~ENHANCING WATER SUPPLY RELIABILITY~

An interdisciplinary research project to enhance predictive capacity on the Colorado River

Annual Report, Phase III
September 2011

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Memorandum

TO: JIM PRAIRIE, HYDRAULIC ENGINEER, CADSWES, RECLAMATION
GUSTAVO CHAVARRIA, GRANTS OFFICER, PHOENIX AREA OFFICE, RECLAMATION

FROM: KIYOMI MORINO, ON BEHALF OF BONNIE COLBY, DAVE MEKO, PETER TROCH AND CONNIE WOODHOUSE, UNIVERSITY OF ARIZONA

DATE: October 26, 2011

RE: QUARTERLY REPORT, PHASE III
ENHANCING WATER SUPPLY RELIABILITY PROJECT

The enclosed materials constitute the annual report for Phase III of the University of Arizona – Reclamation, *Enhancing Water Supply Reliability* study. This ongoing collaboration has brought together an interdisciplinary team that is finding new ways to work together with the end goal to inform better management of water supply risks to end-users in the Lower Colorado River Basin through improved understanding of hydrologic variability, better predictive skills, and management of supply risk. The project has contributed to the education of six Master's students[1] and four PhD students[2] over the lifetime of the project and supports one postdoc[3]. Since the last report a number of high-quality products have been developed, including academic manuscripts and guidebooks. Equally important is the ongoing collaboration between Reclamation staff and the University of Arizona faculty, postdoctoral research associates and graduate students.

[1] Masters degrees have been awarded to: Katie Pittenger MSC 2006 (Agricultural and Resource Economics); Lana Jones MSc 2008 (Agricultural and Resource Economics); Michael O'Donnell MSc 2010 (Agricultural and Resource Economics); Laura Lindenmeyer MSc 2006 (Hydrology); Matthew Switanek MSc 2008 (Hydrology); and Rachel Beagles MSc 2011 (Hydrology).
[2] PhD degrees have been awarded to: Scott St. George PhD 2007 (Geosciences); Kiyomi Morino PhD 2008 (Geography); Dustin Garrick PhD 2010 (Geography); and Matthew Switanek PhD expected 2012 (Hydrology).
[3] Post-doctoral Research Associate: Dr. Kiyomi Morino (Dendrochronology).

Research Update

For the period April 2011 through September 2011

Economics Sub-group.

The economics sub-group, consisting of Dr. Bonnie Colby, Brett Fleck and Elizabeth Schuster, is focused on research and preparation of stakeholder materials on innovative, voluntary transfer agreements to enhance supply reliability for urban and habitat water needs in the Lower Colorado River Basin. Three guidebooks in this series for stakeholders were completed in 2009 and 10. These provide practical information for water supply climate change adaptation through water banks, water auctions, and dry-year contracts.

In 2011, the economics team has been working with stakeholders in the lower Colorado River basin to complete three additional guidebooks, one of which is a Spanish translation. The guidebooks report on the findings of the economics team regarding how to implement effective voluntary transactions between agriculture, municipalities and environmental programs to help the lower Colorado River basin region cost-effectively adapt to supply variability and extended drought. We have met with irrigation district managers, County extension agents and representatives from the Lower Colorado Region, Bureau of Reclamation. One new guidebook has been completed and was made available online in August 2011. The other two guidebooks are pending and will be released by the end of the year.

In addition, we have produced a sophisticated statistical model that shows how water lease prices vary with changes in the housing market and with regional drought conditions. This is useful to those planning for urban supply reliability, because one supply reliability strategy is to lease water from agricultural water users to get a city through a dry period. This model helps demonstrate how lease prices change, and therefore how the expense of acquiring supplemental supplies would change, under varying climate cycles and housing market conditions. We are in the process of submitting this for publication.

The outreach, publications and dialogue that are part of this project have helped make water managers more aware of temporary water transactions as a cost-effective supply reliability option. We continue to see more examples of dry year leases, dry year options, water banking and other innovative arrangements used to help get cities, environmental programs and water using industries through extended drought in their region.

