Title: **Disentangling the Influence of Antecedent Temperature and Soil Moisture on Colorado River Water Resources**

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Names/Affiliations of other cooperators and partners:  
CO-PIs: Adam Csank (Nipissing U./Univ. of Nevada, Reno), Greg Pederson (USGS-Bozeman)  
Other Partners involved in project: Stephanie McAfee (Univ. of Nevada, Reno), Greg McCabe (USGS-Denver), Steve Gray (USGS-Anchorage)

**Proposed start date and estimated duration of project:** 1 January 2014, 24 months  
**Total project funding requested from the CSC:** $135,248

**Keywords:** water resource management, Colorado River basin, tree-ring reconstructions

**Project Summary:** The main goal of this project is to better understand how the set of hydroclimatic factors: prior summer/fall soil moisture, cool season precipitation/snowpack, and late winter/spring temperatures, contribute to low annual flows on the Colorado River. This understanding is critically important to resource managers who are currently anticipating the impacts of climate variability and change on limited water supplies in the upper Colorado River basin (UCRB). The sensitivity of runoff to warming temperatures and dry soils in prior seasons has been recognized, but to date, a comprehensive analysis of the relationships between these factors, and how they vary over time and impact different periods of annual low flow has not been undertaken for the UCRB. We will use a combination of instrumental data, tree-ring reconstructions, and downscaled CMIP5 projections to investigate first, the historical droughts and changes in the influence of the three hydroclimatic factors on low flows over time, and then the hydroclimatic factors associated with a broader range of droughts that have occurred over past centuries, including conditions in major sub-basins. Finally, we will test the sensitivity of annual low flows to different scenarios of changes in soil moisture, winter precipitation, and winter/spring temperatures projected by CMIP5 models, and compare climate conditions associated with historic/paleo low flows to those associated with low flows derived from downscaled projections. The project will build on existing tree-ring reconstructions of flow, snowpack, and winter precipitation and generate new reconstructions of soil moisture and temperature. To develop the proposal, we have engaged with a group of Colorado River basin water managers who have assisted in directing research questions and ensuring the project is relevant to resource management. This group of water managers will form an advisory board to guide the analysis and generation of research products through interaction with the science team, an interdisciplinary group with expertise in climatology, paleoclimatology, hydrologic modeling, and climate projection analysis, with extensive experience working with resource managers. Additional partnerships with WWA and CLIMAS will promote a broader exposure to and use of project results by water resource management through a workshop for resource managers and articles featured in WWA and CLIMAS online publications for stakeholders.
GENERAL PUBLIC SUMMARY

Snowmelt-fed rivers of the western US are becoming especially vulnerable to warmer springs which hasten snowmelt. Warming temperatures also contribute by drying soils before the snow falls in winter, causing more snowmelt to soak into soils instead of running off into rivers. Thus, while snowpack is very important to water supplies, temperature can also have an important impact on river flow and water supplies. Instrumental records of flow, temperature, soil moisture, and winter precipitation are too short to assess the range of different combinations of climate conditions that can impact river flow; however, tree rings can be used to reconstruct climate conditions hundreds of years in the past. In this study, we will use existing Colorado River streamflow and winter precipitation reconstructions for past centuries, along with new spring temperature and fall soil moisture reconstructions developed under this study, to evaluate past droughts, many of which have far exceeded the length and severity of droughts recorded in the gage record. Water managers are very interested in using these extended records to assess the range of possible conditions that may be expected to occur and to help determine how warming temperatures may influence river flow and water supply in the future.
I. OBJECTIVES/JUSTIFICATION
A major challenge to water resource management in the southwestern US is anticipating and planning for the effects of climate change on water supplies (USBR and USACE, 2011). Changes in precipitation have obvious and direct effects, but warming temperatures can also impact water supplies in a variety of ways; by influencing snowpack amount and snowmelt timing, evapotranspiration and soil moisture, exacerbating the effects of drought, and increasing demand for water (Garfin et al. 2013). Our research team specializes in close collaborations with the water resource community. In this proposal, a number of water managers and water users in the Southwest have pointed us toward the overarching goal of this project, namely gaining a better understanding of how a set of hydroclimatic factors contributes to low flows on the Colorado River. In turn, water managers and users will use this information to guide expectations for climate change impacts on future flows. It is clear that reduced snowpack is a leading cause of low flows, but recent observations and research have indicated that other factors, including antecedent soil moisture conditions and temperature effects on snowpack may play an important role in exacerbating or mitigating the impacts of low snowpack on total water year streamflow (Flint et al. 2009, McCabe and Wolock, unpublished). Guided by input from the water resource community, we focus on three hydroclimatic factors: prior summer/fall soil moisture, cool season precipitation/snowpack, and late winter/spring temperatures. We focus on these factors because 1) prior work suggests they are key controls on runoff, and 2) they are variables for which reconstructions of past conditions from tree rings are possible. Extended hydroclimatic records from tree rings are critical because the period of instrumental data is too short to assess the full range of natural variability that is possible.

Our project has three main lines of stakeholder-driven inquiry:
• Given instrumental records for the 20th and 21st centuries, how have the contributions of antecedent soil moisture, winter/spring temperatures, and total cool season precipitation varied during the major periods of low flow in the upper Colorado River basin (UCRB)?
• Using tree-ring reconstructions of pre-1900 antecedent soil moisture, temperature, and precipitation, are contributions of these three factors to low flows over past centuries similar to those of the 20th and 21st centuries? Are there differences in these contributions between cooler and warmer time periods? Have contributions changed over time?
• What is the sensitivity of UCRB low flows to different scenarios of changes in antecedent soil moisture, winter precipitation, and winter/spring temperatures projected by CMIP5 models? How do results relate to conditions during significant low flow events captured in the instrumental and paleo record?

II. BACKGROUND
Water resource management has traditionally relied on gage data for planning and management. Severe droughts in recent decades, coupled with the specter of anthropogenic climate change have motivated resource managers to incorporate new information into planning. One new tool adopted by a number of resource managers has been tree-ring based reconstructions of water year streamflow (see http://treeflow.info/applications.html) (e.g., Woodhouse and Lukas 2006, Prairie et al. 2008, Rice et al. 2011). Although these reconstructions document important information on the range of drought conditions that have occurred – in most cases, more severe and/or persistent than any in the gage records – they do not provide information about the specific climatic conditions that contributed to these periods of low flow. While reconstructions
of various hydroclimatic variables have been generated for locations that coincide with western US watersheds, including annual temperature, cool season precipitation, Palmer Drought Severity Index, and snow water equivalent (e.g., Salzer and Kipfmueller 2005, Gray et al. 2007, Cook et al. 2009, Pederson et al. 2011), no studies have targeted reconstructions for a comprehensive analysis of the major hydroclimatic components within a specific basin. The Colorado River basin provides an excellent basis for pursuing such a study: reconstructions of Lees Ferry and other major sub-basin flows, snowpack (Woodhouse et al. 2006, Pederson et al. 2011), and winter precipitation (S. Gray, unpublished) already exist, a wealth of tree-ring data exists to reconstruct other moisture-related variables, and new research results with oxygen isotopes from tree rings show promise for winter/spring temperature reconstructions. In addition, a group of water managers that has actively supported the use of tree-ring data in resource management in the past is interested in engaging with this study to generate data and information relevant and useful to resource management (see letters of support).

