Colorado River Basin Climate

Paleo • Present • Future

Special Publication for Association of California Water Agencies
and Colorado River Water Users Association Conferences

November 2005

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Foreword

The Colorado River has historically been an abundant source of supply for water users in the United States and Mexico. With growth of demands on this water supply, the time of historical abundance has ended. The previous five years of drought remain manifested in low reservoir levels. The Secretary of the Interior is beginning preparation of first-ever shortage criteria for the reservoir system. These conditions demonstrate the need for a strong scientific foundation in understanding climatic and hydrologic conditions that influence Colorado River water supplies. We know that droughts will inevitably occur in the future – a future made more uncertain by the impacts of climate change and increased hydrologic variability. Uncertainty surrounding the magnitude of water supplies will be coupled with increased competition for these supplies as the Southwest's population continues its rapid growth.

I encourage those attending this conference to become informed about the uncertainties associated with our present understanding of Colorado River Basin climate and hydrology, and to incorporate them in water management decision-making. In California, we are placing increasing emphasis on integrated regional water management planning as a way to enable us to better respond to hydrologic variability through use of a diversified portfolio of resource management strategies.

Lester A. Snow, Director

Contents

Introduction

The Colorado River Basin was already experiencing drought conditions in 2003 when California agencies signed the Colorado River Quantification Settlement Agreement to reduce their use of river water to the State's basic apportionment, entailing a reduction in actual water use of some 800,000 acre-feet. Subsequently, the river basin completed five consecutive years of drought in 2004. Total river system storage declined to almost half of combined reservoir capacity toward the end of the drought period. The single driest year of the five-year period was in 2002, when estimated natural flow into Lake Powell was 43 percent of average.

Water year 2005 was above-average for the Colorado River Basin, resulting in partial replenishment of significantly depleted reservoir storage, especially in Lake Powell. Water supply conditions for 2006 remain unknown. An important climate predictor for many parts of the Unites States, the El Niño Southern Oscillation (ENSO), is presently neutral with respect to equatorial Pacific sea surface temperatures, meaning that there is not a strong signal as to likely wetness or dryness in the coming year.

Only about 100 years of usable recorded streamflow measurements exist for the Colorado River Basin, as is typical in most western river systems. Basin water supply is strongly dependent on snowmelt runoff in high-elevation portions of the Upper Basin, with about 15% of the watershed area producing about 85% of the entire basin's average annual runoff. Researchers have used proxy data, such as from tree rings in the Upper Basin, to develop a reconstructed streamflow record predating the period of measured record. Reconstructions indicate that there have been periods of drought more sustained and severe than those in the gaged record, and even the recent five-year drought period (2000-2004) is not unprecedented. Conversely, the early 20th century wet period is relatively atypical in the context of the past five centuries.

Efforts to develop tree ring-based reconstructions of streamflow in the Basin began in the 1970s. Since then, there have been several reconstructions of Colorado River flows, including an updated reconstruction for flow at Lee's Ferry that is currently in progress. The National Research Council is presently conducting a science review of Colorado River hydrology, including evaluation of the different analyses that have been performed, to produce an improved hydrologic baseline that can be used by interested agencies in their water management decision-making.

It was during a wet period in the measured hydrologic record that the 1922 Colorado River Compact established the basic apportionment of the river between the Upper and Lower Basins. At the time of Compact negotiations, it was thought that an average annual flow volume of about 21 million acre-feet (MAF) was available for apportionment. The Compact provided for 7.5 MAF of consumptive use annually for each of the basins, plus the right for the Lower Basin to additionally develop 1 MAF of consumptive use annually. Subsequently, a 1944 Treaty with Mexico provided a volume of water of 1.5 MAF annually for Mexico. During the period of measured hydrology now available, the river's average annual natural flow has been about 15 MAF at Lee Ferry.

The Lower Basin's growth to full use of its interstate apportionment in the 1990s, combined with drought, has recently focused attention on how the river might be administered during times of shortage. There are no extant shortage operations criteria for the reservoir system. The U.S. Bureau of Reclamation (USBR), acting on behalf of the Secretary of the Interior, is beginning development of shortage guidelines for reservoir operations.

About this Publication

The intent of this publication is to provide readers with an overview of hydroclimate-related information for the Colorado River Basin. The following articles describe the basin's climate, its variability, and factors influencing it over varied timescales. Background is also provided on how climate and hydrology information are obtained and how forecasts are made. The articles begin by examining the very long-term perspective – that of paleohydrology – and move on to more recent climate conditions. Climate influencing factors such as El Niño and La Niña are discussed, together with their implications for water supply conditions. Near-term weather and runoff forecasting procedures are outlined, along with the level of uncertainty associated with such forecasts. The impacts of climate change on longer-term future conditions are summarized, and the extent to which these impacts can now be quantified is discussed. Reference materials – USBR's Federal Register notices regarding development of shortage guidelines , Internet sources for further climate information, and Governor Schwarzenegger's Executive Order regarding a study of climate change impacts – are also provided.

Viewpoints expressed in the articles are those of the authors, and do not necessarily represent the views of the California Department of Water Resources.

Acknowledgements

Many of the following articles were contributed by organizers of a May 2005 workshop to develop hydroclimate reconstructions for Colorado River Basin decision support, funded by the National Oceanic and Atmospheric Administration (NOAA). The Department appreciates the assistance provided by Gregg Garfin (Climate Assessment for the Southwest, University of Arizona), Jessica Lowrey (Western Water Assessment, University of Colorado), Bradley Udall (Western Water Assessment, University of Colorado), and Connie Woodhouse (NOAA, National Climatic Data Center's Paleoclimatology Branch) in compiling and reviewing the articles as a follow-up to the outreach goals of the workshop. The Department thanks all of the authors for their contributions to this conference publication.

From Tree Rings to Streamflow

Connie Woodhouse PhD, *Physical Scientist, NOAA Paleoclimatology Program, National Climatic Data Center*
Jeff Lukas, *Professional Scientist, Institute of Arctic and Alpine Research, University of Colorado*

Streamflow records are limited in length to the past 100 years or so, but records of past streamflow can be estimated using tree-ring data. The development of a tree-ring reconstruction of a streamflow record is conceptually fairly simple. In short, tree-ring data for the modern period are calibrated with the streamflow record to generate a statistical model describing the relationship between them, and then the model is applied to the entire multi-century tree-ring record.

Why tree-ring reconstructions work

Tree growth is usually controlled by climate conditions during the year prior to and including the growing season. At lower and middle elevations in many parts of the Western U.S., variations in tree growth generally reflect the amount of soil moisture at the onset of the growing season, which is controlled by variations in precipitation, and, to some degree, temperature, humidity, and wind. Since streamflow likewise integrates these variables over the course of the previous seasons, water year (October to September) streamflow is often very strongly correlated with tree growth.

Chronologies – the basic building blocks

The basic unit of tree-ring data is the chronology--a time-series of annual values derived from the ring-width measurements of 10 or more trees of the same species at one site. To create a tree-ring chronology, cores taken from the trees with an increment borer are cross-dated (patterns of narrow and wide rings are matched from tree to tree) to account for missing or false rings, so that every annual ring is absolutely dated to the correct year. Then all rings are measured to the nearest thousandth of a millimeter using a computer-assisted measuring device. After growth-related trends are statistically removed, the ring-width values from all sampled trees for each year are averaged to create a time-series of annual ring-width indices--the chronology. Over 600 moisture-sensitive tree-ring chronologies have been developed in the Western U.S., many of them for the express purpose of reconstructing streamflow. Even with this large existing network, new tree-ring chronologies are often needed in order to robustly reconstruct streamflow in a particular basin.

Identifying data for the streamflow reconstruction

Once a gage record has been selected for reconstruction, the next step is assessing the suitability of both the tree-ring data and the streamflow data. The first requirement is that the two records overlap for at least 50 years, to allow for adequate calibration and validation of the reconstruction model. Usually only tree-ring chronologies that have a statistically significant ($p<0.05$) correlation with the gaged record are used in the reconstruction process. Other statistical characteristics of both the tree-ring and streamflow data are then evaluated. The most important consideration is that neither has a significant linear trend over time, since that may make the model unstable. A linear trend in a streamflow record is usually caused by human manipulation of the watershed. Using “natural” flow records, as described later, avoids these effects.

Tree-ring chronologies that have been evaluated for suitability as described above become part of a pool of potential predictors for the reconstruction model. Depending on the availability of tree-ring data for a particular region, this pool will include from 5 to 50 chronologies. When the number of chronologies is large, they are often reduced, using principal components analysis, into one to several primary modes of variability, or principal components. Then these principal components are used as the predictors.

The chronologies in the predictor pool are not necessarily located in the same watershed as the gage record. The atmospheric flows of moisture that influence both tree growth and streamflow are regional, crossing watershed divides, so trees in one basin may capture a significant portion of the variability in streamflow in another basin. An additional consideration in the selection of chronologies for the predictor pool is the length of the chronology. The length of the final reconstruction is limited by the shortest chronology that contributes to it. If a reconstruction must extend to a certain year (e.g., 1600), then all chronologies starting after 1600 should be excluded from the pool of potential predictors.

Generating (calibrating) a reconstruction model

Nearly all streamflow reconstruction models are generated using multiple linear regression. The predictors, whether chronologies or principal components derived from them, are entered into the regression with the gage record (or predictant). A number of different regression approaches can be used, but in all cases, the regression process determines which set of predictors constitutes a model that best fits the gage data. The resulting regression equation is a weighted linear combination of predictors, of the form: $y = a_1x_1 + a_2x_2 + a_3x_3 + b$ where y is the gaged flow, x_n is a tree-ring predictor, a_n is the coefficient for that predictor, and b is the y-intercept.

Validation of the model

After the model is generated, the skill of the model is tested using a set of validation statistics. There are a number of ways to go about validating the model (or comparing several competing models to select the best), using data not included in the calibration process. A set of years may be set aside for model validation, or a set may be generated in the calibration process by calibrating on all but one case, estimating that case, then removing a different case, and estimating that one, repeating until each case has been omitted and estimated (sometimes called the "leave-one-out" method). The validation assesses the ability of the chosen set of predictors to estimate streamflow, by using the calibration model on data not contained in the model.

Evaluating the quality of the reconstruction model

The reconstruction is evaluated statistically to see how well it compares to the observed gage record. The correlation coefficient (R) and explained variance (R^2) describe the goodness-of-fit of the model to the calibration data. A good streamflow reconstruction model will have an R^2 over 0.50 (i.e., it explains 50% of the variance in the gaged record during the calibration period), and the best reconstructions explain up to 80% of the variance. A visual assessment of the reconstruction is also important. The reconstruction should appear to capture both year-to-year and decadal-scale variability (Figure 1). Water managers tend to be most interested in accurate reconstruction of extreme low flows, so the model's fit to that subset of values can be a critical measure of quality.

Generating the reconstruction

Once the model is calibrated and validated, the predictors and their regression coefficients are used to reconstruct estimates of streamflow for the years of the tree-ring chronologies prior to the period of the gage record. This is done by entering the predictors' values into the regression equation and calculating the streamflow for each year.

Uncertainty in the reconstruction

Because all reconstructions fail to capture some portion of the variance in the gage record, there are uncertainties in the reconstructed values due to the differences between observed gaged and reconstructed

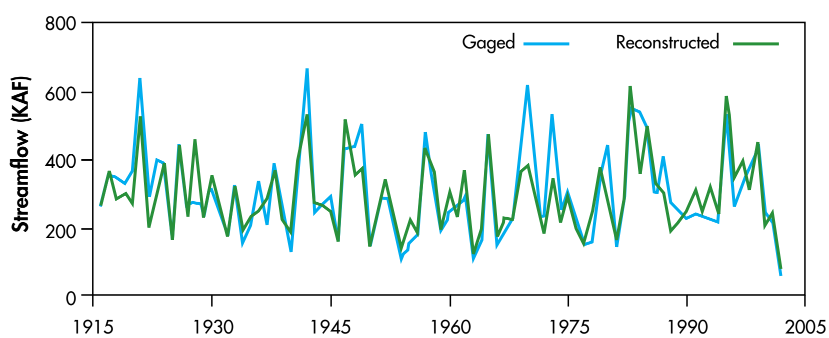

Figure 1. Calibration/verification period (1916-2002) for a tree-ring reconstruction of the South Platte River at South Platte, Colorado. The reconstruction explains most of the variance (R2 = 0.76) of the gaged record and captures the extreme low flows, including 2002. The gaged flow record, corrected for depletions, was provided by Denver Water. Units for flow are 1000 acre-feet (KAF).

values . This uncertainty can be described by confidence intervals (CIs) around the reconstruction that allow probabilistic statements about reconstruction confidence; e.g., there is 95% confidence that the actual flow for year X is within +/- 12,400 acre-feet of the reconstructed value. The typical method of deriving the confidence intervals is to calculate them from the root mean squared error (RMSE), which quantified the average difference between the observed and reconstructed values.

Also, any extremely high or low reconstructed flows that are outside of the variability of the gaged flows (that is, extrapolations), are less certain than the reconstructed flows within that range of variability (interpolations), since the reconstruction model was "trained" on that range of variability.

Another source of uncertainty in the reconstruction is errors in the gaged record itself. While the process of making a flow reconstruction creates the impression that the gaged record is the "gold standard", the physical reality is more complicated. Streamflow gages directly measure stage height, not discharge, so uncertainties in the stage-discharge relationship (rating curve) lead to measurement error, typically on the order of +/- 5%.

