2009 Annual Report of the Western Water Assessment

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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, the WWA has focused on building relationships and networks with water-resource decision-makers, and has 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.

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.

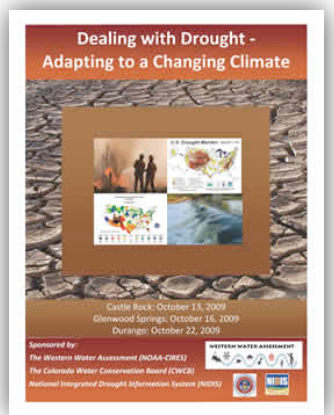
In 2008, WWA reviewed its research scope through interactions with stakeholders, our advisory board, and federal partners. As a result, WWA formed three focused research themes. Beginning in 2009, the WWA refocused its research and decision-support products; all WWA projects fall within three major thematic categories: (1) Decision Support for the Colorado River Basin and Headwaters; (2) Ecological Vulnerabilities, Impacts, and Adaptation, and (3) Emerging Initiatives and Adaptation Strategies to Inform Climate Services. Although individual projects are aligned within specific themes for management purposes, there is significant overlap between and among projects within these themes. The core management team is responsible for identifying and coordinating these cross-cutting projects.

Activities within each theme for the July 1 2009–June 30 2010 year were selected through an internal competition and are outlined in the Statement of Work submitted last year to NOAA. This Annual Report covers all work funded by WWA and activities of our core research team during the 2009 calendar year (January 1 2009 to December 31 2009). As such, many of the proposed activities here are not yet complete as several months remain in the funding period.

Major Highlights from 2009

As in the past, 2009 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.

"Dealing with Drought: Adapting to a Changing Climate" Workshop Series



In conjunction with the Colorado Water Conservation Board (CWCB), WWA presented the "Dealing with Drought–Adapting to a Changing Climate" workshop series during October 2009 in three locations around Colorado: Castle Rock, Glenwood Springs, and Durango. These workshops built on themes and information from both the WWA-CWCB *Climate Change in Colorado* report (2008) and the October 2008 Colorado Governor's Conference on Managing Drought and Climate Risk. The WWA, CWCB, and the

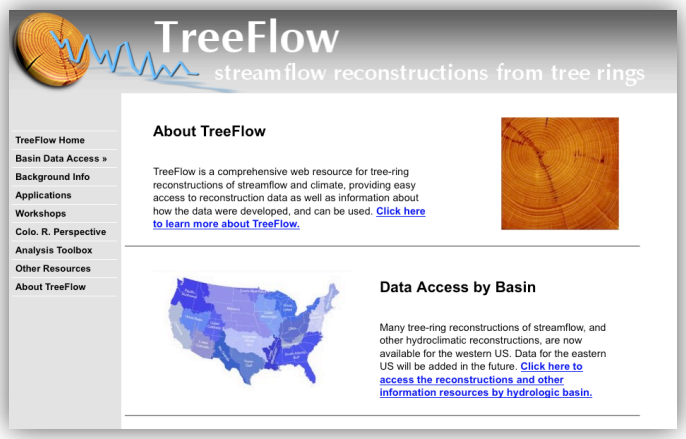
National Integrated Drought Information System (NIDIS), along with the Colorado State University Colorado Climate Center (CCC) and the Mountain Studies Institute sponsored this series of workshops. The 80 participants represented diverse sectors and interests affected by drought and climate, including water resource management, agriculture, land-use planning, forest & range management, watershed protection, environmental organizations, and tourism & recreation. Collectively, the participants' decision-making affects natural resources in every river basin in Colorado.

The primary objectives of these workshops were to improve the climate literacy of the participants, provide input into the ongoing update of the state Drought plan, document participants' understanding of climate change in Colorado, and address concerns and questions among this group of stakeholders about climate change. The workshop objectives were achieved through pre- and post-workshop evaluations, instructional presentations, breakout discussions, and the distribution of climate and drought information in printed form.

The details of our observations and results of the evaluations are discussed further in a white paper available on the WWA website (workshop report). The full set of presentations and materials provided at the workshops are available at http://wwa.colorado.edu/climate_change/drought09.html.

TreeFlow (http://treeflow.info): A Resource for Paleohydrologic Data

Paleohydrologic data and information from tree rings are increasingly recognized as a valuable tool for drought planning and water resources management. The recent severe and prolonged drought and a growing awareness of the regional impacts of global climate change, coupled with an increased in demand for water that far exceeds demands during the 1950s drought, have made water managers in the western U.S. realize the need for new tools for drought planning and water management. The development of high-quality tree-ring based reconstructions of streamflow for a growing number of western rivers has coincided with this realization. Information from the paleo record combined with future projections may yield the most likely range of future scenarios for planning purposes. To meet the growing demand by resource managers for a clearinghouse of such information, WWA, in collaboration with researchers from the Climate Assessment for the Southwest (CLIMAS), developed a web portal to access paleo records.



The new, expanded TreeFlow web resource (http://treeflow.info) went live for review in late June 2009 and was publicly announced to stakeholders in September 2009. The top-level sections of the site include: (1) basin-based access to paleohydrology data for over 60 gages across the western US; (2) background information on tree-ring data and how the streamflow reconstructions are developed; (3) descriptions of several current applications of the data to water management; (4) agendas, presentations, and reports from 13 tree-ring workshops from 2006 to 2009; and (5) a multi-page feature, Colorado River Streamflow: A Paleo Perspective. The site also includes a fully text-annotated PowerPoint presentation describing the generation of paleohydrology data and their use in water resource management (http://treeflow.info/docs/treeflow_reconstructions&applications_annotated.ppt).

Ecosystem Management: Network Expansion

In 2009, WWA initiated the Ecological Vulnerabilities, Impacts, and Adaptation research theme. Through three new research projects within that theme, WWA gained visibility and credibility with ecosystem stakeholders, expanding WWA's overall stakeholder network, and laid the groundwork for future collaborative research on climate-ecosystem vulnerabilities.

The "Forests, Climate, and Change" project entailed significant outreach to stakeholders and scientists that allowed WWA to assess its appropriate role in aiding decision-makers facing the climate-driven mountain pine beetle (MPB) epidemic in Colorado and southern Wyoming. Project accomplishments in 2009 included hosting a science-stakeholder meeting to facilitate connections, convey the state of the science on MPB impacts, and identify opportunities for co-producing decision-support information. Key ecosystem stakeholders in the region that participated in the meeting included the U.S. Forest Service, Bureau of Land Management, Boulder County Parks and Open Space, Our Future Summit, and the office of U.S. Sen. Mark Udall.

Two other WWA projects engaged directly with federal ecosystem management agencies to address climate vulnerabilities specific to their resources. For the project, "Effects of Mountain Pine Beetle on Water Quality in Colorado", WWA worked with the National Park Service to assess water quality at 200 sites within and around Rocky Mountain National Park. These efforts focused on detecting changes in nutrient loads and evidence of pesticide use in mountain streams. For "Climate Change Impacts on Public Lands in the Upper Colorado River Basin", WWA worked in collaboration with the Bureau of Land Management to examine climate vulnerability and resilience in pinyon-juniper woodlands of southwestern Colorado. The results indicate that soil type may be a significant driver of landscape response to drought in that particular region.

Project Summaries

The project summaries in Table 1, 2 & 3 provide a brief overview of specific research projects funded in 2009.

Decision Support for the Colorado River Basin and Headwaters

Table 1.

Project Title:	**Stochastic Streamflow Simulation at Interannual and Interdecadal Time Scales and Implications to Water Resources Management in the Colorado River Basin**
Primary Investigator(s):	E. Zagona, R. Balaji
Contributors:	K. Nowak, C. Bracken, C. Jerla, R. Callejo, J. Prairie
Core Funding:	WWA, USBR, CADSWES *FUNDING 2009: JAN–DEC*
Summary:	The US Bureau of Reclamation wishes to better understand the climate drivers to streamflow variability as a tool for better water management. There is increasing evidence that the interannual (year-to-year) variations in the western US hydro-climate are driven by large-scale climate features such as ENSO, PDO, AMO, etc. and that the current record dry spell could be a result of cooler than normal tropical Eastern Pacific and warmer than normal tropical Western Pacific (a La Nina pattern) and Indian Oceans. Recent studies suggest that the annual cycle in precipitation is shifting earlier in the western US, perhaps caused by global climate change. There is the potential for substantial reduction in stream flow in coming decades due to climate change, which will have a significant impact on the water resources in the basin and also on the socioeconomic health of the western US. To manage the water resources efficiently, realistic scenarios of streamflows at short (interannual) and long (interdecadal) time scales are crucial. This research will improve techniques for both seasonal forecasting and long-term

projections as well as investigate adaptation strategies for reservoir management.

Proposed Work:

The project will accomplish these via the following tasks:

Develop methods for projecting streamflows at interdecadal time scales based on (i) historical record, (ii) paleo data and (iii) climate change projections using frequency analysis and global climate variables.

Apply these projections to evaluate the robustness of current operating policies as expressed in the CRSS basin water planning model, including the new shortage policies recently agreed to, with respect to hydrologic variability reflected in historic flows, the paleo record, and climate change projections. Explore what policy options are available to mitigate impacts of potential adverse flow scenarios within the interim guidelines through 2026 and with new policy alternatives thereafter.

Develop a set of predictors for spring flow volume/shape in Upper Basin by identifying relationships between seasonal streamflows and large-scale climate variables (global sea surface temperatures, sea level pressures, winds features, etc.) using nonparametric multi-model regression techniques, previously successfully applied in other basins.

Develop a probabilistic midterm operations model that incorporates current operating policies. This will be done in collaboration with the Reclamation Colorado River Technical Modeling Team and river system operations. This model will eventually be used as part of Reclamation's business processes for seasonal forecasts with stakeholders.

The midterm operations model will be used to determine skills in the system operating variables and potential alternative (adaptive) policies will be identified that can improve system efficiency. The proposed policies will be tested with the historic hydrology.

Progress/Results:

Interannual Scale

The use of natural flow forecasts in the probabilistic midterm model is a long-term goal for the interannual component of this project. These values will eventually be obtained from the River Forecast Center. In an effort to lay some groundwork in this area C. Bracken performed a comprehensive analysis of Reclamations and the RFC's natural flows. This analysis led to a meeting with the RFC after which we have a much better understanding of magnitude of such an effort and what must be done in the near future to move forward with the PMM.

Bracken spent time becoming familiar with using RiverWare and current RiverWare models (particularly the 24 Month Study). These skills were used to write the first set of operational rules (and accompanying documentation) in the PMM for the Fontenelle Reservoir. These rules were developed in collaboration with Reclamation operator K. Grantz. A similar methodology will be applied to the remaining 24 Month Study reservoirs. Work is currently underway on the Flaming Gorge Reservoir.

In addition, Bracken reversed the rule order in the Expanded 24 Month Study model. The original rule ordering (1,2,3,…) had persisted for legacy reasons. The updated ordering (…,3,2,1) will facilitate the development of new rule sets in the PMM.

Interdecadal Scale

We have developed a method that directly simulates daily data at multiple locations from a single annual flow value via K-NN resampling of daily flow proportion vectors. The procedure is simple, data driven and captures observed statistics quite well. Furthermore, the generated daily data are continuous and display lag correlation structure consistent with that of the observed data. In addition, the method is compatible with any streamflow generation technique (e.g. AR-1, K-NN, ISM, etc.) and is not limited to a specific timescale (results were very good for monthly and seasonal disaggregation in addition to daily). Presently, we have resubmitted the manuscript entitled "A Non-parametric Stochastic Approach for Multisite Disaggregation of Annual to Daily Streamflow" to Water Resources Research after responding to reviewer comments.

In the realm of stochastic simulation, we have continued working with the wavelet framework of Kwon et al. (2007) with application to the entire upper Colorado River Basin by disaggregating the simulated flows using the aforementioned disaggregation method. We find that this approach can capture the spectral properties of data at the multiple sites along with the distributional properties (such as mean, variance, Probability Density Functions etc.). Consequently, the drought and surplus statistics are very well captured.

Furthermore, we have used similar wavelet methods to analyze the dominant variance peaks from paleo-reconstructed streamflow data in order to better understand longer-term variability. These results show that the strength of persistent modes of variability can oscillate with time. One example is decadal-scale variability, which has been quite strong in recent years but was subdued in the early 1900's. As such, we have further modified the method of Kwon et al. (2007) to capture the nonstationarity of variance strength in the simulated traces.

As a compliment to the wavelet-based analysis and simulation, we have also conducted a Principal Component Analysis (PCA) of the natural flow record for all 29 locations in the Colorado River Basin. This will aid in identifying large-scale drivers of variance throughout the Basin. The leading 2 principal components (PCs) explain nearly 85 % of the total variance. We have shown that all locations are related to PC1 similarly, while PC2 is divided roughly into the upper and lower basins. As such, we hypothesize that PC1 is likely tied to continent scale circulation, which affects the entire basin, while PC2 may be linked to a phenomena such as ENSO, where the

	impact is more regional and is dependant on the climatic mode.
Presentations:	On November 19, 2009, Ken Nowak attended the Colorado River Forecasting Service's Fall Technical Meeting at NOAA's Salt Lake City river forecast center and gave a presentation entitled, "Water Supply Risk on the Colorado River: Can Management Mitigate?" On October 5, 2009, Ken Nowak gave a presentation, entitled "Research Update," at the Colorado River Hydrology Work Group meeting held at CADSWES in Boulder, CO. On December 2, 2009, Cameron Bracken gave a presentation at the Salt Lake City River Forecast Center entitled "A Multi-Site Seasonal Ensemble Streamflow Forecasting Technique." On October 5, 2009, Cameron Bracken gave a presentation to the Colorado River Hydrology Working Group meeting at CADSWES in Boulder, CO
Publications:	Bracken, C., B. Rajagopalan, and J. Prairie, A Multi-Site Seasonal Ensemble Streamflow Forecasting Technique, Water Resour. Res., doi:10.1029/2009WR007965, in press. (Accepted 2 November 2009)
Partners/Stakeholders	USBR

Project Title:	**Historical and Potential Future Changes in Temporal Precipitation Variability in the Colorado River Basin**
Primary Investigator(s):	G. Guentchev
Contributors:	J. Eischeid, J. Barsugli, D. Raff, L. Brekke
Core Funding:	UCAR, CLIVAR, CPAPP, USBR, SNWA, WWA *FUNDING 2009: JAN–DEC*
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.
Proposed Work:	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.
Progress/Results:	The statistical significance of the Model minus Observed precipitation variability measures (assessed using a "moving" block bootstrapping approach; Wilks 1997) for the historical 1951-1999 period was completed and the results were presented at a poster session at the AGU Fall meeting in San Francisco and also at the Colorado River Hydrology Group meeting on October 5th, 2009 at CADSWES Boulder CO. In addition, the majority of the work regarding the statistical significance of the Future Model minus Historical Model precipitation variability differences was completed during these 6 months. Three periods of interest are used for the future changes: 2001-2049, 2026-2074 and 2051-2099. Two sets of downscaled GCM data for 30 projections (downscaled by Brekke et al. 2007, and by Jon Eischeid) and 3 SRES scenarios (A2, B1 and A1b) are utilized in these future period comparisons.
Presentations:	Guentchev, G., Barsugli, J. Eischeid, J., Raff, D., and Brekke, L. "How well do the GCMs replicate the historical precipitation variability in the Colorado River Basin?", December 14th, 2009, San Francisco, AGU Fall meeting, poster session. Guetchenev, G. (October 2009) "Statistical significance of the model-observed differences in precipitation variability for the historical 1951-1999 period", October 5-6, 2009, Colorado River Hydrology Group meeting, Boulder, CO.
Partners/Stakeholders	USBR, SNWA

Project Title:	**Identifying Lessons from the Murray-Darling Basin Potentially Applicable to the Colorado River**
Primary Investigator(s):	D. Kenney
Contributors:	R. Pulwarty
Core Funding:	WWA, NIDIS *FUNDING 20009: JULY–DEC*
Summary:	As climatic and hydrologic information regarding the Colorado River continues to improve, it becomes increasingly apparent that the current institutional structure in the basin constrains decision-makers in how they use this new information and how they can adapt to the challenges of climate variability and change. In the spirit of identifying potential "new institutional pathways," the Murray-Darling Basin (MDB) (Australia) experience may provide insightful to decision-makers in the Colorado Basin, as several fundamental components of the institutional environment in the MDB have been successfully modified over time, most recently driven by the need to adapt to a "climate shift" and a desire to implement more sustainable patterns of water management.
Proposed Work:	Several elements of the MDB institutional environment are potentially relevant as a basis for comparison and insight, including: the use of basinwide planning processes and/or river basin commissions; the relationship between States and the national (federal) government (especially as it involves decisions about interstate allocation); the specification of water rights/entitlements among users, sectors, and jurisdictions (including indigenous/native communities) at both the interstate and sub-state scale; the use (and limits) of markets for water reallocation; the mechanisms used to ensure adequate flows for environmental purposes; the role of the government is supporting/shaping the role of the agricultural sector (both historically and looking forward); and the roles of key climate information providers. In this project, these elements of the MDB institution will be reviewed and compared to the Colorado River Basin, with the aim of identifying transferrable lessons.
Progress/Results:	Research to date has primarily focused on the relationship between the basin plan (and related elements of Australia's new Water Act) to the evolving structure of state-federal relations in that country. It is this element of Australia's reforms that may ultimately be most salient to the Colorado River, as a persistent challenge in the Colorado is the promotion of real basin-wide planning and action within a framework of state-centric water allocations/rights. This issue has been investigated through literature, interviews (including a visit to Boulder by Daniel Connell organized by partners at The Nature Conservancy), ongoing consultations with the Assistant Director of the Murray-Darling Basin Authority, and by attendance at a meeting at Northern Arizona University in July entitled: "Watershed Management and Policy Development: Learning from Australia." Ultimately, the goal of this project is to use the sweeping reforms in the Murray-Darling Basin as a mechanism for stimulating and broadening discussions about the prospects for institutional reform and climate change adaptation in the Colorado River Basin. This is now occurring, as evidenced by the successful efforts of the WWA and the NRLC (Natural Resources Law Center) to secure funding from the Walton Family Foundation to support a Colorado River Governance Initiative, which is now examining a suite of possible institutional reforms on the river. The Murray-Darling case is one of the featured reform options under consideration.
Partners/Stakeholders	NIDIS