Paleo-hydrology Sub-groups

SUB-GROUP 1 – Dave Meko and Kiyomi Morino. During the reporting period, DM and KM have focused on two areas: 1) Lower Basin streamflow reconstructions and 2) developing a paleo-based approach for informing water management under climate change. In the first area of focus, multiple chronologies have been developed and/or updated for the purposes of streamflow reconstruction in the Lower Basin. At least eight chronologies in and around the Little Colorado have been updated. Potentially more can be leveraged from the Monsoon Project pending their relationship with target hydroclimatic variables. Additionally, a recent field trip to southern Utah bolstered sample depth for sites that could be used for

hydroclimatic reconstruction of the Paria, Kanab and/or Virgin Rivers: three new sites were collected and two existing sites were updated.

In the second area of focus, we are exploring a novel method for increasing predictive capacity in water supply reliability. Predictive capacity in water management generally refers to the ability to forecast future climate, streamflow or both; in other words, it is only considered in terms of hydroclimatology. Water supply for human use, however, is a coupled system, comprised of hydroclimatic input and water management, including both the built environment, eg., reservoirs and canals, and the rules that govern how water is routed within the built environment, i.e., policy. Here, we examine the potential for predictive capacity in the ***coupled*** system. We use subsets of paleodata to force CRSS over a thirty year period. We then tally the total amount of shortage accumulated in the Lower Basin over the management horizon and use these data as a metric for vulnerability, where more shortage accumulated amounts to greater vulnerability. We then looked at the relationship between mean streamflow and total shortage over increasing time frames. Figure 1 shows each of the correlations for four different streamflow input scenarios. Each scenario consists of all 30-year periods within the paleo record (Meko et al 2007) where mean streamflow is at target +/- 0.25 maf, and target is 13.5, 14.0, 14.5 and 15.0 maf. Each correlation shows the relationship between the mean of the first n years up to 30 years and total shortage. Results suggest that the driest scenarios (13.5 and 14.0 maf) show the highest correlations, and therefore potential for predictability. We have developed preliminary regression models for each scenario with the goal of making them relevant to upcoming evaluations of current guidelines. Providing Reclamation with these analyses with the goal of jointly producing a manuscript for publication is forthcoming.

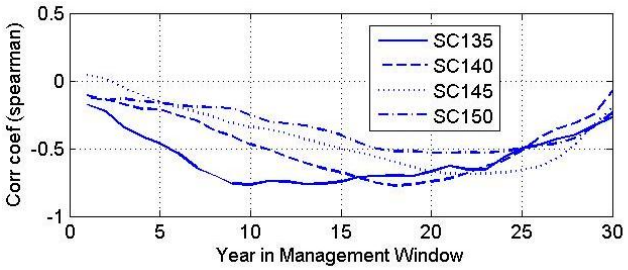

Figure 1. Correlations between mean streamflow and total deficit to the Lower Basin for four near-future streamflow scenarios (see text).

SUB-GROUP 2 – Connie Woodhouse, Mary Glueck and Brewster Malevich. The main goal of this component of the project has been to identify and characterize CRB droughts, the ocean/atmospheric conditions that have accompanied them, and the role of ENSO.

Prior to April, we had defined a set of seven upper Colorado River basin droughts based on the Lees Ferry gage record and a criteria of consecutive below average flow years broken by less than two non-drought (above average) years (the shortest, a 4-yr drought in the 1940s, was dropped due to minimal impacts). These six droughts were characterized by seasonal precipitation and temperature, and the ocean/atmosphere circulation patterns that accompanied drought. A set of the most often used

circulation indices were also evaluated in the context of these periods of drought. The bulk of this work had been to compile graphics of time series and spatial patterns associated with each drought

This summer, a draft of the summary report was generated that built on the results from the analyses above. The report includes methods and analysis approaches, comparisons of all drought periods, a narrative for each drought, and a summary of the main features common to all droughts. A summary finding of particular examined composite maps of cool season SST and 500mb for the years when Lee's Ferry flow was less than 10 MAF (eight years). Interestingly (and perhaps not surprisingly), no consistent SST pattern resulted, but a very distinctive 500mb pattern emerged, characterized by a Northern Hemisphere wave train, with a center of high pressure over the western US. This pattern is unlike one that represents ENSO (Figure 2). It is more similar to a Pacific North American (PNA) pattern, but with the Rocky Mountain center of high pressure shifted south and slightly west.