Our initial research will focus on the hydroclimatic controls on UCRB flow for the instrumental period. Anticipating the impacts of climate change has highlighted the growing importance of warming temperatures. Several studies have examined the sensitivity of streamflow to temperature (see references in Vano et al. 2013), but an investigation on the influence of temperature during particular periods of low flow has not been explored. Likewise, although it is acknowledged that dry antecedent soil condition exacerbated the extreme low flows of 2002 (A. Pineda, Northern Colorado Water Conservancy District, pers. comm.), few studies have tried to assess impacts of late winter/spring temperatures, soil moisture, and winter precipitation on low flows. Recent research by Pederson et al. (2013) has documented the influence of warming spring temperatures on UCRB snowpack, but investigating the cascading linkage from snow, to soil moisture, to annual water yield remains undone.

As we move on to the new reconstructions (soil moisture and temperature), several challenges exist. First, records of measured soil moisture are virtually non-existent, at least for the length of time need for reconstruction model calibration. Instead, we will employ a monthly water-balance model (MWBM) that uses an accounting procedure to compute the allocation of water among various components of the hydrologic system including potential and actual evapotranspiration, snow accumulation and melt, soil moisture storage, and runoff (McCabe and Wolock 2011b). Inputs to the MWBM are mean monthly temperature, monthly total precipitation, latitude, and soil moisture storage capacity. Runoff estimates from the MWBM have been verified and successfully applied for a range of climatic and physiographic regions across the globe (McCabe and Wolock 2011a; McCabe and Wolock 2011b). Additionally, soil moisture storage estimates from the MWBM have been applied in agricultural studies as well as global water balance analyses (Thornthwaite 1954, Mintz and Walker 1993, Cornwell and Harvey 2008). Alternatively, fall low flows have been used as a proxy for antecedent moisture (L. Kaatz, pers. comm.), and our partners at the Colorado Basin River Forecast Center (CBRFC) have generated modeled soil moisture that could also be used (K. Werner, pers. comm.).

The second challenge is to reconstruct winter/spring temperatures from tree rings. To date, only reconstructions of warm season or annual temperatures have been generated from tree rings (e.g., Briffa et al. 1992, Salzer and Kipfmueller 2005). Previous studies have demonstrated some
evidence for a winter temperature signal in $\delta^{18}O$ derived from tree-ring cellulose (Saurer et al. 2008, Edwards et al. 2008). The temperature signal is linked to the strong relationship between air temperature and the $\delta^{18}O$ value of precipitation (Rozanski et al. 1993, Kohn and Welker 2005). The $\delta^{18}O$ of falling snow reflects the air temperature during precipitation; in spring the cumulative temperature signal recorded in the snowpack is transferred into soil water and taken up by the trees and incorporated into wood (Edwards et al. 2008). Our ongoing work in the Upper Colorado River Basin indicates that oxygen isotopes from these trees record late winter/spring temperatures (Csank et al. 2013). We will use this established relationship to provide records of late winter/spring temperatures to determine how winter/spring temperatures have impacted low flow in the past. In addition, correlation and partial correlation analyses indicate that some moisture-limited UCRB tree-ring sites contain information on spring temperatures that could be extracted. Partial correlations provide a way of determining the influence of a set of multiple climate variables on the tree-ring record, while accounting for correlation between the climate variables (Zar 1999).

The final part of our project concerns the application of general circulation models (GCMs) in UCRB water resource management. GCMs are our best source of information about future climate, but two characteristics make applying them to water management questions challenging. First, most models are at relatively coarse spatial resolution and so are unable to capture fine climate details that are critical in understanding stream flow in the large and topographically complex UCRB. Downscaling techniques that combine high-resolution observed climate information with the changes projected by climate models provide a partial solution to this complication. Second, there is uncertainty in the future climate because we do not know actual future emissions, different models project somewhat different changes, and the temporal progress of regional climate is not identical between models, e.g., the timing of ENSO events is not the same (Hawkins and Sutton 2009). One way of accommodating this uncertainty is to test the sensitivity of water year flow to a selection of future climate scenarios for a specified future time period (e.g., Brekke et al. 2009, Hay and McCabe 2010). We will take this approach, along with results from the tree-ring analyses in order to investigate the flow response to altered measures of winter/spring temperatures, antecedent soil moisture, and winter precipitation, as projected by CMIP5 models.

The integration of tree-ring based reconstructed hydroclimatic records into water resource management has been accomplished in a range of ways (e.g., Rice et al. 2009). Feedback so far from our water resource partners has likewise suggested a number of ways the information from this study could fulfill management needs. For example, one key need of the CBRFC is an understanding of the impact of the fall soil moisture on the flow forecasts issued during the fall and spring. K. Werner (CBRFC) suggests the results of this study could elucidate the variability...
of that condition, and allow recent (and current) years to be assessed in a long-term context, for example, where a specific year’s soil moisture state falls with respect to percentile ranking with the other years. Denver Water hopes to gain a better understand of the impact of warming on drought and insights on how their water supply system could respond to long-term warming. The reconstructions can provide inputs into partners’ system models to test these responses. Products such as graphics showing the contributions of each factor towards total annual water year streamflows, and relationships between various factors, as well as their statistical properties, are several that have been mentioned by our water manager partners. By nature, a project of this sort cannot dictate in advance the exact products and applications that will be produced, but these results will be co-produced in an interactive and iterative process between the science team and resource manager partners.

III. PROCEDURES/METHODS: Research questions and procedures to address these questions are as follows:

1. Can we identify variable contributions of the three hydroclimatic factors discussed above to low flows in the gage record, and have these contributions varied over time? We will identify key low flow periods from the Lees Ferry natural flow record, and use gridded climate data (PRISM, Daly et al. 2008) and modeled soil moisture (McCabe and Wolock 2011a, b or other) for the full UCRB and three sub-basins to evaluate the relative importance of these factors for each period of drought. Factors will be assessed for relative importance over time and by ENSO phase. One method explored will be using multiple linear regression to obtain coefficients for each climate factor, then computing the contributions of factors to runoff from these coefficients to assess contributions (e.g. Fig. 2, contributions to snowpack).