Project Title:	**Reconciling Colorado River Flow Projections**
Primary Investigator(s):	D. Cayan, T. Das, D. Lettenmaier, J. Overpeck, H. Hartmann, R. Webb, M. Hoerling, B. Udall
Contributors:	J. Barsugli, J. Eischeid
Core Funding:	NOAA CPO Cross-RISA *FUNDING 2009: JAN–DEC*
Summary:	Milly et al. (2008) argue that stationarity, a concept that is at the heart of most water resources operations and planning methods, "is dead". The implicit assumption associated with stationarity is that the past is a reasonable representation of the future (at least in a statistical sense), and therefore risks of unfavorable outcomes (e.g., inability to meet demands for water) can be estimated by methods that resample from past observations, e.g., of climate and/or streamflow. Variations of such approaches have been widely used in water planning studies for the Colorado River basin. On the other hand, recent papers by Seager et al. (2007), Christensen and Lettenmaier (2007), and Milly et al. (2005) (hereafter S2007; CL 2007; and M2005, respectively) have suggested that substantial changes in runoff may occur over the next century in the Colorado River Basin. However, the range of estimated impacts on Colorado River discharge (all based on IPCC 2007 model runs) is large – from a low at 2050 of about 6% in CL2007, to over 18% in S2007. Not surprisingly, the region's water managers view with great concern the potential for large changes in the flow of the Colorado River. Of even greater concern, though, has

	been the wide range of projections – as large as 45% in Hoerling and Eischeid (2007) by mid century. to 1901-1970, interpolated to USGS water resources regions. Results are replotted from M2005; taken from Backlund et al (2008).
Proposed Work:	Evaluate alternative data sets; extend to current year and quality control. Diagnose reasons for differences in temperature sensitivities among models. Reconciliation of climate scenarios. Evaluate Colorado River discharge sensitivities from NARCCAP runs. Continued diagnosis of the role of high elevation feedback on projected future sensitivities. Preliminary analysis of AR5 GCM scenarios. (See original proposal for additional details.)
Progress/Results:	Although several papers directly related to this work have been published this year, the final steps of work on this project have not yet been completed. Completion is expected in the coming six months and results will be reported in subsequent years.
Deliverables:	Stakeholder Meeting Technical and stakeholder papers
Publications:	Barsugli, J., K. Nowak, et al. (2009). Comment on 'When Will Lake Mead Go Dry?' Water Resources Research 45(W09601). Rajagopalan, B., K. Nowak, J. Prairie, M. Hoerling, B. Harding, J. Barsugli, A. Ray, and B. Udall (2009), Water supply risk on the Colorado River: Can management mitigate?, Water Resour. Res., 45, W08201, doi:10.1029/2008WR007652.
Partners/Stakeholders	In addition the participating RISA groups, the project includes representatives from OI/USBR&USGS, USDA/NRCS, NOAA/GFDL, Seven Basin States, WGA, and NOAA/CPO/CDEP funded ARCs. Stakeholders include a water managers from the Bureau of Reclamation (Powell, Mead) and State governments of Utah, Wyoming, and Colorado, urban/local water supply managers (Denver, Salt Lake City, Northern Colorado Water Conservancy District), and ecosystems/environmental/recreational resource managers (Forest Service, EPA, NPS, USGS/BRD, NGOs).

Project Title:	**Colorado River inflows between Lakes Mead and Powell: Past, Present and Future**
Primary Investigator(s):	J. Barsugli
Core Funding:	WWA *FUNDING 2009: JULY–DEC*
Summary:	It is estimated that over 800,000 acre-feet a year of water flows into the Colorado River between Glen Canyon Dam and Hoover Dam. These flows are not nearly as well known as the flow at Lees Ferry. For example, in writing our critique of Barnett and Pierce's "When Will Lake Mead Go Dry?", we discovered that they completely ignored these inflows in their water balance calculations. Even for those who are aware of these flows, their magnitude can be in dispute. A referee of our manuscript called into question our estimate, citing public information available on the Web. Due to increasing demand and potentially decreasing headwaters flows, these flows can "make or break" the water budget of the Lower Colorado. In contrast to the Colorado Headwaters, climate models show consistent drying in this region, so these flows may be particularly vulnerable to climate change. Others are interested in these flows for a number of reasons. The CBRFC (Greg Smith) has independently investigated is working with Reclamation to reconcile their modeling assumptions on this stretch of the river. The USGS (Ted Melis) is also interested in sharing information on these flows.
Proposed Work:	I propose to coordinate a workshop that focuses on the water supply aspect of these flows and that brings together scientists working on this issue with the goal of reconciling the data and modeling assumptions used to estimate the historic flows, and to discuss the potential for climate change impacts. The goal of the workshop is to lead to a publication that summarizes the state of knowledge on these flows so that this information. In addition to coordinating, I would like to research the relation of historical climate variability to the observed flows. This seems like something we could nail down fairly quickly – at least the present state of the data and modeling assumptions.
Progress/Results:	Work on this project was delayed due to emerging high-priority activities requiring J. Barsugli's involvement. This

	project will proceed in 2010 under a no-cost extension and results will be reported in subsequent years.
Partners/Stakeholders	USBR

Project Title:	**Impacts of coupled climate change and dust deposition on water resources in the Colorado River Basin**
Primary Investigator(s):	T. Painter, J. Deems
Core Funding:	WWA, NSIDC *FUNDING 2009: JULY–DEC*
Summary:	Recent results have shown that desert dust deposition on mountain snowpack in the Colorado River Basin (CRB) shortens snow cover duration by approximately one month through its enhancement of absorbed solar radiation (Painter et al., 2007). From analysis of dust loading in lake sediments in the mountains of the CRB (Neff et al., 2008; Reynolds et al., 2009), we know that the sustained disturbance of previously stable lands in the Colorado Plateau and Great Basin that began in the latter half of the 1800s has led to a 5-fold increase in dust deposition over that of the previous 5000 years. Based on this evidence, we hypothesize that the accelerated melt associated with this dramatic increase in dust deposition has affected the basin hydrograph and ultimately decreased yield by increasing evapotranspiration and decreasing soil moisture. Our initial modeling indicates that the increased dust loading (represented by a modified snow albedo parameterization) has markedly modified the hydrograph and decreased annual water yield in the upper basin (above Lee Ferry, AZ) by an average of 5% or 0.8 MAF since significant dust deposition began (Painter et al., 2009a), with a total loss of yield of 70 MAF across 1915-2003. Several studies have shown decreasing trends in peak snow accumulation in the CRB over the past century (e.g. Hamlet et al., 2005; Barnett et al., 2008), and projections of future climate scenarios point to decreases in streamflow due to atmospheric warming and decreases in precipitation (Christensen et al., 2004; 2007). Climate warming has also been projected to increase the frequency and severity of drought, to increase interannual precipitation variability, and to increase the areal expanse of desert regions. These responses should increase the frequency and magnitude of dust emission from deserts in the southwest US under continued levels of soil disturbance. It is likely that the impacts of a warming climate on snow accumulation, snowmelt, and CRB water yield will be strongly enhanced by increased dust emission and deposition on mountain snowpacks. By contrast, modified land management practices in desert systems of the Colorado Plateau and Great Basin may provide a means to increase water yield or mitigate losses.
Proposed Work:	We propose to examine the range of changes to water yield in the upper CRB by coupling potential climate change scenarios and dust deposition scenarios. The Variable Infiltration Capacity (VIC) macroscale hydrologic model will be used to simulate the snow cover and melt across the basin, and the naturalized hydrograph and annual CRB water yield at various gages in the CRB culminating at Lee Ferry, AZ, for the historic period of 1915-2008, and for three future time periods: 2010-2039, 2040-2069, and 2070-2100. In year 1, we will assess how PDL and EDL dust scenarios modify the water balance and yield relative to the ADL across the historical period of 1915-2008. We will also intensively study the period 2000 – 2008 as this coincides with the NASA EOS Terra satellite record during which we have data from the Moderate Resolution Imaging Spectroradiometer with which to infer radiative forcing and directly assess radiative forcings by dust represented by VIC. In order to perform this assessment, we will compare the spatially distributed radiative forcings by dust in snow from VIC (intermediate products) with radiative forcings in snow inferred from the MODIS Dust Radiative Forcing in Snow (MOD-DRFS) model (Figure 2), developed by PI Painter (Painter, 2009b).
Progress/Results:	Initial VIC model set-up in progress. Collaboration established with UW researchers for ensuring VIC model version and driving data coherence with ongoing “Reconciling Projections of Future Colorado River Stream Flow” project. Submission of paper to Proceedings of the National Academy of Sciences. Complete installation of full energy balance and radiation tower at Grand Mesa. This establishes the 3rd tower in the growing Western Energy Balance over Snow (WEBS) network that is operated by PI Painter with Chris Landry, Center for Snow and Avalanche Studies (CSAS). Myriad invited talks including headlining Annual Meeting of the Colorado River Water Conservancy District, press release at NASA Symposium for Earth System Science at 20 years, and presentation of results to Anne Castle, Assistant Secretary of Interior for Water and Power. Complete processing of energy balance and snowmelt model data for Senator Beck Study Plot and Swamp Angel Study Plot, Senator Beck Basin Study Area for 2004-2009. Generalized tools are now established for easier processing of data for 2010 and beyond and for the Grand Mesa Study Plot. Processing of these data provide constraints for the VIC modeling described in the proposed work.
Presentations:	Painter: Guy F. Atkinson Distinguished Lecture Series, Department of Geology and Geophysics, University of Utah, *Where Deserts and Mountains Collide: the Implications of Accelerated Snowmelt by Desert Dust*, May 2009. Painter: NASA Earth System Science at 20 years Symposium, Where Mountains and Deserts Collide: Implications

	of Accelerated Snowmelt by Disturbed Desert Dust, National Academy of Sciences, Washington, DC, June 2009. Painter: When Deserts and Mountains Collide: The Impact of Desert Dust on Snowmelt Hydrology in the Colorado River Basin, Jet Propulsion Laboratory Science Visitor and Colloquium Program, Pasadena, CA, August 2009. Painter, Belnap: *What's the Dirty Secret of Dirty Snow?* Annual meeting of the Colorado River Water Conservancy District, Grand Junction, CO, September 2009. Painter, Belnap, Udall: *Impact of Desert Dust on Snowmelt Resources in the Colorado River Basin,* Briefing to Anne Castle, Assistant Secretary of the Interior for Water and Science, and many others. Department of Interior, Washington, DC, October 2009. Painter: Briefings of congressional staffers, US House Subcommittee on Water and Power + US Senate Subcommittee Energy and Water Resources + Senator Mark Udall (CO), *Impact of Desert Dust on Snowmelt Resources in the Colorado River Basin*, Washington DC, October 2009. Painter: *Dirty Little Secrets of the Greatest Snow on Earth*, Green Month Sustainability Lecture Series at Park City, sponsored by Swaner and the University of Utah Office of Sustainability, (with Peter Metcalf and Jim Steenburgh), October 2009. Deems and Painter: *Desert Dust Impacts on Colorado River Basin Snowpack and Runoff* Emerging Issues in Climate Change - UNEP Expert Workshop, New Delhi, India, December 2009 Deems: *Dust on Snow: Early Snowmelt in the Colorado River Basin*, Aspen Center for Environmental Studies, Naturalist Nights Lecture Series, February 2010 Painter: University of Utah Office of Sustainability, *Dirty Little Secrets of the Greatest Snow on Earth* (with Jim Steenburgh), University of Utah, February 2010. Painter: Alta Environmental Center, *Dirty Little Secrets of the Greatest Snow on Earth* (with Jim Steenburgh), Alta, Utah, February 2010. Painter, et al.: *Water yield loss in the Upper Colorado River basin driven by dust radiative forcing in snow*, Fall Meeting American Geophysical Union, San Francisco, CA December 2009. Bryant, Painter: *Radiative forcing by desert dust in the Colorado River Basin from 2000 to 2009 using coupled satellite and in situ measurements*, Fall Meeting American Geophysical Union, San Francisco, CA December 2009. Skiles, Painter, Barrett: *A five-year record of radiative and hydrologic forcing by desert dust in the Colorado River Basin*, Fall Meeting American Geophysical Union, San Francisco, CA December 2009.
Publications:	Painter, T.H., J.S. Deems, J. Belnap, A.F. Hamlet, C.C. Landry, B. Udall. Water yield loss in the Upper Colorado River basin driven by dust radiative forcing in snow, *PNAS, in review*.
Partners/Stakeholders	CWCB, Conservancy Districts, USBR, USGS, CSAS

Project Title:	**Seasonal Forecasts**
Primary Investigator(s):	K. Wolter
Contributors:	NOAA CPC
Core Funding:	WWA *FUNDING 2009: JAN–DEC*
Summary:	Building on a decade of involvement with the WATF and water managers from various Colorado water districts, I will continue this partnership that entails monthly updates of my forecast webpage (*http://www.cdc.noaa.gov/people/klaus.wolter/SWcasts/*).
Proposed Work:	This translates into a monthly synthesis of recent climate conditions on spatial scales from the Front Range of Colorado to global ENSO-related features, as well as the execution and interpretation of my experimental climate forecast products, culminating in widely disseminated 'Executive Summaries'. This information is also an important component of the WWA Intermountain West Climate Summary (IWCS).
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 (http://www.cdc.noaa.gov/people/klaus.wolter/SWcasts/) 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. This includes sending out my "executive summary" to interested parties, mostly water managers, and media folks. I helped to edit the IWCS in terms of its ENSO assessments and forecast discussions (including my own experimental SWcasts).

	On the national scale, my climate forecasts are used by wildfire managers in the western U.S. (10th annual fire assessment workshop in April 2009), 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 (http://www.cdc.noaa.gov/people/klaus.wolter/MEI/) departs from NOAA's Niño 3.4 SST index, but this was not the case in 2009), and expected ENSO impacts in the U.S. I also contribute to CPC's monthly ENSO Diagnostic Discussion (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/) by briefing all interested parties on my monthly updated MEI ahead of CPC's release date. Related to my role on the WATF, I have continued to be active on the "Drought Plan Subcommittee" for the Colorado Drought Plan, which included a meeting in Denver in December; also, a NIDIS Meeting on drought indices (SWSI) jointly with CWCB in August (Boulder), in which I agreed to help with evaluating the SWSI for Colorado in the context of the Colorado Drought Plan. This work will be performed in 2010, with support from NIDIS.
Presentations:	Wolter, A New and Improved Multivariate Enso Index (MEI), American Meteorological Society Meeting, January 14, 2009 Wolter, Seasonal Outlook through March 2009, Colorado Water Availability & Flood Task Force, January 22, 2009 Wolter, Seasonal Outlook though May 2009, Colorado Water Availability & Flood Task Force, February 25, 2009 Wolter, Let it snow, Let it Snow, Let it Snow!, Bixby Elementary School, March 6, 2009 Wolter, Seasonal Outlook through June 2009, Colorado Water Availability & Flood Task Force, March 20, 2009 Wolter, Experimental Seasonal Climate Forecasts, Binational Drought Science Conference, March 23, 2009 Wolter, Thoughts About the Next Three to Five Months in North America, with Special Focus on (South-)Eastern U.S. Videoconference, Eastern Seasonal Assessment Workshop, National Interagency Fire Center (NIFC), April 14, 2009 Wolter, Thoughts About the Upcoming Spring & Summer in North America, with Special Focus on (South-)Western U.S. , National Interagency Fire Center Workshop, April 14, 2009 Wolter, "Natural" Climate Variability, Western Region Climate Change Workshop, April 15, 2009 Wolter, Seasonal Outlook through September 2009, Colorado Water Availability & Flood Task Force, April 22, 2009 Wolter, Seasonal Outlook through September 2009, Colorado Water Availability & Flood Task Force, May 27, 2009 Wolter, Seasonal Outlook through October 2009, Colorado Water Availability & Flood Task Force, June 18, 2009 Wolter, Long Term Weather Outlook, Colorado Water Availability & Flood Task Force, July 16, 2009 Wolter, Long Term Weather Outlook, Colorado Water Availability & Flood Task Force, August 26, 2009 Wolter, Climate Change in Colorado: Present, Past, and Future, Boulder Audubon Society, September 22, 2009 Wolter, What Does El Niño Mean for Drought in Texas?, National Drought Forum, October 7, 2009 Wolter, El Niño as a 'Drought-Buster' in Texas: How Reliable is it, or What Can we Expect this Winter? Are the September Rains a Sign of Things to Come?, Drought Monitor Forum, October 8, 2009 Wolter, Panelist, Seasonal Weather Indices , MDA EarthSat Weather Meeting, October 15, 2009 Wolter, What can the Upper Colorado Basin Expect this Winter?, NOAA National Integrated Drought Information System Weekly Drought Webinars, November 10, 2009 Wolter, Reliability of ENSO signal in Western U.S. in last decade, California Water Resources Workshop , November 30, 2009 Wolter, Upper Colorado 2009-10: Quo Vadis?, Seven States Meeting, December 8, 2009 Wolter, Snow Storms, Science Day Lecture, October, 2009 Wolter , What can California Expect This Winter?, Winter 2010 Outlook Workshop, November 3, 2009
Publications:	12 monthly executive summaries, available upon request
Partners/Stakeholders	WATF, NOAA CPC, CWCB, Colorado Water Providers