More critically, nearly all of the streams whose records have been reconstructed with tree rings have human modifications (diversions, reservoirs, etc.) upstream of the gage in question. Since these modifications alter the flow regime on multiple time scales, the gaged record is no longer representative of actual variations in water supply. Accordingly, these gaged records must be corrected to account for the modifications, creating what is variously called a "natural", "undepleted", or "virgin" flow record.

The calculation of a natural flow record requires records, estimates, and/or models of different variables, each of which has its own inherent uncertainty. For example, the calculation of natural flow for gages in the upper Colorado River Basin by the U.S. Bureau of Reclamation requires data on consumptive agricultural use, reservoir regulation, exports out of and imports into the basin, and municipal and industrial uses. So while a natural flow record is a far better representation of actual water supply, it does contain greater uncertainties than the gaged record on which it is based.

Summary

The main requirements for successfully reconstructing streamflow are a long gaged record that has been corrected for modifications to the flow regime, and a pool of moisture-sensitive tree-ring chronologies from the region around the gage. Because the moisture signal contained in tree rings in the Western U.S. is generally quite strong, the statistical methods used to generate the reconstruction have a straightforward task. The resulting reconstructions have proven valuable in providing a multi-century perspective on water supply variability across the West.

Paleoclimate Overview

Connie Woodhouse PhD, *Physical Scientist, NOAA Paleoclimatology Program, National Climatic Data Center*

Weather is the set of environmental conditions measured by instruments such as thermometers and rain gages over a period of hours to several days. Climate is the weather we expect over the period of a month, a season, a decade, or a century, resulting from the mean state of the atmosphere-ocean-land system. Paleoclimate is the climate of the past, before the development of weather recording instruments, and is documented in biological and geological systems that record variations in climate in their structure.

Why is information on past climates important?

Understanding how frequently climate events such as droughts have occurred in the past and the character of those events is important for assessing the range of conditions that may occur in the future. Although past events cannot be used to predict the future, they can provide baseline information of natural climate variability. Knowledge about the possible range of natural climate variability at a variety of time scales is critical for water management and is key for future planning, particularly in arid regions such as the Colorado River Basin. Gages and other instrumental recorders of climate have operated for only a little over 100 years in the best cases, and typically for much shorter periods of time. Records of this length are not very useful for assessing how often a 1930s or 2002-type drought event occurs. However, environmental recorders of climate do exist which can be used to extend the instrumental records back in time. These records cannot exactly duplicate the instrumental records, but they can provide estimates of past conditions.

Sources of paleoclimatic information on drought

Environmental recorders of climate, called proxy records, come from a variety of sources, each with its own characteristics, including where they are found, what they record, how long the records are, and the precision and resolution of the dating. In the Western U.S., some of the primary sources of information on past drought are historical documents, tree rings, sand dunes, and lake sediments. Historical documents and tree rings provide the most detailed record of past climate in terms of the resolution of the information (daily to annual), but are limited in length to times scales of less than a year to several thousands of years, for the most part. Records of past climate from dunes and lake sediments are much longer, going back tens of thousands of years, but these proxies provide less temporally detailed information, on the order of decades to centuries.

Historical documents

Historical documents in the form of letters, diaries, newspaper accounts, and early instrumental measurements can provide accurately dated, detailed accounts of short-term climatic variability and events (e.g., severe storms, early snowfall, extreme low flows in rivers). Unfortunately, in the Western U.S., very few of these records extend prior to the mid-19th century. The interpretation of some of these accounts can be problematic as they may be biased due to the perspectives of the observer. There are a number of early instrumental records for climate stations in the Western U.S., but most records are short and/or discontinuous, with irregular observations. However, some work has been done to piece records together to obtain a more complete record of 19th century climate for areas such as the Rocky Mountains. These data can also be useful in validating climate information found in other proxy records.

Tree-ring data

Tree rings provide annually or seasonally resolved data that are precisely dated to the calendar year. Tree-ring records commonly extend 300 to 500 years into the past, and a small number are thousands of years long. Trees that are sensitive to climate reflect variations in climate in the width of their annual rings. Thus, the ring-width patterns contain records of past climate. Trees that grow in arid or semi-arid areas, and on open, dry, south-facing slopes, are stressed by a lack of moisture. These trees can be used for reconstructing climate variables such as precipitation, streamflow, and drought. To develop a reconstruction of past climate, tree-ring data are calibrated with an instrumental record for the period of years common to both. This process yields a statistical model that is applied to the full length of the tree-ring data to generate a reconstruction of past climate. The reconstructions are only estimates of past climate as the tree-ring based reconstructions do not explain all the variance in the instrumental records. However, they can explain up to 60-75% of the total variance in an instrumental record.

Sand dune sediments

Large areas of the intermountain basins of the Western U.S. contain sand dunes and other dune-related features, most of which are now stabilized by vegetation. Sand dunes and sand sheets were deposited by the wind in times of drought and contain a wealth of information about episodes of drought and aridity over the course of the Holocene, which is the period since the end of the most recent widespread glaciation, about 10,000 years ago. The layers of sand, representing periods that became too dry to support vegetation, are interspersed with layers of soil, which reflect periods that were wet enough to allow soil to form and support plant life. The soil layers, which contain organic materials, can be dated with radiocarbon dating techniques. The dates from the soil layers between layers of sand can be used to bracket times of drought as signified by the presence of sand. Since there is a lag in time in the vegetation and dune response to climate conditions, this record is fairly coarse in terms of time scales that it can resolve (typically centuries or longer). In addition, radiocarbon dating, with a dating precision of +/- 5% (or more during certain periods in the Holocene), contributes to low temporal resolution of this record. However, recent work has used optically stimulated luminescence techniques to date sand grains, producing records with a decadal scale resolution for the past 1,000 years.

Lake sediments

Materials that flow, wash, or blow into lakes (e.g., water, dust, small plant parts, pollen) and materials produced in lakes (biological or chemical) are indicators of the environmental conditions at the time of deposition. Consequently, cores taken from lake bottoms contain a record of past environmental variability. The cores are sampled at regular intervals, and then analyzed to examine the biologic and geochemical composition of the core over time. Biological indicators of environmental variability, including changes in the types and amounts of certain small organisms that live in the lake, can reflect changes in lake salinity or depth. Chemical analyses of oxygen isotopes, total inorganic carbon, and magnetic susceptibility can indicate evaporation, lake volume and size change, air and water temperature, and inflows. The series of biological and chemical variations are anchored in time using radiocarbon dating and paleomagnetic secular variations (50-100 year accuracy), so are similar in dating precision to the dune sediments. These records extend tens of thousands of years and longer.

What do these sources say about climate over last 2000 years?

Paleoclimatic records from different sources can be pieced together to provide a history of climate variability over many time scales and regions. Three examples of past droughts in the Western U.S. are described below to illustrate the range of variability documented in these paleoclimatic records. The locations of some of the paleoclimatic records mentioned in these examples are shown in Figure 1.

The 2002 Colorado Drought in a 500-Year Context

Severe drought in 2002 impacted much of the Western U.S., but was particularly severe in Colorado. A survey of tree growth at 12 sites in the Colorado Headwaters region indicates the 2002 growth ring, averaged among the sites, was the smallest ring since 1851, and the third smallest ring in the period from 1440-2002. A tree-ring based reconstruction of water year streamflow averaged for three gages in this region (Blue, William's Fork and Fraser Rivers) for the years 1437-2002 shows 1851 to be the lowest flow year in this period, followed by 1845 and 1685. Flow in 2002 ranks eighth lowest in this record. The first permanent non-Indian settlement in Colorado was founded at Conejos in San Luis Valley in 1851, so there are no historical records to document this extreme drought year. However the occurrence of wildfire, recorded in scars of trees across Arizona, New Mexico and Colorado, indicates this to be a year of extraordinarily widespread fire in the context of the past three centuries, and supports the evidence for a very dry year. Although not the driest year in a 500-year context, 2002 was certainly among the driest, with wildfires burning over large areas of the Western U.S., including the largest on record in Colorado.

Drought in the Late 16th Century

A remarkably widespread and persistent period of drought in the late 16th century is evident in a large number of proxy records for the Western U.S. Tree-ring data document drought conditions that ranged across western North America from Northern Mexico

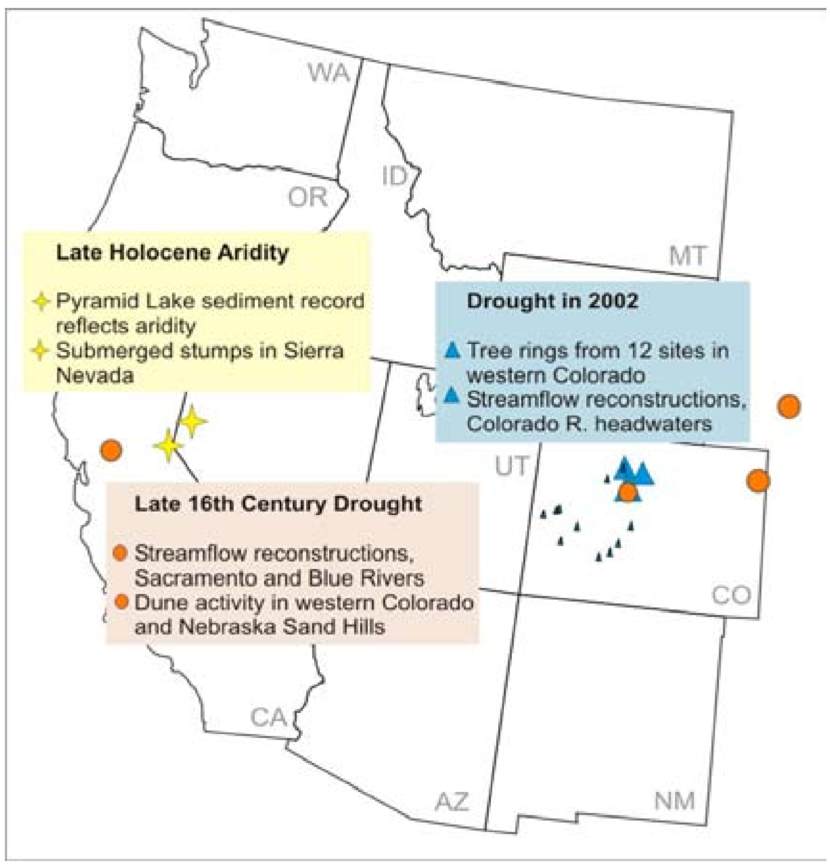

Figure 1. *Locations of some of the proxy records mentioned and the droughts they document.*

to British Columbia. Tree-ring based streamflow reconstructions for the Sacramento River and Blue River (in the Upper Colorado River watershed) show concurrent drought conditions in both of these watersheds in the late 16th century. This was one of the few periods of drought shared by both the Sacramento and Blue River reconstructions over the 500 years common to both records. During the period from 1580-1585, there were four years with concurrent drought conditions in both watersheds. Drought was particularly severe in the Sacramento River reconstruction which indicated the driest three-year period in the entire reconstruction (extending to A.D. 869) was 1578-1580. In addition to the Western U.S., there is also evidence of severe sustained drought in the western Great Plains about this time, with widespread mobilization of sand dunes in eastern Colorado and the Nebraska Sand Hills.

Late Holocene Aridity and the Medieval Climatic Anomaly

Many paleoclimatic records in the Western U.S. suggested a period of increased aridity about 1000 years ago. High-resolution (sampling interval of five to eight years) lake sediment records from Pyramid Lake in the western Great Basin document long-term variations in hydrologic variability and changes in lake size over the last 3000 years. In this record, two periods of intense aridity occurred between about A.D. 800 and A.D. 1350. Remains of trees now submerged in several lakes and bogs in the Sierra Nevada, radiocarbon dated to determine when they were killed by rising water, reflect two similar periods of drought, about A.D. 1000 and A.D. 1250. In addition, a network of drought reconstructions from tree-ring data indicates an increase in drought area in the central and western U.S. from about A.D. 900-1300. While these proxies are not indicative of individual droughts, all point to widespread periods of increased aridity at about the same time.

Summary

- A variety of environmental recorders of climate, called proxy data, are available, each with its own characteristics related to where and how they record past climate.
- Paleoclimatic proxy records provide a way to evaluate current

climate in a long term context, and allow an assessment of climate variability over a broader time frame than afforded by instrumental records alone.

• Used together, proxy records can provide a more complete picture of past climate over a range of time and space scales.

Future Research

• Updated and new data collections and networks of data, especially high resolution data for the past 2000 years

• Proxies for ocean conditions independent from terrestrial proxies

• Methods to better describe uncertainty and confidence levels in proxy records and climate reconstructions

Climate Factors on Colorado River Basin Water Supply

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Kelly T. Redmond PhD, *Regional Climatologist and Deputy Director, Western Regional Climate Center, Desert Research Institute*

Introduction

The waters of the Colorado River originate primarily in the high mountain basins of Colorado, Utah and Wyoming, and flow through seven states and two countries. With headwaters about 1500 and 1700 miles from the Gulf of California, the mainstem Colorado and the Green Rivers, respectively, equally contribute about 80 percent of the flow into Lake Powell, with the remainder mostly from the San Juan River and Mountain Range.

