

**Annual Report of the  
Western Water Assessment  
1 January 2008 to 31 December 2008**





## Table of Contents

<b>WESTERN WATER ASSESSMENT</b>	<b>3</b>
<b>MAJOR HIGHLIGHTS FROM 2008</b>	<b>3</b>
Climate Change in Colorado Report	3
Intermountain West Climate Summary	4
Next steps	5
Table 1. Federal Partnerships on Feature and Focus Articles from the Intermountain West Climate Summary	5
Reconciling Streamflow Projections for the Colorado River	6
Ongoing Stakeholder Engagement	6
Table 2. 2008 Organizations and Committees with WWA Membership	7
Table 3. 2008 WWA-Sponsored Workshops	7
<b>PROJECT SUMMARIES</b>	<b>8</b>
Evolving Activities	8
Table 4. 2008 WWA Project Summaries	8
Legacy Activities	13
Table 5. WWA Legacy Activities	13
<b>LOOKING AHEAD</b>	<b>21</b>
Table 6. Advisory Board Members	21
<b>1. Decision Support for the Colorado River Basin and Headwaters</b>	<b>21</b>
<b>2. Climate Adaptation and the Adaptation-Mitigation Nexus</b>	<b>21</b>
<b>3. Ecological Vulnerabilities, Impacts, and Adaptation</b>	<b>22</b>
<b>Cross-Cutting Research Factors</b>	<b>22</b>
Geographic Focus	22
Timescale Focus	22
Climate Variability vs. Climate Change Focus	23
Stakeholder Focus	23
Academic Discipline	23
Cross-RISA Activities	23
Assessments, Climate Products and Outreach	23
<b>APPENDIX I. PERSONNEL AND STAKEHOLDERS</b>	<b>25</b>
Table A-1. WWA Personnel	25
Table A-2. WWA Stakeholders and Partner	26
<b>APPENDIX II. PRESENTATIONS</b>	<b>30</b>
<b>APPENDIX III. AWARDS</b>	<b>35</b>
<b>APPENDIX IV. PUBLICATIONS</b>	<b>35</b>
<b>APPENDIX V. MEDIA COVERAGE</b>	<b>38</b>



## Western Water Assessment

Using multidisciplinary teams of experts in climate, water, law, and economics, the Western Water Assessment works with decision-makers across the Intermountain West to produce useful information about natural climate variability and change. In the West, many of the impacts of climate change will be delivered through changes in the hydrologic cycle that have and will continue to affect our water resources. As a consequence, since its inception 10 years ago, WWA has focused on building relationships and networks water-resource decision-makers, and subsequently used these interactions to develop practical research programs and useful informational products. The successes of the WWA model of stakeholder-driven research programs are demonstrated by the project summaries highlighted in this report.

Beginning in 2009, WWA will be refocusing its research and decision-support products; all WWA projects will fall within 3 major thematic categories: (1) Decision Support for the Colorado River Basin and Headwaters; (2) Climate Adaptation and the Adaptation-Mitigation Nexus; and (3) Ecological Vulnerabilities, Impacts, and Adaptation. This will require an expansion of our stakeholder base beyond the water resource community. Consistent with this effort we are broadening our formal mission statement:

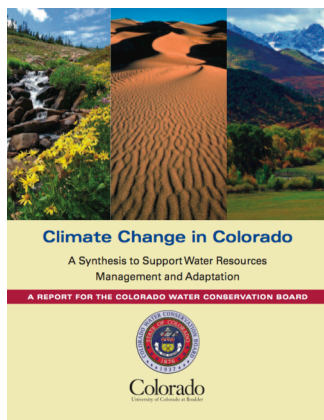
**The mission of the WWA is to identify and characterize regional vulnerabilities to and impacts of climate variability and change, and to develop information, products and processes to assist decision-makers throughout the Intermountain West.**

## Major Highlights from 2008

As in the past, 2008 was an exciting year for the WWA research team. Our projects and outreach efforts were well received by our stakeholder community, and several major endeavors emerged as particularly important efforts.

### Climate Change in Colorado Report

In October 2008, WWA released the [Climate Change in Colorado report](#) at the Governor’s Conference on Mitigating Risks of Drought and Climate Change. The Colorado Water Conservation Board, in support of Governor Ritter’s Colorado Climate Action Plan, commissioned the report. The document is a synthesis intended to support water resources, management, and adaptation efforts throughout the state. WWA adapted an IPCC Working Group I approach to the process, including considerable stakeholder review and comment periods. As a consequence of our interactions with the water management community about their decision processes and needs, there was significant participation by decision makers throughout Colorado.



The report was led by WWA researchers A. Ray (NOAA), J. Barsugli (CIRES), and K. Averyt (WWA), but over 50 individuals contributed to the document. The six chapters synthesize findings from diverse sources on observations and projections, and connect the climate science with the concerns of the water management and drought mitigation communities.

This Climate Change in Colorado report has fostered the visibility and value of NOAA (and WWA) in serving the public by making science, some of it funded by NOAA, available to the water management community. It was also an opportunity to showcase WWA-sponsored research, including ongoing initiatives by N. Doesken and K. Wolter to identify good-quality observational datasets and interpret information in the context of the experimental climate divisions developed by K. Wolter.

The report received significant attention in the media and was a finalist for the Governor’s Research Impact Award. The document provided a springboard for several climate initiatives within the state (e.g. La Plata County Climate Action Plan), and WWA has been busy addressing the demand



for public outreach about climate in Colorado. The authors have given over 30 public presentations about the report, and have presented scientific findings at several major convenings. Currently, at least two manuscripts are being drafted about the process used by WWA to develop the document.

As a follow-up, WWA is now developing a Colorado Climate Roadshow. In collaboration with M. Shafer (SCIP), WWA is busy adapting the CPO-funded Climate 101 training workshop first tested in Oklahoma to Colorado. The intention is to add a Colorado-specific module to the training that is based on the Climate Change in Colorado report, test the workshop in a few locations, and then bring the information to stakeholders across the state.

## Intermountain West Climate Summary

The [Intermountain West Climate Summary \(IWCS\)](#) continues to be WWA's most prominent outreach and education product. WWA distributes the IWCS to over 400 decision makers, scientists and climate information providers; and based on our tracking, the January 2009 IWCS page was viewed by about 800 individual people. The IWCS provides the latest climate information in a simple compact document aimed at managers, planners, and policy makers with water-related interests. By improving awareness and understanding about forecasts as well as climate phenomena, the climate summary helps WWA facilitate a dialog among potential users, researchers and operational providers of climate information with the ultimate goal of providing enhanced climate services.

Since January 2005, the IWCS has been released eight times each year, but in 2009 our distribution mechanism and process will change. The changes are in response to a 2008 initiative to evaluate whether the IWCS was providing stakeholders with the most relevant and useful information, and determine whether WWA was fulfilling the educational goal of enhancing climate literacy through the IWCS.

Recognizing that CLIMAS had undertaken a similar initiative in the past, we worked with them to create a 35-question user survey focused on several big-picture questions:

- How often and when do stakeholders read the IWCS?
- Is the technical level of the text, articles and graphics adequate?
- How do decision makers use the information in the IWCS?
- What are our stakeholder types? Do we need to reach a broader audience?
- What other sources of climate and hydrologic information are people consulting?
- When is climate information most important to users?
- Can we combine or better synthesize information?
- How is the summary best disseminated? Print or web-based?
- How many people receive the IWCS beyond our distribution list?
- What information do we need our stakeholders to consider that they current do not perceive as important?

The results of the survey confirmed that the IWCS is helping WWA achieve our goals of increasing climate awareness and literacy, facilitating a dialog between climate scientists and stakeholders, and providing enhanced climate services. Our stakeholders feel that the IWCS provides a valuable service by interpreting and translating climate information and forecasts. The results showed that the technical level of our writing style is on target, and our readers value the annotation of the maps and graphics. We found that most readers use the information in the IWCS to increase their knowledge of climate and hydrologic conditions, as well as to present this information to their colleagues and governing boards. This feedback validates the use of WWA resources in producing the IWCS.

From the survey results, we were able to make significant changes to the IWCS, which decreased production time without compromising the quality or utility of the product. Our new production schedule will be dissemination of a full IWCS five times each year, with two mini-summaries during critical water management decision times in the spring and summer. Also, the IWCS has been transformed to a web-based format, which has significantly reduced production time dedicated to layout.



**Next steps**

The results of our user survey, continued “hits” on our IWCS website, and the ever-increasing number of people asking to be added to the distribution list confirms to WWA that the IWCS is valued by our stakeholders and is a WWA success story. Stakeholders want the IWCS to continue, and we hope that it can with some help from our operational counterparts. Because of operational component of presenting current conditions and forecasts for regional decision makers, WWA plans to apply to a NOAA TRACS grant to help us transfer the operational component of the IWCS to the Western Regional Climate Center.

If transitioned, WWA would continue to develop and write Feature Articles and Focus Pages in a WWA newsletter that would also highlight WWA research and products. Historically, each IWCS contains one Feature Article, which summarizes current climate and water-related research and one Focus Page, which describes a climate service (Table 1). We have, and will continue to collaborate with other climate information providers and university researchers to write these articles. This collaboration is of great benefit to both WWA and the organizations represented by our collaborators. WWA is able to present the most recent climate research and services to our stakeholders, and the scientists and climate information providers receive a summary of their research or climate service that can serve as a simple explanatory document that they can use on their website. These documents are produced as pdfs that can easily be transferred to NOAA and other climate service providers as guidance for users.

**Table 1. Federal Partnerships on Feature and Focus Articles from the Intermountain West Climate Summary**

Feature Articles	
North American Monsoon Variability: Implications to Water Resources Management in the Southwestern US	Balaji Rajagopalan (CU-Boulder), Katrina Grantz (USBR Upper Colorado Region)
Desert Dust Enhancement of Mountain Snowmelt, by Andrew P. Barrett, National Snow and Ice Data Center, University of Colorado	Thomas H. Painter (University of Utah), Christopher C. Landry (Center for Snow and Avalanche Studies)
Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation	Andrea Ray (NOAA ESRL), Joseph Barsugli (CU-Boulder), Kristen Averyt (WWA), Klaus Wolter (CU-Boulder), Martin Hoerling (NOAA ESRL), Nolan Doesken (CSU), Brad Udall (WWA), Robert S Webb (NOAA ESRL)
Focus Pages	
Climate Service Activities in the National Weather Service Central Region	Doug Kluck (NWS Central Region-Climate Services Program Manager), Eileen McKim (NWS Central Region-Climate Services Program) , Jessica Lowrey (WWA)
Meet the MJO	Jon Gottschalck (NOAA Climate Prediction Center), Andrea Ray (WWA)
Forecast Consolidation for Seasonal Climate Outlooks	David Unger (NOAA Climate Prediction Center) and Ava Dinges (WWA Intern)
Low Flow Related Impacts in the Upper Colorado River Basin	Donna Woudenberg (National Drought Mitigation Center, NWS Advanced Hydrologic Prediction Service)



## Reconciling Streamflow Projections for the Colorado River

The goal of this project is to reconcile future Colorado River streamflow projections by evaluating the various methodologies and models being used in projections and to understand why different modeling approaches produce varying flow reduction amounts. Within the Upper Colorado River Basin, projected reductions in naturalized streamflow by the mid 21st century tied to climate change range significantly based on findings from recent scientific literature. Projected reductions in streamflow range from ~45% by Hoerling and Eischeid (2007), 10 to 25% by Milly et al (2005), ~18% by Christensen et al. (2004), and ~6% by Christensen and Lettenmaier (2007). In addition, the recent Seager et al (2007) analysis of future P-E (a proxy for runoff) suggests an "imminent transition to a more arid climate in southwestern North America". This wide range of future Colorado River streamflow projections makes it difficult for decision makers and water managers to prepare and plan for potential future reductions in streamflow resulting from climate change.

Through 2008, WWA led a series of cross-RISA discussions culminating in "model bakeoff". The goal: to narrow the range of projections so that decision makers can identify vulnerabilities and develop planning strategies. Participating scientists evaluated the suite of downscaled GCM runoff predictions from the IPCC AR4 models, and compared results for three hydrological models run over the entire Colorado River basin (VIC, NOAA, SAC).

In November 2008, the RISAs and the Southern Nevada Water Authority co-hosted a stakeholder meeting to discuss the results, thus far, of these efforts. Project PIs presented talks on project background, the important of scale, streamflow sensitivities to temperature and precipitation, and future work directions. The afternoon was devoted to hearing perspectives from the stakeholders on future project directions and the usability of the information provided. Attendees included many key water managers from across the West, including the Southern Nevada Water Authority, Metropolitan Water District, Salt River Project, Central Arizona Project, Colorado Springs Utilities, Reclamation, the Upper Colorado River Commission, the Nature Conservancy, Trout Unlimited and Living Rivers, as well as Tribes, and consultants. Letters from stakeholder attendees of the workshop are posted on the project website:

[http://wwa.colorado.edu/current\\_projects/CO\\_River/rcn\\_strmflw\\_corvr.html](http://wwa.colorado.edu/current_projects/CO_River/rcn_strmflw_corvr.html).

In addition to enhancing our understanding of the physical science, we are also trying to understand how this information feeds into the decision making process. Initial findings from this project indicate that there is broad and deep confusion over the variety of available climate change scenarios and how differences affect Colorado River flow projections. In addition, the different approaches that decision-makers use for incorporating uncertainty require that projections be made available in different ways. One approach, scenario planning, requires a small set of projections with logically consistent connections to user-generated narratives about social, economic and political characteristics of potential futures. Robust decision making, another approach, requires many time series of projections that can be used in probabilistic assessments of the potential failure of specific policy and management alternatives. Each approach requires a different means of presenting scientific information, which will eventually be brought to bear on the results of the model comparison exercises.

## Ongoing Stakeholder Engagement

During 2008, WWA continued its long-standing reputation with stakeholders and decision-makers as a trusted source of climate information. Collectively, WWA researchers gave over 60 public talks and seminars (Appendix II), were cited or quoted by the media over 75 times (Appendix V), and served as members of many committees and organizations (Table 2). In addition, in our continuing efforts to expand climate literacy, WWA sponsored several workshops across the Intermountain West (Table 3).