Project Title:	**TreeFlow: A Drought Planning Resource for Water Management in the Western U.S.**
Primary Investigator(s):	J. Lukas, C. Woodhouse
Contributors:	S. Gray
Core Funding:	NOAA CPO *FUNDING 2009: JAN—JUN*
Summary:	Paleohydrologic data and information from tree rings are increasingly recognized as a valuable tool for drought planning and water resources management. The recent severe and prolonged drought and a growing awareness of the regional impacts of global climate change, coupled with an increased in demand for water that far exceeds demands during the 1950s drought, have made water managers in the western U.S. realize the need for new tools for drought planning and water management. The development of high-quality tree-ring based reconstructions of streamflow for a growing number of western rivers has coincided with this realization. With support from NOAA CPO, we are working hard to engage resource managers and foster partnership to develop tree-ring reconstructions and applications for region-specific water management and drought planning needs. Examples of the applications of the reconstructions to water resource management now abound (see below), but a prime testimony to the acceptance of the reconstructions as an important and useful source of information is the recently approved Colorado River Environmental Impact Statement, which includes methodologies for alternative hydrologic scenarios that incorporate tree-ring reconstructions of Colorado River flow (Bureau of Reclamation 2007). While the streamflow reconstructions are valuable for the broader range of hydrologic variability they document, the past record of streamflow will not be an exact analogue for future flows because of global climate change due to human activities. Because of uncertainties in the model projections, information from the paleo record combined with future projections may yield the most likely range of future scenarios for planning purposes.
Proposed Work:	The goal of this project is to expand the usefulness and value of streamflow reconstructions for drought planning and water management to a broader range of water providers and resource managers. This goal will be accomplished using a two-pronged approach that includes 1) an updated and comprehensive web-based resource for data, applications, and analysis that addresses regional needs and interests, and that is designed to be expandable to include additional regions of interest and reconstructions that are generated in the future, and 2) the development of a web-based paleo toolkit to facilitate applications and use of streamflow reconstructions. The main objectives of this study are: To develop a centrally organized web page resource that incorporates the resources from both TreeFlow and the workshop web pages, while also addressing region-specific water management needs and interests To develop a paleo toolkit for analyzing gage records in the context of the centuries-long reconstructions and to assess future hydrologic scenarios by combining GCM results with paleo flows.
Progress/Results:	The new, expanded TreeFlow web resource (http://treeflow.info) went live for review in late June 2009 and was publicly announced to stakeholders in September 2009. The top-level sections of the site include: (1) basin-based access to paleohydrology data for over 60 gages across the western US; (2) background information on tree-ring data and how the streamflow reconstructions are developed; (3) descriptions of several current applications of the data to water management; (4) agendas, presentations, and reports from 13 tree-ring workshops from 2006-2009; and (5) a multi-page feature, Colorado River Streamflow: A Paleo Perspective. The new TreeFlow site entailed the development of content and code for about 100 new HTML pages, including pages for each of 60-some paleohydrology datasets across the western US (http://treeflow.info/basin.html). The new TreeFlow site also included the development of a fully text-annotated PowerPoint presentation describing the generation of paleohydrology data and their use in water resource management (http://treeflow.info/docs/treeflow_reconstructions&applications_annotated.ppt). Planned followup work (using SARP funding) in 2010 includes the finalizing of the "paleo toolkit", and work with Wyoming and Utah collaborators on ancillary pages and resources.
Presentations:	Lukas, J. "TreeFlow: Using tree-ring paleohydrology as a planning tool." Western Watersheds and Climate Change - Water and Aquatic System Tools Workshop (USDA Forest Service). Boulder, CO, November 18, 2009. Lukas, J. "Tree-ring paleohydrologies and their application to water management in Colorado and the West." Hydrologic Sciences and Water Resources Engineering Seminar**,** University of Colorado, Boulder, CO, February 4, 2009. Lukas, J. "What tree rings tell us about hydrologic variability in Colorado and Denver Water's watersheds." Denver Water Planning Forum, Denver, CO, January 15, 2009.
Publications:	Lukas, J. (2009). "TreeFlow: A Comprehensive Web Resource for Tree-ring Reconstructions of Streamflow." Intermountain West Climate Summary **5**(5).

Partners/Stakeholders	Regional, state, local, and private water providers and agencies, and other water users, such as stakeholders in the agriculture and hydropower sectors.

Ecological Vulnerabilities, Impacts, and Adaptation

Table 2.

Project Title:	**Forests, Climate, and Change**
Primary Investigator(s):	E. Gordon, J. Lukas
Contributors:	L. Dilling, S. van Drunick, J. McCutchan, A. Ray
Core Funding:	WWA *FUNDING 2009: JULY–DEC*
Summary:	We propose to bring WWA's longstanding role in science synthesis and assessment, in support of decision making and adaptation, to bear on vulnerabilities and impacts arising from climate-related changes in forest ecosystems. During the first year, we will focus on the ongoing mountain pine beetle (MPB) infestation, which has been linked to recent climate trends and is causing significant and widespread changes in forest ecosystems in Colorado and adjacent states. Impacts to water resources and the risk of high-severity fire are cited as the most serious management concerns. A recent letter from the Colorado congressional delegation to several federal agencies, requesting funding and action to deal with the infestation, indicates the very high stakeholder salience of MPB-related risks and vulnerabilities.
Proposed Work:	We have gathered input for this proposal from several key stakeholders and scientists, including Marc Waage, Denver Water; Rick Cables, USFS; Therese Glowacki, Boulder County Parks & Open Space; Gary Severson, NWCCOG, and Tania Schoennagel, CU forest ecologist. They agreed that WWA could serve a useful role as a coordinator and provider of information for decision support on forest-change issues, and their guidance is reflected in the proposed products and outreach below. We propose to solicit input from a broader set of stakeholders in MPB-affected areas to identify information needs for decision making. We will then develop science synthesis products to fill the broadest needs, and propose new research to fill critical gaps. Concurrently, and in the light of the science synthesis products, we will examine current planning and management responses to the MPB infestation. Gordon will incorporate this information into a broader dissertation examining whether responses to major ecological vulnerabilities present in Colorado, such as fire, drought, and beetle attacks, can inform strategies for successful adaptation to climate vulnerability and climate change. We will also work closely with Andrea Ray regarding her proposed interactions with federal resource managers to ensure coordination of activities and information that would serve the interests of both projects.
Progress/Results:	The bulk of work for this project has been to orient WWA and ourselves with ongoing discussions and debates over dealing with the mountain pine beetle epidemic in Colorado and southern Wyoming. Doing so has made us known to persons involved in the issue and has helped us carve out a further role for WWA in the arena of forest-climate interactions. To date, we have met individually with: Rick Cables and Polly Hays, USFS Region 2 Marc Waage and Don Kennedy, Denver Water Tania Schoennagel, CU-Boulder/INSTAAR Tony Cheng, Colorado Forest Restoration Institute Chuck Rhoades and Linda Joyce, USFS Rocky Mountain Research Station Therese Glowacki and Chad Julian, Boulder County Parks and Open Space Paige Lewis and Mike Babler, The Nature Conservancy Gary Severson, Northwest Colorado Council of Governments On December 7, 2009, we organized a broadly scoped meeting entitled "Making Connections: Pine Beetles, Water, Climate, Fire, and the Future Forest." The 40 participants represented a diverse set of stakeholders (including water managers, land managers, and policymakers) and scientists researching beetle-related issues. We conducted the meeting by arranging informal panels on water impacts, the fire-beetle connection, climate and the future forest, and policy and politics. The meeting provided participants with the opportunity to meet and talk with each other, and to assess the current state of both decisionmaker concerns and scientific research. Many participants commented that they found the meeting useful and that it was helpful in bridging the stakeholder-scientist divide. We noted in particular continued debate over scientists' and policymakers'

	assessments of the fire risk of beetle-killed forests and the resulting policy implications. To further science-stakeholder connections related to bark beetle issues, we solicited responses from meeting attendees to a survey aimed at understanding stakeholder concerns and future scientific efforts. We are using the results of this survey to help build content for the Bark Beetle Information Clearinghouse, a web-based source for contacts, scientific literature, newspaper articles, and other content we hope will be useful for stakeholders and others concerned about the bark beetle epidemic. Our proposed deliverables (see below) included two science synthesis reports, one on water-related impacts of beetle infestations and one on climate-related effects on beetle infestations. During the course of the project, we have discovered that the Colorado Water Institute had engaged John Stednick, a professor at Colorado State University, to write a report on water impacts. We are awaiting further information about this report before looking for an additional relevant opportunity, but Gordon has already engaged potential co-authors and reviewers for a paper when we better understand how it can be useful without being redundant. Lukas is beginning the process of compiling existing research to develop a synthesis report on climate-beetle connections. During the course of our investigation, we also discovered that researchers across a number of institutions, including CU-Boulder, CSU, NCAR, NOAA, and USGS are all working on new research related to the impacts of beetle infestations on water quality and quantity. We are currently soliciting feedback on a proposed water-beetles science symposium to be held in the spring. Finally, as part of early efforts to define his PhD dissertation work, Gordon is preparing a paper arguing for an empirical approach to defining success or failure in adaptation. This paper would contend that the ongoing bark beetle infestation in Colorado and elsewhere across North America makes a good case study for understanding how various regions have successfully or unsuccessfully adapted to a major environmental change. The paper was accepted to the ICARUS workshop on Climate Vulnerability and Adaptation: Theory and Cases in February 2010 at the University of Illinois at Urbana-Champaign. We would like to emphasize that, due to the exploratory and open-ended nature of this project, the scope of our deliverables has changed somewhat when compared to our original project proposal.
Presentations:	Gordon, E. and Lukas, J. Identifying Policymakers' Science Needs for Climate Adaptation in National Forests. Poster Presented at American Geophysical Union, December 17, 2009.
Publications:	Gordon, E. and Dilling, L. An Empirical Approach to Defining Success in Adaptation. Abstract accepted to ICARUS Workshop on Climate Vulnerability and Adaptation: Theory and Cases, February 11-13, 2010.
Partners/Stakeholders	Forest and land managers (USFS, BLM, NPS, CSFS); water resource managers (Denver Water, Northern, CRWCD, local water utilities); Colorado public officials at the federal, state, county, and municipal levels; interagency MPB task forces and cooperatives

Project Title:	**Climate Change Impacts on Public Lands in the Upper Colorado River Basin**
Primary Investigator(s):	J. Neff
Contributors:	BLM
Core Funding:	WWA, NIDIS *FUNDING 2009: JULY–DEC*
Summary:	The Federal Government is responsible for the management of much of the land in the western United States; in Colorado alone, the Bureau of Land Management and US Forest Service administer over 35% of the acreage of the state. These lands encompass a vast array of ecosystems that range from deserts to alpine tundra and include uses as diverse as wilderness recreation and resource extraction. All of these environments, whether pristine or highly disturbed, will change as the result of climate change and the nature and impacts of these changes represents one of the major emerging challenges to land managers in the coming decades. Climate is a primary driver of ecological process and ecosystem structure. In the western US, drought is a major cause of changes in ecological communities and ecosystem function. Recent work, including that supported by the WWA, clearly indicates the potential for severe and repeated regional drought cycles (Woodhouse and Lukas, 2006). Recent regional multi-year drought events have resulted in major changes in ecosystems such as the recent widespread mortality of pinyon trees in the Four Corners Region (Breshears et al., 2005) and there is evidence that aridity may increase in the future due to climate change (Cook et al., 2004). The implications of these potential changes range from management of forest systems with extensive drought-related mortality to costly and destructive increases in the frequency and severity of wildland fire (c.f. Westerling et al., 2006); events that have broad consequences for both human (Butry et al., 2001) and biogeochemical systems (Wiedinmyer and Neff, 2007). The basic and critical role of climate and drought ecosystem dynamics is clear, the broader issue of how climate change can and should inform decision-making on federal lands is far less so.

	Changes in climate will impact land management decision-making on multiple levels. Climate change may become (and arguably already has become) a component of existing federal laws such as the National Environmental Protection Act (NEPA), and the Endangered Species Act (ESA). New legislation such as proposed cap and trade systems for carbon could also impact management of a wide range of ecosystems that have relatively large rates of carbon exchange with the atmosphere (forests in particular). Finally, climate change will impact managers because it will alter the state or function of ecosystems (what do pinyon forests become when the trees die due to drought?) and because many federal agencies have implicit or explicit planning time horizons that are measured in decades (what species of trees should be planted at a site following a large wildland fire?). Nearly all the federal agencies have had some direction to consider climate change in planning but in many or most cases, limited guidance as to how to do so. Of the major land management agencies in the Western US (the USFS, BLM and the National Park Service-NPS), the BLM in particular has had relatively little institutional focus on climate change adaptation planning and is therefore the primary focus of this proposal.
Proposed Work:	In this project, we propose to work with the BLM in Colorado, Utah, and at the national office to initiate the process of evaluating how climate change will impact public lands. Over the past two years, we have established a close working relationship with the San Juan Public Lands Center in Durango, CO (a joint USFS and BLM land management center) and in collaboration with BLM staff at the center, developed an initial project preparing analysis of potential climate changes to the SW Colorado region using the North American Regional Climate Change Assessment Program (NARCCAP) simulations. With NOAA and WWA support, we propose to leverage our existing work evaluating potential climate change impacts to the region to support a broader spatial evaluation of land areas particularly vulnerable to potential climate changes.
Progress/Results:	In 2009, we initiated several efforts to move forward on our proposed work. In the area of *refining and utilizing downscaled GCM projections*, we are partnering with a group of researchers including Imitiaz Rangwala (NOAA postdoc) and Joe Barsugli (CIRES AND WWA) to examine NARCCAP simulations for the Four Corners region (as a test case for a broader regional evaluation of the downscaled projections). We received a supplement to our BLM funding for climate impacts work in the Four Corners region that allowed us to hire Karen Cozzetto as a *new postdoctoral fellow* working on this project. Karen will be jointly supported by the BLM and NOAA western water assessment for 2010 (Cozzetto is supported by WWA rather than Fernandez as was proposed in the original budget). Karen is leading efforts to address the deliverables proposed in our original proposal: **Deliverables 1 and 4:** Report to BLM managers on the use of existing rangeland assessment and monitoring protocols for climate change impacts analysis and website hosted at CU (under the http://moab.colorado.edu site that summarizes ongoing and potential climate impacts to public lands. In consultation with the BLM, we have initiated a **monthly conference call to discuss climate change science support for land management decisions**. The first conference call will be held on January 27, 2010 and will focus on downscaling and drought impact projections. The purpose of these calls is to provide a venue for science/management interaction. A number of people including BLM state office, San Juan Public Lands Office, CU Boulder, NOAA and USGS personnel will participate in these calls. We are preparing a **bimonthly newsletter for distribution to BLM and Dept. of Interior staff** that provides updates on projects and overviews of issues related to climate change assessments and impacts analysis. The first newsletter is available at http://moab.colorado.edu/ClimateImpactsPublicLands/newsletter_2010_01. These newsletters will provide a rapid and relatively informal mechanism for communicating research progress to managers. These news letters will be hosted on a new website at CU Boulder that will address the deliverables under #4 below. This website is currently under construction and will be hosted at http://moab.colorado.edu/ClimateImpactsPublicLands . **Deliverables 2 and 3:** We are currently carrying out the initial modeling efforts to address our deliverables 2 and 3 below. We are using an arid land vadose zone hydrology model developed by Eric Tilton at CU Boulder to simulate soil water dynamics and evaluate likely plant water stress during drought conditions. We are using the model initially for two case studies of pinyon juniper ecosystems near Durango, CO. Our goal is to carry out simulations for a range of case study combinations that are representative of the common soil, elevational, and vegetation combinations on the Colorado Plateau. This approach allows us to focus our efforts on understanding the mechanisms, including the interaction between vegetation and soil type, that control ecological responses to drought in this region. A similar type of effort using spatially resolved models would increase the complexity of the analysis and likely decrease the quality of mechanistic understanding that emerges from the analysis. Using our modeling approach we are focusing on the following dynamics in the near term. First, we are modeling the water stress associated with historical (observational record) droughts on the Colorado Plateau. This is done by using climate records to drive our model for different vegetation, soil and elevational combinations. The resulting data will then be analyzed to determine how soil conditions (e.g. depth/texture), vegetation composition (e.g. forest, shrubland, grassland), and elevation (e.g. evaporative potential) moderate or amplify the effects of regional droughts. These results will be classified into different categories based on the landscape characterization above and the type (winter, summer) and duration (short, multiyear) of drought. From these classifications, we will generate a maps of categorical variables that represents potential landscape scale vulnerability to drought cycles. This analysis will become the core part of a publication that we will prepare for a peer reviewed journal in the summer of 2010.