Within the 242,000 square mile U.S. portion of the basin, the highest one-seventh of the basin supplies about six-sevenths of the total flow, and many of the lower reaches lose water under natural conditions. Most of this precipitation supply falls in winter as snow. Thus, climatic influences on these interior mountain ranges are key factors governing the supply of water in the river from one year or decade to the next.

Through multiple re-use, the river provides water supply needs for 28 million people, a number expected to continue to grow in coming decades as the Southwest's population continues to expand at the fastest rate in the Nation. The river basin has been developed through an extensive infrastructure system that was designed to buffer

Figure 1. *What a difference a winter makes! Lower Lake Mary, near Flagstaff, Arizona. Left: September 15, 2004. Right: April 13, 2005.* *Photos by Kelly T. Redmond.*

against the region's significant climate variability. Of note, however, the system has not been thoroughly tested by events of the magnitude that we have learned from the paleoclimate record may occur. The recent drought has provided a taste of what is possible, though not the full meal.

Climate Teleconnections and Influences

The Colorado River Basin (Basin) is a snowmelt-driven system that depends on winter snowfall for its dry (summer) season supply. Spring precipitation can be important, but summer precipitation is usually nearly negligible in altering water supply, though it does influence demand. On an annual basis, supply variability is typically several times larger than demand variability.

Studies in the last two decades have revealed that faraway portions of the Pacific Ocean affect temperature and precipitation patterns in the Western U.S. Chief among these is the El Niño / La Niña alternation in sea surface temperature on the equator between Peru and the Date Line. Because of strong -- though varying -- relationship of sea surface temperature to a pressure alternation between the central Pacific and Indonesia, this overall phenomenon is often referred to as ENSO (El Niño - Southern Oscillation) (see Figure 4).

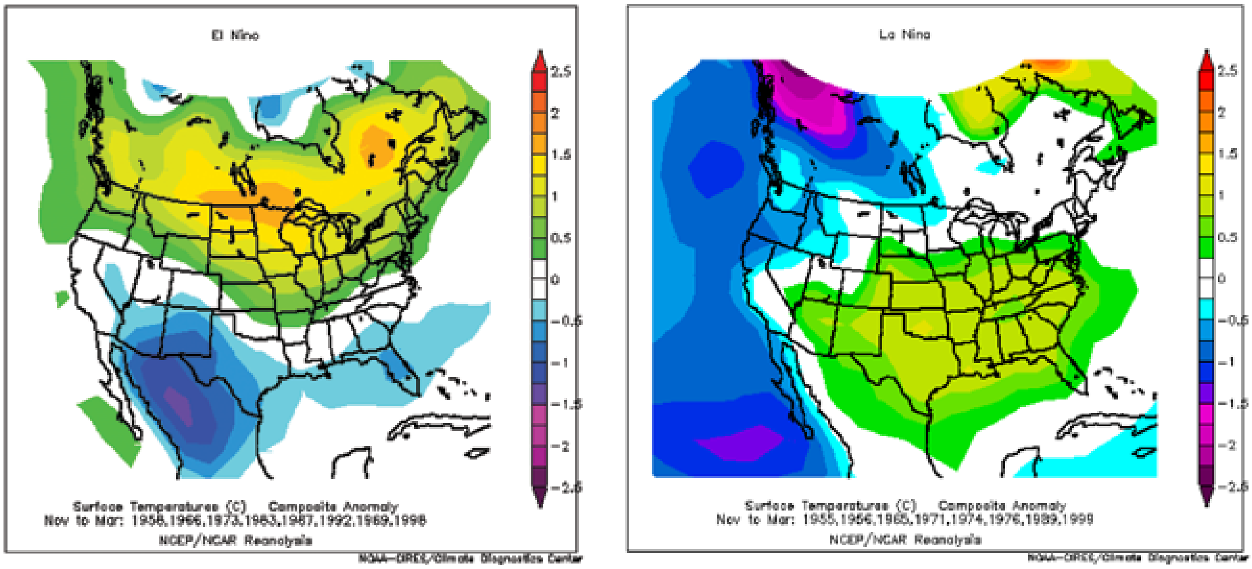

Figure 2. *El Niño and La Niña mean temperature anomalies, or departures from average, for winter (November-March). El Niño years are ending in 1958, 1966, 1973, 1983, 1992, 1969 and 1998. La Niña years are ending in 1955, 1956, 1965, 1971, 1974, 1976, 1989 and 1999. Credit: NOAA-CIRES/Climate Diagnostics Center, www.noaa.cdc.gov.*

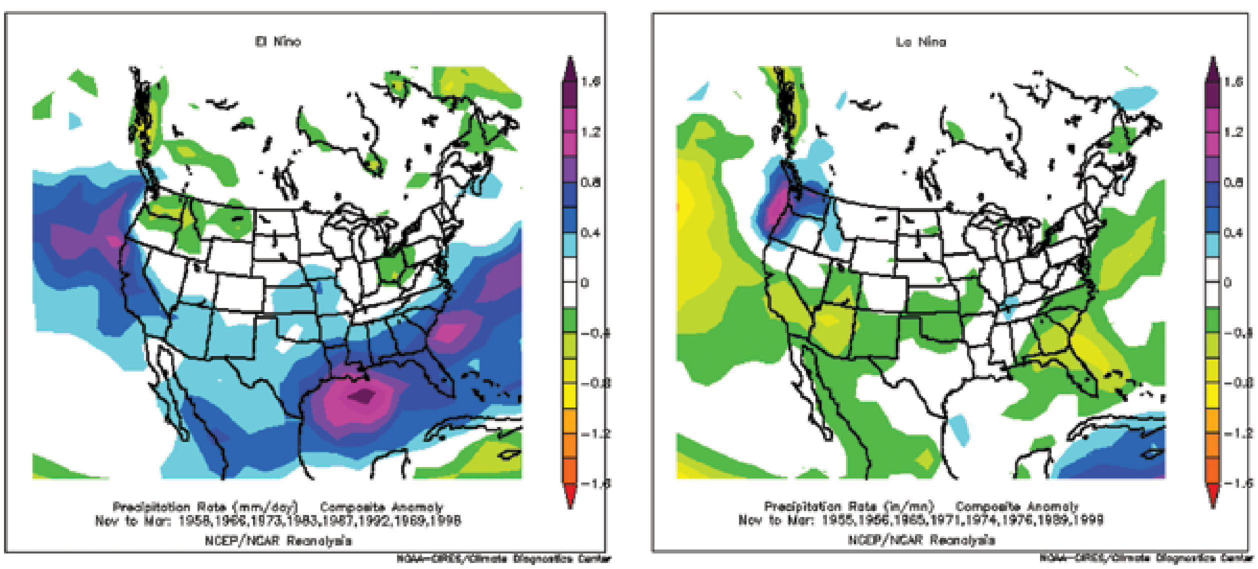

Figure 3. *El Niño and La Niña mean precipitation rate anomalies, or departures from average, for winter (November-March). El Niño years are ending in 1958, 1966, 1973, 1983, 1992, 1969 and 1998. La Niña years are ending in 1955, 1956, 1965, 1971, 1974, 1976, 1989 and 1999. Credit: NOAA-CIRES/ Climate Diagnostics Center, www.cdc.noaa.gov.*

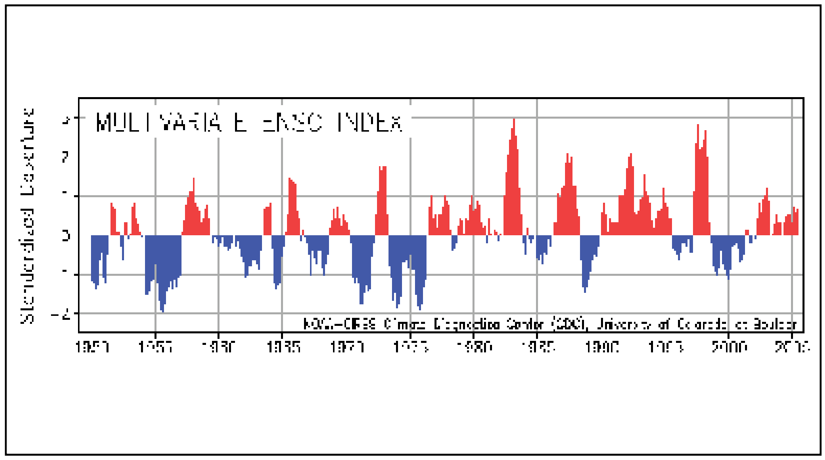

Figure 4. *Multivariate ENSO Index. Values greater than +0.5 generally indicate El Niño conditions, and those less than -0.5 generally indicate La Niña conditions. Credit: NOAA-CIRES/Climate Diagnostics Center, www.cdc.noaa.gov people/klaus.wolter/MEI/.*

The warm phase of ENSO, El Niño or negative Southern Oscillation, typically brings wet and cool winters to the Southwest U.S., and dry and warm winters to the Pacific Northwest and northern Rockies. The opposite cool phase of ENSO, La Niña or positive Southern Oscillation, has been reliably associated with dry and warm winters in the Southwest for the past 75 years, and to a less reliable extent with wet and cool winters in the northern West. The understanding of ENSO and its effects on the Basin are crucial in predicting winter snowpack. Despite much searching, western North America climate relationships to ENSO appear to be confined to the winter half year, with slight or ambiguous associations with summer climate. In the Basin, the strongest relationships are seen in the Lower Basin, south of the San Juan Mountains of Colorado. The relationship becomes less clear farther north, and begins to have the opposite effect in the upper Green River basin and the Wind River mountains in Wyoming. The division is at approximately Interstate 80, or a line from San Francisco to Cheyenne. Figures 2 and 3 show how temperature and precipitation rate can differ in the Upper and Lower Basins during El Niño and La Niña events. Much of whatever modest skill climatologists have at 3-9 month lead time in forecasting western precipitation arises from ENSO and its effects. This north/south

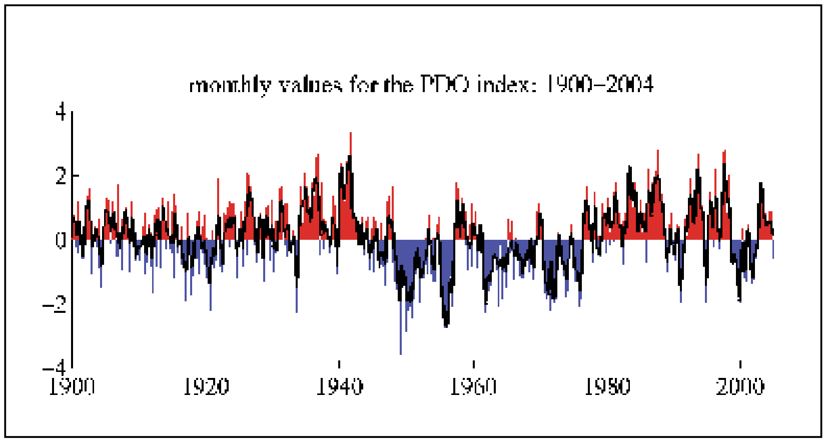

Figure 5. *Pacific Decadal Oscillation (PDO) monthly index, 1900-2004. Red shading indicates warm phase, and blue indicates cool phase. Credit: http://tao.atmos.washington.edu/pdo/.*

geographic accident is somewhat unfortunate, because main runoff contributions originate in central Colorado, northern Utah, and Wyoming, where weak or opposing ENSO relationships prevail.

El Niño connections operate on interannual time scales (Figure 4). Since the memorable 1982-83 El Niño, scientists have uncovered other potential climate connections to the West, some of which take years or decades to proceed through their presumed cycle. One of these, the Pacific Decadal Oscillation, or PDO, is defined by anomalous sea surface temperature, sea level pressure and wind stress along the Pacific coast. Its warm phase has been associated with above average precipitation in the Southern U.S. and below average precipitation, snowpack and streamflow in the Northwest U.S., similar to El Niño conditions. Its cool phase is associated with the opposite climate patterns, analogous to extended La Niña conditions. Figure 5 shows that PDO is more persistent than ENSO and generally has a period on the order of decades. ENSO and PDO effects may reinforce or cancel each other.