**Table 2. 2008 Organizations and Committees with WWA Membership**

Organization	WWA Participants
USGCRP Climate Change Science Program Unified Synthesis Product	Udall, Pulwarty
Intergovernmental Panel on Climate Change	Pulwarty, Averyt
Climate Change and Western Water Group (CCAWG)	Ray
Joint Front Range Climate Change Vulnerability Study (JFRCCVS)	Averyt, Barsugli, Ray, Lowrey, Wolter
Water Availability Task Force	Wolter
NOAA Climate Prediction Center	Ray, Lowrey
Western States Water Council	Udall, Pulwarty, Webb
Western Governors' Association	Udall, Pulwarty, Webb
National Integrated Drought Information Service	Pulwarty, Averyt, Udall, Lowrey, Ray
Water Utilities Climate Alliance	Udall, Barsugli
Carpe Diem Project	Udall, Kenney
Lower Colorado: USBR and CADSWES	Udall, Ray, Barsugli
Association of Metropolitan Water Agencies	Udall
Water Research Foundation	Udall
University of Colorado Energy Institute	Klein, Kenney, Averyt
Federal/Congressional Relations	Udall, Averyt
American Water Resources Foundation	Lowrey

**Table 3. 2008 WWA-Sponsored Workshops**

Title	Date	Location	Details
NIDIS Remote Sensing for Drought Monitoring Workshop	February 6–7, 2008	Boulder, CO	<a href="http://www.drought.gov/portal/server.pt/community/drought.gov/202/remote_sensing_workshop">http://www.drought.gov/portal/server.pt/community/drought.gov/202/remote_sensing_workshop</a>
Dust in Snow Workshop	February, 2008	Montrose, CO	
Forecast Verification Workshop	February 19, 2008	Boulder, CO	75 participants
Technical workshop on Tree-Ring Reconstructions of Streamflow	March 26, 2008	Salt Lake City, UT	15 participants <a href="http://www.colorado.edu/treeflow/saltlake2008.html">http://www.colorado.edu/treeflow/saltlake2008.html</a>
Technical workshop on Tree-Ring Reconstructions of Streamflow	May 30, 2008	Albuquerque, NM	25 participants <a href="http://www.colorado.edu/treeflow/abq2008.html">http://www.colorado.edu/treeflow/abq2008.html</a>
Technical workshop on Tree-Ring Reconstructions of Streamflow	June 13, 2008	Durango, CO	10 participants <a href="http://www.colorado.edu/treeflow/durango2008.html">http://www.colorado.edu/treeflow/durango2008.html</a>
Technical workshop on Tree-Ring Reconstructions of Streamflow	November 13, 2008	Boulder City, NV	50 participants <a href="http://www.colorado.edu/treeflow/nevada2008.html">http://www.colorado.edu/treeflow/nevada2008.html</a>
Reconciling Streamflow Projections on the Colorado River	November 14, 2008	Las Vegas, NV	60 participants <a href="http://www.colorado.edu/current_projects/CO_River/rcn_strmflw_nov2008.php">http://www.colorado.edu/current_projects/CO_River/rcn_strmflw_nov2008.php</a>
Evolving Regional Frameworks for Ag-to-Urban Water Transfers	December 11, 2008	Boulder, CO	<a href="http://envs.colorado.edu/about/event_details/727/evolving_regional_frameworks_for_ag_to_urban_water_transfers">http://envs.colorado.edu/about/event_details/727/evolving_regional_frameworks_for_ag_to_urban_water_transfers</a>
Climate Change Modeling for Front Range Water Providers	February 1, 2008	Denver, CO	25 participants <a href="http://www.colorado.edu/climate_change/cc_model_wrkshp.html">http://www.colorado.edu/climate_change/cc_model_wrkshp.html</a>





## Project Summaries

### Evolving Activities

Although we are changing tack and improving our research strategies, many projects we have funded in the past will continue to evolve and serve our stakeholders. The project summaries in Table 4 provide a brief overview of specific research projects funded in 2008, with continuing WWA involvement through 2009.

**Table 4. 2008 WWA Project Summaries**

Project Title:	Ensemble Hydrologic Forecasting and Simulation Tools
Primary Investigator(s):	R. Balaji, K. Nowak
Contributors:	J. Barsugli, B. Udall, M. Hoerling, A. Ray
Core Funding:	WWA, CEAE, CADSWES, USBR
Summary:	Population growth and a changing climate will tax the future reliability of Colorado River water supply. It is important for the water managers and stakeholders to obtain insights into the system-wide water supply risk in face of streamflow variability under changing climate and demand growth. This effort requires two components – (i) a tool to generate streamflow scenarios that combines observed, paleo-reconstructions and future projections and (ii) a water balance model that realistically represents the system at a large scale. We developed a novel tool that combines the observed and paleo-reconstructed flows (Prairie et al., 2008) – in that, the paleo-flows were used to provide the ‘hydrologic state’ (i.e., wet or dry) information and the observed flows were used to generate the magnitudes. This approach generates a rich variety of flow scenarios capturing the variability exhibited over the past 6-7 centuries. Climate change projections were superimposed on these streamflow scenarios and were used to drive a heuristic water balance model that captures the storage, inflow, losses and deliveries from the system. Risks to water supply were estimated for each year into the 50-year (2008-2057) future under different management alternatives.
Progress/Results:	Under current practices in the absence of climate change we find a 5% risk of reservoir depletion through 2026 increasing to 9% by 2057, demonstrating resilience to demand growth and natural climate variability. A 20% reduction in Colorado River average flow due to climate change by 2057, increases risk through 2026 to less than 12%, but greatly increases risk to 52% in 2057. However, we find management alternatives can greatly reduce risk – under aggressive management the risk reduces to 32%. A lower rate of climate change induced flow reduction, demand adaptation and aggressive management can further reduce the risk to around 10% - suggesting substantial flexibility in existing management could mitigate the increased risk.
Partners/Stakeholders	CEAE, CADSWES, USBR
Publications:	Rajagopalan, B., K. Nowak, J. Prairie, M. Hoerling, B. Harding, J. Barsugli, A. Ray and B. Udall, Water Supply Risk on the Colorado River: Can Management Mitigate?, (in review), Water Resources Research, 2008. Barsugli, J., K. Nowak, B. Rajagopalan, J. Prairie and B. Harding, Comment on “When Will Lake Mead Go Dry?”, (in review), Water Resources Research, 2008.
Presentations:	Invited: B. Rajagopalan, K. Nowak, J. Prairie, B. Harding and M. Hoerling, A Streamflow Generation Technique Under Climate Change Using Paleo and Observational Data for Colorado River, presented at the AGU Hydrology Days Conference, Fort Collins, CO, Mar 26-28, 2008. B. Rajagopalan, K. Nowak, M. Hoerling, B. Harding, A. Ray, J. Barsugli, B. Udall, Climate, Growth and Drought Threat to Colorado River Water Supply, presented at the AGU Fall meeting, Dec 15-19, 2008, San Francisco, CA.





<b>Project Title:</b>	<b>Historical and Potential Future Changes in Temporal Precipitation Variability in the Colorado River Basin</b>
Primary Investigator(s):	G. Guentchev
Contributors:	J. Eischeid, J. Barsugli, D. Raff, L. Brekke
Core Funding:	UCAR, CLIVAR, CPAPP, BoR, Southern Nevada Water Authority
Summary:	This project is focused on assessing the historical characteristics and the potential future changes in precipitation variability throughout the Colorado River Basin. Three gridded data sets derived from precipitation observations are used in this analysis: the Maurer et al. (2002) data set, the Hamlet and Lettenmaier (2005) data set, and the PRISM data set (Daly et al. 1994, 1997). In addition, the projections of a set of about 30 CMIP3 GCM runs are utilized in this project. As an initial step the homogeneity of the observed gridded data sets was evaluated using the methodology proposed by Wijngaard et al. (2003). Next, a set of variability measures was chosen to represent the historical (1951-1999) and projected future temporal precipitation variability. These measures were utilized to assess the differences between the model simulated and the observed precipitation variability for the historical period. These differences indicate how skillfully the models represent the observed precipitation variability.
Presentations:	“Homogeneity testing of Hamlet and Lettenmaier (2005) and PRISM (Daly et al., 1994) gridded data sets for the Colorado River Basin” Galina Guentchev, Joe Barsugli, Jon Eischeid, poster for the CPASW in Norman, OK, March 2009.
Next Steps:	The final stage of this project is to evaluate the potential future precipitation variability changes in the Colorado River Basin based on the A2, B1, and A1B projections from the same set of GCM runs.
<b>Project Title:</b>	<b>Colorado Climate Center: Climate Trends Website</b>
Primary Investigator(s):	N. Doesken, K. Wolter
Contributors:	Colorado Climate Center
Core Funding:	WWA
Summary:	WWA will build on its collaboration with the State Climatologist to establish climate extension services. CCC will build and maintain capacity to respond to the large and growing demand for climate information. This will involve managing and expanding the new “Colorado Climate Trends” website, working with WWA on climate and water workshops, enhancing integrated climate monitoring activities in the state and other special activities and collaborative opportunities that will occur in the coming year.
Progress/Results:	The website has been reviewed and tested and is fully functional. It has not been released to the public, however, pending completion of station history narratives for each long-term station, and improvement of the presentation of running means during periods of missing data. When this website is launched for the public, WWA will be identified as a partner and supporter.
Next Steps:	For 2009, Doesken and Wolter plan to develop a best-practices for observational datasets document.
<b>Project Title:</b>	<b>Joint Front Range Climate Change Vulnerability Study</b>
Primary Investigator(s):	D. Yates, J. Lowrey, B. Udall, J. Barsugli
Contributors:	K. Averyt, A. Ray, C. Anderson
Core Funding:	American Water Works Association Research Foundation, plus collaborators listed below
Summary:	This project involves several Front Range water providers working together to study the potential impacts of climate change on water resources in Colorado. The team will use a variety of downscaled GCM projections in two different hydrology models to identify streamflow changes in 2040 and



Summary:	This project involves several Front Range water providers working together to study the potential impacts of climate change on water resources in Colorado. The team will use a variety of downscaled GCM projections in two different hydrology models to identify streamflow changes in 2040 and 2070. WWA is serving on an internal advisory committee to provide guidance on choosing GCMs and emissions scenarios along with climate variables and data sets to put into the hydrology models. In addition, WWA organized an education workshop for the water providers that covered the fundamentals and differences of GCMs, emissions scenarios, downscaling techniques, and hydrology modeling. Once future streamflows are obtained, WWA will provide guidance on planning for and communication of results.
Progress/Results:	In 2008, this project secured funding, spent time learning about climate change projections, downscaling methods, and hydrology models, and chose consultants. WWA contributed the education piece and continues to fill that role. In addition, WWA provided guidance on choosing climate scenarios and downscaling methods for the project. Currently the consultants are building and calibrating hydrology models of the Upper Colorado, South Platte, and Arkansas River Basins.
Partners/Stakeholders	Aurora Water, Boulder, Colorado Springs Utilities, Denver Water, Fort Collins, Northern Colorado Water Conservancy District, Colorado Water Conservation Board; Funded entities are NCAR (D. Yates) and Riverside Technology Inc.
Presentations:	<p>“Climate Models and Emissions Scenarios” J Barsugli Feb 2008</p> <p>“Climate Models and Emissions Scenarios: Take 2” J Barsugli October 2008</p> <p>“Climate Change Adaptation: A Look at the Literature” J Lowrey April 2009</p> <p>Jen Martin May 2009</p> <p>Brad Udall June 2009</p>
Next Steps:	After models are completed and calibrated, the consultants will use downscaled climate change projections to create a series of future streamflows for several points in each basin. The water

<b>Project Title:</b>	<b>Dust in Snow</b>
Primary Investigator(s):	T. Painter
Contributors:	J. Deems, A. Hamlet
Summary:	The Dust in Snow research through the Snow Optics Laboratory (SOL) at the University of Utah and previously the Snow Hydrology Albedo Group at the National Snow and Ice Data Center (NSIDC) has addressed WWA’s mission by exploring a largely unrealized forcing of melt and climate change through absorption of solar radiation by dust deposited from disturbed lands of the Colorado Plateau and Great Basin. In collaboration with the CSAS, we have actively engaged water managers and water stakeholders in the Colorado River, Rio Grande, Arkansas, and South Platte basins. Their interest and desire to understand better how dust affects their resources has led to the formation of the Colorado Dust on Snow monitoring program (CODOS). CODOS is a collaborative between CSAS and the SOL (Utah) that is sustained by funding from myriad water conservancy districts and stakeholders.
Progress/Results:	<p>In February 2008, we co-organized a meeting with water managers and stakeholders in Montrose, CO. This meeting was followed upon with a meeting with the Colorado Basin River Forecast Center. In spring 2008, we performed multiple sampling missions across the state of Colorado to establish the framework for the distributed monitoring of dust deposition and presence in the snowpack that is now the CODOS. These missions involved collection of samples for analysis of optical properties and provenance. Regular sampling of dust concentrations, bulk samples, and dust loadings during depositional events continue with the CSAS in the Senator Beck Basin, San Juan Mountains. The alpine and subalpine energy balance towers were maintained and data collected and QC/QAd. We have presented research at meetings ranging from AGU to ESA. Our outreach has been extensive from international media to the classroom in high schools in SW Colorado.</p> <p>Toward the end of the year, we initiated the modeling effort to determine the impact of dust deposition on water yield in the Colorado River Basin with Jeff Deems and Alan Hamlet of the Civil Engineering Department at the University of Washington. This effort has provided compelling</p>



	evidence with the VIC model that dust has affected a 5+% loss of yield due to enhanced evapotranspiration and loss of soil moisture. We have also distributed a biweekly dust advisory to participating districts and stakeholders that assesses and summarizes our observations of dust loading, stratigraphy in the snowpack, and implications for melt acceleration.
Partners/Stakeholders	University of Washington, University of Utah, CSAS, NSIDC, Colorado Water Conservation Board, Conservancy Districts
Next Steps:	Agreement on the Colorado State budget for 2009 likely brings substantial funding for CODOS in order to expand operations.

<b>Project Title:</b>	<b>WWA Website Reorganization</b>
Primary Investigator(s):	J. Lowrey, K. Averyt, A. Ray, C. Goemans, J. Lukas, J. Malmberg, C. Alvord
Contributors:	B. Udall
Core Funding:	WWA
Summary:	This project was a major undertaking by WWA to reorganize its website, and make the portal more user-friendly. Web development is a primary research and outreach tool that can serve as a clearinghouse of information, education resource, facilitate project collaboration, and foster partnership for a wide range of user groups.
Progress/Results:	WWA worked closely with a consultant to redesign the homepage, subpages, and html programming needs. The new webpage content and presentation is centered on topic headings to appeal to a wide range of user groups and corresponding knowledge base. Topic headings include: "Colorado River", "Front Range", "Western Hydrology", "Water Management and Drought", "Climate Variability and Change", and "Forecasts and Outlooks." The new website went live in August 2008.
Next Steps:	As WWA transitions into a new phase requiring expanded stakeholder outreach and engagement, the website will be reorganized and content will be added.

<b>Project Title:</b>	<b>Evaluation of Communication Practices by Colorado Round Tables</b>
Primary Investigator(s):	J. Martin
Contributors:	K. Tracy, R. Craig
Core Funding:	WWA
Summary:	Conducting a study of the communicative practices of water roundtables in Colorado looking at discursive strategies, problems and dilemmas interact and experience and how participants negotiate their communicative aims along with the larger group aims. This dissertation will add to the body of knowledge on public participation in environmental issues, specifically water issues. There is work on how watersheds, roundtables, but currently there is no research on the communicative practices in water roundtables. This study will add to the literature in communication, political science, and environmental studies.
Progress/Results:	Three out of six chapters are completed.
Partners/Stakeholders	Members of the IBCC, CWCB, and South Platte and Denver Metro Roundtables
Next Steps:	Defend first three chapters before Committee in the first week of May. Target for final defense is second week in July.