2. Can we develop skillful and management-relevant reconstructions of antecedent summer/fall soil moisture, and winter/spring temperatures from tree-ring data? For antecedent (prior summer/fall) soil moisture, we propose calibrating the reconstruction on modeled soil moisture. The modeled soil moisture adds some uncertainty, so we will rely on the variability in modeled soil moisture for the calibrations, rather than raw magnitudes. We will use the large network of existing moisture-sensitive tree-ring chronologies in the UCRB and standard model calibration/verification approaches to develop the reconstructions (e.g., Woodhouse et al. 2006). For winter/spring temperature reconstructions we will leverage an ongoing NSF-funded project to extend oxygen isotope analysis an additional three to five centuries (data currently extends only to 1900) at three tree-ring sites in the UCRB. To complement this approach, we will investigate the feasibility of extracting temperature information from moisture-sensitive trees using partial correlations, removing the moisture signal and retaining independent temperature variability, as described in the Background. As above, standard model calibration and validation approaches will be employed.

Figure 2: Precipitation and temperature contributions (stacked bars) resulting in a given year's snowpack anomaly are shown for the winter and spring. In these plots, cooling (warming) results in positive (negative) values for temperature contributions (Pederson et al. 2013).
3. Can the most critical regions/hydroclimatic factors (or set of factors) that led to severe low flows at Lees Ferry over the past 300-500 years be identified through case studies and spatial analysis of the sub-basins? We will examine the major low flow periods at Lees Ferry, and sub-basins of the UCRB to assess whether different sets of climatic factors are important in the sub-basins for a set of low flow periods at Lees Ferry. Identification of common or unusual sets of climatic and spatial factors that have led to low flows in the past will be conducted using common interval PCA/EOF analyses on the individual sub-basin reconstructions, and accompanied by anomaly mapping procedures similar to those employed in Pederson et al. (2011). Analyses will be conducted for the individual contributions to runoff (described in #1 above) for specific low flow periods and for the length of record.

4. In simulations with the MWBM, what combinations of antecedent soil moisture, winter precipitation (snow and/or rainfall), and winter/spring temperatures induce flow levels at or below the extreme lows identified in the historical and paleo record, and where do these conditions fall within the range of CMIP5 projections? We will test the sensitivity of flow by driving the MWBM with high-resolution climate fields describing a range of future conditions, and then compare climate conditions associated with historic/paleo low flows to those associated with low flows derived from downscaled CMIP5 projections.

III. GEOGRAPHIC SCOPE: Upper Colorado River basin, with major sub-basins (San Juan/Dolores, Colorado/Gunnison, and Green/Yampa River basins) of the UCRB.

IV. EXPECTED RESULTS AND PRODUCTS:
Milestone 1: Instrumental data analysis for UCRB low flow years/periods completed. Products: 1) modeled soil moisture data, 2) analysis of variable contributions of hydroclimatic variables to UCRB droughts, 1906-2008, 3) project web page , and 4) report to Advisory Board (AB); solicitation of feedback.

Milestone 2: Reconstructions of prior soil moisture and winter/spring temperature and analysis completed. Products: 1) Final reconstructions of soil moisture and temperature, 2) analysis of variable contributions of these variables and winter precipitation to Lees Ferry and sub-basin droughts over past centuries, 3) AGU presentation, 4) report to AB; solicitation of feedback.

Milestone 3: Climate change sensitivity testing and analysis completed. Products: 1) sensitivity analysis results, 2) manuscript draft for PNAS, 3) report to AB; solicitation of feedback.

Milestone 4: Final products and workshop. Products: 1) management-identified information and products, 2) final report to AB, 3) final reconstructions and tree-ring data submitted to NOAA WDC-A, 4) project web page completed, with data access, 5) article on WWA and/or CLIMAS websites with results relevant to water management, 6) workshop for water resource managers.

V. TECHNOLOGY/INFORMATION TRANSFER:
Through collaboration with our advisory board, our intention is to generate information and products that are broadly useful to CRB water stakeholders. Our advisory board will help us identify participants for our final workshop, which will make results available and promote interaction with a broader management audience. Our colleagues at the Western Water Assessment (WWA) and Climate Assessment for the Southwest (CLIMAS) will also assist in identifying interested stakeholders for this workshop. Information about the project, results, data, and information will be made available on the TreeFlow (treeflow.info) web site. We will work
with CLIMAS and WWA to feature articles and permanent links so that data and results are available to a range of stakeholders beyond the direct scope of this project (see letters). We will also work with the Southwest CSC and its LCC partners to find the best ways to feature this information on their web site in a way that is accessible to resource managers.

VI. DOCUMENTATION OF MANAGEMENT APPLICATION / RELEVANCE:
From the onset, this proposal has been written with input from our management partners from Bureau of Reclamation, Colorado River District, NOAA Colorado Basin River Forecast Center, Denver Water, and the Salt River Project to ensure the research questions and anticipated outcomes are relevant to water resource management. Our partners (see list below) have also agreed to serve on an advisory board for the project. Although we have identified some results and products, as with any science project, specific outcomes cannot always be guaranteed, and we anticipate communicating with the advisory board at regular intervals to report results and seek advice on directions to take, given research outcomes. This will be an iterative process that allows our management partners to help guide the science as results are achieved. This will be particularly important in determining what types of analyses and the form final products will take that is most useful and usable to address management needs. As stated above, the pool of intended users will be broadened through a final interactive workshop.

VII. COOPERATORS/PARTNERS:

**Science partners with significant contributions:**

**Steve Gray:** Alaska Climate Science Center, DOI/US Geological Survey, Anchorage, AK, 907-786-6780, sgray@usgs.gov. Role: contribution of winter precipitation reconstructions; science/management advice. Type of contribution: In-kind. **Stephanie McAfee:** Department of Geography, University of Nevada, Reno, MS 154, Reno, NV 89557, 775-784-6999; smcafee@unr.edu. Role: preparation of downscaled future climate scenarios. Type of contribution: Technical, in-kind. **Greg McCabe:** U.S. Geological Survey, Denver Federal Center, MS 412, Denver, CO 80225, 303-236-7278; gmccabe@usgs.gov. Role: water balance modeling. Type of contribution: Technical, in-kind

**Water management partners**

Dave Kanzer, Eric Kuhn, Colorado River District (State of CO); Charlie Ester, Jon Skindlov (Salt River Project, Arizona); Laurna Kaatz, Steve Schmitzer, Mark Waage (Denver Water, Colorado); Jim Prairie, Carly Jerla (Bureau of Reclamation, Lower Colorado District); Paul Miller, Kevin Werner, Michelle Stokes (NOAA Colorado Basin River Forecast Center)

**Arrangements and mechanisms for establishment and execution of partnerships:** We will hold quarterly teleconferences with PIs and science partners to coordinate contributions, assess results and provide feedback to and from water managers. The water managers who have already engaged with us in generating this proposal will form our Advisory Board, and will be updated on the progress of the study every six months. Progress reports will be more than one-way flow of information but will be the mechanism to provide feedback and suggestions for study and analysis directions. Twice a year PI/Advisory Board meetings will take place in person and/or via teleconference; other communication will be email, phone calls, and teleconferences.