Climate Trends

In addition to climate cycles affected by sea surface temperatures, overall climate trends show a recent warming in Western U.S. winters (see Figure 6 and 8). This warming trend mirrors annual

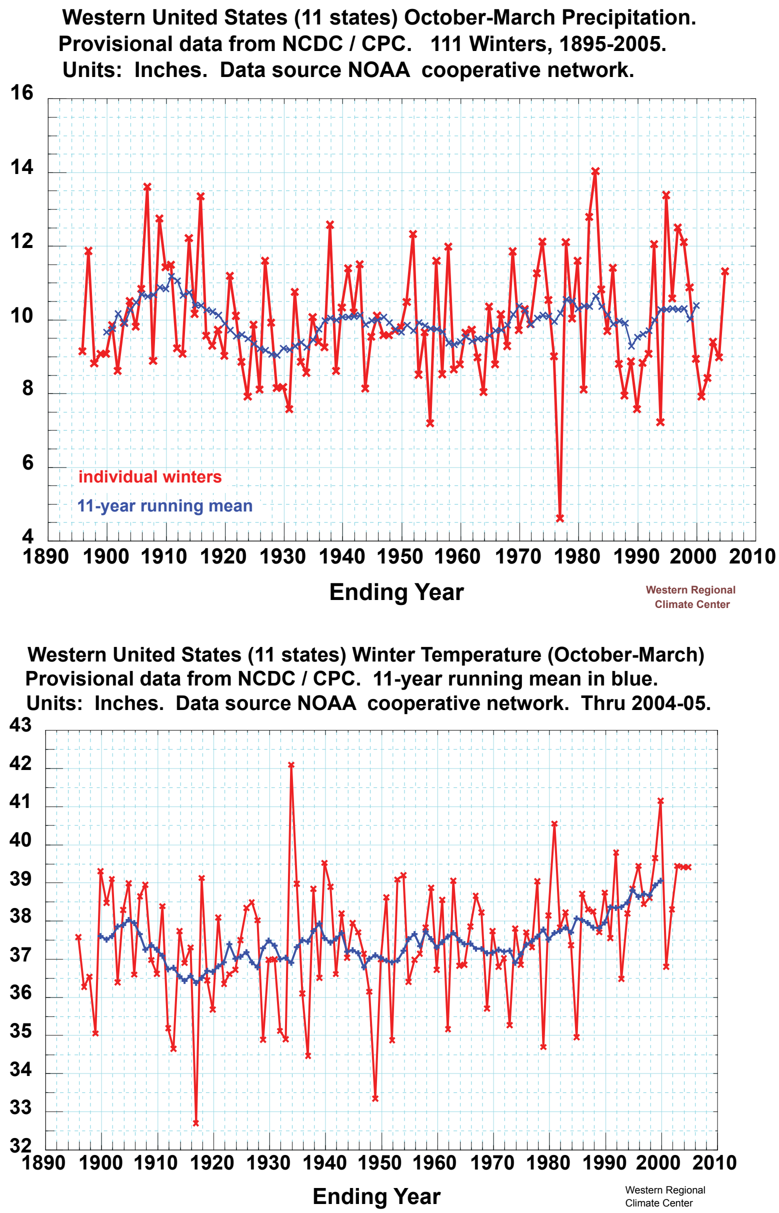

Figure 6. *Western U.S. winter precipitation and temperature, 1895-2005.*

global temperature trends. Warmer than average winter temperatures have been evident across the region, particularly over the last six years. In addition to this temperature trend, the Western U.S. has also experienced a drought in the last six years, although this is not associated with a longer drying trend (see Figure 7). While the anomalously high snowfall in the winter of 2004-05 was a healthy step towards alleviating drought conditions, one wet year can not fill all of the reservoirs and aquifers in the Basin (see Figure 9).

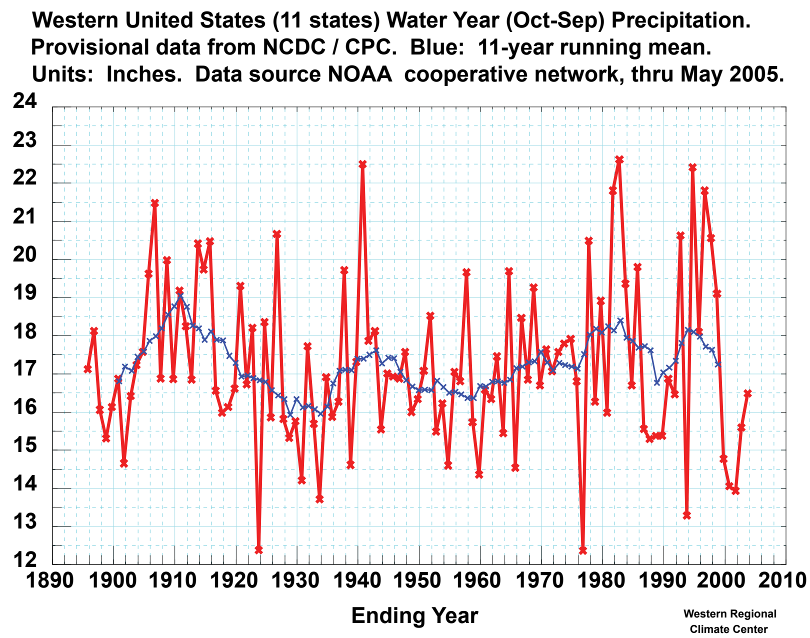

Figure 7. *Western U.S. annual water year precipitation, 1895-2005.*

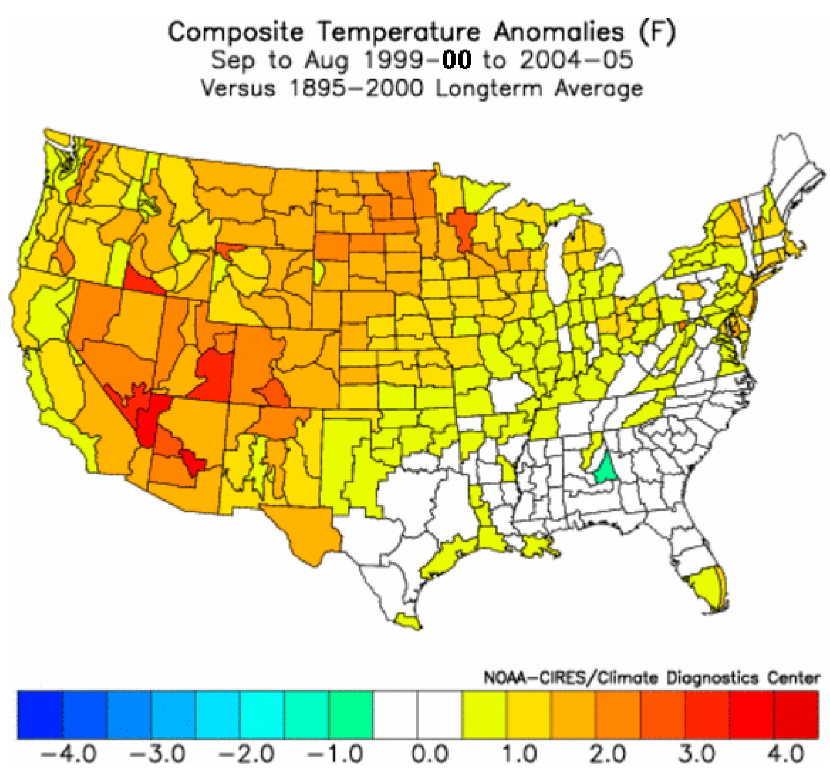

Figure 8. *1999-2005 Temperature departure from 1895-2000 long term average. This depicts the warm temperatures that have accompanied the recent dry period in the Western U.S. and the Basin. Credit: NOAA-CIRES/Climate Diagnostics Center, www.cdc.noaa.gov.*

Overall, El Niño winters tend to have more wet days, more precipitation per wet day, and more persistent wet episodes in the southwestern U.S. All of these favor increased runoff. The San Juan Mountains and River, for example, exhibit an ENSO relationship and contribute to a somewhat positive correlation between ocean temperature and winter snowpack. Additional studies have shown that this association is accentuated for runoff in comparison with climate. Of note, extremely high or low flow is better correlated with ENSO than is total runoff volume.

Thunderstorms during the Southwest summer monsoon are dramatic, but contribute little to streamflow in the Basin. Although these summer convective storms bring some relief to the dry season water demand, the precipitation that falls is not usually a large contributor to the runoff and streamflow of the Basin. It has been suggested that heavy snow winters may lead to reduced monsoon activity, perhaps by inhibiting the land-sea temperature contrast that drives monsoon development. It is important to note that one single aspect of the climate system can not be used to describe all of the variability due to the complicated interrelations among these and other elements of the climate system.

Summary and Future Needs

Climatologists know that long-term drought is related to changes that take place in the Pacific and Indian Oceans. In the past few decades, they made progress in defining these changes that are often repetitive in nature, including ENSO and PDO. The Basin and the West have warmed in recent decades, and likely have in the past from climate change. Yet, there is much left unknown about other global influences on the Basin, such as the Madden-Julian Oscillation near India.
A continued strong need exists for observations of climate variables such as temperature, precipitation, snowfall and streamflow, and in particular at the higher elevations. The current available records of about 100 years are too short to effectively show some long term

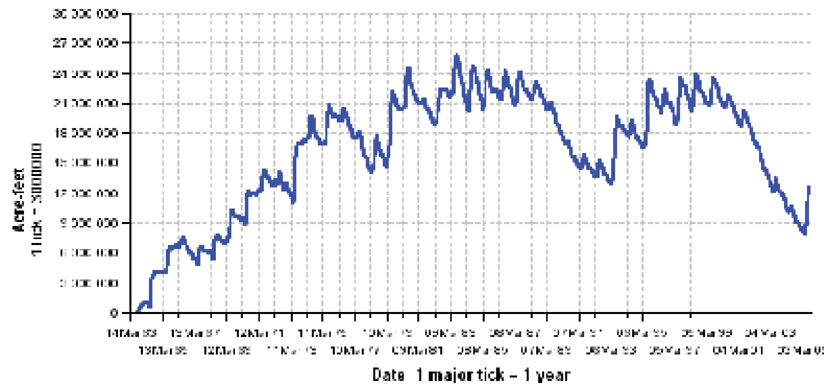

Figure 9. *Lake Powell storage since the closure of Glen Canyon Dam. Notice the recent multi-year dry period, and the contribution of the wet winter of 2004-05. Credit: http://www.usbr.gov/uc/index.html.*

trends or extreme events. It is common for water managers to use these historical records to calculate probabilities and possible future scenarios, which may not reflect the actual extremes that have occurred.

Improvements in regional scale modeling as well as long-term and seasonal forecasting are also needed. In order to achieve this goal, however, climate scientists will need to better understand the global drivers of climate in the Basin and then apply this knowledge at a relatively small scale.

A continual dialogue is needed between climate and water researchers and decision makers on the ground. Two-way clear communication is crucial for climatologists to explain the science and uncertainties, and for the managers to clarify issues that they need addressed. Patience is a key factor in maintaining long-term relationships as answers come slowly, and only through knowledge gained during each ENSO or PDO phase and each water year will more evidence and data come to light.

Seasonal Forecasting: Skill in the Intermountain West

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People have long been interested in outlooks of climate, as shown by the popularity of the Farmer's Almanac for over two centuries. More recently, climate scientists have been producing official climate forecasts on a regular basis. This article describes what seasonal forecasts are, the scientific basis for making forecasts, and the skill of these forecasts over the U.S. West including California and the Colorado River Basin.

A seasonal climate forecast is about the *average* conditions over a future period of time, rather than a prediction for a particular day. (The latter is commonly called a weather forecast.) In addition, a seasonal climate forecast is a prediction of the *departure* from the normal march of the seasons. So, saying that summer comes after winter is hardly a seasonal forecast! What we really wish to know is whether this summer will be abnormally hot and whether a drought will leave our crops stunted where typical summer rains normally nourish the soil.

Therein lies a most curious situation. While the daily weather much beyond two weeks is nearly impossible to predict accurately, the seasonal climate is, at times, quite predictable. The reason is that

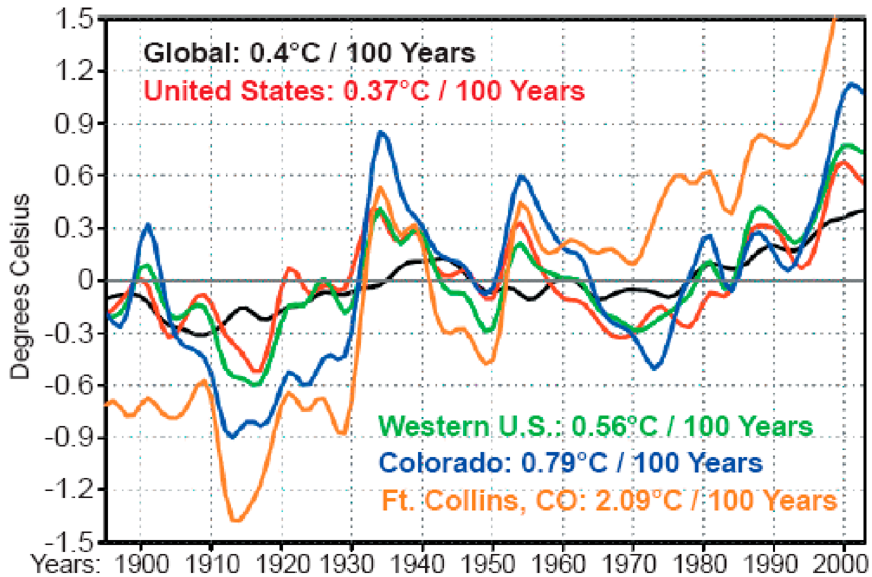


Figure 1: *Temperature trends for different regions of the globe since 1900. The Western U.S. has warmed about 1°F, Colorado 1.5 °F and Fort Collins about 4°F during the last 100 years. (1°C is approximately 2°F.)*

the climate system has a modest degree of memory, which is mostly imperceptible on a daily basis, but detectable in the average of seasons. Long-term temperature trends also provide valuable clues to the future.

The memory of climate conditions can influence the future seasonal state of the atmosphere, and leave a definable and predictable signal. Climate memory is most prevalent in the world oceans, where cool or warm anomalies in the sea surface can take months, and sometimes years, to revert to normal. Unusual land surface conditions, such as excess spring soil moisture accumulated from heavy rains or deep early winter snow cover, may also provide memory. Climatologists have only recently fully understood the "granddaddy" of these signals, an irregular prolonged warming (or cooling) of the tropical Pacific Ocean, known as El Niño (or La Niña) or collectively as the El Niño/Southern Oscillation (ENSO). In the late 20th century, climate scientists have finally been able to unravel the global mystery linking tropical Pacific Ocean conditions to the subsequent seasonal climate of many far-away places, including the United States. ENSO is the phenomenon that has formed the backbone of modern seasonal forecasting.