<b>Project Title:</b>	<b>Web-based Seasonal Guidance for Water Managers and the Climate Prediction Center</b>
Primary Investigator(s):	K. Wolter
Core Funding:	WWA
Summary:	Improve ability of federal, state, and local water managers to plan water operations during drought by providing a regional climate forecast. Forecast will be input to CPC seasonal outlooks.
Progress/Results:	Depending on drought conditions, I give monthly-to-seasonal briefings to the Colorado Water Availability Task Force and other stakeholders on my experimental climate outlooks as well as on other climate forecast products. These briefings are based on my monthly updated webpage ( <a href="http://www.cdc.noaa.gov/people/klaus.wolter/SWcasts/">http://www.cdc.noaa.gov/people/klaus.wolter/SWcasts/</a> ) that covers the recent and projected evolution of the ENSO phenomenon, discusses the most recent Climate Prediction Center (CPC) climate forecasts, and examines in detail my own experimental forecast guidance for the full interior southwestern U.S., with special emphasis on Colorado. On the national scale, my climate forecasts are used by wildfire managers in the Western U.S. (9th annual fire assessment workshop in April 2008), and by CPC, both for seasonal climate forecasts and in particular for the U.S. Drought Monitor Outlook. My contributions to CPC involve monthly conference calls ahead of the official forecast release date in which I contribute my latest experimental forecasts, and give my general assessment of the ENSO situation (this can differ from the official NOAA assessments when my Multivariate ENSO Index ( <a href="http://www.cdc.noaa.gov/people/klaus.wolter/MEI/">http://www.cdc.noaa.gov/people/klaus.wolter/MEI/</a> ) departs from NOAA’s Niño 3.4 SST index, such as in the fall of 2008 when CPC’s position was that we were in ENSO-neutral conditions, while my assessment was that we had already slipped back into La Niña), and expected ENSO impacts in the U.S. I also contribute to CPC’s monthly ENSO Diagnostic Discussion ( <a href="http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/">http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/</a> ) by briefing all interested parties on my monthly updated Multivariate ENSO Index ahead of CPC’s release date.
Presentations:	4 presentations to the Water Availability Task Force last year (January, March, April, and July); 1 presentation to the National Seasonal Assessment (Wildfire) workshop in April that encompassed all of the Western U.S. and Alaska; 1 presentation each to the Colorado Association of Lawn Care Professionals (September), to the Grand County Wilderness Group (November), and to a general public audience here in Boulder (November) about the winter outlook specifically; a related presentation was to California water managers in November that featured both my forecasts for California (separate funding) and for the Upper Colorado basin (November) – a total of 9 presentations with my seasonal forecast guidance in them.



## Legacy Activities

Much of our work has proven successful, to the extent that projects and products have evolved into an operational service. Throughout 2008, WWA challenged scientists to determine if a project should evolve or could be transferred for operation to a Federal entity or stakeholder partner. Table 5 is a compilation of 2008 projects that will become WWA legacy activities beginning in 2009; these projects have either become service-oriented activities that will be funded elsewhere, are being transferred to another RISA as a consequence of changing personnel, or have been completed.

**Table 5. WWA Legacy Activities**

<b>Project Title:</b>	<b>Multi-format Primer on Dendrohydrology</b>
Primary Investigator(s):	J. Lukas, C. Woodhouse
Core Funding:	WWA
Summary:	We will extensively annotate our PowerPoint instructional workshop presentation on tree-ring reconstructions so that it can serve better as a stand-alone information resource, or primer, on dendrohydrology. The content and graphics from the presentation will also be developed into a print-format resource (~20-25 pages) that can be distributed as hardcopy or PDF.
Progress/Results:	As of spring 2009, the annotation of the PowerPoint presentation (~90 slides) is nearly complete. The print-format primer will be based almost entirely on text and graphics from the presentation. Both products will be completed by July 2009.
<b>Project Title:</b>	<b>User Survey of WWA Paleo Efforts</b>
Primary Investigator(s):	J. Lukas, C. Woodhouse
Contributors:	Jennifer Rice, University of Arizona
Core Funding:	WWA
Summary:	As part of our ongoing paleo research and outreach, WWA will survey stakeholders with regard to relevance, usability, and future directions of our paleo efforts. Semi-structured interviews with three Colorado Front Range water utilities will be conducted, and a web-based survey will be sent to participants in the tree-ring technical workshops.
Progress/Results:	The work on this project was principally completed in spring 2008, with the final report by contributor Jennifer Rice submitted to WWA in June 2008. Rice, Woodhouse, and Lukas have submitted a manuscript on the project results to JAWRA, and that manuscript is currently in post-review revision, with publication expected in 2009. Also, Rice presented on the project at the AGU annual meeting in 2008.
Publications:	Rice, J. L., Woodhouse, C. A., and Lukas, J. J. In revision. Science and decision-making: Water management and tree-ring data in the western United States. Journal of the American Water Resources Association.
Presentations:	Rice, J.L., C.A. Woodhouse, and J.J. Lukas, 2008. Evaluating the Effectiveness of Science for Decision-Making: Water Managers and Tree- Ring Data in the Western United States. Fall Meeting, American Geophysical Union, 15-19 December 2008, San Francisco, CA, GC33B-0771.



<b>Project Title:</b>	<b>TreeFlow Website &amp; Workshop Outreach</b>
Primary Investigator(s):	J. Lukas, C. Woodhouse
Core Funding:	WWA
Summary:	We will continue to meet demand among managers and stakeholders for technical workshops on how the reconstructions are generated and assessed. The primary goal is to provide managers and stakeholders with the tools to better interpret and apply the reconstructions to planning. These workshops also spur valuable follow-up interactions and knowledge transfer with participants. Each workshop will be tuned to the location and interests of the participants. The WWA website will continue to post materials from the workshops for interested parties who are not able to attend.
Progress/Results:	<p>Lukas and Woodhouse held four technical workshops in 2008, in Salt Lake City, UT, Albuquerque, NM (supported by a Cross-RISA grant), Durango, CO, and Boulder City, NV, providing over 100 water managers and stakeholders with information about how the tree-ring data and reconstructions of streamflow are generated, the characteristics of these data, and how water entities are successfully incorporating the data into modeling and planning. In lieu of a separate workshop in California, Woodhouse presented at the Southern California Workshop on Water Conditions and Drought Preparednes (CaDWR) in October 2008.</p> <p>New web pages in the TreeFlow web resource were created for all four workshops held in 2008, with summary reports and access to the presentations and new data and products.</p> <p>Based on feedback from the Durango, CO, workshop, Lukas also developed a two-page, tri-fold brochure on tree-ring reconstructions for Animas River stakeholders in cooperation with the Mountain Studies Institute (<a href="http://www.mountainstudies.org/Education/pdfs/Animas_treering_brochure_RevC.pdf">http://www.mountainstudies.org/Education/pdfs/Animas_treering_brochure_RevC.pdf</a>).</p> <p>Woodhouse presented at the 2008 AGU annual meeting about the workshops and the iterative evaluation process used to improve them.</p>
Partners/Stakeholders	CLIMAS, CIG
Publications:	Web pages for the four 2008 workshops, accessible through <a href="http://www.colorado.edu/treeflow/workshops.html">http://www.colorado.edu/treeflow/workshops.html</a>
Presentations:	Woodhouse, C.A. and J.J Lukas, 2008. Paleohydrology Workshops for Water Resource Managers Using an Iterative Evaluation Process. Fall Meeting, American Geophysical Union, 15-19 December 2008, San Francisco, CA, GC33B-0770.
<b>Project Title:</b>	<b>Non-Parametric Paleo Reconstructions</b>
Primary Investigator(s):	S. Gangopadhyay, J. Lukas, C. Woodhouse, R. Webb
Contributors:	B. Harding
Core Funding:	WWA, USBR
Summary:	Non-parametric techniques have been successfully used in other areas of hydrologic modeling, but have not yet been applied to tree-ring reconstructions. This project, funded by WWA and the US Bureau of Reclamation, aims to develop and prove a methodology for using a non-parametric k-nearest-neighbor technique to generate a streamflow reconstruction, for the Colorado River at Lees Ferry, which is driven more directly by the tree-ring data. A preliminary reconstruction for Lees Ferry has been successfully generated using the new non-parametric methodology, and was presented to the Colorado River Hydrology Working Group (US Bureau of Reclamation) in January 2008. Work in the coming year will include testing techniques for reconstructing extreme high and low flows.
Progress/Results:	A manuscript was drafted in 2008 describing the project deliverables, and is in press at Water Resources Research and is available on the WRR website as of April 2009.
Partners/Stakeholders	AMEC Earth & Environmental



Publications:	Gangopadhyay, S., Harding, B. L., Rajagopalan, B., Lukas, J. J., and Fulp, T. J. In press. A non-parametric approach for paleohydrologic reconstruction of annual streamflow ensembles. <i>Water Resources Research</i> , doi:10.1029/2008WR007201
<b>Project Title: Dendrohydrological Website (TreeFlow)</b>	
Primary Investigator(s):	J. Lukas, C. Woodhouse
Contributors:	K. Hirschboeck, D. Griffin (U. Arizona/CLIMAS), S. Gray (U. Wyoming/State Climatologist)
Core Funding:	WWA, Cross-RISA
Summary:	The TreeFlow web resource at WWA ( <a href="http://www.colorado.edu/treeflow">http://www.colorado.edu/treeflow</a> ) was developed in 2007 to provide easy access to tree-ring reconstructions of streamflow and climate as well as information about how they can be used. In 2008 a major revision and expansion of TreeFlow will begin, to expand its scope to cover most of the western US and provide an improved user interface to allow access to data and information organized by major hydrologic basin.
Progress/Results:	New pages were created for all four technical workshops that were held in 2008. The Rio Grande TreeFlow web resource was also developed to showcase new data products developed for the Albuquerque workshop The expansion and revision of TreeFlow began in fall 2008 and is ongoing in spring 2009. Pages for the Lower Colorado River Basin have been completed. The new TreeFlow website will debut in summer 2009, hosted on a CLIMAS web server as a Cross-RISA product under its own URL.
Partners/Stakeholders	CLIMAS, WY State Climatologist's Office
Publications:	Various upgrades to the TreeFlow web resource: <a href="http://www.colorado.edu/treeflow/">http://www.colorado.edu/treeflow/</a> New web pages for the four 2008 technical workshops, accessible through <a href="http://www.colorado.edu/treeflow/workshops.html">http://www.colorado.edu/treeflow/workshops.html</a> Rio Grande TreeFlow web pages: <a href="http://www.colorado.edu/treeflow/riogrande/">http://www.colorado.edu/treeflow/riogrande/</a>
<b>Project Title: Paleohydrology Data</b>	
Primary Investigator(s):	J. Lukas, C. Woodhouse,
Core Funding:	WWA, USBR, Cross-RISA
Summary:	Paleohydrologic datasets developed as part of WWA-funded projects and delivered to project collaborators and/or stakeholders in 2008.
Presentations:	Data: Tree-ring reconstruction of annual precipitation, Gunnison River Basin, CO, 1130-2002, delivered to Jim Prairie, US Bureau of Reclamation. Data: Tree-ring reconstruction of annual streamflow, Animas River at Durango, CO, 1470-2002, archived at WWA: <a href="http://www.colorado.edu/treeflow/durango2008.html">http://www.colorado.edu/treeflow/durango2008.html</a> Data: Tree-ring reconstruction of annual streamflow (NRCS gaged flow), Rio Grande at Otowi Bridge, NM, 1450-2002, archived at WWA: <a href="http://www.colorado.edu/treeflow/riogrande/">http://www.colorado.edu/treeflow/riogrande/</a> Data: Tree-ring reconstruction of annual streamflow (naturalized flow), Rio Grande at Otowi Bridge, NM, 1450-2002, archived at WWA: <a href="http://www.colorado.edu/treeflow/riogrande/">http://www.colorado.edu/treeflow/riogrande/</a> Data: Tree-ring reconstruction of annual streamflow, Canadian River near Sanchez, NM, 1604-1997, archived at WWA: <a href="http://www.colorado.edu/treeflow/riogrande/">http://www.colorado.edu/treeflow/riogrande/</a> Data: Tree-ring reconstruction of annual streamflow, Mora River near Golondrinas, NM, 1622-1997, delivered to Mark Murphy, New Mexico Interstate Stream Commission. Data: Tree-ring reconstruction of annual streamflow, Rio Pueblo de Taos near Taos, NM, 1540-2002, delivered to Gilbert Suazo, Taos Pueblo. Data: Tree-ring reconstruction of annual streamflow, Rio Lucero near Arroyo Seco, NM, 1540-2002,





delivered to Gilbert Suazo, Taos Pueblo.

<b>Project Title:</b>	<b>Dendrohydrological Capacity Building</b>
Primary Investigator(s):	J. Lukas, C. Woodhouse
Contributors:	S. Gray (U. Wyoming/State Climatologist), Matthew Bekker (BYU)
Core Funding:	WWA
Summary:	Compared to Colorado, the states of Wyoming and Utah have been underserved with respect to the development and application of dendrohydrological data. This is changing with new university research capacity in both states. Collaboration will continue with Wyoming State Climatologist Stephen Gray to help meet the needs of stakeholders in Wyoming. New collaborative work with Brigham Young University researcher Matthew Bekker will help meet the needs of stakeholders in Utah.
Progress/Results:	In March 2008, M. Bekker participated in the tree-ring technical workshop in Salt Lake City, UT organized by Lukas, and presented his work on streamflow reconstructions for the Wasatch Front to a group of Utah water managers and stakeholders. Bekker will provide on the ongoing expansion of the TreeFlow website to the Great Basin.  In late 2008 into spring 2009, Gray has been collaborating with Lukas and Woodhouse on developing streamflow reconstructions for the Yampa, Little Snake, and White River Basins, including SW Wyoming, and a manuscript to be submitted for publication in 2009. Gray is also collaborating with the expansion of the TreeFlow website for the Wyoming portions of the Upper Colorado, Platte, and Upper Missouri basins.