**Leveraged Funding:**

1. **USGS funding or projects:**

Pederson: 25% time USGS National Research Program (NRP) funding to support this work.
McCabe: Funding from the USGS NRP to perform hydrologic research and development will be leveraged to help with this project.

2. Other funding:
Woodhouse: a) CLIMAS co-PI with support for one graduate student for two years on work that complements this project, b) Co-PI, Reclamation cooperative agreement with the University of Arizona, “Enhancing Water Supply Reliability Through Improved Predictive Capacity and Response” (Agreement R12AC30022) is addressing complementary research (see letters).
Woodhouse, Csank, Pederson: Project builds on ongoing NSF grant “Reconstructing Winter Temperatures in the Rocky Mountains Using Tree-Ring Oxygen Isotopes” (Grant 1103566).
McAfee: Start-up funds for summer salary will be leveraged for this project.

VIII. FACILITIES/EQUIPMENT:
All science partners in the project have access to the computing resources needed to carry out project tasks. Laboratory space and equipment for isotopic pre-processing of previously collected samples are available at the University of Nevada, Reno, including a microscope and Foredom flexible shaft drill (Foredom Electric Co., Bethel CT) and space equipped with a fume hood and a microbalance. Samples will be submitted to the University of Arizona Environmental Isotope Laboratory for mass spectrometric analysis of oxygen isotope ratios using a ThermoFinnigan TC/EA directly coupled to a Delta Plus XP IRMS via continuous flow.

IX. WORK AND REPORTING SCHEDULE:
- July 1, 2014: Milestone 1
- Fall 2014: Science team/Advisory Board Meeting
- December 30, 2014: Milestone 2
- March 30, 2015: Annual report to Director, Southwest CSC
- July 1, 2015: Milestone 3
- Fall 2015: Science team/Advisory Board Meeting
- December 30, 2015: Milestone 4
- March 30, 2016: Project completed; final report to Director, Southwest CSC

X. QUALIFICATIONS OF PROJECT PERSONNEL:
Connie Woodhouse: Expertise in western US hydroclimatology, paleodrought, dendrohydrology; interactions with resource managers (also see Synergetic Activities in CV)
Greg Pederson: Expertise in paleoclimatology, dendrochronology; focus on climate change, drought, water resources, recent western snowpack decline with warming (CV section c); substantial experience with resource managers (CV section d).
Steve Gray: Expertise in both modern and paleo climatology, and paleoclimate reconstructions; extensive experience in linking climate science & resource management, esp. water resources.
Greg McCabe: Lead Scientist within the USGS National Research Program, co-author of water balance model used in this study; expertise in hydroclimatology, hydrologic modeling.
Stephanie McAfee: Expertise in analysis of climate data, climate model output, and applications of downscaled climate projections to hydrological applications; analysis of large data sets.

XI. LEGAL AND POLICY-SENSITIVE ASPECTS: None
BUDGET JUSTIFICATION

Institution 1: University of Arizona

Salary: One week of salary for PI-Woodhouse in 2014 and 2015. Fringe is 30%.
Travel: Travel funds of $1,256 are requested for PI Woodhouse in both 2014 and 2015 for two PI/advisory board meetings in Salt Lake City in 2014 and one PI meeting and a stakeholder workshop in 2015 (flights $350, 2 nights per trip @ $90 per night, and $49 meal per diem for 2 days). Rates are based on State of AZ per diem. Rates are based on State of AZ per diem.
Other: Lab fees: We request stable isotope analyses, $22,320, based on the U. of AZ Environmental Isotope Laboratory cost of $18.60/sample, for a total of 1200 samples (300 samples in 2014, 900 in 2015). This provides for the analysis of 400 rings from three sites.
Publication costs: We have budgeted $750 in 2015 to cover page charges. Stakeholder workshop: We request $650 in 2015 to cover coffee breaks and lunch.

Institution 2: USGS

Salary: Two weeks of salary are requested for PI Pederson during each of 2014 and 2015.
Travel: Travel funds in the amount of $1,628 is requested in both 2014 and 2015 for two PI/advisory board meetings in Salt Lake City in 2014 and one PI meeting and a stakeholder workshop in 2015 (airfare $500, 2 nights per trip @ $96 per night, $61 meal per diem for 2 days). Travel funds of $3,556 are also requested for Gray and McCabe in both 2014 and 2015 for two PI/advisory board meetings in Salt Lake City in 2014 and one PI meeting and a stakeholder workshop in 2015 (flights for Gray $800 and McCabe $350, 2 nights per trip @ $96 per night, and $61 meal per diem for 2 days). Rates are based on federal government per diem.

Institution 3: University of Nevada, Reno

Salary: Funding for a student technician to conduct chemical pre-processing for isotope analysis is requested (full time summer 2014; part time fall 2014; $22.50/hour for 800 hours totaling $18,000), supervised by PI Csank (moving to UNR in May 2014). Two weeks of summer 2014 salary ($3,350) is requested for PI Csank. Fringe is 10% for the technician; 31.3% for PI Csank.
Travel: Travel funds in the amount of $2,000 are requested for McAfee and Csank in both 2014 and 2015 for two PI/advisory board meetings in Salt Lake City in 2014 and one PI meeting and a stakeholder workshop in 2015 (flights @ $361, 2 nights @ $90 per night, $49 per diem for 2 days). Travel rates for Salt Lake City used as an example, exact locations to be determined.
Supplies: In 2014, $5,000 is requested for laboratory supplies for the chemical pre-processing of tree ring samples for isotope analysis (expendable supplies such as, vials, sample trays, chemicals, silver capsules and pipettes).

