Colorado River Basin”
Colorado Water Congress Annual Convention, Denver, CO

January 28, 2011



B. Udall

Concluding General Session Presentation: "Balancing water supply and the environment: A common challenge in the two hemispheres"

Colorado Water Congress Annual Convention, Denver, CO

February 2

B. Udall

"Climate change and the Colorado River: Implications for Nevada"

Nevada Water Resources Association Meeting, Reno, NV

February 23, 2011

E. Gordon and E. Pugh

"A conceptual model of water quantity impacts from insect-induced tree death in coniferous forests"

Poster presented at Front Range Student Ecology Symposium, Fort Collins, CO

March 9, 2011

N. West

"Native Communities and Climate Change Database and decisionmaking resources"

Northern Arizona University Institute for Tribal Environmental Professionals Climate Change Training

March 11, 2011

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 15, 2011

T. Bardsley

"An introduction to the Western Water Assessment"

Utah Water Users Workshop, St. George, UT

March 16, 2011

J. Lukas

"Influences on the variability of Colorado River Basin snowpack and runoff, and the outlook for spring-summer 2011"

Lower Colorado River Tour - Water Education Foundation, Boulder City, NV

March 16, 2011

J. Lukas

"Climate change and projections of future Colorado River flows"

Lower Colorado River Tour - Water Education Foundation, Boulder City, NV



March 16, 2011

J. Lukas

“The long perspective on Colorado River flow from tree rings”

Lower Colorado River Tour - Water Education Foundation, Lake Havasu City, AZ

March 17, 2011

J. Lukas

“Dust-on-snow and beetles-on-trees: Impacts from Colorado River flows”

Lower Colorado River Tour - Water Education Foundation, Yuma, AZ

March 29, 2011

T. Bardsley

“Climate sensitivity analysis for public water supply”

Utah State University Spring Runoff Conference, Logan, UT

April 4, 2011

K. Averyt

“The Energy–Water Nexus”

Georgia Water Resources Conference, Athens, GA

April 29, 2011

S. Gray

“Long-term perspective on climate and water resources in western Wyoming”

US Forest Service Natural Resources and Climate Change Workshop, Cody, WY

April 29, 2011

J. Lukas

“Ongoing and projected climate change in Wyoming and the West”

US Forest Service Natural Resources and Climate Change Workshop, Cody, WY

May 10, 2011

K. Averyt

“The Energy-Water Nexus in the United States”

Harvard University Kennedy School of Government, Cambridge, MA

May 10, 2011

K. Averyt

“The Energy-Water Nexus in the United States”

Massachusetts Institute of Technology

June 8, 2011

J. Lukas



“The future hydrology of the Upper Colorado River Basin under a changing climate – an update on the state of the science”

Upper Colorado River Commission - Annual Meeting, Boulder, CO

June 13, 2011

D. Cordalis

“Native communities and climate change”

National Congress of American Indians Mid-Year Conference, Milwaukee, WI

July 12, 2011

D. Kenney

“Policy and legal implications of reduced Colorado River flows”

Universities Council on Water Resources Annual Conference, Boulder, CO

July 12, 2011

K. Nowak

“Colorado River decadal projections: A spectral approach”

Universities Council on Water Resources Annual Conference, Boulder, CO

July 12, 2011

J. Barsugli

“Does the downscaling method matter for climate change adaptation on the Colorado River?”

Universities Council on Water Resources Annual Conference, Boulder, CO

July 12, 2011

J. Deems

“Desert dust impacts on snowmelt and runoff in the Upper Colorado River Basin”

Universities Council on Water Resources Annual Conference, Boulder, CO

July 14, 2011

K. Averyt

“Energy impacts from adaptation to future water supply”

National Climate Assessment Preliminary Meeting, College Park, MD

July 18, 2011

L. Dilling

“The role of information in climate change adaptation on western public lands”

Practical Solutions for a Warming World: AMS Conference on Climate Adaptation, Asheville, NC

July 18, 2011

E. Gordon

“The Colorado Climate Preparedness Project: A systematic approach to assessing state-level adaptation”



Practical Solutions for a Warming World: AMS Conference on Climate Adaptation, Asheville, NC

July 18, 2011

J. Rice, L. Joyce, B. Armel, G. Bevenger, and L. S. Baggett

“Climate adaptation on National Forests: A case study on the Shoshone National Forest, Wyoming”

Practical Solutions for a Warming World: AMS Conference on Climate Adaptation, Asheville, NC

July 19, 2011

J. Teel-Simmonds

“University of Colorado Native Communities and Climate Change Project: Possible Ute Mountain Ute–CU Boulder collaborations”

Ute Mountain Ute Integrated Resource Planning Meeting

July 19, 2011

J. Berggren

“Analyzing expressed stakeholder needs in the Western Water Assessment RISA”

Practical Solutions for a Warming World: AMS Conference on Climate Adaptation, Asheville, NC