	Our future efforts will focus on testing our projected vulnerability against satellite-derived maps of vegetation greenness during the ~2000 regional drought and projections of potential vulnerability to the type and duration of drought periods projected by the NARCCAP simulations. In the absence of reliable precipitation data from the NARCCAP simulations, we will focus on increase in evapotranspiration associated with rising temperatures and carry out a sensitivity analysis that focuses on potential changes in precipitation.
Presentations:	None. *(NOTE: informal presentations to BLM personnel have taken place and a short workshop is scheduled for later in February 2010)*
Publications:	Website content: http://moab.colorado.edu/ClimateImpactsPublicLands/Welcome2.html
Partners/Stakeholders	BLM

Project Title:	**Effects of Mountain Pine Beetle on Water Quality in Colorado**
Primary Investigator(s):	J. McCutchan, S. van Drunick
Contributors:	E. Gordon, T. Detmer, J. Lukas
Core Funding:	WWA *FUNDING 2009: JULY–DEC*
Summary:	A recent outbreak of mountain pine beetle (*Dendroctonus ponderosae*) is changing the structure of montane pine forests in Colorado. Lodgepole pines have suffered high mortality in many watersheds, and the extent of affected watersheds is growing. The current outbreak is not unprecedented; similar outbreaks have occurred previously in Colorado and elsewhere in western North America. However, the effects of the current outbreak will be long-lasting (i.e., decades to centuries). Climate change may alter the dynamic equilibrium between the mountain pine beetle (MPB) and lodgepole forests in Colorado. For example, if the climate becomes warmer and drier, the conditions that support MPB outbreaks–warm winter temperatures and low soil moisture–may become dominant, and the distribution of lodgepole pine may be altered. Tree mortality caused by MPB is affecting forest resources and tourism across western North America; however, large-scaled die offs over most of a watershed also change the magnitude and timing of hydrologic fluxes. Growing forests intercept some of the precipitation and nutrients within a watershed. Therefore, the loss of forest biomass reduces evapotranspiration and increases the yield of water and nutrients, although such changes have not been well quantified in Colorado. Reduced evapotranspiration and greater water yield may increase weathering rates and particulate export in watersheds affected by MPB. Concentrations of nutrients and particulates affect the distribution and abundance of aquatic organisms, including algae, aquatic invertebrates, and fish. Increased nutrient concentrations also affect the growth of algae in lakes and reservoirs that are used as water supplies. Thus, changes in the export of nutrients and sediment from forests to streams can cause problems for water users (e.g., through increased treatment costs) and can alter the function of aquatic ecosystems (e.g., through changes in food web structure). In areas where pesticides (e.g., carbamates or pyrethroids) are applied to control MPB populations, runoff into streams may result in further changes in water quality.
Proposed Work:	Because water chemistry in streams reflects multiple processes, including patterns of atmospheric deposition, mineral weathering, nutrient uptake, and human perturbations, understanding the effects of MPB on water chemistry is particularly complicated in watersheds with substantial human influence. We propose to capture two "snapshots" of water quality across Rocky Mountain National Park, which includes watersheds spanning the full range of damage by MPB and also is free of many of the human influences that could confound an analysis of the effects of MPB on water chemistry. The snapshot will consist of a set of ~160 water samples collected on a single date, during the middle of the growing season (mid August). A second snapshot will be conducted during snowmelt runoff (~80 samples; spring 2010) on a subset of the locations sampled in 2009. Samples for pesticide analysis also will be collected from streams in areas where trees are being sprayed for MPB (e.g., inholdings in Moraine Park and Wild Basin). The surveys, in combination with GIS analyses (e.g., using maps of tree mortality from U.S. Forest Service aerial surveys) will provide information on spatial and temporal patterns of water chemistry in watersheds affected to varying degrees by MPB.
Progress/Results:	With help from National Park Service personnel and volunteers, we collected water samples and field data from over 200 locations in and around Rocky Mountain National Park on 18 August 2009. The sampling locations included watersheds affected to varying degrees by mountain pine beetle; for example, the upper Cache la Poudre watershed is relatively unaffected by pine beetles, the North St. Vrain watershed is moderately affected, and the North Inlet watershed has suffered widespread tree mortality due to mountain pine beetle. Water samples have been analyzed for pH, specific conductance, anions (nitrate, nitrite, sulfate, chloride), cations (calcium, magnesium, sodium, potassium, ammonia), dissolved organic carbon, dissolved organic N, particulate N, particulate C, total dissolved phosphorus, particulate P, and absorbance spectra (UV, visible). A set of photos was

	taken at each location and these images are now being analyzed (e.g., for estimation of conifer health at the sampling locations). Relevant data layers (e.g., elevation, vegetation cover, tree mortality) for the sampling area have been assembled and GIS analyses are in progress. Data analysis for the 2009 sampling will be completed in early spring. Although data analyses for the 2009 sampling are not yet complete, preliminary analyses have shown that the effects of mountain pine beetle on nutrient chemistry in streams of Rocky Mountain National Park have been modest in comparison with some other examples of forest disturbance (e.g., clear cutting). Mountain pine beetle may significantly increase nutrient concentrations in some lakes and reservoirs, in that the changes could result in measurable changes in phytoplankton growth or water clarity, but it does not appear that such changes will be dramatic (except possibly in the case of widespread fire). Based on the results of sampling in 2009 and information on pesticide applications (provided by the National Park Service), a subset of the initial sampling locations will be sampled repeatedly in 2010. As in 2009, water samples will be analyzed for fractions of nitrogen, phosphorus, and carbon in order to further evaluate the effects of mountain pine beetle on export of nutrients in stream water. These samples also will be analyzed for carbamates. Sampling multiple dates at each location may be necessary for detection of pesticides in stream water (if present above detection limits) since timing of the movement of pesticides is uncertain. Repeated sampling also will provide better estimates of nutrient loading (i.e., to reservoirs used as water supplies) than is possible with a single sampling date.
Presentations:	None. *(NOTE: Several in 2010)*
Publications:	None. *(NOTE: Coming in 2010)*
Partners/Stakeholders	National Park Service (Rocky Mountain National Park), water-management agencies (e.g., Northern Colorado Water Conservancy District), local municipalities, and water users

Emerging Initiatives and Adaptation Strategies to Inform Climate Services (formerly Climate Adaptation and the Adaptation-Mitigation Nexus)

Table 3.

Project Title:	**A Drought Impact and Vulnerability Indicator Suite**
Primary Investigator(s):	W. Travis, L. Dilling, R. Klein, K. Gangwer
Contributors:	A. Ray
Core Funding:	WWA *FUNDING 2009: JULY–DEC*
Summary:	A key need identified by NOAA's science advisory board (Social Science Working Group, 2009) is improved measures of socio-economic impacts and better indicators of societal vulnerability to atmospheric hazards so that NOAA can measure outcomes of its programs and target needs. While we are getting good at measuring, even forecasting, the physical state of the weather and climate, we operate with only the most rudimentary measures of social impacts and vulnerabilities. But, as the NRC Panel on Strategies and Methods for Climate-Related Decision Support (2009) just concluded, decision support requires development of both the tools for decision-making and the information on which to apply those tools. They highlight the problem of measuring hazard loss and vulnerability (pp. 4-3, 4), and they recognize that "*Research is needed to develop indicators of adaptive capacity that can address the diversity of types of disruptive events; assess effects by region, sector, human activity, and time scale; incorporate assessments of coping capacity (e.g., emergency preparedness and response systems, insurance systems, disaster relief capabilities); and consider diverse types of impacts (e.g., on life and health, economic systems, business organizations, governments, and communities.*"(p. 4-12). They laud the RISAs for focusing on information relevant to regions and key sectors. This project would advance these goals by developing key indicators of drought and other climate-related vulnerability in the WWA research area at appropriate scales. Vulnerability assessment requires both physical and social data, which together can reveal sensitivities and trends, and indicate where climate-related resources could be best targeted for reducing vulnerability. We have basic climatological and water resources measures (e.g., snowpack, streamflow, reservoir storage levels, and water deliveries). And though some institutions with proven drought vulnerabilities such as municipal water utilities have developed and routinely apply their own vulnerability and impact indicators (e.g., supply/demand ratios), much of what we know about the societal impacts of drought impacts comes from anecdotal and media accounts.
Proposed Work:	Canvass the WWA team to assess measures already employed, rejected, or attempted, and to build a target list of indicators based on previous work and contact with stakeholders. Then develop, collect and refine a suite of quantitative indicators that reveal the type, magnitude, and net impacts in key sectors, especially urban water,

	agriculture, ecosystems, recreation, and the general economy, for the geographic area served by the WWA. Start with broader indicators, and extend these measures back at least to the 1976-77 drought (and before if data of adequate quality can be located), test them with the WWA team and selected stakeholders. In each case we must evaluate quality, availability, and usefulness.
Progress/Results:	During August-December, 2009, we developed a roster of drought indicators and tested several for Colorado and the three-state (Colorado-Wyoming-Utah) region. Agricultural: Crop yields (depression; but confounding factors) Planted vs. harvested acres (% abandoned) Livestock inventories Ag income Agricultural Disaster declarations Crop insurance Water Supply and Ecological: Declared water shortages in deliveries Formal urban water use restrictions ("Fourth of July Index") Other drought "emergency" and "disaster" declarations (e.g., FEMA Presidential Disasters; local emergencies---e.g., Atlanta and Austin) Wildfire indices (#, area, costs) Gangwer attended the WWA climate workshop in Glenwood Springs to become familiar with WWA presentations and user groups, and we presented initial results for the above indicators to the WWA team on Dec. 3 for feedback. Our data gathering, discussions with agencies, and feedback from the WWA team caused us to focus on the agricultural production and crop insurance measures, and indicators of declared supply shortages, and to explore use of drought intensity measures (e.g., PDSI) for impacts normalization.
Presentations:	December 3, 2009, WWA team meeting, "Can We Measure Drought Vulnerability Over Time?" Bill Travis and Kristin Gangwer. Forthcoming: April 15, 2010, AAG Annual Meeting, "Assessing Drought Impacts and Vulnerability in the US Intermountain West." Kristin Gangwer and Bill Travis.
Publications:	None. *(NOTE: Coming in 2010)*
Partners/Stakeholders	NIDIS; national climate service; state, regional, and local units who manage drought, plan future water resources, and think about climate change adaptation

Project Title:	**Evaluating the Utility of an Uncertainty Framework for Regional Climate Information**
Primary Investigator(s):	K. Averyt
Contributors:	R. Webb
Core Funding:	WWA *FUNDING 2009: JULY–DEC*
Summary:	Lack of knowledge regarding uncertainty associated with climate models and projections can hinder decision-makers from implementing climate adaptation strategies. A formalized scientific uncertainty rubric may prove a valuable tool for those using climate information for regional adaptation planning. The Intergovernmental Panel on Climate Change (IPCC) uses standard uncertainty terminology to convey degrees of scientific uncertainty to international policy makers; both quantitative, probabilistic assessments (very likely (>90%), likely (>66%), etc.) and more subjective confidence assessments (high confidence, etc.) are used by the different IPCC Working Groups. This terminology has become an integral part of the international science policy vernacular. The US Global Climate Research Program adopted similar terminology for its Scientific Assessment Products (SAP). However, the different SAP documents used different likelihood expressions. The lack of homogeneity complicates the communication of scientific uncertainty in support of regional adaptation planning, as regional climate syntheses cull statements from different sources including the IPCC Assessment Reports and USGCRP SAPs. For example, in crafting the Colorado Climate Report, a document developed by the Western Water Assessment

	(WWA) to support adaptation planning for water managers, statements incorporating uncertainty language were culled from many IPCC and SAP Reports. Although quoting IPCC and SAP statements containing uncertainty terminology proved useful to the Colorado Report audience, there was no mechanism for the WWA to apply "likelihood" and "confidence" terminologies to the state-specific studies not included in international and national assessments. Developing a regional uncertainty framework for the Colorado Report was not practical given the short time line for developing the report and the small team of scientists working on the project (relative to the IPCC).
Proposed Work:	We propose developing a process for addressing uncertainty in regional climate issues. The first part of this effort will be an assessment of how uncertainty is currently being handled on regional scales. The second part will be an effort to leverage the stakeholder relationships developed through the Cross-RISA Reconciling Colorado River Flows project to develop a best-practices framework for communicating regional uncertainty. In future years, we hope to test this framework and evaluate its utility through RISA partners. We hope to broach the following research questions: Is an uncertainty index necessary? Would an uncertainty index based on the IPCC and USGCRP models tailored to regional climate issues be valuable to users? Likelihood or confidence—which is more useful for adaptation? At what point does a user decide that a climate projection actionable? Will one framework work for all? Or can a typology approach be used to guide uncertainty issues?
Progress/Results:	For this project, I worked with the NOAA Near-Term Opportunities (NTO) Team to compile the major international, federal, regional, state, and local documents and initiatives geared toward assessment of climate. I maintained a website with links to these documents at: http://wwa.colorado.edu/assessments/assessments_lists.html. I summarized the process used to generate several of the reports, which became part of a larger report by the NTO Team. As a direct result of evaluating the myriad approaches to assessment, I became interested in the scientific capacity to generate usable science and have a paper in press in BAMS focused on this issue. This project rapidly became enveloped in the follow-up to the Colorado Climate Report, in that we began to explore connections between reducing uncertainty and climate literacy. (See Climate Roadshow for more details).
Presentations:	Averyt, K.B., J. Lowrey, J. Martin and B. Udall (2009) An Uncertainty Framework for Regional Climate Assessments? Climate Prediction Applications Science Workshop, Norman, Oklahoma. http://climate.ok.gov/cpasw/presentations.php Averyt, K.B. (2009) Why the Scientific Culture Impedes Progress Toward Climate Adaptation. Water in the West Panel, AMS.
Publications:	Summary of Assessments (see http://wwa.colorado.edu/assessments/assessments_lists.html) K. Averyt (In Press) Are We Successfully Adapting Science to Climate Change?, Bulletin of the American Meteorological Society.
Partners/Stakeholders	NOAA

Project Title:	**Energy-Water-Climate Nexus: Developing an Energy-Water Decision Support Tools for the Colorado River Basin**
Primary Investigator(s):	K. Averyt, R. Pulwarty, D. Kenney
Contributors:	R. Wilkinson
Core Funding:	NOAA CPO, WWA, NIDIS *FUNDING 2009: JAN–DEC*
Summary:	There is a growing recognition of the interconnectedness of energy demand and water resources. Energy development requires water, and moving and treating water consumes energy. These and related connections create novel challenges in management and offer opportunities to craft solutions with multiple, cross-sector benefits. Energy production accounts for roughly 40% of annual freshwater withdrawals in Colorado, while domestic withdrawals are only 3%. Water demand is projected to increase significantly as calls for "energy independence" are likely to revitalize water-intensive processes needed for energy production such as coal and mineral (e.g. uranium) mining, nuclear power, coal-fired power, oil shale extraction, among others. Farming for biofuels, hydropower, and other renewable energy technologies also pose challenges. For example, water consumption by dedicated energy crops for biofuel production can exceed 265,000 gallons of water per MWh of power generated (R. Wilkinson, pers. com.). Similarly, water resources management consumes significant quantities of energy because water is heavy, so moving it uphill is energy intensive. Energy is an integral component of several facets of water management, just as water is integrated into the energy sector. The changing energy economy and

	water management are further complicated by Colorado's changing climate and population growth. These will alter supply and demand patterns, thus challenging water management in many ways and overwhelming the financial capability of energy and water utilities to pursue adaptation strategies.
Proposed Work:	Research connecting energy, water, and climate is remarkably scarce, despite calls from resource managers and public policy officials for data that will inform planning. The team of researchers and programs organized in this project are well established in each of these three substantive areas (energy, water and climate), and additionally, have a demonstrated record of exploring and cementing cross-sector and cross-disciplinary linkages. A meeting of those currently working on these issues will allow the WWA team to (1) examine the many ways in which these sectors interact, highlighting dangers and opportunities; (2) develop collaborative programs building upon current research and modeling at NOAA, NREL, NCAR and CU through discussion with stakeholders, managers, and planners; (3) identify policy and management pathways that offer solutions that do more than transfer problems among sectors. Subsequently, a significant stakeholder engagement initiative will be developed.
Progress/Results:	The past year has been a successful negotiation of building network capacity and establishing legitimacy in the science of the energy-water-climate nexus. Building upon the model developed at University of California Santa Barbara (see Keller et al., 2010), we tested the model in Colorado River Basin. Specifically, we compared the water consumption associated with currently operational coal-fired power plants with data reported from the energy sector. We then compared water consumption associated with both coal-fired power plants (generating 8000 MW) and concentrated solar thermal plants (also generating 8000 MW) slated for construction that would be drawing water from resources derived from the Colorado River. The results suggest that CSP would consume less water than coal-fired plants because of the types of technologies intended to be used at specific plants. However, through this work, we have identified other groups with similar water for energy models, and their data are not the same as ours. In order to move forward with this work, we need to reconcile the different models and develop the best possible life cycle analysis for different energy producing technologies. This has emerged as a priority, as we cannot move forward with this work until this occurs. To this end, we will be holding a large workshop in 2010 in an attempt to coordinate on the best practices for evaluating water for energy analysis.
Presentations:	K Averyt: Solar Thermal & Coal-Fired Power Plants: Consequences for the Western US and Colorado River Basin, Renewable Energy in the Southwest: Concentrated Solar and Beyond, Tucson, AZ (October 2009)
Publications:	None. *(NOTE: Coming in 2010)*
Partners/Stakeholders	NIDIS, NREL, CU RASEI, Union of Concerned Scientists, Electric Power Research Institute

Project Title:	**Energy-Water-Climate Nexus in the Western US**
Primary Investigator(s):	D. Kenney, K. Averyt
Contributors:	R. Pulwarty
Core Funding:	University of Colorado Energy Institute; WWA
Summary:	There is a growing recognition of the interconnectedness of energy demand and water resources. Energy development requires water, and moving and treating water consumes energy. These and related connections create novel challenges in management and offer opportunities to craft solutions with multiple, cross-sector benefits.
Proposed Work:	We intend to produce (as editors) a book of contributed papers that review various elements of water-energy-climate connections in the American West. An outline has not yet been developed, but it will likely feature a mix of case studies and thematic chapters, highlighting both problems and opportunities associated with this nexus. Already, we have a firm commitment to publish (available upon request) from Edward Elgar Publishing (a major global academic publisher that published Doug's "In Search of Sustainable Water Management" in 2005) (http://www.e-elgar.co.uk/index.lasso), and have received encouragement from several potential collaborators (e.g., Robert Wilkinson of UCSB). Although a book is the tangible product of this effort, its true value is as the skeleton upon which we will build a network of leading researchers and policy-makers active in this field. Similarly, this element of the project should lend itself to additional fundraising activitiesBy having a ready-made publishing outlet available to potential contributors, we are hoping to jumpstart our networking efforts, and thus, build a strong foundation for this substantive element within WWA. Averyt's Colorado case study (described elsewhere) will be one chapter in this effort; it is likely that Doug will need to author an introduction and/or concluding chapter as well, and perhaps even a focused substantive chapter (subject TBD), based on how the outline comes together.