Indirect costs: The University of Arizona MTDC cost rate is 51.5%. University of Nevada-Reno MTDC cost rate is 43.5%. The USGS IDC rate is 13.763%.
BIOGRAPHICAL SKETCH: Connie A. Woodhouse

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Professional Preparation
Prescott College, Environmental Education, BA (1979)
University of Utah, Geography, MS (1989)
The University of Arizona, Geosciences, PhD (1996)

Appointments
Professor (May 2013- present), School of Geography and Development, joint with Geosciences, Laboratory of Tree-Ring Research and Dept. of Geosciences, University of Arizona, Tucson
Associate professor (2007-2013), School of Geography and Development, joint with Geosciences, Laboratory of Tree-Ring Research and Dept. of Geosciences, University of Arizona, Tucson
Physical Scientist (2000-2006), Paleoclimatology Branch, NOAA National Climatic Data Center, Boulder
Research Scientist III, Fellow, (2004-2006), Institute of Arctic and Alpine Research, University of Colorado, Boulder
Adjunct Assistant Professor (2001-2006), Department of Geography, University of Colorado, Boulder
Research Scientist II (1999-2003), Institute of Arctic and Alpine Research, University of Colorado, Boulder
Visiting Scientist (1998-2000), Paleoclimatology Program, NOAA National Geophysical Data Center, Boulder
Research Scientist I (1997-1999), Institute of Arctic and Alpine Research, University of Colorado, Boulder

Synergistic Activities
- PI on Climate Assessment of the Southwest (CLIMAS) Regional Integrated Sciences and Assessments (RISA) programs
- Development of workshop series and web pages for water resources managers on incorporating tree-ring reconstructions of streamflow into management and planning (treeflow.info).
- Development of post-baccalaureate certificate program at the University of Arizona, Connecting Environmental Science and Decision Making
Publications

Five most relevant to proposed research


Other signification publications


Collaborators (last 48 months)
Toby Ault (NCAR), Nichole Barger (U. CO), Chris Castro (U. AZ), Bonnie Colby (U AZ), Edward Cook (Lamont Doherty Earth Observatory), Adam Csank (Nippissing U.), Dan Ferguson (U. AZ), Gregg Garfin (U. AZ), Stephen Gray (USGS), Holly Hartmann (U. AZ), Katie Hirschboeck (U. AZ), Jeanine Jones (CA Dept. Water Resources), Kathy Jacobs (U. AZ), Steven Jackson (U. AZ), Steven Leavitt (U. AZ), Brian Luckman (U. Western Ontario), Jeffrey Lukas (U. Colorado), Jahan Kariyeva (U. AZ),, David Meko (U. AZ), Russ Monson (U. AZ), Kiyomi Morino (U. AZ), Jonathan Overpeck (U. AZ), Greg Pederson (USGS), James Prairie (US BoR), Balaji Rajagopalan (U. AZ), Joellen Russell (U. AZ), David Stahle (U. Arkansas), Thomas Swetnam (U. AZ), Ramzi Touchan (U.AZ), Wim van Leeuwen (U. of AZ), J. Villanueva-Díaz (INIFAP), Park Williams (Los Alamos NL), Erika Wise (U. N. Carolina)
BIOGRAPHICAL SKETCH: Adam Csank

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Professional Preparation
Dalhousie University, Earth Sciences, BSc (2003)
University of Saskatchewan, Geological Sciences, MSc (2006)
The University of Arizona, Geosciences, PhD (2011)
University of Alaska, Anchorage, Post Doc (2011-2012)

Appointments
Assistant Professor (July 2012- present), Department of Geography, Nipissing University, North Bay, Ontario, Canada.

Synergistic Activities
- Associate faculty Nipissing University Masters of Environmental Sciences/Studies program
- Participant in North Bay-Mattawa Conservation Authority (NBMCA) forum on climate change impacts on the NBMCA watershed.
- Co-convener: Special session GC24B Stable Isotopes in Modern and Ancient Boreal Forest Systems: Indicators of Past Environmental Change. 2010 AGU Fall Meeting, San Francisco, CA
- Worked to get tree ring isotope data included in NOAA’s World Data Center for Paleoclimatology (see Csank, 2009)

Publications
Most relevant to proposed research
Other significant publications


Collaborators (last 3 years)

Research Ecologist

U.S. Geological Survey | Northern Rocky Mountain Science Center | gpederson@usgs.gov

(a) Professional Preparation

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<th>Institution</th>
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<td>University of Arizona</td>
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<tr>
<td>Michigan State University</td>
<td>Botany &amp; Zoology</td>
<td>B.S.</td>
<td>2000</td>
</tr>
</tbody>
</table>

(b) Appointments

2010-present  Affiliate Faculty, Earth Sciences Department, Montana State University, Bozeman MT
20 Oct 2010 – Present  Research Ecologist, USGS Northern Rocky Mountain Science Center, Bozeman MT
2007-2010  PhD Student, School of Natural Resources and the Laboratory of Tree Ring Research, University of Arizona, Tucson AZ
2004-2007  Research Scientist, U.S. Geological Survey - Northern Rocky Mountain Science Center, and the Big Sky Institute at Montana State University
2001-2004  Research Assistant, Big Sky Institute - Montana State University

(c) Publications

Relevant Publications


Other Significant Publications


(d) Synergistic Activities Relevant to Projects

**Technical and Data Support for Scientists and Resource Managers:**

- Technical Support for Columbia River Treaty Review: I participate as a science advisor representing the states of Montana and Idaho for the Sovereign Technical Team (STT) assigned to address the potential impacts of climate change on the Columbia River’s future water resources. This information is being used by the U.S. and Canada to support future decisions on related to the standing Columbia River Treaty.

- GNLCC Technical Support: Over the past few years I have provided climate change and resource impacts talks to GNLCC staff and regional resource managers from state and federal agencies. I have also participated in, and provided data for, many regional climate adaptation workshops funded by the LCC, and contributed to the climate change outreach materials produced by the University of Washington’s Climate Impacts Group for the GNLCC and the U.S. Forest Service Regions 1 & 2.

- Technical and Data Support for NGO Adaptation Planning Efforts: At present I serve as a climate change advisory board member for the Yellowstone to Yukon (Y2Y) initiative, and have provided guidance on research and adaptation planning. I have also participated in numerous Y2Y and Wildlife Conservation Society (WCS) climate adaptation meetings for regional managers, providing information on past and likely future regional climates and the potential influence on species or resource of concern.

**Transfer of knowledge:**

- At present I spend a substantial amount of time working on climate change adaptation issues with the NPS, USFS, USFWS, and state and federal water management agencies (BOR). My primary role is often to communicate management relevant information from both the climatic and ecological fields of research, but on many occasions we have generated and provided specific data to resource managers at their request (e.g. streamflow reconstructions, current and forecasted drought conditions).

- I regularly attend and present research at regional, national, and international science.