Who produces these "official" seasonal climate forecasts?

In 1995, the Climate Prediction Center (CPC), a part of NOAA's National Weather Service, began issuing seasonal climate forecasts for precipitation and temperature each month based on dynamical and statistical forecasting techniques. CPC issues forecasts for three-month periods with lead times ranging from 0.5 to 12.5 months. For example, in mid-October, CPC will issue temperature and precipitation forecasts for November-December-January (0.5 month lead), December-January-February (1.5 month lead) and all subsequent forecasts up to November-December-January of 2006-07 (12.5 month lead). CPC forecasts for both temperature and precipitation use a 3-category system: above normal, normal, or below normal, and will indicate if one of these categories is more likely to occur. CPC may also issue an "equal chances" forecast if there is no tilt of the odds towards one category. These forecasts rely primarily upon two critical climate processes: (1) the status of ENSO and (2) long-term upward temperature trends, which climatologists have been observing for the past several decades. In the Western U.S. especially, this temperature trend is pronounced (see Figure 1).

How do we assess these forecasts?

There are two standard measures to assess the performance of forecasts, accuracy and skill. Accuracy is a measure of how close the prediction is to the observed climate variable, such as temperature or precipitation. Skill, on the other hand, measures how well one forecast performs compared to a reference or baseline forecast. "Climatology" is used as a typical baseline forecast, referring to the expected (average) values of temperature or precipitation for a given location and time of year. Climatology is the simplest way to predict future climate, and suggests that the average temperature or precipitation is the most likely outcome, but a range of conditions that have occurred in the historical record are also possible. Forecasters calculate the skill score of their forecasts to evaluate if the forecast provides more information than a simple guess using averages. There are many ways to calculate skill, but in general a positive skill score indicates improvement over averages while a negative skill score indicates that the averages are better. Forecasts are said to be 'skillful' if they show improvement over averages.

What is the skill of CPC forecasts?

In late 2004, NOAA evaluated the forecast skill of ten years of CPC forecasts using averages as the baseline forecast. The skill of CPC official temperature and precipitation forecasts was evaluated by time of year and ENSO status. Considering temperature, CPC forecasts show strong skill for 9 months of the year (Spring to Fall) during non-ENSO years in the western United States (Figures 2 and 3). In ENSO years, the temperature forecasts also show strong skill in winter throughout the entire US, except for California (Figure 4). Considering precipitation, CPC forecasts only show skill during ENSO years, and only then in the Southwest, Northwest, and Southeast (Figure 5).

Along with demonstrating where and when CPC seasonal climate forecasts have skill, the assessment also examined the times and places for which the CPC forecasts lack skill. In general, they have no skill for summer precipitation at any time and any place (not shown), and very low skill for temperature during non-ENSO years in areas outside of the western U.S. (Figures 2 and 3).

In the Colorado River Basin, there is strong skill for temperature during spring to fall of non-ENSO years. In ENSO years, there is also strong skill for temperature during winter. For precipitation, there is no skill during non-ENSO years anywhere in the basin. During ENSO years, precipitation skill is higher in the southern part of the basin (California, Arizona, Nevada, and New Mexico) and lower in the northern part (Colorado, Wyoming, and Utah), including negative skill in the headwaters of the Green River. This means, unfortunately, that the CPC forecasts lack precipitation skill at all times in the areas of the basin which generate the most runoff, namely the Colorado Rockies and the mountains of Utah and Wyoming.

What's the future of climate prediction?

As they say in the mutual fund industry, this past performance is no guarantee for future success. The CPC forecasts evaluated have only been issued for 10 years, barely enough to compile meaningful statistics, and the forecast methodologies used at CPC have evolved and will continue to evolve. In an effort to improve seasonal predictions, climatologists have been searching the globe for new climate drivers since the significance of ENSO was discovered.

Researchers are combing through sea surface temperature records of the North Pacific, the South Pacific, the Atlantic, and all other oceans and seeking to understand their predictive value. Scientists are also engaged in "great archeological digs", in which climate records are being reconstructed for the entire past 1000 years using "proxies" for temperature and precipitation, such as the growth patterns of trees. One difficulty forecasters face is that the climate is changing, and past relationships may no longer be valid. Although anything is possible, most forecasters expect slow gradual progress in forecast skill rather than huge leaps.

So what does all this mean?

Given the current state of forecasting, not all CPC forecasts have the same skill, and not all areas of the country have the same skill. Users should carefully consider these skill scores when valuing these forecasts. Some of the strongest skill in both the temperature and precipitation CPC forecasts is in the West. In particular, during non-ENSO years temperature forecasts in the West during spring to fall are generally better than using long time seasonal averages, and the CPC precipitation forecasts during La Niña and El Niño years in the Lower Colorado River Basin are also better than using long time seasonal averages. Unfortunately, the CPC precipitation forecasts show little skill in the headwaters of the Colorado at any time. Finally, this article has discussed forecast skill, a measure of relative forecast improvement over seasonal averages, and has not considered forecast accuracy, a measure of absolute correctness. Forecasts can be 'skillful', and yet still lack the accuracy or skill needed for decision making. Users need to be very careful relying on these or any other climate forecasts.

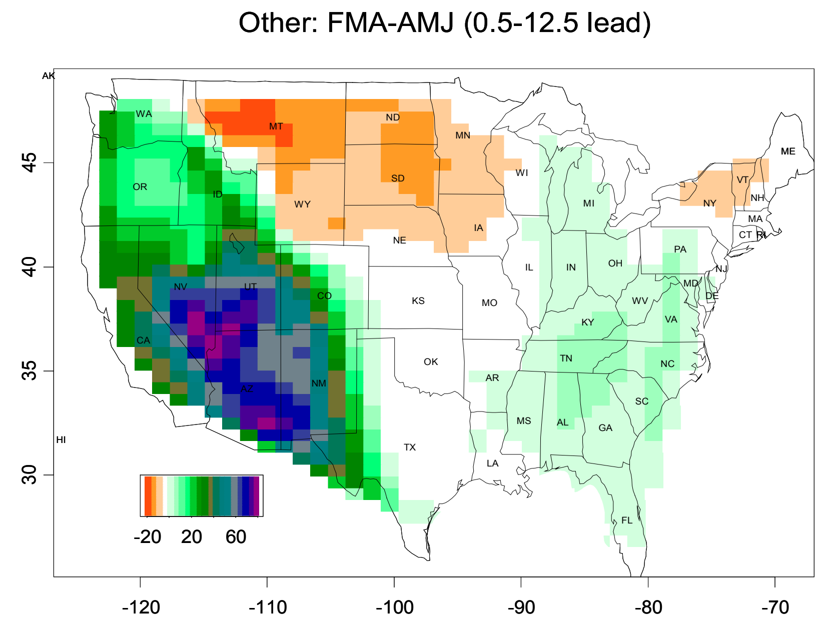
Links:

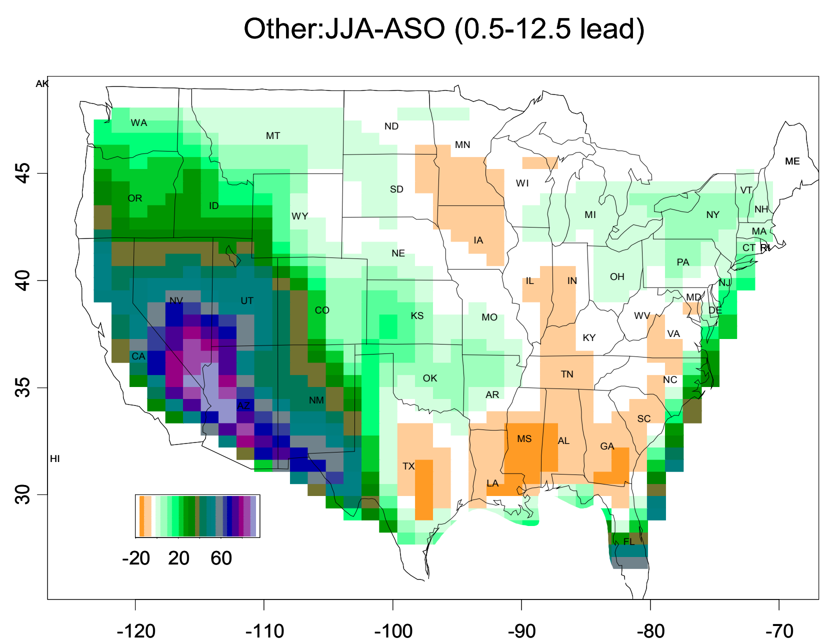
1) Climate Prediction Center Forecasts:
http://www.cpc.ncep.noaa.gov/products/predictions/90day/

2) Skill Study on CPC Forecast by Scientists Robert Livezey and Marina Timofeyeva:
http://www.cpc.ncep.noaa.gov/products/outreach/proceedings/cdw29_proceedings/livezey.ppt

3) Australian Bureau of Meteorology website discussion about 'forecast verification' measures such as skill and accuracy:
http://www.bom.gov.au/bmrc/wefor/staff/eee/verif/verif_web_page.html

The diagrams below show the modified Heidke skill score of CPC forecasts. These scores compare the CPC seasonal forecasts relative to seasonal averages. Heidke skill scores range from negative infinity to 100 with 100 indicating perfect CPC forecasts, zero being no improvement over the seasonal averages, and negative scores indicating the seasonal averages are better than the CPC forecasts. A simplistic way to consider skill scores is to consider the score as a percent improvement (or decline in the case of negative skill) over the seasonal averages. Thus, a score of 20 would indicate a 20% improvement over a forecast based on seasonal averages.





Figures 2 and 3: *Skill scores for February to June and June to October temperature during non-ENSO events, predicted at 0.5 to 12.5 months in advance. Note the strong skill in the western United States during these 9 months. The temperature skill in the remaining 3 months in the West during non-ENSO events is negligible (not shown).*

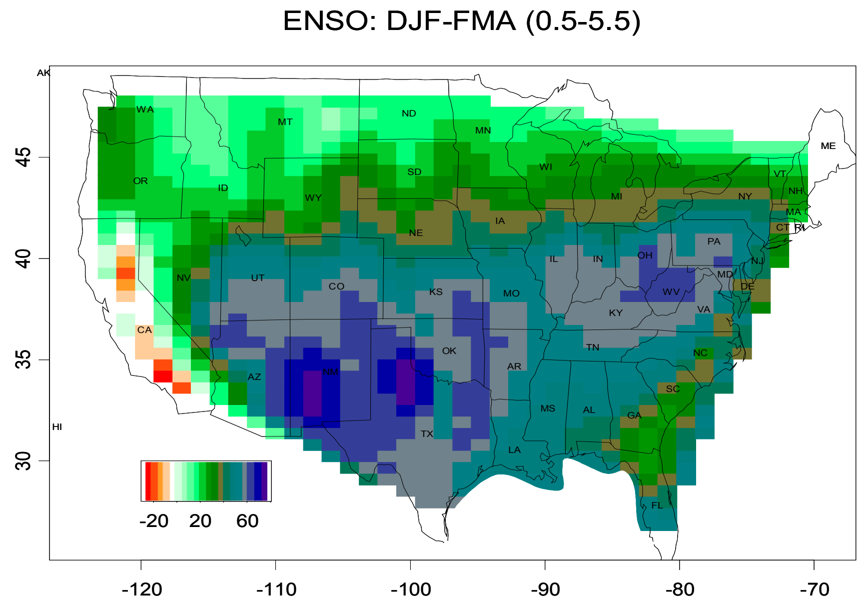


Figure 4: *Skill scores for December to April temperature during El Niño and La Niña events, predicted at 0.5 to 5.5 months in advance. Note the strong skill in most parts of the United States, with Californa the sole exception., This figure demonstrates that ENSO has a predictable temperature component in addition to the more commonly known precipitation signal.*

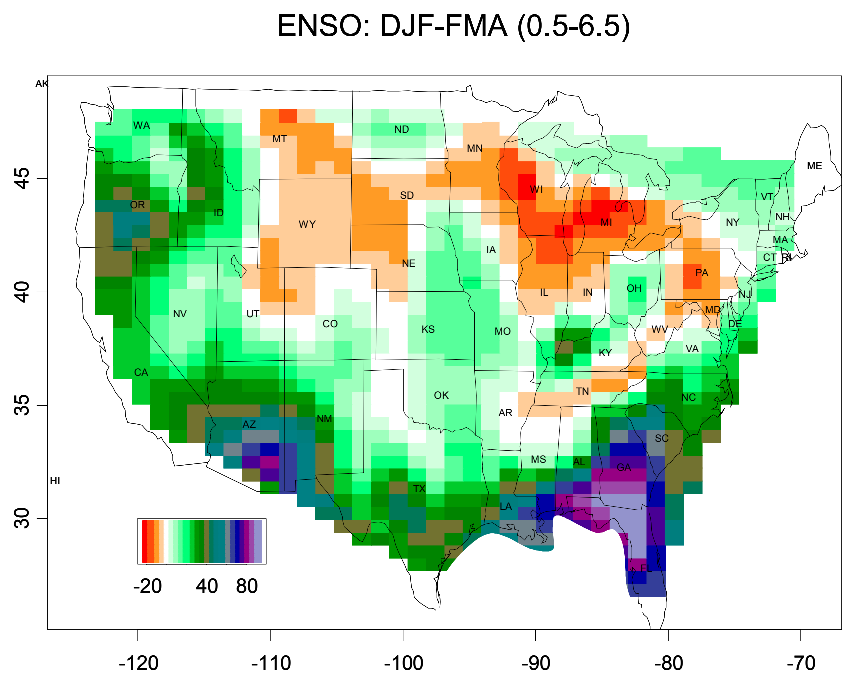


Figure 5: *Skill scores for December to April precipitation during El Niño and La Niña events, predicted at 0.5 to 6.5 months in advance. Note the strong skill in the Southwest, Southeast, and Northwest; areas where ENSO most directly affects precipitation. In the Colorado River Basin strong positive skill is confined to the lower basin, not in the Rocky Mountains which provide about 90% of the runoff. Note the negative skill in NE Utah and SW Wyoming, the headwater areas of the Green River. Precipitation skill from CPC forecasts during non-ENSO years in all seasons is negligible in the entire country (not shown.)*

An Overview of NOAA's Colorado Basin River Forecast Center

David Brandon, *Hydrologist in Charge, NOAA-NWS Colorado River Basin Forecast Center*

Bradley Udall PhD, *Director, University of Colorado Western water Assessment*

Jessica Lowrey, *Research Assistant, NOAA Climate Diagnostic Center*

The National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) has 13 River Forecast Centers (RFCs) located within major river basins throughout the U. S. The mission of the RFCs is to produce the nation's river instantaneous flow, flood, and water supply (volumetric) forecasts to save lives and property, and to enhance the economy and environment. RFC hydrologists are technical experts in operational river and water management forecasting. RFC products and services support many NWS programs including flash flood, river flooding, and river flow warnings, watches and forecasts, and recreation, reservoir management, drought, and seasonal water supply needs.