Progress/Results:	The last 6 months have been extremely busy. The main activities over the past 6 months have involved network building. This has taken several forms. First was attendance in October of the conference in Tucson entitled: "Water and Land for Renewable Energy in the Southwest" hosted by Southwest Hydrology, focused largely on the challenges of concentrated solar. This was followed in November by participation in an invitation-only scoping meeting of the Union of Concerned Scientists (UCS) on the "energy-water collision," which included a discussion of the potential role of UCS in western US water-energy projects. Also during this time, I participated, as an Affiliate in the CU Renewable and Sustainable Energy Institute (RASEI), in efforts to build a network of water-energy researchers in Colorado, including both university-based and federal lab projects. Also, as a team member of the Carpe Diem project (of Exloco), I have helped organize a water-energy meeting that will occur soon in San Francisco. More recently, I have met with officials at the Western Governors' Association about ways to integrate their new work on energy generation siting and transmission with other efforts throughout the West. In each of these efforts, I have been able to introduce partners to WWA research and researchers. Using these networks, two "call for papers" have recently been distributed (to roughly 200 individuals and groups) regarding the book project. Proposals are currently being evaluated.
Deliverables:	Progress towards development of energy-water book, including detailed outline and identification of authors and contributors
Presentations:	None. *(NOTE: Several in 2010)*
Publications:	None. *(NOTE: Book Chapter preparation in 2010)*
Partners/Stakeholders	University of Colorado RASEI, NREL

Project Title:	**Joint Front Range Climate Change Vulnerability Study**
Primary Investigator(s):	D. Yates, B. Udall, J. Barsugli
Contributors:	K. Averyt, A. Ray
Core Funding:	American Water Works Association Research Foundation *FUNDING 2009: JAN–DEC*
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.
Proposed Work:	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 providers will use these streamflow projections to asses the potential vulnerability of their water supplies to climate change. WWA will continue to support this study with climate education and guidance about translating complex climate information to governing boards and communities.
Progress/Results:	The study nears completion (March 2010). The Final Draft had completed review, and revisions are being made. J. Barsugli participated in most of the Front Range group's monthly meetings, provided additional echnical guidance through informal contact with L. Kaatz of Denver, extensively reviewed an early draft and submitted comments on the final draft. In addition, interaction with L. Kaatz on the WUCA white paper on climate models (above) also helped to inform the use of climate model information for this project,
Presentations:	Two presentations (above) to the JFRCCVS. Presentation on the FRCCVS by Laurna Kaatz at AGU.
Publications:	Final Report in Revision (March 2010)

Project Title:	**Colorado Climate Roadshow: Developing a Framework for Identifying Impacts and Vulnerabilities to Climate in Support of Adaptation**
Primary Investigator(s):	K. Averyt, J. Lukas, C. Alvord, J. Barsugli, N. Doesken

Contributors:	M. Shafer, C. McNutt *FUNDING 2009: JULY–DEC*
Core Funding:	CWCB, WWA
Summary:	In 2008, WWA researchers led a major research initiative in Colorado focused on the physical aspects of climate change and variability in the state. The resulting publication (Climate Change in Colorado) was well received and has proven a landmark document for decision-makers across the state. In response, WWA has been working the CWCB to develop a "Colorado Climate Report Roadshow." Further, the initial work on the report has set the stage for a second phase to this endeavor that will focus on the vulnerabilities to the impacts of climate change.
Proposed Work:	The Colorado Climate Roadshow will be comprised of several modular activities. These will include the following general components: "Climate 101", "Climate in Colorado", and "How am I Vulnerable?" The Climate 101 module will be based on the NOAA-funded Climate 101 Workshops developed and implemented in Oklahoma by SCCIP. Barsugli and Doesken will be working with SCCIP to tailor the workshop to Colorado's unique audience. The Climate in Colorado section will be a presentation on the results of the Colorado Climate Report. This component is intended to make global climate change a more salient concept. Lastly, we hope to work with stakeholders to address the question "Why does Climate Matter to Me?" This section will focus on drought in the state, and is intended to enable dialogues across many communities. This component will serve as a scoping mechanism for phase 2 of the Colorado Climate Report by bringing into focus the different vulnerabilities of different sectors in diverse regions of Colorado. There will be an evaluation component to this work. In addition, we intend to transfer the lessons learned here to Utah, and thereby perpetuate the lessons learned by improving the Roadshow model.
Progress/Results:	After initial testing, we realized that the Oklahoma Climate 101 module would not be sufficient for the needs of those in Colorado. Consequently, we re-visited our approach and re-developed much of the material necessary for the workshop, although we did consult our colleagues at SCCIP and at CLIMAS for input into our evaluation tool and powerpoint content. The Western Water Assessment (WWA), in conjunction with the Colorado Water Conservation Board (CWCB), presented the "Dealing with Drought–Adapting to a Changing Climate" workshop series during October 2009 in three locations around Colorado: Castle Rock, Glenwood Springs, and Durango. These workshops built on themes and information from both the Climate Change in Colorado Report and the October 2008 Colorado Governor's Conference on Managing Drought and Climate Risk. The WWA, CWCB, and the National Integrated Drought Information System (NIDIS), along with the Colorado State University Colorado Climate Center (CCC) and the Mountain Studies Institute sponsored this series of workshops. The 80 participants represented diverse sectors and interests affected by drought and climate, including water resource management, agriculture, land-use planning, forest & range management, watershed protection, environmental organizations, and tourism & recreation. Collectively, the participants' decision-making affects natural resources in every river basin in Colorado. The primary objectives of these workshops were to improve the climate literacy of the participants, provide input into the ongoing update of the state Drought plan, document participants' understanding of climate change in Colorado, and address concerns and questions among this group of stakeholders about climate change. The workshop objectives were achieved through pre- and post-workshop evaluations, instructional presentations, breakout discussions, and the distribution of climate and drought information in printed form. Analysis of the workshop evaluations and notes from breakout sessions and discussions yielded the following information: Participants expressed an understanding that climate is changing and will affect Colorado in the pre-workshop surveys and in discussions during the workshop; however, they are unclear about the role climate information plays in decision-making. In all three workshops, the participants, as a group, were able to replicate the diverse list of climate change impacts that scientists have also identified as possibilities. However, most participants indicated that they did not know where to find climate information, they did not know what information they needed, or they did not know how to use it. The suite of responses to pre-workshop evaluation questions indicates a lack of understanding of at least some of the fundamentals of climate. It is worth further work to determine whether incomplete understanding of the fundamentals of climate inhibits action by the decision-makers attending the workshops. Comparison of the pre- and post-workshop evaluation responses suggest that the participants value climate information specific to Colorado but do not know where to find these resources. In the pre-workshop evaluation, those who indicated that they use climate information in decision-making primarily access that information from federal or state-supported sources. A follow-up question on specific sources found that only the National Weather Service and the NOAA Climate Prediction Center resources were consulted regularly by a majority of participants. The climate literacy of participants improved after the workshop. Perhaps related to the improvement in the climate literacy scores, 85% of participants indicated in the post-workshop evaluation that they would be "somewhat more likely" or "more likely" to use climate information to inform resource management and planning after having participated in the workshop; 15% said they would not change their use of climate

	information compared with before the meeting. The greatest increase in perceived utility of climate information for planning purposes was for ENSO information and precipitation forecasts. Although some participants indicated that they would be more likely to use reservoir storage and inflow information after the workshop, the post-workshop increase in participants' attitudes about the usefulness of these climate indicators was less than what was indicated for other observations and forecasts. When asked to identify major challenges posed by climate change, participants most frequently identified those issues that will require cross-sector collaboration and planning. The challenges presented by drought identified by workshop participants also tended involve cross-sector issues, and successful adaptation efforts developed during the 2000s drought tended to involve enhanced trans-boundary communication. Cooperation across sectors was identified as both a positive outcome of the 2000's drought, but was also highlighted as a hurdle to properly dealing with challenges. In general, positive examples tended to involve local collaboration, while hurdles tended to involve difficulties at the state and federal levels. After the workshop, 59% of participants believed that they did not have all the climate information necessary to make a well-informed planning decision. Even so, there was an increased likelihood that participants will use climate information in decision-making, (85% after the workshops vs. 65% before). Given that participants found many of the tools, products, and information resources presented during the workshop useful, it is likely that they will be using these particular resources in the future.
Presentations:	Workshop presentations: http://wwa.colorado.edu/climate_change/drought09.html Averyt, K., C. Alvord, LA Joyce, J Lukas, JJ Barsugli, G Owen, and B Udall (2009), Developing and Evaluating Workshop Frameworks to Improve Climate Literacy, Eos Trans. AGU, 90(52), Fall Meet. Suppl., Abstract U13D-07
Publications:	Averyt, K., Lukas, J., Alvord, C., Barsugli, J., and Doesken, N. (2009). "The 'Dealing with Drought: Adapting to a Changing Climate' Workshops: A Report for the Colorado Water Conservation Board." (http://wwa.colorado.edu/current_projects/pdfdocs/deal_drought_wrkshp_report_FINAL.pdf)
Partners/Stakeholders	NIDIS

Project Title:	**State Drought Planning in the Western U.S.A: Multi-RISA–Agency–NIDIS Collaboration**
Primary Investigator(s):	A. Steinemann
Contributors:	B. Udall, G.M. Garfin, D. Cayan, E. Miles, D. White, M. Finucane
Core Funding:	NOAA CPO *FUNDING 2009: JULY–DEC*
Summary:	The RISA program supports efforts to "improve the link between climate sciences and society" and "provide information that decision makers can use to cope with drought" (NOAA, 2009). NIDIS is designed to "serve as an early warning system for drought…providing those affected with the best available information and tools to assess the potential impacts of drought, and to better prepare for and mitigate the effects of drought" (NIDIS, 2007). These goals, while mutually reinforcing, lead to the question: How can drought information be provided to decision-makers, most effectively, in order to reduce drought effects? More specifically, how can we make the link between drought information (such as climate and hydrologic data and forecasts) and drought action (such as responses and adaptations)? A promising and concrete way is through state drought plans. Drought plans are viewed as a primary defense against drought. The idea is that early warning, and timely action, can help to reduce drought impacts and vulnerability. Drought plans typically specify the links between drought information (operationalized as indicators and triggers) and corresponding actions. While nearly all states have drought plans or programs, they vary widely in their content and perceived effectiveness—and in their use of drought information. Further, despite widespread reliance on plans to manage drought, little prior work has evaluated these plans, their development, and how early warning systems could be used to reduce drought hazards. Recent work (e.g., Steinemann, 2006; Steinemann et al. 2005) has identified a need for improved drought information for state drought preparedness and response. In particular, a survey of state drought managers in all Western Governors' Association states (Fontaine et al., 2009) found that most states lack—but want—"better data" (e.g., more specific, reliable, and consolidated) and "better guidance" for (a) assessing and predicting drought; (b) developing and evaluating indicators and triggers; (c) monitoring drought conditions within their state, and regionally; (d) justifying drought actions, both short term responses and longer term adaptations; and (e) evaluating drought plans, and drought information used by those plans. Notably, these state drought managers also expressed interest and willingness to participate in follow-up discussions and collaborations—and

	each will be involved in this proposed project. To address these opportunities and needs, our project will investigate, evaluate, and seek to improve the integration and value of drought information for reducing drought hazards through state drought planning and decision-making. For instance, drought information (from RISAs and partners) can be linked to drought indicators and triggers, which can then be linked to drought actions. Our activities (detailed below) will include collaborations among the RISAs, NIDIS, NDMC, WRCC, other partners, and state water managers in the WGA, through several fora, including workshops, focus groups, and individual interactions. (1) How can climate information, such as that provided by RISAs, be integrated into drought plans and state drought decision-making? What are the potential and valuable applications of that information, and how would that value be assessed? (2) How can early warning systems, such as that being developed by NIDIS, help to reduce drought impacts and vulnerability? What drought information will provide the needed basis to take actions, both shorter-term responses and longer-term adaptations? (3) How can state drought plans and planning activities take advantage of climate and other drought information? For instance, how can drought information (e.g., nowcasts and forecasts) be translated into drought indicators and triggers? More generally, how can drought plans, and the information they use, be evaluated and improved?
Proposed Work:	Our work will bring together the western RISAs, agency partners (including NIDIS, NDMC, and WRCC), and WGA state drought decision-makers, as well as other agencies and stakeholders identified by the core group. We will conduct group meetings and a workshop (through teleconferences and web-based techniques) to understand user needs for drought decision-making and the potential of climate and drought information. While the specific timing and types of meetings may evolve, we expect to hold early group meetings with the RISAs, partners, and water managers; conduct individual interviews with each state drought manager in the WGA states; then convene the RISAs, partners, water managers, and other identified stakeholders for a Drought Workshop. To gain a deeper understanding of drought issues and stakeholder needs in each state, before the workshop, the PI will interview each of the WGA state drought managers, using a survey instrument (with input from RISAs and partners), to explore the following dimensions, among others, which will also be explored in our workshops: * Use of drought information: To what extent do states incorporate drought information, such as that developed by the RISAs and partners, into their drought plans and programs? What information do they use, and find most useful? Do they incorporate climate change and climate variability into decision-making? What types of information would be needed and useful for making drought decisions? * Value of information: How do states evaluate the importance of drought information to help prepare for and adapt to drought? What are the metrics of value? What is the role of uncertainty? What types of information are needed for early warning, or for longer-term adaptations? What are the relative risks of false assurance (forecast of no drought, but drought develops) or false alarm (forecast of drought, but no drought develops)? * Indicators and triggers: Which ones are currently used? How were they developed? What are their temporal scales, spatial scales, and sectoral emphases? Are they linked with drought management goals? How can they provide early warning? Are they evaluated; how do states know if they work? * Responses and adaptations: What are the actions in the drought plan, and how are they linked with drought information? Have climate adaptation plans been useful for drought adaptation? What are the tradeoffs between short-term adjustments and long-term adaptation? Do short-term responses promote or impair the ability to reduce long-term vulnerability? * Interstate and intrastate drought planning: Do states coordinate with other states on regional drought planning activities? What is the potential or need for an interstate or basin-wide drought plan? Within each state, how do regional and local drought plans mesh with state-level drought plans? * Underserved populations: Do state drought planning activities provide specific interactions with underserved groups, such as tribes? What about areas without equal access to climate and other information? * Effectiveness: How do states know if drought information and plans are effective, and what are the metrics of "effectiveness"? What constitutes "preparedness"? * Lessons: What broader lessons have been learned? What can each state share with other states? What's needed?
Progress/Results:	Work on this project has been delayed. Because funding was allocated already, this project will fall in as a "no cost extension" and results will be reported in subsequent years.
Partners/Stakeholders	National Drought Mitigation Center, Western Regional Climatic Center, NIDIS

Core Activities

The Core Management Team is also responsible for maintaining and fulfilling obligations relating to outreach and education, and promoting communication among the RISAs and with other federal partners. During 2009, the WWA continued its long-standing reputation with stakeholders and decision-makers as a trusted source of climate information. Collectively, WWA researchers gave over 100 public talks and seminars (Appendix II); were cited, quoted or interviewed by the media over 50 times (Appendix V); and served as members of many committees and organizations (Table 4). In addition, in our continuing efforts to expand climate literacy, WWA sponsored several workshops across the Intermountain West (Table 5). There are also several projects that within the purview of core management activities– all of which are focused on enhancing outreach, communication and education (Table 6).

Table 4. 2009 Organizations, Committees and Coordination Activities with WWA Members

- American Bar Association, Public Lands and Land Use Committee, Section on Natural Resources, Energy and Environmental Law
- American Meteorological Society, Climate Change & Variability Committee
- American Water Resources Association
- Association of Metropolitan Water Agencies (AMWA)
- Carpe Diem Project
- Center for Research Conservation (CRC)
- Climate Change and Water Working Group (CCAWG)
- Colorado Division of Wildlife Climate Change Advisory Board
- Colorado Scientific Society
- Coordinated Research Consortium for the Colorado River Delta
- Dividing the Waters Project
- Ecological Society of America
- Frontiers in Ecology and Environment
- Greater Yellowstone Coalition
- Intergovernmental Panel on Climate Change (IPCC)
- Joint Front Range Climate Change Vulnerability Study
- National Integrated Drought Information System Implementation Team
- National Oceanic and Atmospheric Administration, Near-Term Objectives Team: Climate Assessments
- The Nature Conservancy
- Union of Concerned Scientists, Energy and Water in a Warming World Program
- University of Colorado, Renewable and Sustainable Energy Institute
- US Global Change Research Program (USGCRP)
- Water Availability Task Force (WATF)
- Water Research Foundation (WRF)
- Water Utilities Climate Alliance (WUCA)
- Western Snow Conference
- Western States Water Council (WSWC)
- Western Governors' Association (WGA)

Table 5. 2009 WWA-Sponsored Workshops

Title	Date	Location	Details
NIDIS Climate, Drought and Early Warning on Western Native Lands	June 9–11, 2009	Grand Teton National Park, WY	http://wwa.colorado.edu/Proposals/2010/Docs/NIDIS_Jackson_Hole_Report_Mar2010.pdf
Dealing with Drought: Adapting to a Changing Climate	October 13, 2009	Castle Rock, CO	http://wwa.colorado.edu/climate_change/drought09.html
Dealing with Drought: Adapting to a Changing Climate	October 16, 2009	Glenwood Springs, CO	http://wwa.colorado.edu/climate_change/drought09.html
Dealing with Drought: Adapting to a Changing Climate	October 22, 2009	Durango, CO	http://wwa.colorado.edu/climate_change/drought09.html
US Forest Service Western Watersheds and Climate Change: Water and Aquatic System Tools Workshop	November 17–19, 2009	Boulder, CO	http://www.fs.fed.us/rmrs/climate-change/water-watersheds/
Making Connections: Pine Beetles, Water, Climate, Fire, and the Future Forest	December 7, 2009	Boulder, CO	http://wwa.colorado.edu/ecology/beetle/other.html

Table 6. Core Activities

Project Title:	**WWA Website Reorganization**
Primary Investigator(s):	J. Lukas, K. Averyt
Contributors:	B. Udall, A. Ray, C. Alvord
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.
Proposed Work:	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. However, we now need to refine content to reflect our new research foci.
Progress/Results:	In 2009, in addition to routine updating and maintenance, several key enhancements were made to the WWA website, including the development of databases of WWA publications (http://wwa.colorado.edu/about_us/DBPubs.html) and presentations (http://wwa.colorado.edu/about_us/present.html) since 1999. Work will continue in 2010 to develop more content to support the new research foci. The "Tools & Products" section described below is close to completion.