- For the past two years I have run a paleoenvironmental and sustainable forestry field course for the confederated Salish and Kootenai Tribes in northwestern Montana. (see [http://www.nrmse.usgs.gov/TESNAR2012](http://www.nrmse.usgs.gov/TESNAR2012))

- I also feature recently published research projects, data, and overviews on my staff website (see [http://www.nrmse.usgs.gov/staff/gpederson/research](http://www.nrmse.usgs.gov/staff/gpederson/research))

(e) Collaborators & Other Affiliations


**Graduate Advisor(s):**

Dr. Lisa Graumlich, M.S. Advisor, Land Resources & Environmental Sciences, Montana State University

Dr. Lisa Graumlich, Ph.D Advisor, School of Natural Resources, University of Arizona
BIOGRAPHICAL SKETCH: Stephanie A. McAfee

Department of Geography
University of Nevada, Reno
Mailstop 0154
Reno, NV 89557-0154
phone: 775-784-6999
fax: 775-784-1058
email: smcafee@unr.edu

Professional Preparation
Dartmouth College, Earth Sciences, AB (1998)
University of Washington, Forest Soils, MS (2002)
University of Arizona, Geosciences, PhD (2009)

Appointments
Assistant Professor (July 2013 – present), Department of Geography, University of Nevada, Reno
Postdoctoral Fellow (2012 – 2013), Scenarios Network for Alaska and Arctic Planning, University of Alaska Fairbanks
Climate Change Scientist (2010 – 2012), The Wilderness Society, Anchorage, AK
Research Associate (2009 – 2010), National Research Council at NOAA Earth System Research Laboratory
Graduate Research and Teaching Associate (2005 – 2009), University of Arizona
Biologist (2004 – 2005), USGS Forest and Rangeland Ecosystem Science Center
Research Scientist 2 (2002 – 2003), College of Forest Resources, University of Washington
Graduate Research Assistant (2000 – 2002), College of Forest Resources University of Washington

Synergistic Activities
- Development of outreach products for managers and policymakers on precipitation trends, downscaling, and downscaled products.
- Instruction on climate change and climate models for science educators at the Campbell Creek Science Center (2013).
- Assistant for the International Arctic Research Center Summer School 2012, Climate system modeling: Downscaling techniques and practical applications.
- Participant in an NCAR workshop on Uncertainty in Climate Change Research (2012)
- Participant in a science communication workshop lead by Nancy Baron and hosted by the Wilburforce Foundation, Whistler, B.C (2010).
Publications

Most relevant to proposed research:

Other significant publications:

Collaborators & Other Affiliations

Collaborators and co-editors
Erika Wise (U. NC), Adam Csank (Nipissing, U.) Jon K. Eischeid (NOAA- CIRES), Galina Guentchev (NCAR), Jason Leppi (The Wilderness Society), Brendan O’Brien (unaffiliated), Steven Perakis (U.S. Geological Survey), Robert H. Prucha (Integrated Hydro Systems, LLC), Anna L. Springsteen (University of Maine), Ryan Wilson (FWS), Jeremy Littell (USGS), Steve Gray (USGS), Kyle Jolly (NPS), David Gustine (USGS), Patrick Sullivan (U AK-Anchorage), Katrina Bennet (UAF), Peter Bieniek (UAF), Jason Todd (EPA), Paul Duffy (Neptune & Co.)

Graduate advisors
Robert L. Edmonds (University of Washington)
Jonathan T. Overpeck (University of Arizona)
Joellen L. Russell (University of Arizona)

Postdoctoral Advisors
Wendy Loya (The Wilderness Society)
T. Scott Rupp (University of Alaska Fairbanks)
John Walsh (University of Alaska Fairbanks)
Robert S. Webb (NOAA Earth System Research Laboratory)
Biographical Sketch—Stephen T. Gray
U.S. Geological Survey
DOI Alaska Climate Science Center
4210 University Dr.
Anchorage, AK 99577
Tel: 907-786-6780
Mobile: 907-301-7830
sgray@usgs.gov

A. Professional Preparation
University of Tulsa
Biology
B.S., 1994
University of Oklahoma
Botany
M.S., 1998
University of Wyoming
Botany
Ph.D., 2003

B. Appointments
Director
Alaska Climate Science Center
2011-present
State Climatologist
Wyoming State Climate Office, Univ. of Wyoming
2006-2011
Director
Water Resources Data System, Univ. of Wyoming
2006-2011
Assoc. Research Sci.
Dept. of Civil and Arch. Engineering, Univ. of Wyoming
2006-2011
Adj. Assit. Professor
Laboratory of Tree Ring Research, Univ. of Arizona
2006-present
Research Associate
US Geological Survey, Desert Laboratory
2004-2006
Post Doc
Big Sky Institute, Montana State University
2003-2004

C. Representative Technical Publications:


D. Other Representative Publications:


E. Synergistic Activities:

- Development of numerous outreach products (e.g., web portals and non-technical reports) and activities (e.g., interactive workshops) aimed at incorporating knowledge of climate variability and climate change into natural resource management

- Steering Committee (2011-Present):
  - Western Alaska Landscape Conservation Cooperative
  - Arctic Landscape Conservation Cooperative
  - Aleutian and Bering Sea Islands Landscape Conservation Cooperative
  - North Pacific Landscape Conservation Cooperative
  - Northwest Boreal Landscape Conservation Cooperative

- Advisory Board, Alaska Center for Climate Assessment and Policy (ACCAP), NOAA Regional Science and Assessment (RISA) Program, 2012-Present

- Senior Advisor, Ruckelshaus Institute for the Environment and Natural Resources, 2010-Present

- Co-PI, Western Water Assessment, NOAA Regional Science and Assessment (RISA) Program, 2011-12

- Co-Organizer and Facilitator, National Park Service Climate Change Program, Scenario Planning Workshops, 2008-12.

- Member, Wyoming Governor’s Climate Issues Committee, 2008-2011

- Member and Wyoming State Representative, USDA-CSREES Climate Data Analysis and Applications Coordinating Group (WERA-102), 2006-12

- Advisor, Wyoming Water Association, 2006-11

**Gregory J. McCabe, Ph.D.**  
U.S. Geological Survey, Denver Federal Center, MS 412, Denver, Colorado 80225  
gmccabe@usgs.gov phone: 303-236-7278

**Professional Preparation**  
Louisiana State University, Baton Rouge, LA  
Physical Geography/Climatology  
Ph.D. 1986

University of Delaware, Newark, DE  
Physical Geography/Climatology  
M.A. 1984

University of Delaware, Newark, DE  
Physical Geography  
B.A. 1981

**Appointments**  
Lead Scientist, U.S. Geological Survey, Denver, CO  
2011-present

Project Chief, U.S. Geological Survey, Denver, CO  
2001-2011

Physical Scientist, U.S. Geological Survey, Denver, CO  
1991-2001

Physical Scientist, U.S. Geological Survey, West Trenton, NJ  
1988-1991

Assistant Professor, Geography and Planning, University of Memphis, Memphis, TN  
1986-1988