<b>Project Title:</b>	<b>Synthesis and Evaluation of Climate Change Adaptation Options in Western Water Management</b>
Primary Investigator(s):	D. Kenney, R. Klein, J. Lowrey
Core Funding:	WWA
Summary:	This project is based on the assumption that effective climate change adaptation in the water resources sector requires choosing from among a very diverse suite of strategies, and that only by understanding the institutional opportunities/constraints associated with each strategy can the role/value of climate information and services be adequately understood. Research will include a “macro level” overview of adaptation strategies (likely organized by whether they are supply-oriented, demand-oriented, or reallocation-oriented) and their institutional attributes (including how and for whom climate information is potentially useful) as well as two “micro level” studies focused on (a) the role of land-use/water planning disconnects in limiting adaptation options, and (b) opportunities/constraints associated with climate-sensitive water transfers.
Progress/Results (Macro level): J. Lowrey, Kenney, D.	The purpose of the “Macro level” research is to identify how decision makers currently consider climate change in adaptation planning despite imperfect information about climate change impacts, particularly in the water sector. This project began in mid-2008 and by February 2009, I completed a detailed literature review outline. The literature review describes several different adaptation strategies (top-down, bottom-up, and risk assessment), barriers to adaptation depending on the strategy (information uncertainty as well as economic, political and societal barriers), ways to foster opportunities to adapt, and steps for successfully creating an adaptation plan.
Progress/Results (Micro level-land use planning): R. Klein, D. Kenney	Research on the land-use/water planning study (micro item a) has led to the production of a draft (in internal review) white paper entitled: “The Land Use Planning, Water Resources and Climate Change Adaptation Connection: Challenges and Opportunities.” Part I of the paper discusses the disconnect between land-use and water planning. Part II summarizes assured water supply legislation in the western 11 states, as well as other approaches, and discusses the effectiveness of these laws. Part III discusses the relationship between policy responses and demand management, and then looks at the dilemma water managers face: should conserved water serve as a climate “cushion” or should it



<p>Progress/Results (Micro level water transfers): D. Kenney</p>	<p>allow further growth? Part IV provides a summary and conclusion.</p> <p>Work on the water transfer component of the project (micro item b) in 2008 primarily revolved around two elements. The first element is a review of statutes and administrative procedures in the 11 westernmost states (excluding Alaska and Hawaii) assessing the extent to which temporary transfers are considered, structured, and/or encouraged/discouraged. A complete working draft entitled “Water Transfer Rules in the West: State Summaries” is currently under internal review. The other major achievement for this project element was a public event on December 11, 2008, hosted by the Natural Resources Law Center entitled: “Evolving Regional Frameworks for Ag-to-Urban Water Transfers.” Presenters included Ed Smith, General Manager of the Palo Verde Irrigation District in California; Jerry R. Rigby (Rigby, Thatcher, Andrus, Rigby &amp; Moeller, counsel for the Fremont Madison Irrigation District in Idaho; and Peter Nichols (Trout, Raley, Montano, Witwer &amp; Freeman, PC), general counsel of the Lower Arkansas Valley “Super Ditch” Company in Colorado. Responses to these presentations were provided by Mark Pifher, Director, Aurora Water (Colorado); Adam Schempp, Environmental Law Institute, Washington, D.C.; John McKenzie, Executive Director, Ditch and Reservoir Company Alliance; and Larry MacDonnell, Attorney, Author and Professor. The discussion was moderated by David Getches, Dean of the University of Colorado Law School. The event drew approximately 70 attendees, including a mix of attorneys, water management professionals, water rightsholders, and community leaders.</p>
<p>Partners/Stakeholders</p>	<p>Work on the land-use/water planning element (micro item a) has included assisting EPA in the design and hosting of the “Sustainable Water Infrastructure Forum” (December 2-3, Denver).</p> <p>To date, work on the water transfer project (micro item b) has been done in conjunction with other entities and projects, including the Ditch and Reservoir Company Alliance (DARCA) and the Red Lodge Clearinghouse of the Natural Resources Law Center. Attorney Peter Nichols (mentioned above) is also an ongoing collaborator.</p>
<p>Publications:</p>	<p>Micro-level white paper will be completed by May 1; Internal review and posting of the water transfer summary should occur in August, 2009.</p>
<p>Presentations:</p>	<p>“Interactions with Colorado Municipal Water Managers Elevate the Use of Climate Information” Poster presentation by J. Lowrey at AGU in December 2008</p> <p>“Climate change adaptation: a look at the literature” Oral presentation by J. Lowrey to the Joint Front Range Climate Change Vulnerability Study group in April 2009</p> <p>Kenney, D. “Voluntary Mechanisms for Coping with Scarcity and Managing Conflict.” Workshop on Drought in a Changing Climate: Sharing Management Approaches. Australian National University. Canberra, Australia. November 17, 2008.</p>
<p>Next Steps:</p>	<p>The second phase of the “Macro level” research will analyze how thirteen municipalities justified adaptive planning in the face of scientific uncertainty. In addition to looking at information use in adaptation plans, we compare how the plans orient themselves (adapting to projected impacts vs. increasing resiliency to current climate variability), how they address barriers and opportunities for adaptation, and whether they follow some key steps for successful adaptation as outlined in the literature. Adaptation strategies should not be assessed, but rather used to identify how the decision makers plan to evaluate their own adaptation policies. Special attention should be placed on self-defined indicators of success, either of the adaptation plan or of the process that lead to the creation of the adaptation plan. This research will identify any consensus among the municipalities already adapting, and see if the decision makers tend to agree with the points of views expressed in the literature. Insights could be offered into how best to provide information on climate change projections to regional decision makers so that they can begin adaptation planning for a changing climate. The conclusions of this research will not only help decision makers trying to adapt, but it will help researchers orient future research to the informational needs of the decision makers. Efforts are currently underway to hand over this phase of work to the Climate Impacts Group (specifically Ann Steinemann and Lara Whitley Binder).</p> <p>Once the internal review of the land-use/water planning paper (item a) is completed and posted in May, the project will end.</p> <p>Remaining work on the water transfers element include publication of the state summaries, including an assessment of needed (or at least beneficial) reforms. Additionally, a law review article with Peter Nichols is under development primarily to describe the evolution of the water transfer regime in the Arkansas Basin of Colorado.</p>



<b>Project Title:</b>	<b>Colorado Snow Pack Basin-wide Normals</b>
Primary Investigator(s):	K. Wolter, D. Allured
Partners/Stakeholders	M. Gillespie
Core Funding:	WWA
Summary:	This projects aims to construct basin-wide snow pack normals utilizing the longest and most reliable snow course and SNOTEL records. From this, basin-wide anomaly time series that are thus clearly defined and allow for a reconstruction of Colorado’s snowpack history that is not based on changing base-periods and stations, will be computed.
Progress/Results:	We have discussed with Mike Gillespie how their (NRCS) current basin-wide normals are done, how SNOTEL sites have replaced snow course data wherever possible, and which sites are used for which basin. We have downloaded all available data back to the 1930s, and have decided which sites to use based on length (and completeness) of record. We have established that this is a fairly ‘clean’ data set in terms of consistency of snow depth and snow water equivalent (SWE) measurements. We are currently comparing all site records within each of the eight major basins in Colorado to see which ones are the most suitable to (a) represent basin-wide average SWE values, and (b) extend basin-wide averages back as far as possible.
Partners/Stakeholders	USDA NRCS
Next Steps:	We expect to finish this work in May 2009.

<b>Project Title:</b>	<b>Assessment of user needs for climate information and forecasts</b>
Primary Investigator(s):	J. Lowrey, A. Ray
Contributors:	R. Webb
Core Funding:	WWA
Summary:	Rapid population growth, finite water resources, and increasing climate variability are making the western U.S. increasingly vulnerable to drought. Yet water management decision makers have not been taking advantage of all the climate information and forecasts available from NOAA, and other Federal agencies and research institutions. The use of climate information alone cannot decrease a water provider’s vulnerability to water shortages; however, historic observations and climate projections at seasonal to decadal timescales can potentially help them prepare for drought. Given the impact of climate on water supplies, this study was motivated by interest in how climate information providers communicate with municipal water managers, who in turn might use the information to better prepare for water supply shortages on interannual and longer (30–50 year) time scales.  This study sought to identify the uses and needs for climate information, outlooks and projections among the six large water providers in Colorado and to evaluate the factors affecting their annual and long-term decisions. Our study period started after the severe drought in 2002, which caused water managers to rethink their long-term supply plans. We evaluated how the drought affected and possibly changed water management decisions and highlighted why Colorado is unique in terms of water management challenges and adaptation to climate.
Progress/Results:	Through this project, WWA has conducted extensive research on the uses and needs of Colorado municipal water managers for climate information and forecasts. We found that water managers rely heavily on annual snowpack and streamflow conditions and the past hydrologic record in their operations and planning models. However, these water managers do not use climate forecasts quantitatively. They use forecasts only qualitatively and subjectively in decisions for three reasons: 1) the forecasts are not considered skillful enough, 2) the forecasts are not specific to their region or basin of interest, 3) the seasonal averages forecasted are not adequate for their operational models. In contrast, streamflow forecasts are used quantitatively because they are specific to river basins and



	<p>gauge locations, and the format is appropriate for input to operational models. In the past few years, through this project and other WWA education and communication efforts with water managers, we have seen a change in understanding and interest in climate information: water managers are increasingly coming to WWA for information about climate, and guidance about how to use it.</p> <p>As a result of these interactions, water managers are taking steps to use more climate information and to incorporate risk of climate variability in annual operations and long-term planning. For example, they have implemented drought plans that have various stages allowing for different levels of demand, and the stages have triggers based on climate variables like snowpack and forecasted streamflows. WWA workshops and meetings have also fostered communication among water management groups who share water sources and reservoirs in an interconnected system. Water managers are now working together to incorporate common analysis of climate information into hydrology models to assess the range of future streamflows for regional water planning.</p> <p>This collaborative process between WWA and water managers illustrates a critical climate service and a successful RISA communication effort in this region. Results of this project include specific needs of municipal water managers for climate information and research. We will continue to foster education and communication among interconnected groups and provide feedback to NOAA climate services about these needs.</p>
Partners/Stakeholders	Aurora Water, Boulder, Colorado Springs Utilities, Denver Water, Northern Colorado Water Conservancy District, Westminster
Publications:	J. Lowrey, Ray, AJ and Webb RS (submitted March 2009) " Factors influencing the use of climate information by Colorado municipal water managers" Journal of Climate Research
Presentations:	"Interactions with Colorado Municipal Water Managers Elevate the Use of Climate Information" Oral Presentation by J. Lowrey at CPASW 2008 in Chapel Hill, NC
<b>Project Title:</b>	<b>The Influence of Climate Change on the Functioning of Water Rights</b>
Primary Investigator(s):	D. Kenney, R. Klein, C. Goemans
Contributors:	C. Alvord, J. Shapiro
Summary:	Most surface water in the western states is allocated using a prior appropriation system reliant on privately held water rights that are defined by the following elements: the quantity of water to be diverted (or consumed); the type of use (e.g., irrigation); the priority date (i.e., the year of the first diversion); the point of diversion; and some description—either implicit or explicit—of the time frame (e.g., season) associated with use of the right. To the extent that climate change in many basins is resulting in snowmelt occurring earlier and the lengthening of growing seasons, it becomes important to understand how these changes may be changing the scope, size, and more generally, the functioning of water rights regimes that have evolved during different hydrologic conditions.
Progress/Results:	Research on this project concluded in Fall of 2008. Concerns of two types were identified. First, in those states that link water rights to specific calendar dates (that are becoming increasingly out-of-step with natural hydrographs), the yield and/or utility of those rights can theoretically become increasingly devalued. Second, in states that do not attempt to limit the exercise of rights to specific dates, water consumption under a given right may increase, thereby threatening the yield and reliability of other (particularly more junior) users. These problems can potentially occur at many scales, including interstate basins. To date, the study finds that problems of both types are exceptionally rare, and can be managed using existing administrative discretion and water system flexibility—a situation that is unlikely to persist given additional shifts in streamflows and water demands, and given increases in competition for limited water resources. The authors recommend that water managers explicitly design and operate water system models (to the extent possible) to account for interactions between shifts in streamflow timing and water rights, and that states plan for a growing strain on water administration personnel and systems.
Publications:	Kenney, D., R. Klein and C. Goemans. 2009. <i>Preliminary Findings from Western Water Assessment’s “Water Rights and Climate Change Project.”</i> Intermountain West Climate Summary. Feature Article. March 20, Vol. 5, Number 2. Kenney, D., R. Klein, C. Goemans, C. Alvord, and J. Shapiro. 2008. <u>The Impact of Earlier Spring</u>



---

	<p><u>Snowmelt on Water Rights and Administration: A Preliminary Overview of Issues and Circumstances in the Western States.</u> WWA White Paper and Final Project Report.</p> <p>Kenney, D., R. Klein, C. Goemans, C. Alvord, and J. Shapiro. 2007. <i>The Effect of Changing Hydrographs on Compact Apportionments in the Western United States: A Preliminary Analysis of Potential Trouble Spots.</i> WWA White Paper.</p> <p>Kenney, D., R. Klein, C. Goemans, and C. Alvord. 2007. <i>Overview of Western Water Assessment's "Water Rights and Climate Change Project."</i> <u>Intermountain West Climate Summary.</u> Feature Article. November, Vol. 3, Number 8.</p>
Presentations:	<p>Kenney, D. "Climate Change Adaptation and Water Rights." Western Governors' Association, Western States Water Council, and California Department of Water Resources: Climate Change Adaptation Policy Workshop. Irvine, CA; September 25, 2008.</p> <p>Kenney, D. "Statutory and Institutional Challenges to Climate Change Adaptation." New Mexico Convening of Carpe Diem: Western Water and Climate Change. Albuquerque, NM; May 29, 2008.</p>
Next Steps:	<p>While project researchers continue to field questions regarding this subject and this research, the project is otherwise dormant pending an escalation of the emerging issues described in the report.</p>



## Looking Ahead

Currently, the Western Water Assessment is undergoing a significant reorganization intended to broaden the scope of our research and build on the strengths of researchers in the Intermountain West community. After reevaluating our work, we believe that expanding our research scope will better serve our stakeholders. We are realigning our efforts and broadening our scope beyond the water management community. Within this framework, we have added an advisory board comprised of key scientists and stakeholders (Table 6) and developed three research themes to focus WWA research for 2009 and beyond.

**Table 6. Advisory Board Members**

Curtis Brown	Director Research and Development, Reclamation Science and Technology
Terrance Fulp	Deputy Regional Director of the Bureau of Reclamation’s Lower Colorado Region
Jennifer Gimbel	Director, Colorado Water Conservation Board
Melinda Kassen	Director, Western Water Project, Trout Unlimited
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 Colorado Basin River Forecast Center
Robert Wigington	Western Water Policy Counsel, The Nature Conservancy
Jim Verdin	Deputy Director, National Integrated Drought Information System (NIDIS), USGS

The WWA Advisory board was created to help us direct our resources in the most responsive manner possible to our stakeholders and to NOAA. The Advisory Board has, and will continue to provide input into our research themes and proposed projects, and will provide similar input into our entire program.

The following topical research themes have been identified as areas in critical need of scientific contributions. For 2009, we are encouraging interdisciplinary approaches to developing research questions; our intention is for scientists to learn from one another as well as from decision makers, stakeholders, and the public by including a diversity of players in the process.

### 1. Decision Support for the Colorado River Basin and Headwaters

This theme is designed to provide resource managers with the tools, data, and information about climate that are necessary to support management decisions. Projects within this theme incorporate collaborative work with decision makers to develop, interpret, and apply climate information. Addressing topics related to understanding, explaining, and resolving issues related to uncertainty are important components. In most cases, water will be the ‘natural resource’ of note. This theme encompasses work that WWA has been pursuing for many years now, particularly in the Colorado River Basin. We expect ongoing projects will evolve within this framework.

### 2. Climate Adaptation and the Adaptation-Mitigation Nexus

In the climate change vernacular, *adaptation* refers to the human response to inevitable changes in climate, and *mitigation* encompasses the suite of efforts to reduce atmospheric concentrations of greenhouse gases. The Intergovernmental Panel on Climate Change (IPCC) and other major organizations tend to treat these two matters independently, although treating these independently in a planning framework can present conflicts. One example is the national investment and interest in biofuels. Although considered a renewable energy technology, dedicated biofuel crops may not reduce carbon when the larger context is considered (e.g. fertilizer and N<sub>2</sub>O emissions), and the amount of water needed to grow these crops may expand existing water use. Biofuels may thus trade off one benefit for another, increasing vulnerability. Another example



involves water conservation. Conservation that supplies new growth may be mal-adaptive if declining supplies and increased variability occur with climate change.

This theme is an outgrowth of some limited work we have undertaken on climate adaptation and the water-energy nexus. It is being driven by intense stakeholder interest in exactly how to adapt to climate change given the uncertainties, and how not to adapt. This theme is designed to draw attention to the needs of decision makers to find productive adaptive strategies, especially to climate change but also to natural variability. Social science is anticipated to be a significant part of this theme.