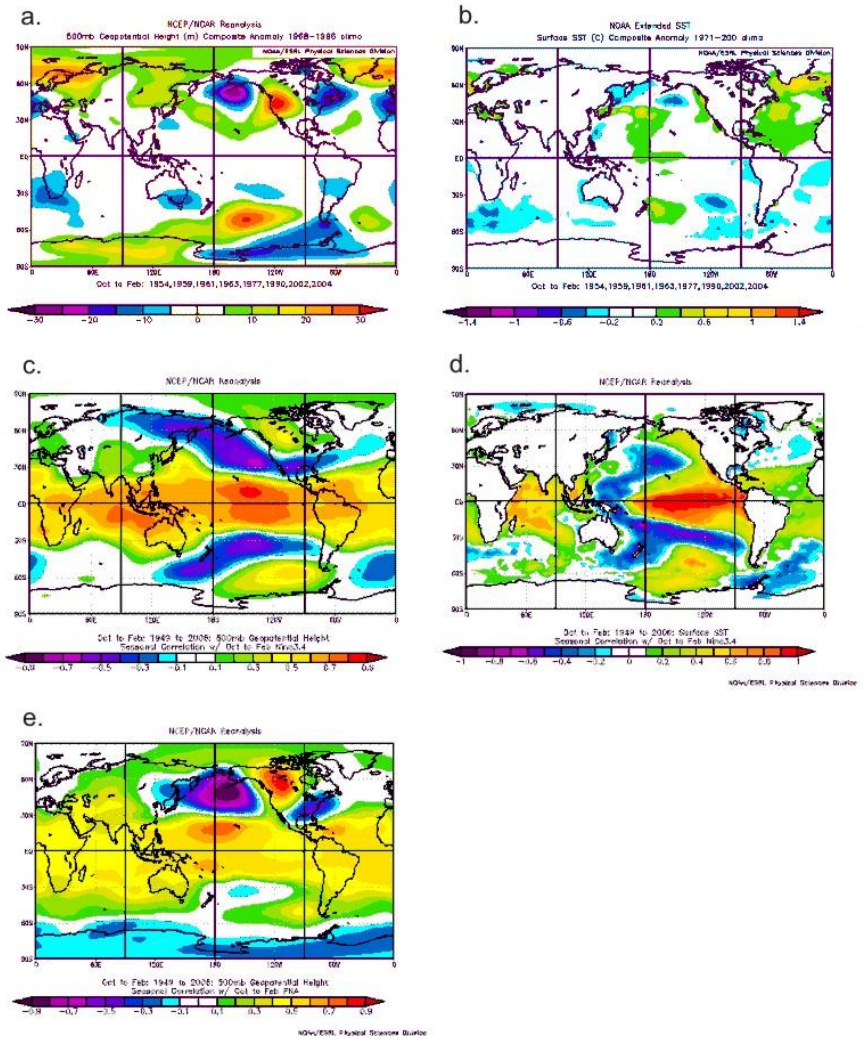

Figure 2. Composite maps for the years 1954, 1959, 1961, 1963, 1977, 1990, 2002, 2004 of Oct-Feb anomalies, a) 500mb heights and b) SSTs. Correlations maps for Oct-Feb c) Nino 3.4 and 500 mb heights, d) Nino 3.4 and SSTs, and e) PNA and 500 mb heights (1949-2006).

Graphics have been compiled and ordered. The next task is to review and refine the graphics (currently in power point format) so that they are in a consistent and publishable format. At that point, the final report should be ready to submit to Reclamation for review. A peer-reviewed paper will be written, based on the report in 2012.