Project Title:	**Best Practices for Identifying Quality Observational Datasets**
Primary Investigator(s):	N. Doesken, R. Gillies, K. Wolter
Contributors:	K. Averyt
Core Funding:	CWCB, WWA *FUNDING 2009: JAN–DEC*
Summary:	The Colorado and Utah state climatologists have developed unique websites that use the best available data to show observed climate trends. The data are available for public access and maps and menus make it easy to find and select data for analysis and graphing. Data graphics can only be viewed after site users are first presented with full accurate descriptions of the history of each station including station moves and observational changes through history that could affect the observed trends.
Proposed Work:	The group will develop a publication of findings and recommendations on best practices for developing and interpreting historic records and time series and it will be submitted to the American Association of State Climatologists online Journal of Service Climatology. This paper will also document our selection process of the best station records in Colorado and Utah in order to facilitate similar analyses in neighboring states. We will attempt to extend this type of analysis and products to neighboring states. If we succeed in enlarging the scope of this project beyond Colorado, the Western Regional Climate Center would be a logical next webhost for Western U.S. products of this type. This feeds directly into support of a National Climate Service.
Progress/Results:	The Colorado Climate Trends website was launched during the fall of 2009 after more than two years of planning, preparation, data analysis and metadata assessment. So far, feedback has been positive and has mostly come from water managers in Colorado who have perused the site. The unique feature of this site is its focus on metadata. Users of time series data usually can easily view narrative descriptions of station changes over time and then see what, if any, impact those changes have had on time series continuity. Graphing tools to accompany the site have not yet been activated. Many of the time series, even for the best selected stations, still have some missing data which had the potential for fouling graphing products. Overall findings based on Colorado data are that there are no pure time series with homogeneous data for the entire period of record going back 80 to 120 years. There are very few station with ideal data for time series analysis even in the past 40-50 years. Station moves, time of observation changes and changes of instrumentation (moving from the traditional liquid in glass thermometers in cotton region shelters to electronic instrumentation in plastic radiation shields all have the potential for introducing discontinuities to long term data records. Recent cool weather during the last few winters and during the summer of 2009 all have provided a noticeable damping to previously observed strong upward trends in temperature. Similar work has not yet been completed in Utah but will

	hopefully be completed in 2010. A manuscript is being outlined that will describe the processes that have been used and the results that have been found.
Presentations:	Nolan Doesken gave a presentation at Colorado Water Congress, January 2010 meeting in Denver describing and showcasing the Colorado Climate Trends website. Presentations at the Climate Roadshow, a joint CWCB, WWA, Colorado Climate Center endeavor referenced climate trends and the Climate Trends website. Brief references to the Colorado Climate Trends website were included in several other presentations during the past year including the South Platte Water Forum and the Arkansas River Basin Water Forum
Publications:	A short article in the Colorado Water Institute newsletter was published describing the Colorado Climate Trends website during the fall of 2009
Partners/Stakeholders	NOAA

Project Title:	**Intermountain West Climate Summary**
Primary Investigator(s):	J. Lukas, C. Alvord, K. Averyt, A. Ray, K. Wolter
Contributors:	G. Bates, E. Gordon, R. Balaji, J. Barsugli, B. Udall, C. Alvord
Core Funding:	WWA *FUNDING 2009: JAN–DEC*
Summary:	The Intermountain West Climate Summary (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 phenomenon, 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. Beginning in March 2009, the IWCS is released five times per year and is posted on the WWA website: http://wwa.colorado.edu/IWCS/index.html (IWCS e-mail: wwasummary@wwa.colorado.edu). The IWCS provides a valuable service by interpreting and translating climate information and forecasts as well as including two types of summary articles. The first is a Feature Article, which summarizes current climate and water-related research and a Focus Page, which describes a climate service.
Proposed Work:	Implement changes to schedule and organization based on 2008 user evaluation: - Make IWCS entirely web based - Decrease frequency from 8 times per year to 5 times per year. - Eliminate redundant pages (state water availability) and combine others (temperature, precipitation, drought monitor, Standardized Precipitation Index) to create single “recent conditions” page Work with Kelly Redmond and the Western Regional Climate Center to submit TRACS proposal to the Climate Program Office and transfer the bulk of the IWCS to the WRCC. WWA will continue to write Feature articles and Focus pages, and include WWA research highlights to create a quarterly WWA newsletter.
Progress/Results:	The new web-based HTML format of the IWCS was unveiled with the March 2009 issue, with a streamlined and more-user friendly content and organization as outlined above. Subsequent issues in 2009 (April, May, July, October) continued this format, and user feedback regarding the change has been uniformly positive. Production of the IWCS now takes far less WWA staff time per issue, with little, if any, loss of overall effectiveness in conveying timely and salient climate information. The Feature Articles and Focus Pages continue to accompany each issue, and remain in PDF format for ease of printing and sharing. Nearly all of these articles are written expressly for the IWCS.
Presentations:	Lowrey, J. Evaluation of the Intermountain West Climate Summary: Lessons for Communicating Climate Information. Climate Prediction Applications Science Workshop (CPASW) 2009, Norman, OK, March 24, 2009.
Publications:	Issues of the IWCS can be found here: http://wwa.colorado.edu/IWCS/index.html
Partners/Stakeholders	M. L’Heureux (NOAA CPC), G. Garfin (CLIMAS), J. Smith (Stratus)

Project Title:	**Climate Training of Federal Scientists**
Primary Investigator(s):	B. Udall, R. Webb, C. Hennig, L. Brekke
Contributors:	K. Averyt
Core Funding:	NOAA, USBR *FUNDING 2009: JULY–DEC*
Summary:	The emerging reality of climate change presents an additional array of complex, new considerations that the Western water community must now integrate into their analysis, planning, and decision-making processes. Climate change scientists are rapidly developing new, useful knowledge. The obstacle to use is the lack of an effective venue for the research community to transfer the new knowledge and capabilities to the Western water community; and provide training on the associated limitations, uncertainties, and correct utilization of the new knowledge and capabilities as they emerge. This need has been consistently identified as a high priority in many recent venues including: February 2008 Climate Change and Western Water Group (CCAWWG) workshop with Reclamation water and environmental compliance practitioners and managers March 2008 U.S. Climate Change Science Program (CCSP) workshop with Western states and municipalities November 2007 Western States Water Council conference:"Water Policies and Planning in the West: Ensuring a Sustainable Future" Finding from September 2007 NRC Report, "Evaluating Progress of the U.S. Climate Change Science Program: Methods and Preliminary Results": "Discovery science and understanding of climate systems are proceeding well, but the use of that knowledge to support decision making and to manage risks and opportunities of climate change is proceeding slowly" Finding from August 2007 GAO Report: GAO-07-863: "Resource managers have limited guidance from their agencies about whether or how to address climate change in management actions and planning efforts"
Proposed Work:	Sponsoring federal agencies will work with the RISA Program universities to develop a training program scope targeted at ensuring relevant, practical integration of best available climate change information into the technical studies that support federal water resource decision-making in the West. Engagement with non-federal, western water management interests (e.g. state, municipal, irrigated agriculture) will be integrated into the development of the training program so that common needs are effectively designed into the training program. This will position the training program to be robust and useful to the Western water community of practice from the onset. Provide structured, technical training to Western water practitioners, planners, technical specialists and/or decision-makers (aka Western water community) through the university-based Regional Integrated Sciences and Assessments (RISA) program. The RISA centers provide access to internationally recognized technical experts in climate change science.
Progress/Results:	All parties agreed to delay work on this project until the regional climate services initiatives within the participating federal entities emerged. This project will fall in as a "no cost extension" and results will be reported in subsequent years.
Partners/Stakeholders	USBR, NOAA

Project Title:	**Informing the Responsible Use of Climate Models & Projections by Stakeholders**
Primary Investigator(s):	J. Barsugli
Contributors:	G. Guentchev, I. Rangwala, L. Brekke, L. Mearns
Core Funding:	WWA *FUNDING 2009: JULY–DEC*
Summary:	The purpose of this project is to connect stakeholders with climate change projection data in a manner that leads to impacts and vulnerability assessments that accurately reflect the state of scientific understanding of the climate. Two trends are about to collide: First, stakeholders (including Federal agencies with land and water management responsibilities to municipal and regional water providers) are clamoring for climate change information to inform impacts assessments. In many cases this translates into a request for downscaled climate projections and

	guidance on how to use the data. Second, many new datasets of downscaled climate projections have recently come online, such as Reclamation's statistically downscaled climate projection archive (http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/), or are about to come online, such as the large and complex NARCCAP (North American Regional Climate Change Assessment Program www.narccap.ucar.edu) archive of dynamically downscaled projections. Without some guidance, there is the potential that this avalanche of information may lead to a confusing array of assessments. For one stakeholder perspective, consider the congressional testimony of David Behar of the Water Utilities Climate Alliance (Behar, 2009): "I've seen from my own personal experience both at the SFPUC and as a board member at MMWD how difficult it can be to access sound climate information. Even a sophisticated water agency has difficulty finding answers to the most basic questions and accessing data compatible with their systems models. University researchers are busy teaching and publishing, agency staff in Washington D.C. are unknown to us, and those who we call "users" of climate information are often left to scramble haphazardly to collect tidbits of information from a multiplicity of sources as we seek to create resilient communities ready to adapt to the effects of climate change." Behar sees the goal of providing "accessible science" as central to a National Climate Service, and commends the RISAs for being a "notable demonstration model." In these terms, the mission of the proposed clearinghouse is to provide "accessible science" to stakeholders in our region regarding downscaled climate projections. Since the NCS has not yet been defined, let alone implemented, it is still essential that the RISAs engage in this activity. We have proposed a cross-RISA component so that the WWA effort can learn from those RISAs who have participated in impacts assessments, and so that common "lessons learned" can be communicated to NOAA regarding these efforts.
Progress/Results:	In retrospect, the success this past year has been in the communication of the use and interpretation of climate change information to various stakeholders. Much of my work along these lines was supported by the collaboration between Western Water and NOAA/ESRL/PSD, particularly with regard to Federal Partners such as the USFWS, USFS, and NWS. Work with Reclamation has included participation in the CCAWWG, as well as the Reclamation Science and Technology Hydrology Working Group. The second success had been work on evaluation of datasets used in climate change. Working with Levi Brekke and David Raff of Reclamation and with Linda Mearns from NCAR, we are developing a proposal to run NARCCAP-based projections through calibrated hydrology modeling for comparison to the "simple" downscaling that is presently used by Reclamation. The intention is to take these results through the evaluation of system performance metrics to judge whether downscaling method makes a difference in decision relevant metrics. The delay in the release of the NARCCAP data has hampered this study, but it will be pursued in the coming months.
Presentations:	Many of these are workshops where the goal was to inform the integration of climate change projections with resource management. Barsugli, J. (2009). Climate Change and Agriculture. Southwest Marketing Network (Sustainable Agriculture), Durango, CO. Barsugli, J. (2009). Bringing Climate Change Home: What Projections Say for Colorado's Water Resources. (Training for high School Science Teachers), Boulder, CO Barsugli, J. (2009). Climate Change at the Regional Level. USFWS Mountain Prairie Region Ecological Services 2009 Project Leaders Meeting, Denver, CO. Barsugli, J. (2009). Whitepaper on Improvements to Climate Models to Provide Useful Information to Water Managers. . Front Range Water Providers Denver, CO. Barsugli, J. (2009). Whitepaper on Improvements to Climate Models to Provide Useful Information to Water Managers. Aspen Global Change Institute, Aspen, CO. Barsugli, J. (2009). Climate Models and Scenarios of Climate Change in the Western United States. USFS Western Watersheds and Climate Change Working Group, Boulder, CO. Barsugli, J. (2009). Gunnison River Climate History and Change. TNC Gunnison Climate Adaptation Workshop, Gunnison, CO. Barsugli, J. (2009). What's needed from climate modeling to advance actionable science for water utilities? . American Geophysical Union, San Francisco, CO.
Publications:	Barsugli, J., J. Joseph, et al. (2009). "Options for Improving Climate Modeling to Assist Water Utility Planning for Climate Change [White Paper]." Water Utility Climate Alliance: 146.
Partners/Stakeholders	Reclamation, CWCB, Front Range Water Providers, ESRL/PSD, BLM, USFWS, USFS, The Nature Conservancy

Looking Ahead

Last year, the Western Water Assessment underwent a significant reorganization intended to broaden the scope of our research and build on the strengths of researchers in the Intermountain West community. We created an Advisory Board of key stakeholders (Table 7) with the intention they would better informing us of the efficacy of the projects outlined above in the regional community. Our first Advisory Board Meeting was held in April 2010, and the input received from that meeting will be reflected in the FY2011 WWA Statement of Work.

Table 7. Advisory Board Members

Timothy Brick	Chairman, Metropolitan Water District, Southern California
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
Jim Verdin	Deputy Director, National Integrated Drought Information System (NIDIS), USGS
Marc Waage	Manager, Water Resources Planning Division, Denver Water
Robert Wigington	Western Water Policy Counsel, The Nature Conservancy

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.

Appendix I. Personnel and Stakeholders

Table A-1. WWA Personnel

Team Member	Title	Expertise
Alexander, Michael	Scientist, NOAA ESRL Physical Sciences Division	Climate Extremes
Alvord, Christina	Research Associate, Western Water Assessment	Tribal Relations, Outreach
Averyt, Kristen	Deputy Director, Western Water Assessment	Climatology, Assessment Processes
Barsugli, Joseph	Research Associate, CIRES, Univ. of Colorado	Climate Dynamics
Bates, Gary	Research Associate, CIRES, Univ. of Colorado	Climate Modeling
Burke, Indy	Director, Haub School & Ruckelshaus Institute, Univ. of Wyoming	Ecology, Renewable Resources
Cozzetto, Karen	Post-doctoral Research Associate, Department of Environmental Studies, University of Colorado	Hydroclimatology, surface water hydrology and ecology
Deems, Jeff	Research Associate, CIRES, Univ. of Colorado	Climate and Snow Modeling
Doesken, Nolan	Colorado State Climatologist, CSU	Climatology
Dilling, Lisa	Assistant Professor, Environmental Studies, Univ. of Colorado	Climate Info. and Decision-Making
Eischeid, Jon	Research Associate, CIRES, Univ. of Colorado	Climate Modeling
Getches, David	Dean, Univ. of Colorado Law School	Natural Resources Law
Gillies, Robert	Utah State Climatologist, Utah State Univ.	Climatology
Goemans, Chris	Assistant Professor, Agricultural and Resource Economics, CSU	Water Resource Economics
Gordon, Eric	Program Manager (beginning July 1 2010), Western Water Assessment	Climate Adaptation
Gray, Stephen	Wyoming State Climatologist, Univ. of Wyoming	Climatology and Paleoclimatology
Guentchev, Galina	Post-doctoral Research Associate, University Corporation for Atmospheric Research (UCAR), CLIVAR, Postdocs Apply Climate Expertise	Climate Modeling
Hoerling, Martin	Scientist, NOAA ESRL Physical Sciences Division	Climate Variability, Hydrology
Jackson, Steve	Professor, Botany, Univ. of Wyoming	Ecology
Kenney, Douglas	Director, Western Water Policy Program, NRLC, Univ. of Colorado	Western Water Policy and Law
Klein, Roberta	Managing Director of CSTPR, Univ. of Colorado	Environmental Policy
Lukas, Jeffrey	Senior Research Associate, Western Water Assessment	Paleohydrology, Forest Ecology
Mahoney, Kelly	Post-doctoral Research Associate, University Corporation for Atmospheric Research (UCAR), CLIVAR, Postdocs Apply Climate Expertise	Extreme precipitation, numerical modeling, warm season convection
McAfee, Stephanie	National Research Council Associate, Physical Sciences Division (PSD), Earth Systems Research Laboratory (ESRL), NOAA	Climate & Biogeochemistry
McCutchan, James	Deputy Director, Center for Limnology, CIRES, Univ. of Colorado	Limnology
Neff, Jason	Associate Professor, Geological Sciences & Environmental Studies, Univ. of Colorado	Biogeochemistry
Neff, William	Director, PSD, NOAA ESRL	Atmospheric Physics
Nowak, Kenneth	PhD Candidate, CADSWES, Univ. of Colorado	Hydrology
Painter, Thomas	Assistant Professor, Geography, Univ. of Utah	Hydrology
Rajagopolan, Balaji	Associate Professor, Civil Engineering, Univ. of Colorado	Hydrology

Team Member	Title	Expertise
Rangwala, Imtiaz	Post-doctoral Research Associate, University Corporation for Atmospheric Research (UCAR), CLIVAR, Postdocs Apply Climate Expertise	High Elevation Climatology
Ray, Andrea	Scientist, Climate Analysis Branch, NOAA ESRL Physical Sciences Division	Climate-Society Interactions, Water Management
Squillace, Mark	Director, NRLC, Univ. of Colorado	Natural Resources Law
Steffen, Konrad	Director, CIRES, Univ. of Colorado	Climatology
Travis, William	Associate Professor, Geography; Director, CSTPR, Univ. of Colorado	Natural hazards; climate impacts and adaptation
Udall, Bradley	Director, Western Water Assessment	Colorado River, Hydrology, Policy
van Drunick, Suzanne	Assistant Director for Science, CIRES, Univ. of Colorado	Hydrology and Ecology
Webb, Robert S	Chief, Climate Analysis Branch, NOAA ESRL Physical Sciences Division	Paleoclimatology
Wolter, Klaus	Research Associate, CIRES, Univ. of Colorado	Climatology

Table A-2. WWA Stakeholders and Partners

FEDERAL	
Organization	Major Contact(s)
Bureau of Land Management	Edward Rumbold (CO), Rodd Hardy (UT), Scott Archer (CO) Jeff Kitchens (CO)
Bureau of Reclamation	Curt Brown, Chuck Hennig, Terry Fulp, Levi Brekke, James Prairie, Carly Jerla, David Raff, Avra Morgan
Environmental Protection Agency	Laura Farris (Region 8)
National Park Service	Brent Frakes (Rocky Mountain Network), Dave Sharrow (Zion NP), Judy Visty (Rocky Mountain NP), Leigh Welling (Climate Change Coordinator)
National Renewable Energy Laboratory	Chuck Kutscher, Robin Newmark, Larry Flowers
Natural Resources Conservation Service	Randy Julander (UT), Mike Gillespie (CO), Lee Hackleman (WY); Jan Curtis (National Water and Climate Center)
National Integrated Drought Information System (NIDIS)	Roger Pulwarty, James Verdin, Chad McNutt, Lisa Darby, Mike Brewer
NOAA Climate Services Division	Ahsha Tribble, Diana Perfect
NOAA ESRL Communications and Outreach	Carol Knight, Anatta, Katy Human
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, Jeff Zimmerman
U.S. Army Corps of Engineers	Thomas Johnson
U.S. Fish and Wildlife Service	David Campbell, George Smith, Tom Czapla
U.S. Forest Service	Linda Joyce, Chuck Rhoades (RMRS), Polly Hays (Region 2), Rick Hopson
U.S. Geological Survey	Michael Dettinger, Dan Cayan, Jay Cederberg, Jayne Belnap, Warren Day, Jenny Briggs
USDA Agricultural Research Service	Jeanne Schneider
STATE	
Organization	Major Contact
California Dept. of Water Resources	Jeanine Jones
Colorado Water Conservation Board	Jennifer Gimbel, Veva Deheza, Taryn Hutchins-Cabibi, Ben Wade
Colorado Division of Water Resources/State Engineer's Office	Alan Martellaro, Don West
Colorado River Commission of Nevada	Nicole Everett
Colorado State Legislature	Gary Lindstrom
Colorado Department of Public Health and the Environment	Ginny Brannon
Colorado Division of Wildlife	Tom Schreiner
New Mexico Interstate Stream Commission	Mark Murphy
New Mexico State Engineer's Office	John Longworth
Utah Department of Natural Resources	Kevin Valcare, Matthew Lindon
Utah Division of Forestry	Scott Zeidler
Utah Division of Water Resources	Craig Miller
Utah Governor's Office	Julie Breckenridge, Lis Cohen
Wyoming Attorney General's Office	Jane Caton
Wyoming State Engineer's Office	Becky Mathisen, Randy Tullis, John Shields, Matt Hoobler
Wyoming Water Development Commission	Bruce Brinkman, Barry Lawrence, L. Mike Besson
LOCAL	
Organization	Major Contact
Aurora Water, CO	D. Alfredo Rodriguez, Kevin Reidy, Amy