### 3. Ecological Vulnerabilities, Impacts, and Adaptation

Ecological impacts of climate change and variability on Western landscapes are often investigated in isolation, despite the fact that these impacts affect water quality, quantity, ecosystem services, and management of human water infrastructure. For example, the impacts of mountain pine beetle on water supplies are not fully understood, but are presumed to increase runoff and nutrient delivery to watersheds in the short-term. Research areas in need of cross-sector integration include climate change impacts to forests, fires, pests, invasive species (quagga and zebra mussels, especially), and the ripple effects of these impacts to ecosystem and economic services, energy production, water quality, quantity, and management. Public lands feature prominently in these impacts and include national parks, national forests, BLM land, as well as state holdings. We are particularly interested in the critical ecosystem and economic services provided by public lands. Federal agencies (including BLM) are now required to include climate change in their planning, providing a significant opportunity. There are emerging needs for this research and methods to implement and apply the science in planning strategies. This theme has a significant nexus with the new demand for climate information by federal agencies such as USFWS.

This is a fundamentally new research direction for WWA. It is being driven by the knowledge that ecosystems provide significant services to humans, are understudied, and changes have the potential to significantly impact humans.

---

In addition, all WWA research will continue to entrain cross-cutting factors that transcend and guide the three research themes. These include geographic focus, timescale, climate variability versus climate change, stakeholder focus, academic discipline, cross-RISA endeavors; and assessments, climate products and outreach.

#### Cross-Cutting Research Factors

##### *Geographic Focus*

While proposals may consider areas outside the Colorado River Basin (e.g. the Colorado Front Range), most of our work will focus on this critical system. There are four RISAs in the West and each covers a broad range of geography. WWA considers itself the 'headwaters' RISA because of its base in Colorado, where the headwaters for the Platte, Arkansas, Rio Grande, and Colorado Rivers are all located. In addition to these hydrologic boundaries, the political (i.e. state) boundaries for our efforts include Colorado, Wyoming, Utah, and New Mexico. The first three are solely the domain of WWA, while New Mexico is considered part of the University of Arizona RISA, CLIMAS. In this round of proposals, we have elected to focus on the Colorado River Basin (CRB) for many reasons: it affects all four states (plus three others and Mexico), it is by far the largest river in our area, there is widespread consensus among decision makers and scientists alike that it is uniquely vulnerable to a number of stresses including growth and climate change, and it is a very high profile river system with broad-based stakeholder interest.

##### *Timescale Focus*

The RISAs were created to take advantage of underutilized seasonal "El Niño" climate signals in the late 1990s. Over the years WWA has focused on three major time scales: paleoclimate, in the form of streamflow reconstructions; seasonal forecasting and observations, in the form of experimental climate predictions for





water managers and our Intermountain West Climate Summary (IWCS); and climate change, in the form of our Colorado Climate Report and ongoing research focusing on climate change and Colorado River flows. In this round of proposals, we will deemphasize our service-oriented work (including paleoclimate reconstructions and workshops, and seasonal forecasting). We instead will focus more on research projects. This will likely mean that our timescale focus shifts more to climate change. Intense stakeholder interest in climate change/variability, and a desire to move beyond the provision of services is the driving force behind this shift in timescale focus.

### *Climate Variability vs. Climate Change Focus*

Another timescale factor includes the distinction between climate variability and climate change. Climate variability for our purposes is usually considered to operate during very short time periods such as weeks, months, or seasons, up to much longer periods including decades; climate change operates on decades and longer scales. In the rush to understand climate change, climate variability is being underplayed despite its importance at the short and medium timescales critical to many decision makers. For example, currently, natural climate variability on the Colorado River is likely a greater threat to reservoir levels than climate change.

### *Stakeholder Focus*

In the past, WWA has focused almost exclusively on water managers. We are expanding our horizons to include other decision makers. This includes environmental NGOs, federal agencies with land and water management responsibilities, and others such as land and energy planners with an interest in water. WWA is increasingly being approached by federal entities including Reclamation, USFWS, USFS, and EPA looking for guidance on climate change including (1) what scientific information is available, (2) how it might be used, and (3) the degree to which it should be trusted for decision making. While we expect most of our work to have strong stakeholder interest and support, there may be some critical but politically sensitive social, economic, or policy vulnerability assessments that need independent, unbiased academic analysis. There is also one other important WWA stakeholder: NOAA. The leadership at NOAA wants to understand the lessons the RISAs are learning, yet the RISAs have not fulfilled this need. WWA's position within the largest federal NOAA lab is unique within the RISA community, and provides an unusual opportunity to enhance communication with NOAA. In addition, NOAA's recent announcement of the creation of a National Climate Service (NCS) makes attention to this stakeholder all the more important. Communicating to the NCS critical needs of regional users is an important RISA goal. Transferring products to an operational entity-- a longtime but rarely executed RISA goal-- is a new, albeit uncertain, possibility with the NCS.

### *Academic Discipline*

WWA's success depends on well-executed interdisciplinary research. While all of our work requires an underlying climate component, this does not limit our efforts to climate science. In the past, WWA has funded work by sociologists, economists, geographers, hydrologists, and others. We are continuing to support projects from all disciplines, and particularly those that integrate among sectors.

### *Cross-RISA Activities*

Some efforts may qualify as 'Cross-RISA' efforts where expertise at another RISA is utilized. Cross-RISA efforts that build upon existing knowledge are supported when appropriate.

### *Assessments, Climate Products and Outreach*

WWA has sometimes characterized its efforts as falling into one of three categories: Assessments, Decision Support, and Outreach. Assessments can be climate assessments (e.g. Colorado Climate Report), or vulnerability assessments based on economics or infrastructure or policy (e.g. past work on Aurora water demand, when Lake Mead will dry or impacts of climate change on water rights.) Decision Support can include forecasts, documents such as the Intermountain West Climate Summary, web portals, or any other product designed to aid decision-making. Some research efforts either fall between these categories, or combine from more than one category (the Colorado Climate Report and the IWCS are potentially both



Decision Support and Outreach.) WWA is interested in a mix of efforts among these categories for our collective work portfolio.

Outreach (and education) deserves special mention. Over the years, WWA has gained substantial credibility with decision makers by providing written and verbal syntheses of research, both our own and others', by maintaining a website, and by holding a variety of workshops on climate change, global climate models, forecast verification, and other topics. In most cases, projects have an outreach component, even if minor. The WWA Core Office has substantial capabilities to provide outreach and they coordinate this function.

---



## Appendix I. Personnel and Stakeholders

**Table A-1. WWA Personnel**

Investigator	Affiliation	Fields of Expertise
Udall, Bradley	Director, Western Water Assessment	Colorado River, Water, Policy
Averyt, Kristen	Deputy Director, Western Water Assessment	Climate, Assessment Processes
Balaji, Rajagopalan	Associate Professor, University of Colorado at Boulder	Hydrology
Barsugli, Joseph	Research Associate, CIRES	Climate Dynamics
Bates, Gary	Professional Research Assistant, NOAA Climate Diagnostic Center	Hydrology, Climate Dynamics
Capotondi, Antonietta	Climate Researcher, CU-CIRES	Oceanography
Dilling, Lisa	Assistant Professor, Environmental Studies, University of Colorado at Boulder	Carbon Cycle Science
Dinges, Ava	Undergraduate Student, University of Kansas	Meteorology
Eischeid, Jon	Sr. Professional Research Assistant, Climate Prediction Center	Climate
Gillies, Robert	Utah State Climatologist, Utah State University	Climate Change
Goemans, Chris	Assistant Professor, Colorado State University	Water Resource Economics
Gordon, Eric	PhD Student, University of Colorado at Boulder	Natural Resource Policy
Guentchev, Galina	Research Fellow, Western Water Assessment, BoR, SNWA	Climatology
Hoerling, Martin	Research Associate, CIRES	Climate Variability, Snowpack, Hydrology
Kenney, Douglas	Director, Western Water Policy Program and Senior Research Associate, Natural Resources Law Center	Western Water Policy and Law
Klein, Roberta	Managing Director of Center for Science and Technology Policy Research	Environmental Policy
Lowrey, Jessica	Associate Scientist, CIRES	Policy, Water Management, Outreach
Lukas, Jeff	Professional Scientist, INSTAAR Dendrochronology Lab	Paleoclimatology, Tree-Ring Analysis
Malmberg, Julie	PhD Student, University of Colorado at Boulder	Climate-Society Interactions
Martin, Jenifer	PhD Student, University of Colorado at Boulder	Communication, Discourse Analysis
McCutchan, James	Deputy Director, Center for Limnology, CU-CIRES	Limnology
Neff, Jason	Assistant Professor, CU Geological Sciences and Environmental Studies	Biogeochemistry
Nowak, Kenneth	PhD Student, University of Colorado at Boulder	Civil Engineering
Painter, Thomas	Assistant Professor, Geography, University of Utah	Hydrology
Pulwarty, Roger	Director, NIDIS; Physical Scientist, NOAA Physical Sciences	Climate Analysis and Impacts Assessment
Ray, Andrea	Physical Scientist, NOAA-OAR Climate Diagnostics Center	Climate-Society Interactions, Water Management
Travis, William	Associate Professor, University of Colorado at Boulder Director, Center for Science and Technology Policy Research	Environment-Society Interactions
van Drunick, Suzanne	Assistant Director for Science, CU-CIRES	Hydrology and Ecology
Webb, Robert S	Chief, Climate Analysis Branch, NOAA, Physical Sciences Division	Paleoclimatology
Wolter, Klaus	Research Associate, CIRES	Climatology



**Table A-2. WWA Stakeholders and Partner**

<b>FEDERAL</b>	
<b>Organization</b>	<b>Major Contact</b>
Bureau of Reclamation	Curt Brown (Science and Tech Prgm.), Chuck Hennig (Science and Tech Prgm.), Terry Fulp (LC Region), Levi Brekke (Tech Service Ctr.), Christopher Cutler (UC Region), Donald Frevert (Tech Service Ctr.), James Prairie (UC Region), Ryan Christiansen (UC Region)...plus many others
Environmental Protection Agency	Laura Farris (Region 8)
National Park Service	Brent Frakes (Rocky Mountain Network), Dave Sharrow (ZION NP), Judy Visty (Rocky Mountain NP)...plus several others
Natural Resources Conservation Service	Randy Julander (UT), Mike Gillespie (CO), Lee Hackleman (WY); Jan Curtis (National Water and Climate Center)
NIDIS	Roger Pulwarty, Jim Verdin, Mike Brewer
NOAA Climate Services Division	Ahsha Tribble, Diana Perfect
NOAA ESRL Communications and Outreach	Carol Knight, Anatta
NOAA National Drought Mitigation Center	Mike Hayes
NWS Billings, MT WFO	Donald Moore
NWS Boulder, CO WFO	Larry Mooney, Mike Baker, Treste Huse
NWS Central Region HQ	Doug Kluck
NWS Cheyenne, WY WFO	John Eise, Melissa Goering
NWS Climate Prediction Center	Wayne Higgins, Michelle L'Heureux, Ed O'Lenic, Jon Gottschalck, Mike Halpert
NWS Colorado Basin River Forecast Center	Kevin Werner, Michelle Schmidt
NWS Grand Junction, CO WFO	Joe Ramey, John Kyle
NWS Hastings, NE WFO	Michael Lewis
NWS Missoula, MT WFO	Robert Nester
NWS Missouri Basin River Forecast Center	Gregg Schalk, John Lague, Tom Gurss
NWS North Platte, NE WFO	Brian Hirsch, Christopher Buttler
NWS Pocatello, ID WFO	Mike Huston
NWS Riverton, WY WFO	Arthur Meunier, Brett McDonald, James Fahey
NWS Salt Lake City, UT WFO	Brian McInerney
NWS Southern Region HQ	Victor Murphy
NWS Western Region HQ	Andrea Bair
U.S. Army Corps of Engineers	Thomas Johnson
U.S. Bureau of Land Management	Edward Rumbold (CO), Rodd Hardy (UT), Scott Archer (CO)
U.S. Fish and Wildlife Service	David Campbell, George Smith
U.S. Forest Service	Rick Hopson, Linda Joyce
U.S. Geological Survey	Michael D. Dettinger (SCRIPPS), Dan Cayan (SCRIPPS), Jay Cederberg (Utah Water Science Center)...Greg McCabe, David Clow, plus others
USDA Agricultural Research Service	Jeanne Schneider





Roaring Fork Conservancy, CO	Sharon Clarke
S. Adams County Water and Sanitation Dist.	Greg Fabisiak
Salt Lake City Public Utilities	Larry Alserada
Southern Nevada Water Authority	Patricia Mulroy, Rick Holmes
Taos Pueblo	Gilbert Suazo
Upper Gunnison River Water Conservancy District, CO	Ralph Grover
Utah Water Users Association	Carley Burton
Weber Basin Water, UT	Mark Anderson
Western Area Power Authority	Clayton Palmer
<b>UNIVERSITY</b>	
<b>Organization</b>	<b>Major Contact</b>
CLIMAS; University of Arizona	Dan Fergusen, Jonathan Overpeck, Gregg Garfin, Holly Hartmann
Climate Impacts Group; Univ. of Washington	Dennis Lettenmaier, Phillip Mote, Lara Whitley Binder, Nate Mantua
Colorado Climate Center; Colorado State University	Nolan Doesken
Colorado State University	Reagan Waskom, Dan Smith
Desert Research Institute; Western Regional Climate Center	Kelly Redmond
Kansas State University	Mary Knapp
SE Climate Consortium; Florida State	David Zierdan
Univ. of Nevada; Civil and Env. Engineering	Thomas C. Piechota
University of Nebraska; High Plains Regional Climate Center	Ken Hubbard, Kenneth Dewey
University of New Mexico	Amy Ellwein
University of Utah	Phil Dennison, John Matsen
University of Wyoming	Jaqueline "JJ" Shinker, Diana Hulme, Glen Tootle
Utah State Climatologist; Utah State University	Robert Gillies
Weber State University	Dan Bedford
Western State College	George Sibley
Wyoming State Climatologist; University of Wyoming	Stephen Gray,
<b>OTHER/Non Profit</b>	
<b>Organization</b>	<b>Major Contact</b>
Water Research Foundation	Rob Renner, Kenan Ozekin
Arapahoe Basin	Tim Finnigan
Bloomberg (media)	John Lippert
Carpe Diem (EXLOCO)	Kimery Wiltshire
Carver Schwarz McNab & Bailey, LLC	Dave Bailey
Climate Science Forum	Michael Fortune
Colorado Water Congress	Doug Kemper
Conservation International	Hannah Campbell
Environmental Defense	Jennifer Pitt
Fox News	Rick Reichmuth
Gunnison Energy Corp.	Jason Hoeler



High Country Citizen’s Alliance	Steve Glazer
Indigenous Waters Network	Gary Collins
Living Rivers/Colorado River Keepers	John Weisheit
Mountain Studies Institute	Korin Nydick
MWH Global	Gerald Gibbens
NCAR	David Yates, Kathy Miller, Linda Mearns
NPR-Denver	Jeff Brady
Omaha World Herald	Nancy Gardner
Pacificorp	Darce Guyman
Resource Media	Theo Stein
Rocky Mountain Climate Organization	Tom Easley, Stephen Saunders
RTD Denver	Michael Carlson
Sierra Club	Barbara Williams
Sustainable Tucson	Madeline Kiser
Tetra Tech	John Edrich
The Nature Conservancy	Tom Iseman, Robert Wigington
Trout Unlimited	Melinda Kassen
Vail Resorts	Luke Cartin
Walsh Environmental	Margit Hentschel
Water Utility Climate Alliance	David Behar (San Francisco Public Utilities Comission), Paul Flemming (Seattle Public Utilities), Brandon Goshen (Metropolitan Water District), Angela Licata (New York City dept. of Environmental Protection), Marc Waage (Denver Water), Rick Holmes (Southern Nevada Water Authority)
Western Governor’s Association	Madeline West, Rich Halvey
Western Resource Advocates	Bart Miller, Stacy Tellinghausen
Western States Water Council	Tony Willardson, Craig Bell





## Appendix II. Presentations

January: Climate Challenge

Colorado School of Mines, Golden, CO

Barsugli, J

January 18, 2008: Seasonal Outlook through June 2008

Water Availability Task Force, Denver, CO

Wolter, K

January 24-25, 2008: Water, Climate, Uncertainty: What's the future of the Rio Grande as the climate warms?