July 19, 2011

L. Dilling

“Building and comparing stakeholder databases and networks across RISAs”

Practical Solutions for a Warming World: AMS Conference on Climate Adaptation, Asheville, NC

August 18, 2011

B. Udall

Panel discussant

How the West was warmed: Forum on climate and water

August 18, 2011

J. Lukas

“Natural hydroclimatic variability – the long view from tree-ring paleo records”

UCAR COMET Advanced Hydrological Sciences Virtual Course, Boulder, CO

August 30, 2011

B. Udall

Opening Keynote Address

NOAA Water Cycle Science Challenge Workshop

September 14, 2011

B. Udall

“Lessons in water management from Australia for the Colorado River Basin”

University of Colorado Engineering Forum, Boulder, CO



September 15, 2011

B. Udall

“Stranger in a strange land: Lessons from an extended stay in Australia”

Colorado River District Annual Water Seminar, Grand Junction, CO

<http://www.youtube.com/watch?v=ULrwmukFt5I>

September 27, 2011

E. Gordon

“Bark beetles and western forests: What is the problem?”

Presentation to Public Environmental Policy Course at University of Colorado-Boulder

October 11, 2011

B. Udall

“Australia 2001-2010: A decade of climate extremes and public policy responses”

Geological Society of America Annual Meeting, Minneapolis, MN

October 22, 2011

B. Udall

Panel speaker for “Water, water everywhere”

Society of Environmental Journalists Annual Meeting, Miami, FL

October 24, 2011

J. Lukas

“Climate change in Wyoming and the west and implications for wildlife management”

Presentation to Wyoming Game and Fish Department senior staff meeting

October 31, 2011

J. Deems

“Desert dust impacts on snowmelt and hydrology in the Upper Colorado River Basin”

Upper Colorado River Basin Forum at Colorado Mesa University, Grand Junction, CO

October 31, 2011

E. Gordon

“Using climate and water expertise to support stakeholders in the Upper Colorado River Basin”

Upper Colorado River Basin Forum at Colorado Mesa University, Grand Junction, CO

November 1, 2011

B. Udall

“New challenges in water research”

Water Utility Climate Alliance General Managers’ Retreat, Las Vegas, NV

November 3, 2011



B. Udall

“Twenty years of water reform in Australia: Any lessons for the American West?”

Center for Science and Technology Policy Noontime Seminar, Boulder, CO

November 8, 2011

B. Udall

“Downscaling, upscaling & a few things in between: Assessing climate risk, making decisions”

Carpe Diem West Academy Webinar

November 14, 2011

J. Lukas

“Paleohydrology of the Lower Colorado River Basin—Project status and results”

Colorado Water Institute Advisory Board Meeting, Denver, CO

December 1, 2011

J. Lukas

“Beetle impacts on runoff timing and volume at the watershed scale”

Utah Bark Beetles and Watershed Workshop - USDA Forest Service and WWA, Salt Lake City, UT

December 1, 2011

E. Gordon

“Overview of Western Water Assessment’s work on beetles and water”

Utah Bark Beetles and Watershed Workshop - USDA Forest Service and WWA, Salt Lake City, UT

December 1, 2011

T. Bardsley

“Overview of the Western Water Assessment”

Utah Bark Beetles and Watershed Workshop - USDA Forest Service and WWA, Salt Lake City, UT

December 1, 2011

J. Deems

“Bark beetle impacts on snowmelt processes and tree water use”

Utah Bark Beetles and Watershed Workshop - USDA Forest Service and WWA, Salt Lake City, UT

December 1, 2011

E. Gordon

“Hydrologic impacts at stand scales: Conceptualized implications for water yield”

Utah Bark Beetles and Watershed Workshop - USDA Forest Service and WWA, Salt Lake City, UT

December 1, 2011

J. Lukas

“Beetles, dust accumulation, and climate change: Unraveling drivers of snowmelt in the

Intermountain West”



Utah Bark Beetles and Watershed Workshop - USDA Forest Service and WWA, Salt Lake City, UT

December 5, 2011

J. Lukas

“Climate & the Colorado River in the 21st century: Assessing the risk to basin water supplies”
State of the Rockies Project Seminar Series - Colorado College, Colorado Springs, CO

December 5, 2011

J. Deems

“Impacts of current and future dust deposition on Colorado River Basin hydrology”
2011 American Geophysical Union Fall Meeting, San Francisco, CA

December 5, 2011

B. Udall

“The continuing evolution of water management in Australia”
2011 American Geophysical Union Fall Meeting, San Francisco, CA

December 6, 2011

K. Averyt

“Does climate attribution matter?”
2011 American Geophysical Union Fall Meeting, San Francisco, CA

December 6, 2011

K. Mahoney

“From regional to storm-scale: NARCCAP-driven high-resolution simulations to evaluate changes in extreme precipitation events”
2011 American Geophysical Union Fall Meeting, San Francisco, CA