	Klabunde, Mike McHugh
Boulder County Parks and Open Space	Chad Julian, Therese Glowacki
Centennial Water and Sanitation District, CO	John Hendrick, Rick McLoud
Cheyenne Board of Public Utilities, WY	Clint Bassett, Herman Noe, Timothy Wilson
City of Boulder, CO	Carol Ellinghouse
City of Fort Collins, CO	Dennis Bode, Donnie Dustin
City of Lafayette, CO	Douglas Short, Peter Johnson
City of Louisville, CO	Dan Mathes, Tom Phare
City of Thornton, CO	Emily Hunt, Mark Koleber, Greg Johnson
City of Westminster, CO	Mike Happe, Josh Nims, Stu Feinglas
Colorado River Water Conservation District, CO	Eric Kuhn, Dave Kanzer
Colorado Springs Utilities	Brett Gracely, Kevin Lusk, Leon Basdekas
Colorado Waterwise Council	Paul Lander
Denver Water	Mark Waage, Robert Steger, Laurna Kaatz, Don Kennedy
Metropolitan Water District of Southern CA	Jan Matusak, Peter Jacobsen
Mojave Valley Irrigation and Drainage Dist., AZ	Donald Currie
Northern Colorado Water Conservancy District, CO	Andy Pineda, Esther Vincent
Provo River Water Users Assoc.	Jeff Budge
Pueblo Water Board, CO	Alan Hamel
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
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
UNIVERSITY	
Organization	Major Contact
Climate Assessment for the Southwest (CLIMAS), University of Arizona	Dan Ferguson, Jonathan Overpeck, Gregg Garfin, Gigi Owen, Zack Guido
Univ. of Washington	Dennis Lettenmaier, Lara Whitley Binder
Colorado Climate Center, Colorado State University	Nolan Doesken
Colorado Forest Restoration Institute, Colorado State University	Tony Cheng, Jessica Clement
Colorado Water Institute, Colorado State University	Reagan Waskom
Colorado State University	Jason Sibold, Jessica Clement, Dan Smith, Jose Salas, Monique Rocca
Desert Research Institute; Western Regional Climate Center	Kelly Redmond
Kansas State University	Mary Knapp

National Center for Atmospheric Research	David Yates, Kathy Miller, Linda Mearns
Southeast Climate Consortium; Florida State	David Zierdan
University of Nevada	Thomas 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	Indy Burke, Jaqueline Shinker, Diana Hulme
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
OTHER/Non Profit	
Organization	Major Contact
American Water Works Association Research Foundation	Rob Renner
Arapahoe Basin Ski Area	Tim Finnigan
Bloomberg (media)	John Lippert
Carpe Diem (EXLOCO)	Kimery Wiltshire
Carver Schwarz McNab & Bailey, LLC	Dave Bailey
Climate Science Forum	Michael Fortune
Colorado Foundation for Water Education	Kristin Maharg
Colorado Water Congress	Doug Kemper
Conservation International	Hannah Campbell
Environmental Defense	Jennifer Pitt
Forest Health Task Force (Summit County, CO)	Howard Hallman
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	Koren Nydick
MWH Global	Gerald Gibbens
National Public Radio - Denver	Jeff Brady
Omaha World Herald	Nancy Gardner
Pacificorp	Darce Guyman
Resource Media	Theo Stein
Rocky Mountain Climate Organization	Tom Easley, Stephen Saunders
Regional Transportation District (RTD) - Denver	Michael Carlson
Sierra Club	Barbara Williams
Sustainable Tucson	Madeline Kiser
Tetra Tech	John Edrich

The Nature Conservancy	Robert Wigington
Trout Unlimited	Melinda Kassen
Vail Resorts	Luke Cartin
Walsh Environmental	Margit Hentschel
Water Utility Climate Alliance	David Behar (San Francisco Public Utilities Commission), Paul Fleming (Seattle Public Utilities), Brandon Goshen (Metropolitan Water District), Angela Licata (New York City Dept. of Environmental Protection)
Western Governors' Association	Madeline West, Rich Halvey, Tom Iseman
Western Resource Advocates	Bart Miller, Stacy Tellinghausen
Western States Water Council	Tony Willardson, Craig Bell

Appendix II. Presentations

January 11, 2009
K Wolter
International Weather and Climate Events of 2008
American Meteorological Society Meeting, Atlanta, GA

January 13, 2009
K Averyt
Panelist, Water in the West
American Meteorological Society, Phoenix, AZ

January 14, 2009
K Wolter
A New and Improved Multivariate Enso Index (MEI)
American Meteorological Society Meeting, Phoenix, AZ

January 15, 2009
J Lukas
What Tree Rings tell us About Hydrologic Variability in Colorado and Denver Water's Watersheds
Denver Water Planning Forum, Denver, CO

January 21, 2009
K Averyt
Water in the West
University of Colorado at Boulder, Boulder, CO

January 22, 2009
K Wolter
Seasonal Outlook through March 2009
Colorado Water Availability & Flood Task Force, Denver, CO

January 27, 2009
B Udall
Climate Change and Water: Adaptation Challenges
National Research Council Panel: America's Climate Choices: Adapting to the Impacts of Climate Change, Washington, D.C.

January 28, 2009
J Deems
Desert Dust Impacts on Colorado River Basin Snowpack and Runoff
Emerging Issues in Climate Change - UNEP Expert Workshop, New Delhi, India

January 28, 2009
B Udall
Climate Change in Colorado
Presentation to Colorado Water Conservation Board, Denver, CO

February 4, 2009
J Lukas
Tree-ring Paleohydrologies and their Application to Water Management in Colorado and the West
Hydrologic Sciences and Water Resources Engineering Seminar, University of Colorado, Boulder, CO

February 9, 2009
B Udall
Risk of Colorado River Reservoir Drying and Implications for River Management in the 21st Century
, Boulder, CO

February 11, 2009
B Udall
Climate Change and the linkage to Water Resources: What Everyone Should Know
EPA Region 8 Meeting, Denver, CO

February 18, 2009
J Barsugli
Panelist
CO-LABS Panel on Climate Change and Water, Denver, CO

February 20, 2009
K Averyt
Climate Change in Colorado
Agriculture Group, Greeley, CO

February 24, 2009
J Barsugli
Climate Change 101
Utah's Water Supply Conference , Salt Lake City, UT

February 25, 2009
K Wolter
Seasonal Outlook though May 2009
Colorado Water Availability & Flood Task Force, Denver, CO

March 6, 2009
K Wolter
Let it snow, Let it Snow, Let it Snow!
Bixby Elementary School, Boulder, CO

March 10, 2009
B Udall
Climate Change and Water: Adaptation Challenges
Wasatch Sustainability Summit, Salt Lake City, UT

March 17, 2009
B Udall
Climate Change and the Relationship to Water Resources
Johnson Foundation Conference on Water, Racine, WI

March 20, 2009
K Wolter
Seasonal Outlook through June 2009
Colorado Water Availability & Flood Task Force, Denver, CO

March 23, 2009
K Wolter
Experimental Seasonal Climate Forecasts
Binational Drought Science Conference, San Diego, CA

March 24, 2009
J Barsugli
Colorado River: Out of Water or Out of Context
Climate Prediction Applications Science Workshop , Norman, OK

March 25, 2009
K Averyt
An Uncertainty Framework for Regional Climate Assessments?
Climate Prediction Applications Science Workshop , Norman, OK

March 25, 2009
K Nowak
Nonparametric Daily Disaggregation of Annual Streamflow Values
Colorado State University Hydrology Days, Fort Collins, CO

March 25, 2009
B Udall
Climate Change in Colorado, A Synthesis to Support Water Resources Management and Adaptation
Joint Agriculture Committee, Denver, CO

March 25, 2009
B Udall
Climate Change in Colorado
Joint Agriculture Committee, Colorado Legislature, Denver, CO

March 27, 2009
B Udall
Resolving Projections for the Colorado River Basin
Border Governors' Binational Drought Conference, San Diego, CA

April 3, 2009
K Nowak
Water Supply Risk on the Colorado River: Can Management Mitigate?
University of Colorado Hydrologic Science Symposium, Boulder, CO

April 3, 2009
B Udall
Climate Change, Water and The West
Southwestern Water Conservation District, Durango, CO

April 3, 2009
B Udall
Climate Change, Water and The West
Southwestern Water Conservation District, Durango, CO

April 7, 2009
B Udall
Water Resources and Drought
US Climate Change Science Program Workshop on Enhancing US Contributions to Working Group 2 of the Intergovernmental Panel on Climate Change AR5, Washington D.C

April 10, 2009
J Barsugli
Climate Change and Agriculture
Southwest Marketing Network , Durango, CO

April 12, 2009
N Doesken
Colorado Climate Trends Website
Arkansas River Basin Water Forum, Longmont, CO

April 14, 2009
J Barsugli
Climate Models: Interpretation and Use
National Weather Service Climate Change Training, Boulder ,CO

April 14, 2009
K Wolter
Thoughts About the Next Three to Five Months in North America, with Special Focus on (South-)Eastern U.S. Videoconference
Eastern Seasonal Assessment Workshop, National Interagency Fire Center (NIFC), Shepherdstown, WV

April 15, 2009
K Wolter
Thoughts About the Upcoming Spring & Summer in North America, with Special Focus on (South-)Western U.S.
National Interagency Fire Center Workshop, Boulder, CO

April 15, 2009
K Wolter
"Natural" Climate Variability
Western Region Climate Change Workshop, Boulder, CO

April 15, 2009
B Udall
The Western Water Assessment: Connecting Climate Science with Decision Making in the Rocky Mountain West
National Weather Service Western Region Climate Change Workshop, Boulder, CO

April 15, 2009
B Udall
The Western Water Assessment: Connecting Climate Science with Decision Making in the Rocky Mountain West
National Weather Service Western Region Climate Change Workshop, Boulder, CO

April 21, 2009
B Udall
Resolving Projections for the Colorado River Basin
Project Update Meeting, Boulder, CO

April 22, 2009
K Wolter
Seasonal Outlook through September 2009
Colorado Water Availability & Flood Task Force, Denver, CO

April 28, 2009
K Nowak
Water Supply Risk on the Colorado River: Can Management Mitigate?
Southern Nevada Water Authority - Las Vegas Wash Coordination Committee Meeting, Las Vegas, NV

May 2, 2009
T Painter
Where Deserts and Mountains Collide: the Implications of Accelerated Snowmelt by Desert Dust
Guy F. Atkinson Distinguished Lecture Series, Department of Geology and Geophysics, University of Utah, Salt Lake City, UT

May 5, 2009
B Udall
Climate Change Adaptation and Water Resources
Uniersity Corporation for Atmospheric Research Office of Government Affairs House Briefing, Washington, D.C.

May 14, 2009
J Barsugli
Climate Change at the Regional Level
US Geological Survey Science Center , Fort Collins, CO.

May 27, 2009
K Wolter
Seasonal Outlook through September 2009
Colorado Water Availability & Flood Task Force, Denver, CO

June 2, 2009
K Nowak
Using Wavelets for Spectral Analysis of Streamflow Data in the Colorado River Basin
Colorado River Hydrology Working Group, Boulder, CO

June 15, 2009
T Painter
Where Mountains and Deserts Collide: Implications of Accelerated Snowmelt by Disturbed Desert Dust
NASA Earth System Science at 20 years Symposium, Washington, D.C.

June 18, 2009
K Wolter
Seasonal Outlook through October 2009
Colorado Water Availability & Flood Task Force, Denver, CO

July 14, 2009
B Udall
The Regional Integrated Sciences Assessment Perspective on Climate Services
Climate Working Group Meeting, Broomfield, CO

July 16, 2009
K Wolter
Long Term Weather Outlook
Colorado Water Availability & Flood Task Force, Denver, CO

July 27, 2009
J Barsugli
Bringing Climate Change Home: What Projections Say for Colorado's Water Resources
Training for High School Science Teachers, Boulder, CO

July 29, 2009
B Udall
A Proposed Framework for Collaborative Colorado River Decision Making Supported by Social and Physical Science
Presentation to Mike Connor, Commissioner Bureau of US Bureau of Reclamation, Assistant Department of Interior Secretary Anne Castle, Washington, D.C.

August 10, 2009
J Barsugli
Summary of Recent Papers on the Colorado River
Teleconference, Front Range Water Providers, Teleconference

August 14, 2009
T Painter
When Deserts and Mountains Collide: The Impact of Desert Dust on Snowmelt Hydrology in the Colorado River Basin
Jet Propulsion Laboratory Science Visitor and Colloquium Program, Pasadena, CA

August 19, 2009
D Kenney
The Last Drop: Colorado River Drought and Climate Change
The National Center for Atmospheric Reserach Journalism Fellows, Boulder, CO

August 20, 2009
J Barsugli
The Certain Uncertain Future of the Colorado River, Panelist for "Integrating Climate Change and Water Planning"
Colorado Water Congress Summer Conference, Steamboat Springs, CO

August 25, 2009
J Barsugli
Climate Change at the Regional Level
US Fish and Wildlife Service Mountain Prairie Region Ecological Services 2009 Project Leaders Meeting, Denver, CO

August 26, 2009
K Wolter
Long Term Weather Outlook
Colorado Water Availability & Flood Task Force, Denver, CO

September 9, 2009
B Udall
Resolving Projections for the Colorado River Basin
Colorado River Board of California, Ontario, CA

September 15, 2009
J Barsugli
White paper on Improvements to Climate Models to Provide Useful Information to Water Managers
Front Range Water Providers, Boulder, CO

September 16, 2009
K Averyt
Invited Panelist & Presenter
Climate Services for Water Managers, Webinar

September 18, 2009
T Painter
What's the Dirty Secret of Dirty Snow
Colorado River Water Conservancy District Annual Meeting, Grand Junction, CO

September 21, 2009
J Barsugli
White paper on Improvements to Climate Models to Provide Useful Information to Water Managers
Aspen Global Change Institute, Aspen, CO

September 22, 2009
K Wolter
Climate Change in Colorado: Present, Past, and Future
Boulder Audubon Society, Boulder, CO

September 29, 2009
B Udall
Global Climate Change Impacts in the U.S.: Water Resources Findings
Global Change Impacts in the United States Webinar, Webinar

October 2, 2009
B Udall
Global Biogeochemical Cycles : Humanity's 21st Century IQ Test
University of Colorado Center for the American West Board Retreat, Estes Park, CO

October 5, 2009
G Guentchev
Statistical Significance of the Model-Observed Differences in Precipitation Variability for the Historical 1951-1999 Period
Colorado River Hydrology Group meeting, Boulder, CO

October 7, 2009
K Wolter
What Does El Niño Mean for Drought in Texas?
National Drought Forum, Austin, TX

October 8, 2009
J Barsugli
Climate in Colorado
American Planning Association, Estes Park, CO

October 8, 2009
K Wolter
El Niño as a 'Drought-Buster' in Texas: How Reliable is it, or What Can we Expect this Winter? Are the September Rains a Sign of Things to Come?
Drought Monitor Forum, Austin, TX

October 14, 2009
B Udall
Climate Change Adaptation: Water Sector Wishes, Wants, Constraints and Cravings
University Corporation of Atmospheric Research Forum, Boulder, CO

October 15, 2009
K Wolter
Panelist, Seasonal Weather Indices
MDA EarthSat Weather Meeting, Las Vegas, NV

October 20, 2009
B Udall
Water Sector Needs and Wants from Climate Models
Aspen Global Change Institute, Aspen, CO

October 22, 2009
K Averyt
Solar Thermal & Coal-Fired Power Plants: Consequences for the Western US and Colorado River Basin
Renewable Energy in the Southwest: Concentrated Solar and Beyond, Tucson, AZ

October 22, 2009
T Painter
Dirty Little Secrets of the Greatest Snow on Earth
Green Month Sustainability Lecture Series at Park City, sponsored by Swaner and the University of Utah Office of Sustainability, (with Peter Metcalf and Jim Steenburgh), Salt Lake City, UT

October 27, 2009
D Kenney
Interstate Water Allocation in the United States: Part 2 -- The Colorado River
Presentation to the General Institute for Water Planning (GIWP), People's Republic of China, Beijing, China

November 2, 2009
B Udall
Board of Directors' Retreat
Metropolitan Water District of Southern California 2060, Los Angeles, CA

November 3, 2009
K Wolter
What can California Expect This Winter?
Winter 2010 Outlook Workshop, San Diego, CA

November 10, 2009
K Wolter
What can the Upper Colorado Basin Expect this Winter?
NOAA National Integrated Drought Information System Weekly Drought Webinars, Boulder, CO

November 17, 2009
J Barsugli
Climate Models and Scenarios of Climate Change in the Western United States
US Forest Service Western Watersheds and Climate Change Working Group, Boulder, CO.