The Colorado Basin River Forecast Center (CBRFC) is responsible for the entire Colorado Basin and the Great Basin, including all or part of seven states with an area of 303,450 square miles (Figure 1). The basin includes topography ranging from near sea level to over 14,200 feet in elevation, from dry deserts to snowy alpine areas. Among the River Forecast Centers, CBRFC is unique because nearly 80% of the runoff in the basin comes from snowmelt, and the basin has the largest evaporation rates of any RFC region.

CBRFC works closely with local Weather Forecast Offices (WFOs) within its area of responsibility (Figure 1). RFCs provide river forecasts and other hydrologic technical support to the WFOs. In turn, the WFOs prepare Flood and Flash Flood Warnings and Watches, and disseminate these products to local emergency managers, media, and the public. CBRFC also works closely with the United States Department of Agriculture's Natural Resource Conservation Service, which collects data on snowpack through its automated SNOTEL and manual snow course networks. Working together, the two entities

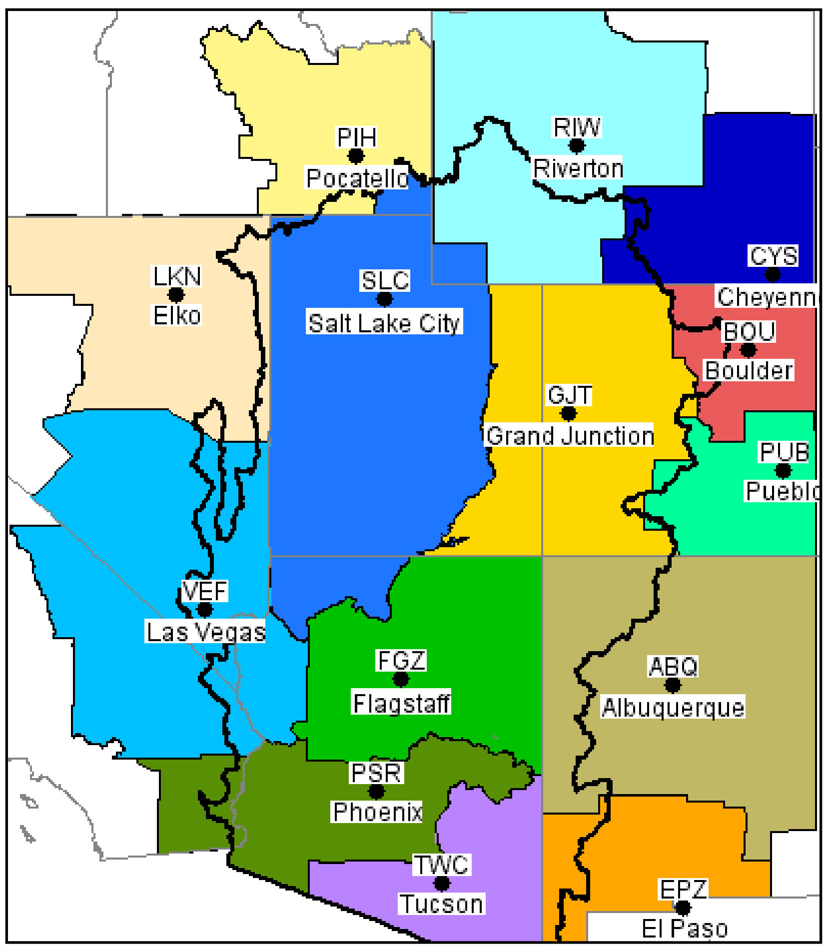


Figure 1. *Map showing NWS wather forecast offices in the Western U. S. with an outline of the area that is the responsibility of the Colorado Basin River Forecast Center.*

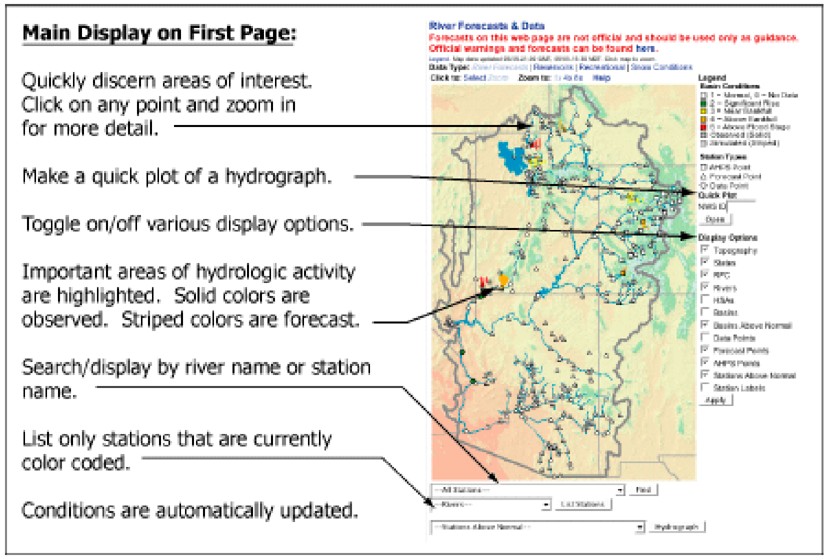


Figure 2. *Interactive map of the Colorado River Basin as seen on the CBFRC website. Text explains all the interactive user choices.*

analyze streamflows and issue joint seasonal volume forecasts, also known as water supply products. CBRFC distributes much of its products and services through an interactive web page located at: http://www.cbrfc.noaa.gov. Many features of the web page allow a user to customize their request for given forecasts and data (Figure 2). Seasonal water supply and reservoir supply and snowmelt peak flow products are also available.

CBRFC uses a series of computer models known as the NWS River Forecast System (NWSRFS) to create river forecasts. NWSRFS can produce a seamless suite of river forecast products from hours to seasons. Products can be probabilistic or single values, and forecast displays range from simple text to complex graphics. NWSRFS consists of three parts: 1) a Calibration subsystem, 2) an Operational Forecast subsystem, and 3) an Ensemble Streamflow Prediction subsystem. The Calibration subsystem allows a forecaster to calibrate a river basin using historical information. The Operational Forecast subsystem provides capabilities to run the models, make modifications, and to produce short-term forecasts. The Ensemble Streamflow subsystem provides short- to long-term probabilistic forecasts. All three parts are linked together through model calibration so that compatibility is retained, e.g., between initial conditions of soil moisture, precipitation, snow, and streamflow over time and space.

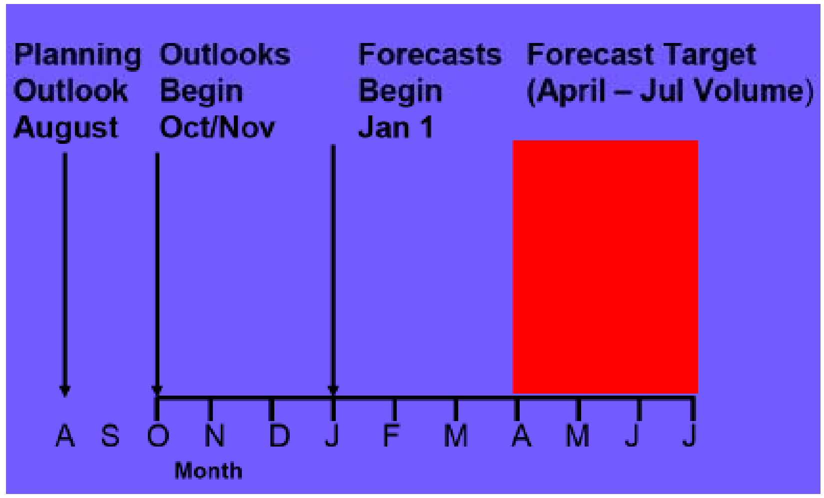


Figure 3: Timeline for early season outlooks. CBRFC forecasters begin making April – July runoff outlooks in October and November, and then begin making forecasts January 1. The outlooks are based on initial basin conditions like soil moisture, and climate signals such as El Niño and La Niña, but the forecasts are additionally based on snowpack.

The Ensemble Streamflow Prediction subsystem (ESP) can produce probabilistic forecasts for a variety of user output choices. Output choices can be peak flows, minimum flows, flow volumes, number of days to reach or fall below a specific flow for flexible periods in the future. The probability information can be displayed in various formats. ESP uses historical streamflow, historical weather data, future weather forecasts and future climate variability to produce the probability forecasts.

CBRFC uses the ESP methodology to produce forecasts of water supplies for the April – July runoff season, which are valuable to water managers, reservoir operators and agricultural water users throughout the Colorado River Basin. They start by creating Outlooks (very simple forecasts) in October or November of the previous year and then begin issuing forecasts in January, based on the snowpack levels as of January 1 (Figure 3) and NOAA Climate Prediction Center 30- to 90- day precipitation and temperature seasonal outlooks. These forecasts are updated each subsequent month through June, and one can find these forecasts in the monthly water supply publications on the CBRFC website at: www.cbrfc.noaa.gov/wsup/wsup.cgi.

In order to make the water supply outlooks in October and November and the forecasts starting in January, ESP uses four climate-related

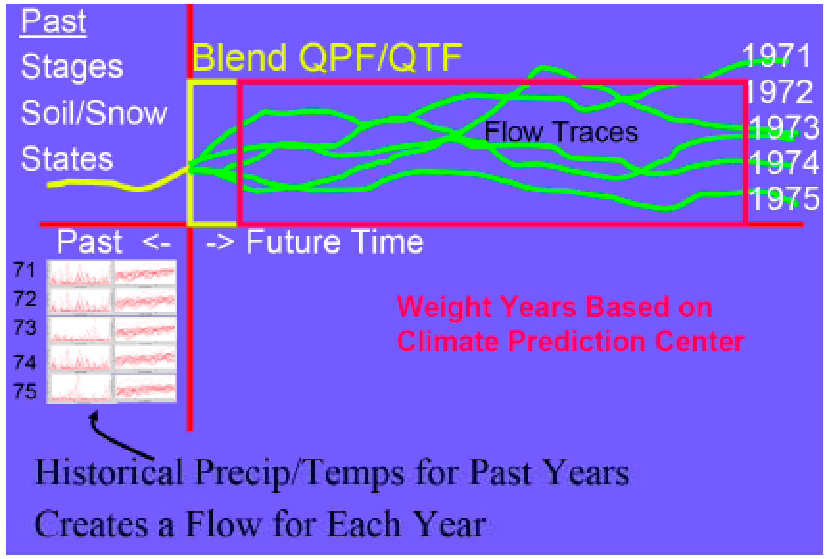


Figure 4: *Graphic depiction of the ensemble members of an NWSRFS forecast. The forecast begins with the current streamflow and watershed conditions and then it uses different weather conditions of past years to create many forecasts, or ensembles, for the future streamflows.*

drivers. Together, these drivers provide the inputs to the streamflow forecast model. The first driver is based on historical observations and climatology. It is basically the best guess based on what has happened in the past, or in other words, the average. In order to improve on a forecast of average, ESP also uses several initial watershed conditions, which together compose the second climate driver. These conditions reflect the current water supplies in the basin that will eventually contribute to April – July streamflows. They include antecedent or previous streamflows, soil moisture state, snow pack, reservoir status, and the carryover effect of protracted wet or dry periods. This last condition is based on a climatological observation that wet periods are typically followed by more wet periods, and vice versa for dry periods. The third climate driver incorporated into the ESP model is based on NWS weather and climate predictions. These predictions are particularly useful for streamflow predictions during strong El Niño-Southern Oscillation events. Finally, the last driver corrects for known climate model bias to improve the accuracy of the predictions. ESP uses all four of these drivers to produce probabilistic streamflow forecasts.