Report appendices have been compiled that include 1) a report of the Critical Period of Record (by Brewster Malevich), 2) an annotated PowerPoint presentation of the role ENSO in UCRB drought (from American Geophysical Union Fall Meeting, 2010), 2) correlation maps showing associations between circulation indices and Colorado River flow, and 4) references and sources for circulation indices and climate data.

Hydrology Sub-group

No research activities were conducted during this period[4].

[4] The account for this sub-group was in deficit for much of this reporting period due to a delay in the arrival of funds.

Project Deliverables: A summary

For the period April 2011 through September 2011

The deliverables of this project include a number of manuscripts published in leading journals, posters and presentations made at academic meetings, and book chapters. All materials listed below, including PowerPoint presentations, can be provided in pdf format upon request.

Publications

Journal articles

[none]

Book chapters

Bark, R.H., Garrick, D., **Morino, K.**, and C.A. Scott. 2011. Climate change, water resources, and adaptive management in the Colorado River Basin. In, Vieira, R., Scott, C.A. and C. Tucci (eds.) *Water and Climate Modeling in Large Basins*. Brazilian Water Resources Association.

Theses and Dissertations

[none]

Other

Schuster, E., **Colby, B.**, Jones, L., and O'Donnell, M. August, 2011. *Understanding the Value of Water in Agriculture*. Accessed October 17, 2011 http://ag.arizona.edu/arec/pubs/facultypubs/Value%20of%20Water%20in%20Agriculture%20Colby%2010_2011.pdf

Workshops

Presentations & Posters

Bonnie Colby. 2011. Remote Sensing: New Opportunities For Building Supply Resilience, Water Education Foundation, Colorado River Symposium, September. PRESENTATION.

Bonnie Colby. 2011. Smart Fallowing: New Strategies in Agricultural Forbearance, Natural Resources Law Center Conference, June. PRESENTATION.

Malevich. S.B. 2010. Updating the 12-year CPR for the Colorado River basin. Graduate Student Research Blitz, University of Arizona, Tucson AZ, Feb. 1. PRESENTATION.

Other presentations on the CO River

Woodhouse, C.A. 2011. Tree Rings and Water Resource Management in the Southwest. Water Management and Climate Change in Northern Arizona, Northern Arizona University, Flagstaff, Arizona, June 8. PRESENTATION.

Woodhouse, C.A. and **K. Morino**. 2011. Water Resource Management Informed by Paleohydrologic Data: Examples from the Western U.S. Final Science Meeting: IAI CRN 2047, Documenting,

Understanding and Projecting Changes in the Hydrological Cycle in the American Cordillera. Tilcara, Argentina, April 3-9. PRESENTATION

Woodhouse, C.A., **K. Morino**, and J.J.Lukas. 2011. Water Resources Management Informed by Paleohydrologic Data: An Example From the Colorado River Basin. Porto Galinhas, Brazil, September 25-29. PRESENTATION

Media Coverage

[none]

Honors

[none]

Project Leveraging

Connie Woodhouse: Climate Assessment for the Southwest (CLIMAS) program, a NOAA-funded project at the University of Arizona that links science with stakeholders; Western Water Assessment (WWA) program, a NOAA-funded project at the University of Colorado that links science with stakeholders; NSF-funded North American Monsoon project: shared chronology collection and development for both projects. **Dave Meko**: NSF-Funded North American Monsoon project: shared chronology collection and development for both projects. **Peter Troch**: City of Phoenix, CAP, Salt River Project funding to explore water availability issues in Salt and Verde rivers (Principle Investigator: **Gregg Garfin**). **Bonnie Colby**: NOAA-funded Economic Strategies to Address Climate-related Water Supply Variability, 2002-2012. USDA-funded Agricultural Water Management for Economic Viability and Environmental Quality Under Climate Change, U.S. Dept. of Agriculture, Western Regional Project W-190. Walton Family Foundation: Strategies for Improved Instream Flows: Resilient Human and Wildlife Communities in the Colorado River Basin, 2010-12

Partners

Connie Woodhouse and Dave Meko. We are working on a related project in the lower Colorado River basin with collaborators at the University of Colorado who are funding through the Colorado River District and the State of Colorado. **Bonnie Colby**. Public agencies: U.S. Dept. of Agriculture, Arizona Department of Water Resources, Central Arizona Project, Salt River Project. Other collaborators: The Nature Conservancy, Western Regional Office; Western Resource Advocates, Environmental Defense.