**Adjunct Appointments**  
Geography, University of Denver, Denver, CO  
2004-present

Research Affiliate, Institute of Arctic and Alpine Research,  
University of Colorado, Boulder, CO  
2000-present

Earth and Atmospheric Sciences, Metropolitan State University of Denver, Denver, CO  
1999-present

**Synergistic Activities**  
member, USGS Powell Center Science Advisory Board (2012-present)

member, World Meteorological Organization (WMO) Commission for Hydrology (2005-present)

member, Strategic Science Planning Team for Water (2010 to 2013)

**Selected Peer-Reviewed Publications from Recent Years**


**Collaborators (last 3 years)**
Dave Wolock (USGS), Julio Betancourt (USGS), Lauren Hay (USGS), David Legates (U DE), Subhrendu Gangopadhyay (USBR), Michael Dettinger (USGS), Steve Gray (USGS), Toby Ault (Cornell), Mark Schwartz (U WI), Ben Cook (NASA), Elizabeth Wolkovich (U BC), Jonathan Davies (McGill U), Eric Evenson (USGS), Rand Orndorff (USGS), Chuck Blome (USGS), Paul Herschberger (USGS), Vicky Langenheim (USGS), Scott Morlock (USGS), Howard Reeves (USGS), Jim Verdin (USGS), Holly Weyers (USGS), Tammy Wood (USGS), Andrew Fountain (Portland St U), Andrew Comrie (U AZ), Greg Pederson (USGS), Julie Vano (U WA), Tom Peterson (NOAA)
REFERENCES CITED


9 August 2013

Dr. Connie Woodhouse
University of Arizona
School of Geography and Development
412 Harvill Building, Box #2
Tucson, Arizona 85721-0076

Dear Connie,

I am writing on behalf of the Climate Assessment for the Southwest (CLIMAS) program at the University of Arizona to offer strong support for your proposal entitled: "Disentangling the Influence of Antecedent Temperature and Soil Moisture on Colorado River Water Resources."

As you better than anyone knows, the water management community in the West is increasingly aware of and sensitive to the utility of paleoclimate research, largely through the efforts of you and your colleagues. The work proposed here addresses a critical gap consistently raised by stakeholders in the Southwest: what are the climatic conditions that lead to reduced flow in the Colorado Basin? The research you and your colleagues have proposed will make great strides forward in answering that question. In addition to the scientific contribution your project will make, we have repeatedly found that a more refined understanding of past conditions has proven to be a productive way to engage regional stakeholders in conversations about projected warming and the increasingly dry conditions we expect. I also fully support the approach you have taken with the proposed work, which involves not simply trying to answer the critical research questions, but directly engaging with the water management community throughout to ensure your results will be relevant and useful.

Your project is directly in line with CLIMAS’ current research priorities, specifically our commitment to investigate drought in the Colorado River basin in collaboration with stakeholders. I am very pleased that your incoming CLIMAS graduate research assistant will be a critical member of the team you have assembled for this project since that will provide further synergies between the CSC and CLIMAS. With a 15 year-long record in the Southwest, CLIMAS also offers a substantial network of collaborators and stakeholders who will have interest in your proposed project. We look forward to working with you to ensure your work reaches them. Specifically, I would be happy to help in any way CLIMAS is able to support the workshop for water managers that I see as a critical component of your project. Similarly, as a CLIMAS co-PI, you have access to our substantial outreach infrastructure (e.g., CLIMAS website, podcasts, the Southwest Climate Outlook) that I believe will be invaluable as you begin to release results from your research.

On behalf of the rest of the CLIMAS team, I am glad to be able to offer our support for this important work. I look forward to the project commencing and learning from you and your colleagues as it progresses.

Sincerely,

Daniel B. Ferguson
Program Director and Co-Principal Investigator
Climate Assessment of the Southwest (CLIMAS)
dferg@email.arizona.edu
August 16, 2013

Dr. Connie Woodhouse  
School of Geography and Development  
University of Arizona  
412 Harvill Building, Box #2  
Tucson, AZ 85721-0076

Dear Dr. Woodhouse,

The CIRES Western Water Assessment (WWA) NOAA RISA program based at the University of Colorado strongly supports your proposal to the Southwest Climate Science Center, entitled “Disentangling the Influence of Antecedent Temperature and Soil Moisture on Colorado River Water Resources.” Given the generally dry conditions in the interior West since 2000 and the large future climate changes anticipated for the region, it is essential to better understand the interplay of specific hydroclimatic drivers of streamflow variability, particularly in the low-flow years that stress water-supply systems. The positive reaction from water resources entities such as Denver Water to the proposal is indicative of the broad stakeholder interest in these questions, and the need for additional data to use in modeling and planning. The proposed “triangulation” of tree-ring data, observed records, and climate model output to isolate, understand, and project these hydroclimatic drivers is a very promising approach.

Were the proposal to be successful, we would look forward to helping you connect the research and findings with WWA’s extensive network of stakeholders in the Upper Colorado River Basin. As indicated in the proposal, we will be glad to help you conduct stakeholder workshops, and disseminate project results through our website and other communication channels. We also see a great opportunity for data sharing and other coordination with ongoing WWA research into Upper Colorado River Basin snowpack hydrology, which is using different tools to address complementary questions.

Best regards,

Kristen Averyt, Ph.D.  
Director, Western Water Assessment  
Associate Director, CIRES, University of Colorado Boulder
August 16, 2013

Dr. Connie Woodhouse  
Associate Professor  
School of Geography and Development, Laboratory of Tree Ring Research, and Department of Geosciences  
University of Arizona  
412 Harvill Building, Box #2  
Tucson, AZ 85721-0076

Dear Connie,

I am writing to support your proposal to the DOI Southwest Climate Science Center, “Disentangling the Influence of Antecedent Temperature and Soil Moisture on Colorado River Water Resources.” Carly and I both think the project would benefit our research efforts in the Colorado River Basin. The work you propose is highly complementary to our ongoing cooperative project between Reclamation and your research group at the University of Arizona, “Enhancing Water Supply Reliability through Improved Predictive Capacity and Response.” We are particularly interested in the role of temperature on drought and low flows in the Upper Basin. Understanding the role of winter/spring temperatures during past droughts will provide us with insights on the impact of warming on low flows in the future and under our current persistent drought in the basin.

We are happy to support your project on behalf of Reclamation, and either Carly and/or I are willing to serve as advisory board members for the project.