ESP produces an ensemble-based forecast, which means that the final forecast is based on many individual forecasts put together with more weight on certain individual forecasts that are more likely to be correct (Figure 4). The model starts by looking at current watershed conditions such as river stage, soil moisture and snow pack. Then it uses these conditions, plus historical weather (primarily precipitation amounts and temperatures) over all past years with complete weather data to create a series of forecasts, one for each year of historical weather data. Collectively, the entire series is known as an ensemble, and each forecast is known as an ensemble member. In the next step, the forecaster will weight (emphasize) certain ensemble members more heavily than others if the precipitation and temperature experienced in the historical years used to generate the ensemble member were closer to NWS predictions for the climate for the coming year. Finally, the forecasters then make a frequency distribution using the weighted ensemble members and fit a probability function in order to predict the most probable outcome.

Weighting and creating a probability function are conceptually similar to duplicating ensemble members considered more likely to occur and adding these duplicates to the overall ensemble, and then ordering all the ensemble members (including the duplicates) by predicted flow volume from smallest to largest. The flow in the exact middle of this ordered sequence is the "most probable" flow and is also known as the 50% exceedence flow. In other words, 50% of the predicted flows exceeded this flow, and, conversely, 50% did not exceed it. CBRFC will also generate a 'reasonable maximum' flow (only 10% of the predicted flows exceed this value), and a reasonable minimum flow (90% of the predicted flows exceed this value).

When creating water supply forecasts, CBRFC forecasts 'unregulated' or natural flows because predicting regulated flows is both difficult and is generally a secondary question to the overarching question of 'how much water will we have this year?'. CBRFC has found that by using the ESP methodology, their streamflow forecasts have improved over past forecasts which did not use climate and weather forecast information.

Climate Change in the Colorado River Basin

Gregg Garfin PhD, *Program Manager, Climate Assessment for the Southwest, University of Arizona*

The Colorado River, which flows through seven Western states to the Sea of Cortez in Mexico, provides water to some of the nation's key agricultural areas, as well as to rapidly expanding urban populations. The recent multi-year severe drought has drawn attention to water supply vulnerability in the Colorado River Basin (Basin). During the exceedingly dry years between 1999 and 2004, Colorado River reservoir storage declined rapidly. Drought impacts, including reductions in irrigation water supplies in Colorado and Arizona, mandatory urban water use restrictions in cities such as Denver and Las Vegas, and multi-million dollar investments in tourism infrastructure in order to keep pace with Lake Powell's receding shorelines, have drawn comparison with the potential impacts of climate change. This article briefly examines the state of knowledge about climate change in the Basin and projections of climate change for the region.

Observed Climate Changes

Colorado River Basin Precipitation

The entire basin exhibits strong year-to-year and decadal variability in precipitation. The former is related in part to ocean-atmosphere activity associated with the El Niño-Southern Oscillation (ENSO). El Niño (warm eastern equatorial Pacific Ocean temperatures) frequently,

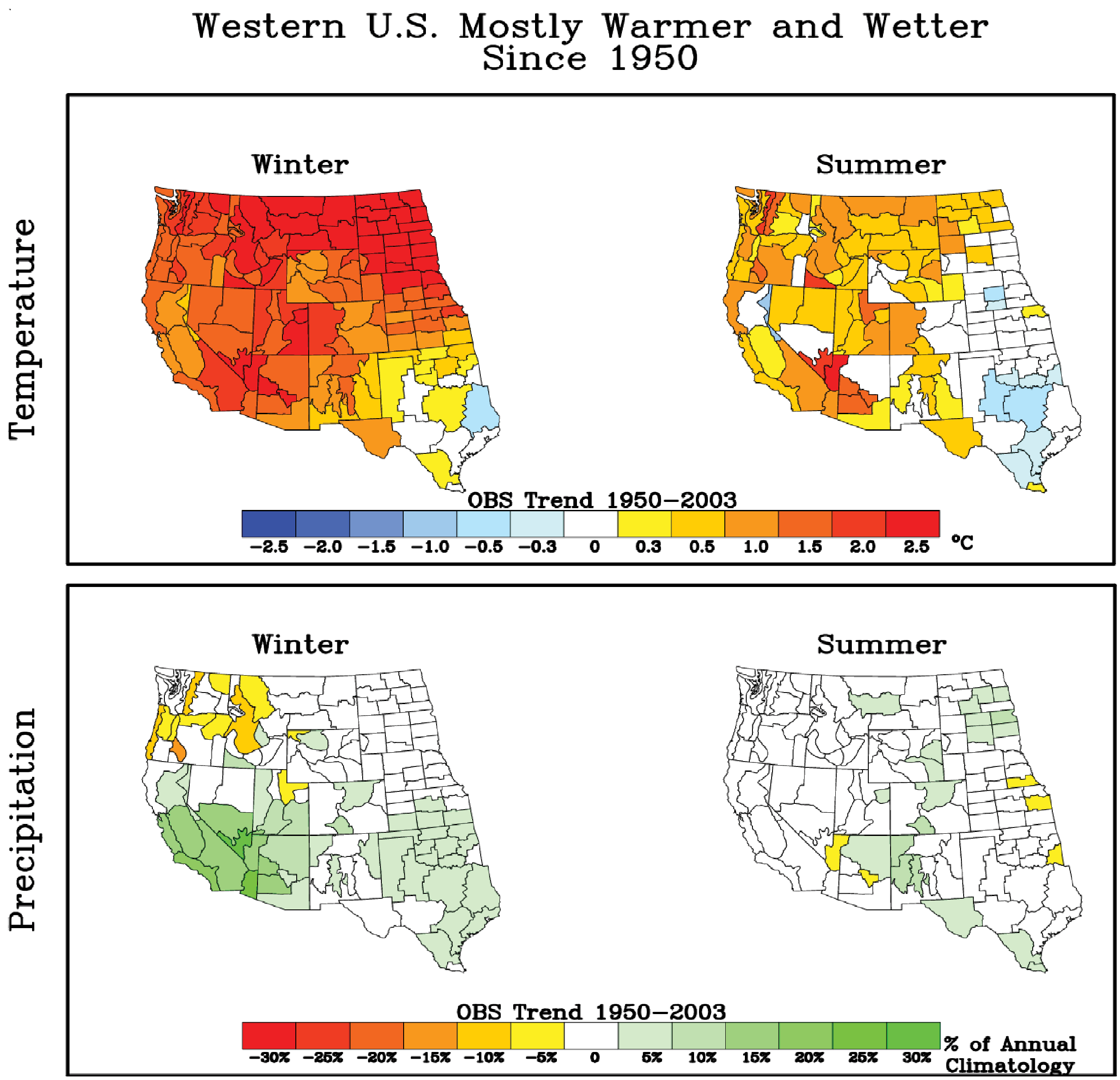


Figure 1. Observed temperature and precipitation trends in the Western U.S. since 1950. (Courtesy of Dr. Martin Hoerling, NOAA-Climate Diagnostics Center).

but not always, brings copious winter precipitation to the Lower Basin and sometimes to both parts of the Basin (noticeably at high elevations in the Upper Basin). El Niño also tends to enhance summer moisture in the Upper Basin. La Niña (cool eastern equatorial Pacific Ocean temperatures) reliably brings dry winters to the Lower Basin. Between 1950 and 2003, most of the Basin, but especially the Lower Basin, exhibited a trend toward increasing winter precipitation (Figure 1). This trend is attributable to changing ocean conditions and is is believed to be related to an increased occurrence of El Niño episodes post-1976. Although scientists anticipate that global warming will contribute to an enhanced hydrologic cycle, there is no evidence for a cause-effect relationship between the known increases in greenhouse gases and the observed wet trend in the Lower Colorado Basin. However, scientists have observed increased hydrologic variability in western North American streamflow since the 1970s, typified by dramatic yearly swings between wet and dry conditions. One characteristic of this increase in variability is that large river basins, such as the Columbia, San Joaquin-Sacramento, and Colorado can experience wet and dry regimes in lockstep. Synchronous West-wide dry and wet regimes would reduce water managers' flexibility to respond to climate changes.

Temperature

Between 1950 and 2003, temperatures increased across the western United States (Figure 1). In the Basin, winter temperatures increased more than summer temperatures, and summer increases were more spatially varied across the Basin. Minimum temperatures (daily low temperatures; taken during the early morning) increased more than maximum temperatures. Winter average temperatures increased by approximately 3.6° F across the Basin. The smallest increases, approximately 1.0° F, were in the southeastern part of the Lower Basin; The highest regional increases were on the order of 4.5° F (central and northwestern Arizona, and eastern Utah). Investigations to understand the causes of the temperature change, using many global climate models, indicate that the warming is attributable to increases in greenhouse gases. Some of this warming results from long-term changes in ocean surface temperatures in the tropics, which are also the consequence of greenhouse gas increases.

Snow

Winter snowpack in the high elevations of the upper basin contributes approximately 85% of the annual runoff to the Colorado River Basin. Recent studies of snowpack and the timing of snowmelt have shown long-term decreases in snowpack, and increasingly early spring snowmelt over the course of the last 55-75 years, especially in the Cascades and Sierra Nevada Mountains. These changes have been attributed to increasing temperatures, especially minimum daily temperatures, and are most pronounced at medium-high elevations (6000-9000 feet). The situation in the Basin is not as clear; while some upper basin snowmelt-dominated observing stations show increases in the fraction of annual streamflow occurring in early spring and associated declines in the fraction of streamflow occurring in late spring, the spatial pattern and strength of these trends lack the consistency of trends in the Cascades and Sierras.

Projected Climate Changes

According to the consensus of research by international climate scientists, globally temperatures are projected to increase by around 5.4°F by 2100, with a range of 2.5° to 10.4°F due to anticipated increases in greenhouse gases [(Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report, 2001]. Projected impacts include polar ice cap melt, rising sea levels, and increased hydrological activity, characterized by more intense precipitation events over some areas, greater extremes, increased variability (including increased risk of drought over continental areas in the sub-tropical mid-latitudes), and greater water vapor transport from ocean to atmosphere.

What are the projections for the Colorado River Basin?

Projections based in the IPCC Third Assessment (2001) climate models show increased temperatures in the Basin in both summer and winter during the 21st century (Figure 2). The preliminary results of new model projections as part of the Fourth Assessment of Climate Change are very similar. Winter temperatures are projected to increase more than summer temperatures, with changes on the order of 2.0-3.6°F, in each season, by 2050. By 2070-2099, models using a greenhouse gas emissions scenario based on assumptions of continuously increasing population, regionally-oriented economic development, and heterogeneous technological change (great change in some countries, little change in others) show 7.2°-9.6°F increases in Basin

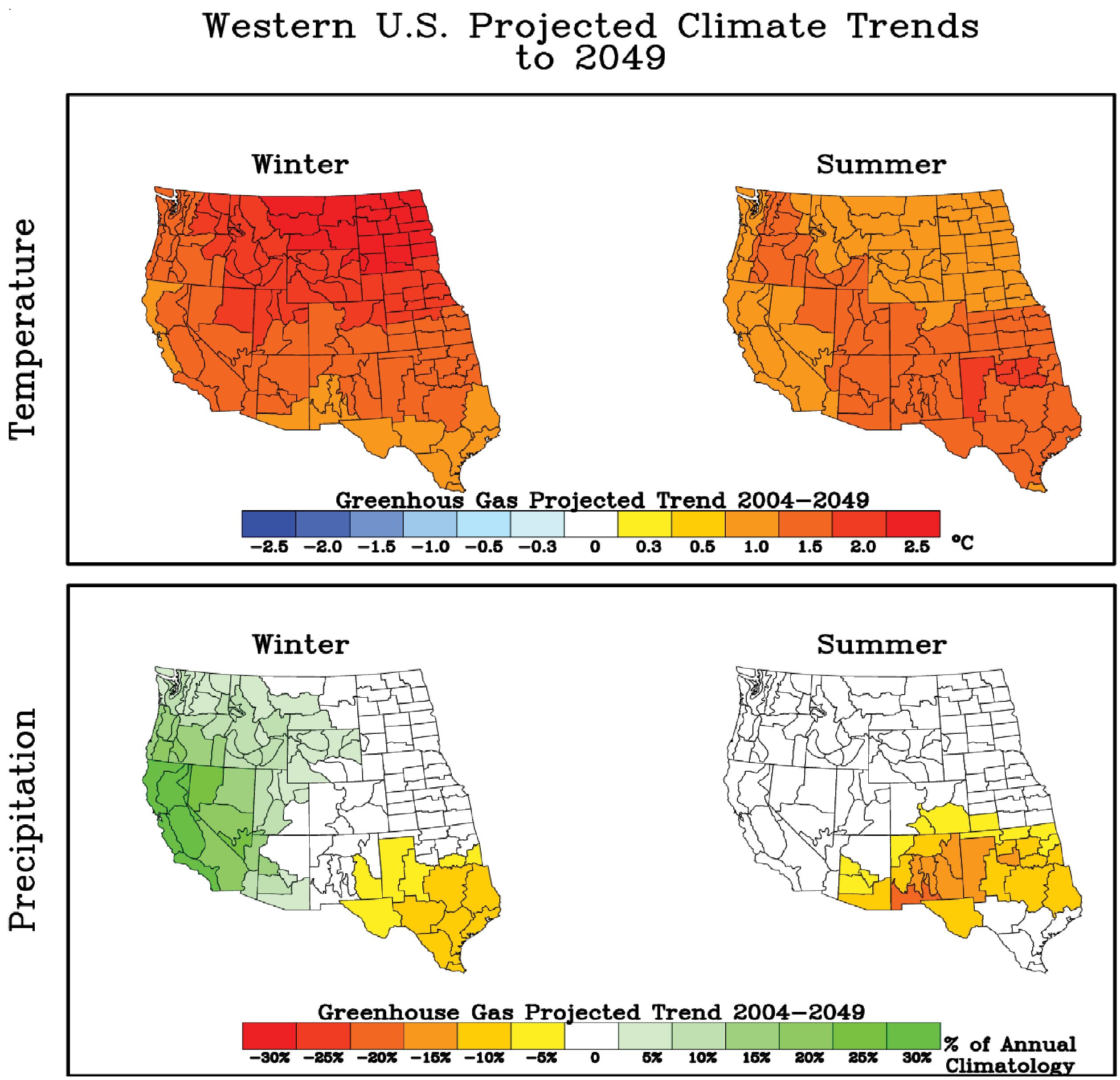


Figure 2. Projected temperature and precipitation changes in the Western U.S. through 2049. (Courtesy of Dr. Martin Hoerling, NOAA-Climate Diagnostics Center).

annual temperature. The highest projections of increased annual temperatures, for a world in which atmospheric CO_2 concentrations are twice as high as during the pre-industrial era, are on the order of 10-15° F warmer than the late 20th century. Scientists are confident in projected warming trends due to the consistent projection of increased temperatures across all models. In contrast, projected precipitation increases in the Basin are relatively inconsistent, hence less reliable. In fact, there are large uncertainties in the direction and magnitude of projected hydrologic change in Western North America, based on the comprehensive synthesis of global change scientists in 2001.