Future Research

The end date for this project was recently changed to September 2012 (from September 2011). The following is a summary of tasks yet to be completed.

Economics Sub-group

We are continuing to work on economic research and to produce guidebooks that summarize findings for Bureau staff and stakeholders. The guidebooks focus on economic strategies to minimize regional costs of shortages, and provide implementation guidelines for one of the key strategies to adapt to the effects of climate change on the hydrologic cycle. Over the next year, the economics sub-team plans to collaborate with Reclamation staff on research related to improving cost effectiveness in various aspects of supply reliability arrangements, particularly on the costs of monitoring and enforcing irrigation forbearance agreements.

Paleohydrology Sub-group

In this sub-group, there is a threefold goal of 1) optimizing the use of tree-ring chronologies in CRSS; 2) analyzing streamflow in select Lower Basin tributaries; and 3) investigating long-term controls on drought variability in the Lower Basin. Five tasks were identified to realize these goals. These are embedded in our descriptions below of future research.

SUB-GROUP 1 – Dave Meko and Kiyomi Morino. [*Task 1: Examine the spatial heterogeneity of runoff variation over the Lower Basin*.] Preliminary analysis of the spatial heterogeneity of runoff variation has been conducted over the Lower Basin using existing chronologies. Principle component analysis of moisture-sensitive tree-ring chronologies in and around the target sub-basins in the Lower Basin (Bill Williams, Virgin, Kanab, Paria, and Little Colorado) suggest a north-west/south-east dipole for the target basins. Further analysis will include characterizing spatial patterns over the Lower Basin for years of high contrast and exploring covariation in the frequency domain for target Lower Basin chronologies. Initial analyses of covariation of Lower and Upper Basin hydroclimate have been conducted. Further work includes incorporating the Gila River and analyzing covariation of target areas in the frequency domain. [*Task 5: Develop new and updated chronologies for hydroclimatic reconstructions and assess their covariance*]. The analysis of spatial heterogeneity and variation of existing chronologies will serve as a template for analysis of updated and new chronologies following chronology development of new and updated material. [*Task 3: Examine decadal variability in the frequency domain*]. Alternative analytical approaches for reconstructing Lees Ferry streamflow are being explored in collaboration with colleagues. Decadal variability will be characterized using spectral analysis. [*Task 2: Use paleodata to inform basin management under climate change*]. A novel approach to inputting paleodata into CRSS and its subsequent analysis has been developed. Final analyses and manuscript drafting are the next phases of this task. Following internal review, the manuscript will be passed on to Reclamation for input and recommendations, then will be edited accordingly and submitted to a peer-reviewed journal.

SUB-GROUP 2 – Connie Woodhouse, Mary Glueck and Brewster Malevich. [*Task 4: Identify and characterize CRB droughts, the ocean/atmospheric conditions that have accompanied them, and the role of ENSO*]. This summer, a draft of the summary report was generated that built on the results from the analyses of seven Upper Colorado River Basin droughts. The report includes methods and analysis

approaches, comparisons of all drought periods, a narrative for each drought, and a summary of the main features common to all droughts. Graphics have been compiled and ordered. The next task is to review and refine the graphics (currently in power point format) so that they are in a consistent and publishable format. At that point, the final report should be ready to submit to Reclamation for review. A peer-reviewed paper will be written, based on the report in 2012.

Hydrology Sub-group

The work we will be completing is related to the seasonal prediction of water availability across the SW, with focus on Lower CRB. It involves the statistical model relating sea surface temperatures to seasonal rainfall, temperature and streamflow.