Law of the Rio Grande, Continuing Legal Education, Albuquerque, NM

Udall, B.

February: K-Nearest Neighbor Resampling Technique (Weather Generation and Water Quality Applications)

Climate change Modeling Workshop for Front Range Water Providers,

Balaji, R

February: Climate Models and Emissions Scenario

JFRCCVS, Boulder, CO

Barsugli, J

February 11, 12, 2008: Water, The West, and Climate Change in the 21st Century

Colorado School of Mines, Golden, CO

Udall, B.

February 15, 2008: The Western Water Assessment: Connecting Climate Science with Decision Making in the Rocky Mountain West

University of Utah, Salt Lake City, UT

Udall, B.

February 22, 2008: Water, Agriculture, and Climate Change in the 21st Century

Colorado Agriculture Big and Small, Greeley, CO

Udall, B.

February 26, 2008: Tree-ring reconstructions of streamflow and their use in water management

Northern Colorado Water Conservancy District, Berthoud, CO

Lukas, J

March: Residential Water Demand: Lessons from Aurora, Colorado

Climate Prediction Applications Workshop, Chapel Hill, NC

Kenney, D

March: Managing Residential Water Demand During Drought in Aurora

VPR Global Water Colloquium, Fort Collins, Colorado

Klein, R

March: Adaptation Planning for Water Resources Management in the Context of Scientific Uncertainty

CPASW, Chapel Hill, NC

Klein, R

March: Interactions with Colorado Municipal Water Managers Elevate the Use of Climate Information

Climate Prediction Applications Workshop, Chapel Hill, NC

Lowrey, J

March 6, 2008: An Improved Multivariate ENSO Index (MEI)

Climate Prediction Applications Workshop, Chapel Hill, NC

Wolter, K

March 6, 2008: Colorado River Water: Past, Present, and Future?

Departmental Seminar Series, Ohio State University

Woodhouse, CA

March 17, 2008: (Updated) Seasonal Outlook through June 2008

Water Availability Task Force, Denver, CO

Wolter, K



March 17, 2008: Tree-Ring Records and Water Management in Colorado  
Conference on "Past and Future Hydroclimatic Variability: Applications to Water Resource Management in the Prairie Provinces,"  
Canmore, Alberta  
Woodhouse, CA

March 19, 2008: Historical and Paleohistorical Reconstructions of the Colorado River  
Symposium on Water History of the Southwestern United States, International Water History Association meeting, Tucson, AZ  
Woodhouse, CA

March 21, 2008: Climate Change on the Colorado River: The State of the Science  
Securing Environmental Flows On The Colorado River In An Era Of Climate Change: Issues, Challenges And Opportunities, Boulder, CO.  
Udall, B.

March 26, 2008: Water, The West, and Climate Change in the 21st Century  
NCAR Congressional Briefing, Boulder, CO  
Udall, B.

March 26, 2008: Tree-ring reconstructions of streamflow and their use in water management  
Reclamation Upper Colorado Regional Office, Salt Lake City, UT  
Lukas, J

April 2, 2008: Monitoring El Niño/Southern Oscillation Behavior with an Improved Multivariate ENSO Index (MEI)  
Workshop on Reconciling ENSO Chronologies for the Past 500 Years, Moorea, French Polynesia  
Wolter, K

April 7, 2008: Global & Regional Climate Change: What do we know & What don't we know?  
Rocky Mountain National Park Service Research Conference, Estes Park, CO  
Wolter, K

April 15, 2008: Seasonal Outlook through September 2008  
Water Availability & Flood Task Force, Denver, CO  
Wolter, K

April 17, 2008: The Medium Term Impact of Natural Disasters in Brazil  
Interdisciplinary Water Resources Seminar , Fort Collins, Colorado  
Goemans, C

April 18, 2008: Water, Energy, and Climate Change  
AWRA Colorado 2008 Symposium, Golden Colorado  
Udall, B

April 22, 2008: Thoughts about the upcoming spring & summer in North America, with special focus on (south-)western U.S.  
National Seasonal Assessment Workshop, Boulder, CO  
Wolter, K

April 24, 2008: Water in the West: A Look at the 21st Century  
CU Law School, Boulder, CO  
Udall, B.

April 25, 2008: Looking Backwards to Plan for the Future: Streamflow Reconstructions Applied to Water Resource Management  
Global Change Interdisciplinary Program luncheon, Institute for the Study of Planet Earth, University of Arizona, Tucson, AZ  
Woodhouse, CA

April 28, 2008: Looking Backwards to Plan for the Future  
Climate Change Impacts on Texas Water Conference, Austin, TX  
Woodhouse, CA

April 29, 2008: Global & Regional Climate Change: What do we know & What don't we know?  
U.S. Forest Service Annual Planning Meeting (Region 2), Lakewood, CO  
Wolter, K

April 30, 2008: What tree rings tell us about the past variability of the upper Rio Grande  
Rio Grande River Guide Rendezvous, Bureau of Land Management, Pilar, NM  
Lukas, J

May 8, 2008: Monitoring El Niño/Southern Oscillation Behavior with an Improved Multivariate ENSO Index (MEI)  
Third WMO Workshop on Advances in Marine Climatology (CLIMAR-III), Gdynia, Poland  
Wolter, K



May 9, 2008: Colorado River Streamflow Reconstructed from Tree Rings: 1200 Years of Hydrological Variability  
University of Arizona College of Law, Environmental Breakfast Club seminar, Tucson, AZ  
Woodhouse, CA

May 13, 2008: Climate Change on the Colorado River: The State of the Science  
NWS Western Water Supply Team Meeting, Boulder, CO.  
Udall, B.

May 21, 2008: The Colorado River at 1900, 2000, and 2100: the past, present, and future of the river  
Oregon State University, Corvallis, OR  
Udall, B.

May 23, 2008: The Water Future of the American West  
Mountain Film in Telluride, Telluride, CO  
Udall, B.

May 29, 2008: A Regional Vision for a National Climate Service  
NWS Webinar,  
Udall, B.

May 30, 2008: Tree-ring-based streamflow reconstructions for the Rio Grande basin  
NMSU Extension Center, NMSU Extension Center, Albuquerque, NM  
Lukas, J

June 2, 2008: The long view of the Rio: What tree rings tell us about the past variability of the Rio Grande, and what it means for the future  
New Mexico chapter meeting, American Water Resources Association, Albuquerque, NM  
Lukas, J

June 9, 2008: Western Water and Climate Change: what the science tells us  
Gates Family Foundation, A Bar A Ranch, Wyoming  
Udall, B.

June 13, 2008: A tree-ring reconstruction of Animas River streamflow and its use in water management  
Fort Lewis College, Durango, CO  
Lukas, J

June 27, 2008: Climate Change on the Colorado River: The State of the Science  
Continuing Legal Education, Reno, NV  
Udall, B.

June 30, 2008: Managing Water in the West  
Western Governors' Association Annual Meeting ,  
Udall, B

July: Climate Change and the Colorado River Is Time Running Out?  
Continuing Legal Education Colorado River Superconference, Denver, CO  
Udall, B

July: ENSO-precipitation associations in Colorado, as viewed in PRISM and new climate divisions  
Annual Meeting of American Association of State Climatologists (AASC), Burlington, VT  
Wolter, K

July 14, 2008: Climate Predictions for 2018  
CLIVAR Science Symposium, Irvine, CA  
Ray, A

July 14, 2008: Tree-Ring Based Reconstructions of Annual Runoff in the Colorado River basin  
CUAHSI Biennial Colloquium, Boulder, CO  
Woodhouse, CA

July 24, 2008: Allocating Water among Competing Uses: The Potential for Water Markets in New Zealand  
Institute for the Study of Competition and Regulation, Wellington, NZ  
Goemans, C

July 25, 2008: Seasonal Outlook into December 2008  
Water Availability Task Force Denver, CO  
Wolter, K



July 26, 2008: The long view of the river: What tree rings tell us about hydrologic variability in Colorado  
Colorado chapter meeting, American Water Resources Association, , Denver, CO  
Lukas, J

July 31, 2008: Climate Change, Streamflows and Ecosystems: What we know, don't know, and need to know.  
Climate Destabilization in the USFWS Mountain-Prairie Region, Denver, CO  
Udall, B.

August 3, 2008: Western Water and Climate Change: what the science tells us  
Udall Scholar Orientation, Morris K. Udall Foundation, Tucson, AZ  
Udall, B.

August 12, 2008: Where is the Interface between Weather and Climate?  
AMS Summer Community Meeting, Boulder, CO  
Wolter, K

August 18, 2008: Water, The West, and Climate Change in the 21st Century  
Center for the American West, French Embassy and Consulates Briefing, Boulder, CO  
Udall, B.

August 19, 2008: Past Climate and Hydrologic Conditions from Tree Rings  
Utah Associated Municipal Power Systems (UAMPS) 2008 Member Conference, Lehi, Utah  
Woodhouse, CA

September 9, 2008: Water Cycle Changes as the Primary Delivery Mechanism for Climate Change Impacts  
Third Interagency Conference on Research in Watersheds, Estes Park, CO  
Udall, B.

September 11, 2008: Climate Change and the Colorado River: Is Time Running Out?  
Continuing Legal Education Western Water Law, Denver, CO  
Udall, B.

September 17, 2008: Overview of Climate Change Impacts and Implications for the U.S. West Managing Water in a Climate Changing  
World: Implications for Irrigation, Drainage and Flood Control  
USCID Water Management Conference, Denver, CO  
Udall, B

September 18, 2008: Seasonal Outlook into March 2008  
Colorado Association of Lawn Care Professionals Annual Mtg., Denver, CO  
Wolter, K

September 22, 2008: Climate Change, Water and the West  
Stroock Forum: Climate Change and Water Management, Laramie, WY  
Udall, B

September 22, 2008: Partnership Opportunities  
Climate Change Adaptation Policy Workshop, Irvine, CA  
Udall, B

September 24, 2008: Urban Water Management Plans and Reconstructed Hydrology  
Western States Water Council/Western Governors' Association, Climate Change Adaptation Policy Workshop, Irvine CA  
Woodhouse, CA

September 25, 2008: Paleohydrology and Applications to Water Resource Management  
Geosciences Departmental Seminar Series, University of Arizona  
Woodhouse, CA

September 20-28, 2008: Placing Recent Droughts in a Long-Term Context with Tree-Ring Reconstructions of Precipitation  
Southern California Workshop on Water Conditions and Drought Preparedness, Ontario CA  
Woodhouse, CA

October: Climate Models and Emissions Scenarios: Take 2  
JFRCCVS, Boulder, CO  
Barsugli, J

October: Lessons learned from the 2000s Western drought: Evolving linkages between research and services  
CDPW/CLIVAR drought meeting , Lincoln, NE  
Ray, A



October 1, 2008: Climate Change, Water and the West  
Colorado Watershed Assembly, Denver, CO  
Udall, B

October 7, 2008: Climate and Colorado: Implications for Wildlife  
Colorado Conservation Summit, Keystone, CO  
Averyt, K

October 8, 2008: Climate Change In Colorado  
Governor's Conference on Drought and Climate Change, Denver, CO  
Barsugli, J

October 8, 2008: The long view of drought in Colorado: What tree rings tell us about hydrologic variability  
Governor's Conference on Managing Drought and Climate Risk, Denver, CO  
Lukas, J

October 18, 2008: Global & Regional Climate Change: What do we know & What don't we know?  
CU Outreach Event at Mountain Research Station, Rocky Mountain Research Station, Niwot, CO  
Wolter, K

October 20, 2008: Paleohydrology from Tree Rings and Applications to Water Resource Management  
Climate Change Institute and Environmental & Water Resources Engineering Seminar, University of Maine  
Woodhouse, CA

October 22, 2008: Climate and Colorado  
Montezuma County League of Women Voters Public Seminar, Cortez, CO  
Averyt, K

October 22, 2008: Partnership Opportunities  
National Association of Water Companies, Santa Fe, NM  
Udall, B

October 23, 2008: Climate and Colorado  
La Plata County League of Women Voters & Fort Lewis College, Durango, CO  
Averyt, K

October 23, 2008: Colorado Climate Report: What climate change means for Colorado  
La Plata County Climate Action Plan Meeting, Durango, CO  
Averyt, K

October 23, 2008: Let it snow, let it snow, let it snow!  
NOAA-ESRL Outreach event, Boulder, CO  
Wolter, K

October 24, 2008: Climate Change and Water  
Continuing Legal Education, Albuquerque, NM  
Udall, B.

November 1, 2008: Climate Change on the Colorado River: The State of the Science  
The Fate and Future of the Colorado River, Pasadena, CA  
Udall, B.

November 4, 2008: ENSO: Monitoring, Impacts, and Prediction  
University of Colorado, Boulder, CO  
Wolter, K

November 9, 2008: What can we expect this winter and beyond?  
Grand County Wilderness Group, Fraser, CO  
Wolter, K

November 13, 2008: Tree-ring reconstructions of streamflow and climate and their application to Colorado River Basin water  
management  
Reclamation Lower Colorado Regional Office,, Boulder City, NV  
Lukas, J

November 14, 2008: Climate Change on the Colorado River: A Quick Review  
Reconciling Colorado River Flows,, Las Vegas, NV



Udall, B

November 17, 2008: Effects of Interannual Variability and Climate Change on the Colorado River: A Perspective  
Colorado River Basin Science and Resource Management Symposium, Scottsdale, AZ  
Udall, B.

November 17, 2008: Water-Energy-Climate: Exploring the Connections for the Western United States  
University of Colorado Energy Initiative, Boulder, CO  
Averyt, K

November 21, 2008: Looking ahead for next two weeks to six months  
'Crystal Ball' Meeting, San Diego, CA  
Wolter, K

November 25, 2008: 'Tis The Season to be Snowy – Or Is It? Outlook for Winter  
'Bring Your Family to NOAA Day", NOAA-ESRL, Boulder, CO  
Wolter, K

December 3 2008: Climate Change and Water  
EPA Sustainable Infrastructure Forum, Denver, CO  
Udall, B.