December 8, 2011

L. Wade

“Beyond Lees Ferry: Assessing the long-term hydrologic variability of the Lower Colorado River Basin”
2011 American Geophysical Union Fall Meeting, San Francisco, CA

December 9, 2011

K. Mahoney

“High-resolution modeling approaches to understanding changes in extreme precipitation projections”
2011 American Geophysical Union Fall Meeting, San Francisco, CA

December 9, 2011

C. Bracken



“A nonstationary hidden Markov model for stochastic streamflow simulation and inter-annual forecasting in the Upper Colorado River Basin”

2011 American Geophysical Union Fall Meeting, San Francisco, CA

December 9, 2011

J. Rice

“A vulnerability tool for adapting water and aquatic resources to climate change and extremes on the Shoshone National Forest, Wyoming”

Poster presented at the 2011 American Geophysical Union Fall Meeting, San Francisco, CA



APPENDIX B: WWA Appearances in Media

January 18, 2011

“Running Toward Empty?”

Climate Central

Quote from Brad Udall

<http://www.climatecentral.org/news/running-toward-empty/>

February 23, 2011

“Dusty Snowpacks Link Water, Energy, Land Management, and Climate Change”

Green Alpha’s Next Economy

Blog post by Jeff Deems

<http://sierraclub.typepad.com/gaa/2011/02/dr-jeff-deems-dusty-snowpacks-link-water-energy-land-management-and-climate-change.html>

March 17, 2011

“Dust, Dust, Stay Away!”

Opensnow.com

Blog post by Jeff Deems

<http://opensnow.com/blog/2011/03/dust-dust-stay-away-thursday-3172011/>

March 29, 2011

“Climate and Drought in the Rockies”

KGNU Radio Show “How on Earth”

Audio interview with Kristen Averyt

<http://howonearthradio.org/archives/tag/kristen-averyt>

June 10, 2011

“Despite Torrential 2011 Flows, Basin Experts Prepare for Water-Strapped Future”

E&E Greenwire

Quote from Jeff Lukas

<http://www.nwra.org/content/articles/despite-torrential-2011-flows-basin-experts-prepar/>

August 26, 2011

“Colorado River...Good to the Last Drop”

Yellowscene Magazine

Quote from Brad Udall

<http://yellowscene.com/2011/08/26/colorado-river-good-to-the-last-drop/>

August 29, 2011

“A Future of Mass Evacuations”

New York Times

“Room for Debate” feature with William Travis



<http://www.nytimes.com/roomfordebate/2011/08/29/what-did-we-learn-from-irene/mass-evacuations-for-hurricane-irene-and-more-to-come>

September 2011

“Running the Climate Rapids”

Confluence: The Carpe Diem West Newsletter

Interview with Kristen Averyt

<http://www.carpediemwest.org/running-climate-rapids>

October 9, 2011

“Lessons for the Colorado River from Drought-Stricken Australia”

High Country News

Audio interview with Brad Udall

<http://www.hcn.org/articles/lessons-for-the-colorado-river-from-drought-stricken-australia/brad-udall-on-australian-water-reform>

October 16, 2011

“Climate: Intermountain West warm & dry in September”

Summit County Citizens’ Voice

Report on October issue of WWA’s Intermountain West Climate Summary

<http://summitcountyvoice.com/2011/10/16/climate-intermountain-west-warm-dry-in-september/>

October 2011

“Speakers Explore Supply, Demand on the River”

Colorado River District Board of Directors Meeting Summary

Picture and caption of presentation by Brad Udall

http://www.crwcd.org/media/uploads/Colorado_River_District_Board_Summary_Oct_2011_compressed.pdf

November 15, 2011

“Power Plants Stressing Freshwater Resources Around the Country”

Treehugger

Quote from Kristen Averyt

<http://www.treehugger.com/energy-policy/power-plants-stressing-freshwater-resources-around-country.html>

November 15, 2011

“Thirsty power plants hurting U.S. water sources – study”

ClimateWire

Article on energy-water research by Kristen Averyt

<http://www.eenews.net/climatewire/2011/11/15/6> (requires subscription)



November 15, 2011

“Report Says Power Plants are Taxing U.S. Freshwater Supplies”

Fuel Fix

Quote from Kristen Averyt

<http://fuelfix.com/blog/2011/11/15/report-says-power-plants-are-taxing-u-s-water-supply/>

November 15, 2011

“South’s Power Plants Stressing Drinking-Water Supplies”

Facing South

Quote from Kristen Averyt

<http://www.southernstudies.org/2011/11/souths-power-plants-stressing-drinking-water-supplies.html>

November 16, 2011

“Power Plants Put Strain on TN’s Freshwater Rivers”

Tennessean

Quote from Kristen Averyt

November 16, 2011

“Where Water & Energy Converge: New Concern”

KQED

Quote from Kristen Averyt

December 2011

A Great Aridness: Climate Change and the Future of the American Southwest

By William DeBuys

Quotes from Brad Udall