November 18, 2009
J Lukas
TreeFlow: Using Tree-ring Paleohydrology as a Planning Tool
Western Watersheds and Climate Change - Water and Aquatic System Tools Workshop (USDA Forest Service), Boulder, CO,

November 30, 2009
K Wolter
Reliability of ENSO signal in Western U.S. in last decade
California Water Resources Workshop , San Diego, CA

December 8, 2009
J Barsugli
Gunnison River Climate History and Change
The Nature Conservancy Gunnison Climate Adaptation Workshop,, Gunnison, CO

December 8, 2009
K Wolter
Upper Colorado 2009-10: Quo Vadis?
Seven States Meeting, Las Vegas, NV

December 8, 2009
B Udall
Western Water Challenges in the 21st Century
Urban Land Institute Annual Meeting, Las Vegas, NV

December 14, 2009
K Averyt
Developing and Evaluating Workshop Frameworks to Improve Climate Literacy
American Geophysical Union Fall Meeting, San Francisco, CA

December 15, 2009
T Painter
A Five-year Record of Radiative and Hydrologic Forcing by Desert Dust in the Colorado River Basin
American Geophysical Union Fall Meeting, San Francisco, CA

December 15, 2009
B Udall
Water Resource Findings from Global Change Impacts in the United States
American Geophysical Union Fall Meeting, San Francisco, CA

December 15, 2009
T Painter
Water Yield Loss in the Upper Colorado River Basin Driven by Dust Radiative Forcing in Snow
American Geophysical Union Fall Meeting, San Francisco, CA

December 16, 2009
J Barsugli
What's Needed from Climate Modeling to Advance Actionable Science for Water Utilities?
American Geophysical Union Fall Meeting, San Francisco, CA

December 16, 2009
T Painter
Radiative Forcing by Desert Dust in the Colorado River Basin from 2000 to 2009 Using Coupled Satellite and in situ Measurements
American Geophysical Union Fall Meeting, San Francisco, CA

December 17, 2009
E Gordon
Identifying Decision-Makers' Science Needs for Adaptation for Climate-Related Impacts on Forest Ecosystem Services
American Geophysical Union Fall Meeting, San Francisco, CA

December 17, 2009
B Udall
The Need for Better Science in the Colorado River Basin to Support Decision Making
Presentation to Department of Interior Secretary Salazar, Assistant Secretary Anne Castle and Chairman Raul Grijalva, Washington, D.C.

October, 2009
N Doesken
Colorado Climate Trends Website
South Platte River Forum, Longmont, CO

October, 2009
K Wolter
Snow Storms
Science Day Lecture, Boulder, CO

October, 2009
T Painter
Impact of Desert Dust on Snowmelt Resources in the Colorado River Basin
Briefing to Department of Interior Assistant Secretary Anne Castle, Washington, D.C.

October, 2009
T Painter
Impact of Desert Dust on Snowmelt Resources in the Colorado River Basin
Briefings of Congressional Staffers, US House Subcommittee on Water and Power, US Senate Subcommittee Energy and Water Resources, Colorado Senator Mark Udall , Washington, D.C.

September 290, 2009
B Udall
Water, Climate Change and Sustainability
Association of State Drinking Water Administrators, Denver, CO

Appendix III. Major Awards

2009 Department of Interior Partners in Conservation Award, Appendix U

2009 Governor's Award for Science, Finalist, Climate Change in Colorado Report

Appendix IV. Publications

Alvord, C. (2009). The Water Year 2009 in Review. Intermountain West Climate Summary **5**(6).

Averyt, K. (2009). Continuing Paths and New Directions for the Western Water Assessment. Intermountain West Climate Summary **5**(5).

Averyt, K., Lukas, J., Alvord, C., Barsugli, J., and **Doesken, N.** (2009). The "Dealing with Drought: Adapting to a Changing Climate" Workshops. Report to the Colorado Water Conservation Board.

Averyt, K., McNutt, C., and Pulwarty, R. (2009). Research Directions in Support of the Fifth IPCC Report: A Report to the USGCRP. Report to the U.S. Global Change Research Program.

Averyt, K., Alvord, C., Joyce, L., **Lukas, J., Barsugli, J.**, Owen, G., and **Udall, B.** (2009). Developing and Evaluating Workshop Frameworks to Improve Climate Literacy American Geophysical Union Fall Meeting Abstract, U13D-07.

Barsugli, J., Anderson, C., Smith, J., and Vogel, J. (2009). What's Needed from Climate Modeling to Advance Actionable Science for Water Utilities? American Geophysical Union Fall Meeting Abstract, H331-08.

Barsugli, J. Nowak, K., Rajagopalan, B., Prairie, J., and Harding, B. (2009). Comment on "When Will Lake Mead go Dry?" by T. P. Barnett and D. W. Pierce. Water Resources Research., **45**, W09601, doi:10.1029/2008WR007627.

Barsugli, J., Anderson C., Smith, J., and Vogel, J. (2009). Options for Improving Climate Modeling to Assist Water Utility Planning for Climate Change. White Paper prepared for the Water Utility Climate Alliance.

Deems, J., Lundquist, J., and Loheide, S. (2009). Climate Change Impacts on Snowmelt Hydrology in Small Sierra Nevada Basins for Ecological Applications. American Geophysical Union Fall Meeting Abstract, H33E-0935.

Flanner, M., Zender, C., Hess, P., Mahowald, N., **Painter, T.**, Ramanathan, V., and Rasch, P. (2009). Springtime Warming and Reduced Snow Cover from Carbonaceous Particles. Atmospheric Chemistry and Physics **9**: 2481-2497.

Gangopadhyay, S., Harding, B., **Rajagopalan, B., Lukas, J.**, and Fulp, T. (2009). A Non-Parametric Approach for Paleohydrologic Reconstruction of Annual Streamflow Ensembles. Water Resources Research **45**, W06417.

Gordon, E., and **Lukas, J.** (2009). Identifying Decision-Makers' Science Needs for Adaptation for Climate-Related Impacts on Forest Ecosystem Services. American Geophysical Union Fall Meeting Abstract, NH41A-1233.

Guentchev, G., Barsugli, J., Eischeid, J., Raff, D., and Brekke, L. (2009). How Well do the GCMs Replicate the Historical Precipitation Variability in the Colorado River Basin? American Geophysical Union Fall Meeting Abstract, U13B-0558.

Hoerling, M., Lettenmaier, D., Cayan, D., and **Udall, B.** (2009). Reconciling Future Colorado River Flows. Southwest Hydrology **8**(3).

Jerla, C., and Prairie, J. (2009). Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead & Efforts Addressing Climate Change and Variability. Intermountain West Climate Summary **5**(1).

Kenney, D., Klein, R., and **Goemans, C.** (2009). Preliminary Findings from Western Water Assessment's "Water Rights and Climate Change" Project. Intermountain West Climate Summary **5**(2).

Kenney, D. (2009). The Colorado River: What Prospect for 'A River No More'. In F. Molle and P. Wester, eds., River Basins: Trajectories, Societies, Environments: Comprehensive Assessment of Water Management in Agriculture., CAB International: Wallingford England**:** 123-146.

Leary, N., **Averyt, K.**, Hewitson, B., and Marengo, J. (2009). Crossing Thresholds in Regional Climate Research: Synthesis of the IPCC Expert Meeting on Regional Impacts, Adaptation, Vulnerability, and Mitigation. Climate Research **40**: 121-131, doi:10.3354/cr00832.

Lowrey, J. Ray, A., and **Webb, R.** (2009). Factors Influencing the Use of Climate Information by Colorado Municipal Water Managers. Climate Research **40**: 103-119.

Lowrey, J. and M. L'Heureux (2009). New ENSO Alert System from NOAA Climate Prediction Center. Intermountain West Climate Summary **5**(5).

Lukas, J. (2009). TreeFlow: A Comprehensive Web Resource for Tree-ring Reconstructions of Streamflow. Intermountain West Climate Summary **5**(5).

Malmberg, J. (2009). The National Center for Atmospheric Research's Marshall Field: Winter Weather Precipitation Research. Intermountain West Climate Summary **5**(1).

Malmberg, J. (2009). The Climate Prediction Center's U.S. Temperature and Precipitation Trend Maps. Intermountain West Climate Summary **5**(2).

Malmberg, J. (2009). The Colorado Avalanche Information Center. Intermountain West Climate Summary **5**(3).

McAfee, S. and J. Russell (2009). Simulated Topography in Western North America Impacts Hemispheric Circulation Patterns and Regional Precipitation in IPCC AR4 Coupled Models. American Geophysical Union Fall Meeting Abstract, GC233A-0712.

Miller, J., **Rangwala, I.**, Chen, Y., and Russell, G. (2009). Climate Change and the Water Vapor Feedback at High Altitudes and Latitudes. American Geophysical Union Fall Meeting Abstract, B33A-0364.

Nowak, K., Rajagopalan, B., and Prairie, J., (In Press). A Non-parametric Stochastic Approach for Multisite Disaggregation of Annual to Daily Streamflow: Water Resources Research.

Overpeck, J., Anderson, C., Cayan, D., Dettinger, M., Dow, K., Hartmann, H., Jones, J., Miles, E., Mote, P., Shafer, M., **Udall, B.**, and White, D. (2009). Climate Services: the RISA Experience.

Painter, T., Deems, J., Belnap, J., Hamlet, A., Landry, C., and **Udall, B**. (In review). Response of Colorado River Runoff to Dust Radiative Forcing and Snow. Proceedings of the National Academy of Sciences.

Painter, T., Deems, J., Belnap, J., Hamlet, A., Landry, C., and **Udall, B.** (2009). Water Yield Loss in the Upper Colorado River Basin Driven by Dust Radiative Forcing in Snow. American Geophysical Union Fall Meeting Abstract, H11E-0881.

Rajagopalan, B., Nowak, K., Prairie, J., **Hoerling, M.**, Harding, B., **Barsugli, J., Ray, A.,** and **Udall, B.** (2009). Water Supply Risk on the Colorado River: Can Management Mitigate? Water Resources Research **45**, W08201, doi:10.1029/2008WR00765.

Rangwala, I. and J. Miller (2009). 20th Century Trends in the Maximum and Minimum Temperatures in Colorado's San Juan Mountains. American Geophysical Union Fall Meeting Abstract, B33A-0363.

Ray, A. (2009). Water Resources Decision-Makers and their needs for Decadal Climate Prediction. Intermountain West Climate Summary **5**(3).

Rice, J., Woodhouse, C., and **Lukas, J.** (2009). Science and decision-making: Water management and tree-ring data in the western United States. Journal of the American Water Resources Association **45**(5): 1248-1259.

Schaepman, M., Ustin, S., Plaza, A., **Painter, T.,** Verrelest, J. and Liang, S. (In press). Earth System Science Related Imaging Spectroscopy – An assessment. Remote Sensing of Environment.

Shreve, C., Okin, G., and **Painter, T.** (In press). Indices for Estimating Fractional Snow Cover in the Western Tibetan Plateau. Journal of Glaciology, **55**(192): 737-745.

Udall, B. and **Averyt, K.** (2009). A Critical Need: A National Interagency Water Plan. Southwest Hydrology **8**(1): 18-19.

Udall, B. (2009). Water in the Rockies: A Twenty-First Century Zero-sum Game. In B. Conover, ed., How the West was Warmed, Fulcrum Publishing.

Udall, B. and R. Pulwarty (2009). US Global Climate Change Impacts Report, Water Sector. American Geophysical Union Fall Meeting, Abstract GC23B-05.

Unified Synthesis Product Team, (2009). Global Climate Change Impacts in the United States. U.S Climate Change Science Program, [B. Udall: Lead Author, Water Sector Chapter].

Wang, S., **Gillies, R.** ,Jin, J., and Hipps, L. (2009). Recent Rainfall Cycle in the Intermountain Region as a Quadrature Amplitude Modulation from the Pacific Decadal Oscillation. Geophysical Research Letters. **36**: L02705, doi:10.1029/2008GL036329.

Wang, S., **Gillies, R.**, Takle, E., and Gutowski Jr., W. (2009). Evaluation of Precipitation in the Intermountain Region as Simulated by the NARCCAP Regional Climate Models. Geophysical Research Letters. **36**: L11704, doi:10.1029/2009GL037930.

Webb, R., Pulwarty, R., Davidson, M., Shea, E., Nierenberg, C., and Dole, R. (2009). Experimental Climate Information Services in Support of Risk Management. American Geophysical Union Fall Meeting Abstract, U13D-05.

Appendix V. Media Coverage

February 24, 2009
Climate change could create Utah water challenges, *Daily Herald*
http://heraldextra.com/news/state-and-regional/article_ccc70c71-15c4-519b-8f33-1fa2fc0dc4bd.html
Joe Barsugli

February 26, 2009
Las Vegas Running out of Water Means Dimming Los Angeles Lights, *Bloomberg.com*
http://www.bloomberg.com/apps/news?pid=20601109&sid=a_b86mnWn9.w&refer=home
Brad Udall

April 20, 2009
Study: Shortages likely on Colorado River by 2050, *San Francisco Chronicle*

http://www.sfgate.com/cgi-bin/article.cgi?f=/n/a/2009/04/20/state/n145427D24.DTL
Brad Udall, Joe Barsugli

April 21, 2009
Study: Shortage likely on Colorado River by 2050, *USA Today*
http://www.usatoday.com/weather/drought/2009-04-21-colorado-river-shortages_N.htm
Brad Udall

April 23, 2009
Dust Storms Escalate, Prompting Environmental Fears: Increase in Dirt Affects Ecosystems in Western States, *Washington Post*
http://www.washingtonpost.com/wp-dyn/content/article/2009/04/22/AR2009042203685.html
Tom Painter, Jeff Deems

May 1, 2009
Colorado Water Congress 2009 Summer Conference ,
http://www.cowatercongress.org/SummerConference/speakersbios.aspx
Joe Barsugli

May 1, 2009
Peak Oil Pioneers, *ASPO-USA*
http://www.aspo-usa.com/peak_oil_pioneers.cfm
Brad Udall

May 7, 2009
Four Corners Summit on Sustainable Cities, *Arizona Technology Council*
http://www.aztechcouncil.org/cwt/External/WCPages/WCEvents/EventDetail.aspx?EventID=510
Brad Udall

May 14, 2009
Climate Change, Water Shortages Conspire to Create 21st Century Dust Bowl, *New York Times*
http://www.nytimes.com/gwire/2009/05/14/14greenwire-climate-change-water-shortages-conspire-to-cre-12208.html?pagewanted=all
Tom Painter, Jeff Deems

May 24, 2009
Colorado Dust Storms Speed Snowmelt, *Los Angeles Times*
http://articles.latimes.com/2009/may/24/nation/na-pink-snow24
Tom Painter, Jeff Deems

Spring 2009
Western Water Policy Program, *Baselines: Newsletter of the Natural Resource Law Center, University of Coloardo*
http://www.google.com/url?sa=t&source=web&ct=res&cd=2&ved=0CBAQFjAB&url=http%3A%2F%2Fwww.colorado.edu%2Flaw%2Fcenters%2Fnrlc%2Flibrary%2FPublications%2FBaselineNewsletters%2F2009_Spring_NRLC_newsletter.pdf&ei=ALbhS8XkJpL-M Xl_a4D&usg=AFQjCNFWkwKWRYhJYVarBICnxBqD31afNQ&sig2=9pQpV-D5tdvxbE8Grqqvh g
Doug Kenney

May 26, 2009
CIRES Researchers Recognized for Role in Historic Colorado River Shortage Agreement, *CIRES, University of Colorado News Room*
http://cires.colorado.edu/news/press/2009/riverAgreement.html
Edie Zagona, Balaji Rajagopalan, Brad Udall

May 30, 2009
Heating up in the West, *Anchorage Daily News*
http://www.adn.com/2008/04/01/361185/march-31-alaska-ranger-hearing.html
Brad Udall

June 1, 2009
Press Release No. 820, *World Meteorological Organization*
http://www.wmo.ch/pages/mediacentre/press_releases/pr_820_en.html
Balaji Rajagopalan

June 1, 2009
The Norbert Gerbier-MIMM International Award Ceremony, *Indian Institute of Tropical Meteorology*
http://www.tropmet.res.in/static_page.php?page_id=107
Balaji Rajagopalan

June 1, 2009
Water Blitz, *Rocky Mountain National Park Continental Divide Research Learning Center*
http://www.nps.gov/romo/parkmgmt/upload/water-blitz.pdf
James McCutchan, Suzanne Van Drunnick

June 23, 2009
Global News Digest, *Water 21*
http://www.iwapublishing.com/template.cfm?name=gndjun2309
Brad Udall

July 1, 2009
Management and water supply on the Colorado River, *UCAR Magazine*
http://www2.ucar.edu/magazine/findings/management-and-water-supply-colorado-river
Balaji, Rajagopalan, Ken Nowak, Joe Barsugli, Brad Udall

July 1, 2009
Western Water Supplies Thretented by Climate Change, *Geology.com*
http://geology.com/press-release/colorado-river-water-supply/
Edie Zagona, Balaji Rajagopalan, Brad Udall

Summer 2009
MySphere: How people work, research, and relax at CIRES, *CIRES, University of Colorado News Room*
http://cires.colorado.edu/science/spheres/water09/mySphere.html
Brad Udall

July 20, 2009
Future of Western Water Supply Threatened by Climate Change, *NASA Earth Observatory*
http://earthobservatory.nasa.gov/Newsroom/view.php?id=39567
Balaji, Rajagopalan, Ken Nowak, Joe Barsugli, Brad Udall

July 20, 2009
Future of Western Water Supply Threatened by Climate Change, Says New CU-Boulder Study, *University of Colorado Office of News Services*
http://www.colorado.edu/news/r/f0f273435508fe6525e5e4903baa539b.html
Balaji, Rajagopalan, Ken Nowak, Joe Barsugli, Brad Udall

July 21, 2009
Colorado River Reservoirs Could Bottom Out, *Terra Daily*
http://www.terradaily.com/reports/Colorado_River_Reservoirs_Could_Bottom_Out_999.html
Edie Zagona, Balaji Rajagopalan, Brad Udall

July 21, 2009
Water Supply Risk on the Colorado River: Can Management Mitigate?, *Science Daily*
http://www.sciencedaily.com/releases/2009/07/090720163555.htm
Balaji, Rajagopalan, Ken Nowak, Joe Barsugli, Brad Udall

July 22, 2009
CU Study warns of Scarce Water, *Denver Post*

http://www.denverpost.com/news/ci_12887585
Balaji, Rajagopalan, Ken Nowak, Joe Barsugli, Brad Udall

Fall 2009
Water Supply Risk on the Colorado River: Can Management Mitigate?, *Public Radio Stations in CO (KGNU, KCFR and KUNC) and Nevada (KNPR)*
Balaji Rajagopalan, Ken Nowak, Joe Barsugli, Brad Udall

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