December 4, 2008: Colorado River Streamflow from Tree Rings: Lessons from the Past, Applications to the Future?  
Adjusting to Less Water: Climate Change and the Colorado River, Glen Canyon Institute, Salt Lake City, UT  
Woodhouse, CA

December 4, 2008: Risk of Colorado River Reservoir Drying and Implications for River Management in the 21st Century  
Adjusting to Less Water : Climate Change and the Colorado River, Glen Canyon Institute, Salt Lake City, UT  
Udall, B.

December 12, 2008: What can we say about 'natural' & 'anthropogenic' temperature variability in Colorado?  
JFRCCVS, Boulder, CO  
Wolter, K

## Appendix III. Awards

Climate Science Paper Award, California Department of Water Resources, November 2008: Meko et al., 2007, "Medieval Drought in the Colorado River Basin", Geophysical Research Letters

Colorado Governor's Research Impact Award Finalist, January 2009: Climate Change in Colorado Report; A.J. Ray, Barsugli, K. Averyt

Department of Interior Partners in Conservation Award, April 2009: Appendix U; B. Udall, R. Webb

## Appendix IV. Publications

Alvord, C. (2008). NIDIS Remote Sensing Workshop: Showcase of Products & Technologies. Intermountain West Climate Summary. Boulder, CO, Western Water Assessment. **4**: 5.

Alvord, C. (2008). National Integrated Drought Information System Drought Portal. Intermountain West Climate Summary. Boulder, CO, Western Water Assessment. **4**: 2.

Averyt, K. B. (2008). Monthly and Annual "State of the Climate" Reports from the National Climatic Data Center. Intermountain West Climate Summary. Boulder, CO, Western Water Assessment. **4**: 3.

Averyt, K. B., R. Pulwarty and B. Udall Colorado's Energy and Water Systems in a Changing Climate. American Geophysical Union Fall Meeting. San Francisco, CA. **H11G-0850 (poster)**.

Averyt, K. B., R. Pulwarty and B. Udall (2008). Energy and Water Resources in a Changing Climate: Towards Adaptation Options in the Western United States. American Geophysical Union Fall Meeting. San Francisco, CA. **PA13C-1354 (poster)**.

Barrett, A. P., T. H. Painter and C. C. Landry (2008). Desert Dust Enhancement of Mountain Snowmelt. Intermountain West Climate Summary. Boulder, CO, Western Water Assessment. **4**: 2.



- Barsugli, J. J., K. Nowak, B. Rajagopalan, J. Prairie and B. Harding (2009-in revision). "Comment on "When Will Lake Mead Go Dry?" " Water Resources Research **submitted Nov. 2008**.
- Clark, M., D. Slater, T. H. Painter, W. Meier, J. Stroeve, A. P. Barrett, B. Raup and M. Serreze (2009-in press). "Scientific and societal uses of remotely sensed snow and ice information.," AGU Monograph: Research and Economic Applications of Remote Sensing Data Products.
- Cline, D., S. Yueh, B. Chapman, B. Stankov, A. Gasiewski, D. Masters, K. Elder, R. Kelly, T. H. Painter, S. Miller, S. Katzberg and L. Mahrt (2009). "NASA Cold Land Processes Experiment (CLPX 2002/03): Airborne Remote Sensing." Journal of Hydrometeorology **10**: 338-346.
- Davis, R. E., T. H. Painter, D. W. Cline, R. L. Armstrong, T. Haran, K. McDonald, R. Forster and K. Elder (2008). "NASA Cold Land Processes Experiment (CLPX 2002/03): Spaceborne Remote Sensing." Journal of Hydrometeorology **9**: 1427-143.
- Dinges, A. (2008). Assessing and Adapting to Climate Change: A Look at Two of the Climate Change Science Program's Latest Products. Intermountain West Climate Summary. Boulder, CO, Western Water Assessment. **4**: 6.
- Dozier, J., Green, R. O., A. W. Nolin and T. H. Painter (2009-in press). "Interpretation of snow properties from imaging spectrometry." Remote Sensing of Environment.
- Dozier, J., T. H. Painter, K. Rittger and J. Frew (2008). "Time-space continuity of daily maps of fractional snow cover and albedo from MODIS." Advances in Water Resources **31**: 1515-1526.
- Flanner, M. G., C. S. Zender, P. G. Hess, N. M. Mahowald, T. H. Painter, V. Ramanathan and P. J. Rasch (2009). "Springtime warming and reduced snow cover from carbonaceous particles." Atmospheric Chemistry and Physics **9**: 2481-2497.
- Gottschalck, J. and A. J. Ray (2008). Meet the MJO. Intermountain West climate Summary. Boulder, CO, Western Water Assessment. **4**: 5.
- Hardy, J., R. E. Davis, Y. Koh, D. W. Cline, K. Elder, R. L. Armstrong, H. P. Marshall, T. H. Painter, G. Castres Saint-Martin, R. DeRoo, K. Sarabandi, T. Graf, T. Koike and K. McDonald (2008). "Cold Land Processes Experiment (CLPX 2002-2003): Local Scale Observation Site (LSOS)." Journal of Hydrometeorology **9**: 1434-1442.
- Kenney, D. S., C. Goemans, R. Klein, J. Lowrey and K. Reidy (2007). Residential Water Demand Management in Aurora: Learning from the Drought Crisis. Colorado Water. Fort Collins, CO, Colorado Water Resources Research Institute. **February/March**: 14-16.
- Kenney, D. S., C. Goemans, R. Klein, J. Lowrey and K. Reidy (2008). "Residential Water Demand Management: Lessons from Aurora, Colorado. ." Journal of the American Water Resources Association (JAWRA) **44**(1): 192-207.
- Kenney, D. S., R. Klein, C. Goemans, C. Alvord and J. Shapiro (2008). The Impact of Earlier Spring Snowmelt on Water Rights and Administration: A preliminary Overview of Issues and Circumstances in the Western States. Western Water Assessment Progress Report. Boulder, CO, Western Water Assessment: 38.
- Kluck, D., E. McKim and J. Lowrey (2008). Climate Service Activities in the National Weather Service Central Region., Intermountain West Climate Summary. Boulder, CO, Western Water Assessment. **4**: 2.
- Liu, J., R. A. Melloh, C. E. Woodcock, R. E. Davis, T. H. Painter and C. McKenzie (2008). "Modeling the view angle dependence of gap fractions in forest canopies: Implications for mapping fractional snow cover using optical remote sensing." Journal of Hydrometeorology **9**(5): 1005-1019.
- Lowrey, J. (2008). Adaptation Planning for Water Resources Management in the Context of Scientific Uncertainty. America Geophysical Union annual meeting. San Francisco, CA. **poster**.
- Lowrey, J. (2008). Workshop Summary: Climate Change Modeling Workshop for Front Range Water Providers. Intermountain West Climate Summary. Boulder, CO, Western Water Assessment. **4**: 2.
- Lowrey, J. (2008). Adaptation Planning for Water Resources Management in the Context of Scientific Uncertainty. American Geophysical Union Fall Meeting. San Francisco, CA. **PA13C-1353 (poster)**.
- Lowrey, J., A. J. Ray and K. B. Averyt (2008). Intermountain West Climate Summary. Boulder, CO, Western Water Assessment. **8 issues**: 171.
- Lowrey, J., A. J. Ray and R. S. Webb (2009-submitted). "Factors influencing the use of climate information by Colorado municipal water managers." Journal of Climate Research.
- Malmberg, J. (2008). The Denver/Boulder National Weather Service Forecast Office. Intermountain West Climate Summary. Boulder, CO, Western Water Assessment. **4**: 2.





- Malmberg, J. (2008). Forecast Verification: Past, Present, and Future. Intermountain West Climate Summary. Boulder, CO, Western Water Assessment. **4**: 3.
- Malmberg, J. and J. Lowrey (2008). Global Climate Patterns and Their Impacts on North American Weather. Intermountain West Climate Summary. Boulder, CO, Western Water Assessment. **4**: 5.
- Neff, J. C., A. P. Ballantyne, G. L. Farmer, N. M. Mahowald, J. Conroy, C. C. Landry, J. Overpeck, T. H. Painter, C. R. Lawrence and R. Reynolds (2008). "Increasing eolian dust deposition in the western United States linked to human activity." Nature Geosciences **1**: 189-195.
- Painter, T. H., K. Rittger, C. McKenzie, R. E. Davis and J. Dozier (2008). "Retrieval of subpixel snow-covered area and grain size from MODIS reflectance data." Remote Sensing of Environment **113**: 868-879.
- Rajagopalan, B. and K. Grantz (2008). North American Monsoon Variability: Implications to Water Resources Management in the Southwestern US. Intermountain West Climate Summary. Boulder, CO, Western Water Assessment. **4**: 4.
- Rajagopalan, B., K. Nowak, M. Hoerling, B. Harding, A. J. Ray, J. Barsugli and B. Udall (2008). Climate, Growth and Drought Threat to Colorado River Water Supply. American Geophysical Union Fall Meeting. San Francisco, CA. **GC43C-0751 (poster)**.
- Rajagopalan, B., K. Nowak, J. Prairie, M. Hoerling, B. Harding, J. J. Barsugli, A. J. Ray and B. Udall (2009-in revision). "Water Supply Risk on the Colorado River: Can Management Mitigate?." Water Resources Research Submitted Nov. 2008.
- Ray, A. J. (2008). Water Resources Decision-Makers and Their Needs for Decadal Climate Prediction Variations. Washington, DC, U.S. CLIVAR **6**.
- Ray, A. J., J. Barsugli, K. B. Averyt, K. Wolter, M. Hoerling, N. Doesken, B. Udall and R. S. Webb (2008). Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation. Intermountain West Climate Summary. Boulder, CO, Western Water Assessment. **4**: 3.
- Ray, A. J., J. J. Barsugli, K. B. Averyt, K. Wolter, M. Hoerling, N. Doesken, B. Udall and R. S. Webb (2008). Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation. Boulder, CO, Colorado Water Conservation Board: 52.
- Ray, A. J., J. J. Barsugli, K. B. Averyt, K. Wolter, M. Hoerling, N. Doesken, B. Udall and R. S. Webb (2008). Climate Change in Colorado: Developing a Synthesis of the Science to Support Water Resources Management and Adaptation. American Geophysical Union Fall Meeting. San Francisco, CA. **H21E-0881 (poster)**.
- Rice, J. L., C. A. Woodhouse and J. J. Lukas (2008). Evaluating the Effectiveness of Science for Decision-Making: Water Managers and Tree-Ring Data in the Western United States. American Geophysical Union Fall Meeting. San Francisco, CA. **GC33B-0771 (poster)**.
- Schaepman, M. S., S. L. Ustin, A. J. Plaza, T. H. Painter, J. Verrelst and S. Liang (2009-in press). "Earth System Science Related Imaging Spectroscopy – An assessment " Remote Sensing of Environment.
- Shreve, C. M., G. S. Okin and T. H. Painter (2009-in press). "Indices for estimating fractional snow cover in the Western Tibetan Plateau." Journal of Glaciology.
- Udall, B. (2008). Water Providers and Trade Groups Wake Up to Climate Change: Implications for the Research Community. American Geophysical Union Fall Meeting. San Francisco, CA. **PA12A-07 (oral presentation)**.
- Udall, B. (2008). Meeting the Water Supply Challenges of Climate Change: Water User Perspectives and Institutional Hurdles. American Geophysical Union Fall Meeting. San Francisco, CA. **GC33C-08 (oral presentation)**.
- Unger, D. and A. Dinges (2008). Forecast Consolidation for Seasonal Climate Outlooks. Intermountain West Climate Summary. Boulder, CO, Western Water Assessment. **4**: 3.
- Wolter, K. (2008). International Weather and Climate Events of 2007. American Meteorological Society Annual Meeting. New Orleans, LA. **(oral presentation)**: January 22, 2008.
- Woodhouse, C. A. (2008). Evidence of Climate Variability and Change from Tree-Ring Records. Geological Society of America Annual Meeting. Houston, TX.
- Woodhouse, C. A. and J. J. Lukas (2008). Paleohydrology Workshops for Water Resource Managers Using an Iterative Evaluation Process. American Geophysical Union Fall Meeting. San Francisco, CA. **GC33B-0770 (poster)**.
- Woudenberg, D. (2008). Low Flow Related Impacts in the Upper Colorado River Basin. Intermountain West Climate Summary. Boulder, CO, Western Water Assessment. **4**: 3.
- Xu, T., X. Quan, J. Eischeid, M. Hoerling and T. Zhang (2008). Diagnosis of Cause(s) for 2007 U.S. Precipitation Extremes. Intermountain West Climate Summary. Boulder, CO, Western Water Assessment. **4**: 2.



## Appendix V. Media Coverage

January 3, 2008: Summit Daily, "December was seventh snowiest on record in Summit"

<http://www.summitdaily.com/article/20080103/NEWS/75868480>

WWA contact(s) or projects: Klaus Wolter

January 7, 2008: Summit Daily News, "Get the powder while the getting is good"

<http://www.summitdaily.com/article/20080107/NEWS/769872828>

WWA contact(s) or projects: Klaus Wolter

January 7, 2008: Summit Daily, "Get the powder while the getting is good"

<http://www.summitdaily.com/article/20080107/NEWS/769872828>

WWA contact(s) or projects: Klaus Wolter

January 8, 2008: Craig Daily Press, "Regional snowpack below average"

[http://www.craigdaily.com/news/2008/jan/08/regional\\_snowpack\\_below\\_average/](http://www.craigdaily.com/news/2008/jan/08/regional_snowpack_below_average/)

WWA contact(s) or projects: Klaus Wolter

January 14, 2008: Rocky Mountain News, "Forecasters stick to dry winter call"

<http://www.rockymountainnews.com/news/2008/jan/14/forecasters-stick-to-dry-winter-call/>

WWA contact(s) or projects: Klaus Wolter

January 14, 2008: Salt Lake Tribune, "U. Professor Explores the Part Pollution Plays in Melting Snow"

[http://www.sltrib.com/ci\\_7964216](http://www.sltrib.com/ci_7964216)

WWA contact(s) or projects: T. Painter

January 14, 2008: Earth Times, "Meteorologists predict dry Colo. Winter"

<http://www.earthtimes.org/articles/show/173543.meteorologists-predict-dry-colo-winter.html>

WWA contact(s) or projects: Klaus Wolter

January 15, 2008: Daily Camera, "Wind season hits Eldora"

<http://www.dailycamera.com/news/2008/jan/15/eldora-among-windiest/>

WWA contact(s) or projects: Klaus Wolter

January 16, 2008: KSL-5, Salt Lake City, "The Grayest Snow on Earth"

WWA contact(s) or projects: T. Painter

January 17, 2008: KCPW, "Midday Metro"

<http://www.kcpw.org/article/5128>

WWA contact(s) or projects: T. Painter

January 21, 2008: Rocky Mountain News, "Don't fret: warmer days ahead"

<http://www.rockymountainnews.com/news/2008/jan/21/arctic-blast-puts-denver-deep-freeze/>

WWA contact(s) or projects: Klaus Wolter

January 21, 2008: USA Today, "Forecaster admits his dry forecasts were all wet"

[http://www.usatoday.com/weather/drought/2008-01-20-colo-snow\\_N.htm](http://www.usatoday.com/weather/drought/2008-01-20-colo-snow_N.htm)

WWA contact(s) or projects: Klaus Wolter

January 21, 2008: Rocky Mountain News, "Metro area to see high of 14 as arctic blast crosses state"