Sincerely,

James R. Prairie, Ph.D.  
Colorado River Hydrology Work Group lead  
Hydraulic Engineer  
Bureau of Reclamation
August 6, 2013

Dr. Connie Woodhouse  
School of Geography and Development  
412 Harvill Building, Box #2  
University of Arizona  
Tucson, Arizona 85721-0076

Subject: Support for Proposed Collaborative Project: Disentangling the Influence of Antecedent Temperature and Soil Moisture on Colorado River Water Resources

Dear Dr. Woodhouse:

The Colorado Basin River Forecast Center (CBRFC) of the National Oceanic and Atmospheric Administration (NOAA) supports your proposed collaborative research entitled Disentangling the Influence of Antecedent Temperature and Soil Moisture on Colorado River Water Resources. We understand that this proposal will be submitted for funding consideration on August 21st, and that you would like to form an advisory board. The CBRFC would be glad to serve on such an advisory board for this important and timely research.

The CBRFC has generated seasonal water supply forecasts for decades throughout the Colorado River basin. Modeled soil moisture has a huge impact on the forecasts we provide. Your research would allow the comparison of past historical flows to historical soil moisture conditions, granting us the opportunity to support and assess the validity of previous research findings and potentially clarify the relationship between soil moisture and runoff that we have only been able to theorize about through models.

Our office maintains a robust hydrologic model, which could potentially bridge the gap between your findings and potential impacts to regional water supply. We also maintain a database of numerous gaged and modeled hydroclimatic variables from which we could share information. Further, our staff is composed of many with expertise in meteorology, hydrology, and climate change, particularly as it relates to water resources throughout the Colorado River Basin. As a member of your advisory board, our office’s expertise may aid in the guidance of this important work.

The proposed project is expected to provide important and needed information related to cool season precipitation, late winter and spring temperatures, and historical soil moisture conditions. We believe that the results of this study will greatly increase our understanding of the interaction and relationship between hydroclimatic variables,
particularly as it relates to antecedent hydrologic conditions within the Colorado River Basin. Through the findings of this study and subsequent increased understanding, we hope to inform our forecasts of streamflow better as well as communicate the driving factors behind our forecasts to Colorado River Basin stakeholders.

We are familiar with your work and that of your collaborators, and have always found it to be exceptional and of the highest quality. We value your professionalism and our past partnerships. We look forward to working with you in the future on this worthwhile project.

Should you have any questions or wish to discuss this matter further, please feel free to contact myself at michelle.stokes@noaa.gov, or 801-524-5130 ext. 322.

Sincerely,

Michelle Stokes  
Hydrologist in Charge  
Colorado Basin River Forecast Center
Dear Ms. Woodhouse:

The Colorado River Water Conservation District (River District) strongly supports the proposed collaborative project and recommends that it be funded. The River District recognizes both the near and long term value of this project and is committed to serving on an advisory board to help ensure that the results and products are useful to water resource managers.

The River District is the principal water policy and planning agency for the Upper Colorado River Basin within the State of Colorado with the specific mission to protect, conserve, use, and develop the water resources of the Colorado River Basin for the welfare of the District, and to safeguard for Colorado all waters of the Colorado River to which the state is entitled.

Results from the proposed investigations could prove very useful to water resource managers in day-to-day and year-to-year streamflow forecasting. As a case in point, the 2013 runoff in the Upper Colorado River Basin came on the heels of an extremely dry 2012. Thus, the antecedent moisture condition throughout the Upper Basin was quite low. There was much discussion and speculation about how the low antecedent moisture would impact volumetric stream flow. Certainly the research you and your colleagues are proposing would improve the knowledge based and could provide a significant step forward in forecasting ability.

Again, the River District supports the proposed collaborative project and recommends that it be funded.

Respectfully,

John M. Currier, P.E.
Chief Engineer
Colorado River District
August 15, 2013

Connie Woodhouse, PhD
University of Arizona
Department of Geography and Regional Development
412 Harvill Building, Box #2
Tucson, AZ 85721-0076

Dear Connie:

Denver Water supports your proposal to the DOI Southwest Climate Science Center, “Disentangling the Influence of Antecedent Temperature and Soil Moisture on Colorado River Water Resources.” We think the project would greatly benefit our interests in the Colorado River Basin.

We are particularly interested in drought characteristics and connections to temperature, as this information is critical for how Denver Water’s system could respond to long-term warming.

We would welcome the chance to interact with you and your colleagues to help develop information and data that is useful to Denver Water.

We are happy to support your project and are willing to serve as advisory board members for the project.

Sincerely,

Robert G. Steger
Manager of Raw Water Supply
August 19, 2013

Connie Woodhouse, Professor  
School of Geography and Development  
University of Arizona  
Tucson, AZ 85721-0076

Dear Dr. Woodhouse,

As manager of Salt River Project’s Water Resource Operations group, I gladly write this letter of support for your proposal to the US Department of Interior, Southwest Climate Science Center (SWSC), tentatively titled “Disentangling the Influence of Antecedent Temperature and Soil Moisture on Colorado River Water Resources.”

Salt River Project (SRP) manages four reservoirs on the Salt River and two on the Verde River with a combined storage of over two million acre-feet that annually receive, on average, almost one million acre-feet of inflow. We deliver nearly a million acre-feet each year to SRP shareholders in the Phoenix metro area (primarily from the reservoir system, but at times supplemented with pumped groundwater).

More than half of the water SRP delivers goes to municipal water treatment plants in the Phoenix metro area. Most of the cities using these plants, including Phoenix and Mesa, also have an allotment of Colorado River water through the Central Arizona Project (CAP). Although SRP does not have a CAP allotment, we did arrange to receive excess CAP water a decade ago in the midst of the recent extended drought in Arizona. We would consider that option again and share the cities’ concern about future flows on the Colorado River.

Your proposed research into low-flow conditions on the upper Colorado River fits well with our concerns about both the upper Colorado and the Salt-Verde basins. As you have mentioned, the role of pre-winter soil moisture may be less important on the Salt-Verde basin than on the upper Colorado. However, the accumulation of winter precipitation and snowpack and the effect of late winter/early spring warm spells are important on both basins. Past research has shown that both basins share extremely dry years. Knowledge of the ways precipitation accumulates on the upper Colorado during low-flow years should have much relevance to the lower Colorado.

We also note that the weather patterns responsible for extended periods of late cool-season warmth often cover both the upper and lower Colorado basins. More intense spring warmth might reduce expected inflow into the Salt and Verde reservoirs. Changes in late spring/early summer temperatures should affect water demand in SRP’s water service territory and also increase electric power demand in the Phoenix area. Any trends and changes in variability of seasonal temperatures through time in Arizona and the region will also be of interest to SRP’s power group.
Water Resource Operations will be glad to serve as advisors to your research group, review your work and make constructive suggestions on the project.

I wish you success with the proposal, and look forward to our collaboration in the future.

Sincerely,

[Signature]

Charles E. Ester III
Manager, Water Resource Operations