[http://ml.newsbank.com/nlsearch/we/Archives?p\\_product=RM&p\\_theme=rm&p\\_action=search&p\\_maxdocs=200&p\\_topdoc=1&p\\_text\\_direct-0=11E52A86036BF230&p\\_field\\_direct-0=document\\_id&p\\_perpage=10&p\\_sort=YMD\\_date:D&s\\_trackval=GooglePM](http://ml.newsbank.com/nlsearch/we/Archives?p_product=RM&p_theme=rm&p_action=search&p_maxdocs=200&p_topdoc=1&p_text_direct-0=11E52A86036BF230&p_field_direct-0=document_id&p_perpage=10&p_sort=YMD_date:D&s_trackval=GooglePM)

WWA contact(s) or projects: Klaus Wolter

January 22, 2008: Fox 21 News, "Colorado in good condition to battle drought"

[http://www.coloradoconnection.com/news/news\\_story.aspx?id=87400](http://www.coloradoconnection.com/news/news_story.aspx?id=87400)

WWA contact(s) or projects: Klaus Wolter

January 23, 2008: Denver Post, "New ice core to heat up research"

[http://www.denverpost.com/news/ci\\_8049043](http://www.denverpost.com/news/ci_8049043)

WWA contact(s) or projects: Brad Udall, Roger Pulwarty

January 27, 2008: Longmont Daily Times-Call, "Brrr ... It's cold out there"

WWA contact(s) or projects: Klaus Wolter

Feb. 2008: National Geographic, "Drying of the West"



<http://ngm.nationalgeographic.com/print/2008/02/drying-west/kunzig-text>

WWA contact(s) or projects: Connie Woodhouse and Jeff Lukas

February 1, 2008: Utilimetrics, "The Price is Right? For Water Conservation, It Better Be"

[https://www.utilimetrics.org/newsletter/index.cfm?fuseaction=Newsletter.showPrintVersion&Article\\_ID=549](https://www.utilimetrics.org/newsletter/index.cfm?fuseaction=Newsletter.showPrintVersion&Article_ID=549)

WWA contact(s) or projects: Chris Goemans/Aurora project

February 1, 2008: LA Times, "Water troubles in the West may worsen"

<http://www.latimes.com/news/local/la-sci-water1feb01.1.7686108.story?ctrack=1&cset=true>

WWA contact(s) or projects: Brad Udall

February 1, 2008: Seattle Times, "Shrinking snowpack a threat for West"

[http://seattletimes.nwsourc.com/html/nationworld/2004157490\\_warmwater01.html](http://seattletimes.nwsourc.com/html/nationworld/2004157490_warmwater01.html)

WWA contact(s) or projects: Brad Udall

February 1, 2008: Denver Post, "Snow's retreat could intensify water wars"

[http://www.denverpost.com/nationworld/ci\\_8134587](http://www.denverpost.com/nationworld/ci_8134587)

WWA contact(s) or projects: Brad Udall

February 6, 2008: cbs4denver.com, "Big snows boost state snowpack"

<http://cbs4denver.com/coloradowire/22.0.html?type=local&state=CO&category=n&filename=CO--BigSnow.xml>

WWA contact(s) or projects: Klaus Wolter

February 6, 2008: Denver Post, "Colorado snowpack best since '97"

[http://www.denverpost.com/technology/ci\\_8179371](http://www.denverpost.com/technology/ci_8179371)

WWA contact(s) or projects: Klaus Wolter

February 6, 2008: Denver Post, "Colorado snowpack best since '97"

[http://www.denverpost.com/kiszla/ci\\_8179371](http://www.denverpost.com/kiszla/ci_8179371)

WWA contact(s) or projects: Klaus Wolter

February 7, 2008: USA Today, "Big snows boost snowpack to best levels in 10 years"

[http://www.usatoday.com/weather/news/2008-02-06-colo-snow\\_N.htm](http://www.usatoday.com/weather/news/2008-02-06-colo-snow_N.htm)

WWA contact(s) or projects: Klaus Wolter

February 9, 2008: Charlotte Observer, "WESTERNERS HELP CAROLINAS' WATER TALKS"

[http://nl.newsbank.com/nlsearch/we/Archives?p\\_product=CO&s\\_site=charlotte&p\\_multi=CO&p\\_theme=realcities&p\\_action=search&p\\_maxdocs=200&p\\_topdoc=1&p\\_text\\_direct0=11EBAB145EC69210&p\\_field\\_direct0=document id&p\\_perpage=10&p\\_sort=YMD\\_date:D&s\\_trackval=GooglePM](http://nl.newsbank.com/nlsearch/we/Archives?p_product=CO&s_site=charlotte&p_multi=CO&p_theme=realcities&p_action=search&p_maxdocs=200&p_topdoc=1&p_text_direct0=11EBAB145EC69210&p_field_direct0=document id&p_perpage=10&p_sort=YMD_date:D&s_trackval=GooglePM)

WWA contact(s) or projects: Doug Kenney

February 10, 2008: Myrtle Beach Online, "Carolinas stuck in water wars"

<http://www.myrtlebeachonline.com/news/local/story/345237.html>

WWA contact(s) or projects: Doug Kenney

February 12, 2008: Boulder Daily Camera, "La Nina may herald an extreme spring for Boulder"

<http://dailycamera.com/news/2008/feb/12/lanina/>

WWA contact(s) or projects: Klaus Wolter

February 12, 2008: Daily Camera, "La Nina may herald an extreme spring for Boulder"

<http://www.dailycamera.com/news/2008/feb/12/lanina/>

WWA contact(s) or projects: Klaus Wolter

February 14, 2008: Denver Post, "Dry-winter forecasts miss mark"

[http://www.denverpost.com/lacrosse/ci\\_8256129](http://www.denverpost.com/lacrosse/ci_8256129)

WWA contact(s) or projects: Klaus Wolter

February 15, 2008: Daily Camera, "Colo. snowpack outlook rosy"

<http://www.dailycamera.com/news/2008/feb/15/snowpack-outlook-rosy/>

WWA contact(s) or projects: Klaus Wolter

March 5, 2008: Boston Globe, "Climate change, drought to strain Colorado River"

WWA contact(s) or projects: Connie Woodhouse

March 6, 2008: Tucson Weekly, "Fluid Situation"

<http://www.tucsonweekly.com/tucson/Currents/Content?oid=107534>

WWA contact(s) or projects: Brad Udall

March 6, 2008: Daily Camera, "February Weather Review"



<http://www.dailycamera.com/news/2008/mar/06/month-was-notable-for-its-normalcy/>  
WWA contact(s) or projects: Klaus Wolter

March 27, 2008: Fox News, "Warming Affects Trees, Streams in West"  
<http://www.foxnews.com/wires/2008Mar27/0,4670.WarmingWest,00.html>  
WWA contact(s) or projects: Brad Udall

March 28, 2008: San Francisco Chronicle, "EPA says it won't rush on emissions"  
<http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2008/03/28/MNVSVRK88.DTL>  
WWA contact(s) or projects: Brad Udall

March 28, 2008: Los Angeles Times, "Global warming felt more in Western U.S."  
<http://www.latimes.com/news/la-na-climate28-2008mar28.0,7769889.story>  
WWA contact(s) or projects: Brad Udall

March 28, 2008: Baltimore Sun, "Global warming felt more in Western U.S."  
<http://www.baltimoresun.com/features/lifestyle/green/la-na-climate28-2008mar28.0,449707.story>  
WWA contact(s) or projects: Brad Udall

April 8, 2008: Denver Post, "Nitrogen affecting Rocky Mtn. park?"  
[http://www.denverpost.com/headlines/ci\\_8846427](http://www.denverpost.com/headlines/ci_8846427)  
WWA contact(s) or projects: Klaus Wolter

April 20, 2008: Arizona Star, "Preview: Is global warming behind region's drought"  
<http://www.azstarnet.com/sn/hourlyupdate/235244.php>  
WWA contact(s) or projects: Connie Woodhouse

April 20, 2008: 7 News, "Cooler Weather Sinks South Into Colorado"  
<http://www.thedenverchannel.com/news/15937833/detail.html>  
WWA contact(s) or projects: Klaus Wolter

April 26, 2008: Sign on San Diego, "Drought could mean climate change"  
<http://www.signonsandiego.com/news/state/20080426-1241-wst-southwestdrought.html>  
WWA contact(s) or projects: Connie Woodhouse

April 27, 2008: Capital Press, "Southwest drought could be cyclical or climate change"  
<http://www.capitalpress.info/main.asp?SectionID=94&SubSectionID=801&ArticleID=41187&TM=60553.41>  
WWA contact(s) or projects: Connie Woodhouse

May 2, 2008: Summit Daily News, "Still Snowing"  
<http://www.summitdaily.com/article/20080502/NEWS/571241595>  
WWA contact(s) or projects: Klaus Wolter

May 22, 2008: Telluride News, "Water everywhere, not enough to drink"  
<http://www.telluridenews.com/news/x1946830630/Water-everywhere-not-enough-to-drink/>  
WWA contact(s) or projects: Brad Udall

May 30, 2008: Albuquerque Journal, "Climate Experts: Adapting Is Key"  
WWA contact(s) or projects: Brad Udall

July 2, 2008: Torrington Telegram, "Water, wildlife and energy issues on tap for Western governors"  
[http://www.torringtontelegram.com/V2\\_news\\_articles.php?heading=0&page=&story\\_id=2041](http://www.torringtontelegram.com/V2_news_articles.php?heading=0&page=&story_id=2041)  
WWA contact(s) or projects: Brad Udall

July 1, 2008: Salt Lake Tribune, "Warming underlies the West's key woes"  
[http://nl.newsbank.com/nlsearch/we/Archives?p\\_product=SLTB&p\\_theme=sltb&p\\_action=search&p\\_maxdocs=200&p\\_topdoc=1&p\\_text\\_direct-0=121A83B14D9E4460&p\\_field\\_direct-0=document\\_id&p\\_perpage=10&p\\_sort=YMD\\_date:D&s\\_trackval=GooglePM](http://nl.newsbank.com/nlsearch/we/Archives?p_product=SLTB&p_theme=sltb&p_action=search&p_maxdocs=200&p_topdoc=1&p_text_direct-0=121A83B14D9E4460&p_field_direct-0=document_id&p_perpage=10&p_sort=YMD_date:D&s_trackval=GooglePM)  
WWA contact(s) or projects: Brad Udall

July 1, 2008: Casper Star-Tribune, "Govs hear water warning"  
<http://www.trib.com/articles/2008/07/01/news/wyoming/2b6cb5cb311eb5d3872574780083afc6.txt>  
WWA contact(s) or projects: Brad Udall

July 5, 2008: Vail Daily, "Reservoirs only part of solution"  
<http://www.vaildaily.com/article/20080705/NEWS/323641951/1078&ParentProfile=1062>  
WWA contact(s) or projects: Brad Udall

July 7, 2008: Salt Lake Tribune, "Western govts to mull ways to cut pollution, slow warming, boost energy"



WWA contact(s) or projects: Brad Udall

July 28, 2008: The Hindu, "What's happening to the monsoon?"  
<http://www.hindu.com/2008/07/28/stories/2008072850461100.htm>  
WWA contact(s) or projects: Balaji Rajagopalan

August 14, 2008: The National Newspaper, "West bracing for day the wells run dry"  
<http://www.thenational.ae/article/20080814/FOREIGN/840121667/1014/NEWS&Profile=1014>  
WWA contact(s) or projects: Brad Udall

August 29, 2008: Arizona Capitol Times, "Water washes away Dems' united front"  
<http://www.azcapitoltimes.com/story.cfm?id=9369>  
WWA contact(s) or projects: Brad Udall

October 6, 2008: Rocky Mountain News, "Report: Warming will shrink Colorado's water supply"  
<http://www.rockymountainnews.com/news/2008/oct/06/report-warming-will-shrink-colorados-water-supply/>  
WWA contact(s) or projects: Brad Udall

October 9, 2008: Rocky Mountain News, "State water demand may boil over"  
<http://www.rockymountainnews.com/news/2008/oct/09/state-water-demand-may-boil-over/>  
WWA contact(s) or projects: Brad Udall, Joe Barsugli

October 12, 2008: TMCNews, "Cities learn to conserve water"  
<http://www.tmcnet.com/usubmit/2008/10/12/3698166.htm>  
WWA contact(s) or projects: Doug Kenney

October 18, 2008: Cortez Journal, Durango Herald, "Averyt will discuss climate change"  
<http://www.cortezjournal.com/main.asp?SectionID=1&SubSectionID=1&ArticleID=2617&TM=50590.13>  
WWA contact(s) or projects: Kristen Averyt/Colorado Climate Change Report

October 23, 2008: KDUR 91.9 FM, "Making Waves: Radio Interview"  
<http://www.kdur.org/making%20waves.html>  
WWA contact(s) or projects: Kristen Averyt

November 5, 2008: Daily Camera, "Autumn redux: This year similar to last"  
<http://www.dailycamera.com/news/2008/nov/05/winter-deja-vu/>  
WWA contact(s) or projects: Klaus Wolter

November 18, 2008: Rocky Mountain News, "Chilly weather expected to follow record-setting high"  
<http://www.rockymountainnews.com/news/2008/nov/18/record-heat-today-freezing-drizzle-tomorrow/>  
WWA contact(s) or projects: Klaus Wolter

November 20, 2008: USA Today, "Forecaster says La Nina will bring good snowfall to Colo."  
[http://www.usatoday.com/weather/news/2008-11-20-la-nina-colorado-snow\\_N.htm](http://www.usatoday.com/weather/news/2008-11-20-la-nina-colorado-snow_N.htm)  
WWA contact(s) or projects: Klaus Wolter

November 22, 2008: San Francisco Chronicle, "Experts fear 3rd straight dry winter likely"  
<http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2008/11/21/BAV8149Q32.DTL&tsp=1>  
WWA contact(s) or projects: Klaus Wolter

December 1, 2008: Sacramento Bee, "Normal rainfall predicted for north state this winter"  
<http://www.sacbee.com/ourregion/story/1438420.html>  
WWA contact(s) or projects: Klaus Wolter

December 4, 2008: USA Today, "Climate change, drought to strain Colorado River"  
[http://www.usatoday.com/tech/science/environment/2008-12-05-colorado-river-drought\\_N.htm](http://www.usatoday.com/tech/science/environment/2008-12-05-colorado-river-drought_N.htm)  
WWA contact(s) or projects: Connie Woodhouse and Jeff Lukas

December 4, 2008: Denver Post, "More conflict expected over Colorado River"  
[http://www.denverpost.com/ci\\_11138821](http://www.denverpost.com/ci_11138821)  
WWA contact(s) or projects: Brad Udall, Connie Woodhouse

December 5, 2008: Salon.com, "Climate change, drought to strain Colorado River"  
[www.salon.com/wires/ap/scitech/2008/12/05/D94SFF6G0\\_colorado\\_river/index.html](http://www.salon.com/wires/ap/scitech/2008/12/05/D94SFF6G0_colorado_river/index.html)  
WWA contact(s) or projects: Brad Udall

Winter 2008: WaterWise, "Aurora Study Pinpoints Best Conservation Measures"  
<http://coloradowaterwise.org/waterwisewinter08.pdf>  
WWA contact(s) or projects: Chris Goemans/Aurora project