Two more recent climate change studies focused on potential changes to Western North America hydrology, due chiefly to projected increases in temperature. The first study examined changes in the timing of snowmelt runoff, using a climate model that projected 3.6°-5.4° F temperature increases in the Colorado River Basin by 2070-2099. Scientists found that projected warming would dominate over any projected precipitation increases, resulting in Upper Basin peak snowmelt runoff 5-25 days earlier than average by 2040-2059, and 15-35 days earlier than average by 2080-2099. (In the aforementioned study, average is based on 1951-1980). These findings are consistent with (a) observed trends toward temperature-driven earlier snowmelt during the 20th century, and (b) observed changes in atmospheric circulation that favor a combination of low pressure in the north-central Pacific and high pressure over western North America. However, these projections should not be taken as specific predictions, but rather as reliable indications of the sensitivity of Western U.S. hydrology to the effect of temperature increases on mountain snowpack.

The second study specifically examined the effects of climate change on the hydrology and water resources of the Basin. Scientists based their study on the average of three global climate model runs, using a model that projects modest global temperature increases during the 21st century (on the order of 4° F), and no substantial curbing of greenhouse gas emissions. The coarse spatial scale output of the global climate model were processed through a fine spatial scale hydrology model, in order to generate realistic daily streamflow sequences; projected water distribution and reservoir operation decisions were determined using a modified version of the model used by the U.S. Bureau of Reclamation to represent major physical water management structures and operating policies of the system. The major results are encapsulated in Table 1. Gradually increasing temperatures across the Basin during the course of the 21st century

Period	Temperature change	Precipitation change	Storage change	Hydropower change
2010-2039	+1.8°F	-3%	-36%	-56%
2040-2069	+3.1°F	-6%	-32%	-45%
2079-2098	+3.6°F	-3%	-40%	-53%

Table 1. *Annual average changes for future climate periods (based on Christiansen et al., 2004, in Climatic Change, vol. 62, pages 337-363.).*

combined with reduced snowpack (due to higher spring temperatures and reduced winter-spring precipitation) result in reduced annual runoff, and decreased reservoir storage.

The high sensitivity of the Colorado River system results from the fact that current demands on the system are not much less than average inflows, so slight decreases in the average inflows to Lake Powell and Lake Mead result in substantial degradation of system performance. The implications of these projected decreases in Basin storage include decreased hydroelectric power output and increased chances of shortages for water users. The results of this study are consistent with the results of studies by other researchers. Again, these projections should not be taken as specific predictions of the future, but as a wake-up call regarding indications of decreased reliability of the Colorado River system in the face of increasing temperatures. Moreover, some caution is warranted as these results are based on the output of a single climate model.

Other Factors

As mentioned above, because virtually every drop of water in the Colorado River system is allocated, the system is highly sensitive to changes in runoff and inflow to the major reservoirs. Additional demands on the system, through population growth and increased Upper Basin demands, will heighten system vulnerability in the face of increasing temperatures. A final factor to take into account is the urban heat island enhancement. Increasing urban temperatures, due to changes in land surface and the addition of buildings to the landscape, have been well documented. Urban temperatures, and the extent of the urban heat island are expected to increase as population increases in Western U.S. cities, and as regional temperatures increase due to climate change. The upshot of enhanced urban heat islands is increased demand for water and energy, the latter of which also uses considerable volumes of water.

Summary

Average Western U.S. surface temperatures increased during the 20th century. Global climate models agree that Colorado River Basin temperature increases will accelerate during the course of the 21st century, due to anticipated increases in greenhouse gases. Increased temperatures are likely to lead to increased evapotranspiration and earlier snowmelt. These effects have also been observed during the past half-century or longer. Global climate model precipitation projections are highly uncertain, and there is no consensus regarding Basin precipitation trends. Scientists have observed increased variability in western North America streamflow since the 1970s, the reasons for which are under investigation. All of the aforementioned impacts point to a risk for decreased reliability of the Colorado River system during the 21st century.

Implications for Management

- Decreasing runoff reliability and increasing demands on the Colorado River system will require re-assessment of existing to water resources operations and planning strategies.
- Given present allocation of River Basin water resources, relatively moderate decreases in streamflow will pose considerable challenges to management. This is especially important during extended periods of drought, as some droughts might span several major western North American watersheds.
- As temperatures increase, runoff may decrease even if precipitation increases; thus water management flexibility will be necessary.
- Low flows are likely to be affected more than high flows, which has ramifications for power generation and multi-objective management.
- If progressively earlier snowmelt occurs throughout the Basin, as projected by some models, the predictability and seasonal deliveries of snowmelt and runoff will change. Earlier streamflow may limit the abilities of reservoir operators to balance flood protection and drought storage needs.

Future research

- Sub-basin by sub-basin analysis is necessary to determine which sub-basins are most vulnerable and are most likely to be impacted.
- Regional modeling studies with more realistic topography and higher spatial resolution.
- The probabilities associated with projected temperature increases, extremes, and precipitation variations.
- Better indication of the spatial distribution of projected changes.

Climate Change in California's Sierra

Maurice Roos PE, *Principal Engineer, California Department of Water Resources*

In recent years, evidence has continued to accumulate that global climate change will have significant effects on California's water resources. Global warming could affect many water-related factors, including water supply availability, water use, hydroelectric power generation, sea levels, flood events, and water temperature. Causes of climate change can be natural or of human origin. A major human-induced cause of the expected change is increasing amounts of greenhouse gases, such as carbon dioxide, in the atmosphere as a result of man's activities. California's reservoirs and water delivery systems were largely developed form historical hydrology on the assumption that the past is a good guide to the future. With global warming, that assumption may not be valid.

Runoff from the Sierra Nevada provides much of California's developed water supply, with the Sierran snowpack acting as an important reservoir system. An extensive infrastructure network has been developed along the western slope of the Sierra to provide winter and early spring flood control for downstream communities and farmlands, and then to store later spring/early summer snowmelt runoff to meet water supply needs. Understanding how climate change could affect the existing infrastructure is important to water resources planning.

Background and Climate Predictions

The earth already has a strong greenhouse effect, about 66% due to water vapor and 25% due to carbon dioxide. Without this, average world temperatures would be around 0°F instead of the 60°F we

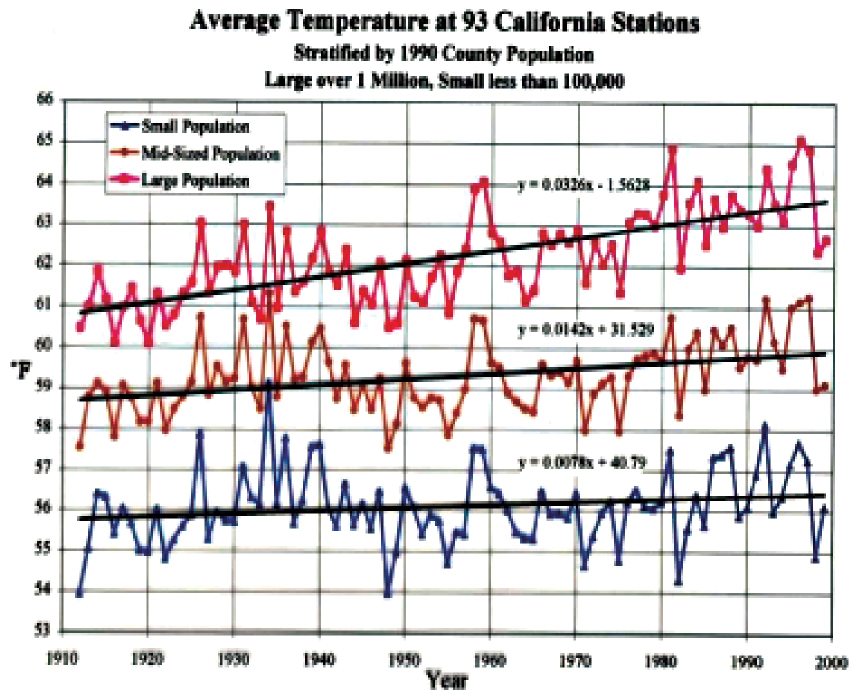


Figure 1

enjoy. The concern among some climate scientists is that increases in greenhouse gases will change the radiation balance, leading to a rise in global temperatures this century. The Intergovernmental Panel on Climate Change (IPCC), an international group of scientists established in 1988 to study climate change, has issued several reports outlining possible global warming and other possible effects of climate change. A rise of about 1°F has been estimated for the 20th century, partly from natural causes, as a rebound from the "Little Ice Age" of preceding centuries. In 2000, the IPCC projected a global temperature increase by the year 2100 of about 3°C (5°F) with a range from 1.4° to 5.8°C. The changes are not likely to be uniform; climatologists expect more impact of higher carbon dioxide in areas where the amount of atmospheric water vapor is relatively low, such as the Colorado River Basin, the Great Basin, and the Arctic. Figure 1 shows temperature trends for three groups of stations in California in the 20th century. Counties with large populations show more warming than rural counties due to the urban heat island influence. Although not directly related to greenhouse gas increases, local urban warming is another factor influencing water and energy use patterns.

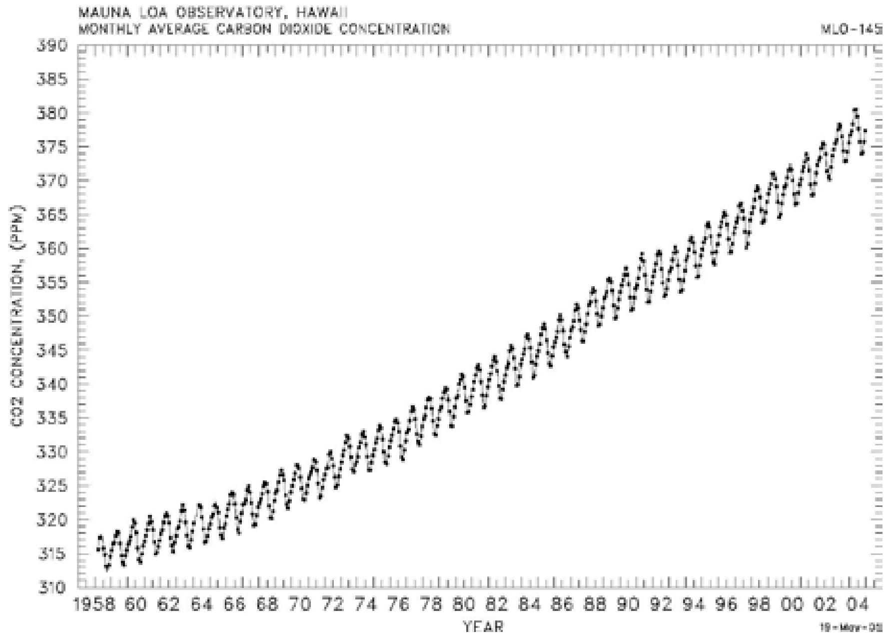


Figure 2. *Atmospheric Carbon Dioxide Concentration as Measured at Mauna Loa, Hawaii. The annual cycle is caused by northern hemisphere vegetation uptake during the growing season. (Source C. D. Keeling and T. P. Whorf, Scripps Institution of Oceanography, via C.D.I A. C., Oak Ridge National. Laboratory)*

Carbon dioxide in the atmosphere has been increasing slowly. The measurements atop Mauna Loa, Hawaii, were started by Dr. Charles David Keeling of Scripps in 1958 and are the longest continuous record of atmospheric CO_2 concentrations in the world (see Figure 2). The average rate of increase in the past couple of decades has been 1.6 ppm per year.

Temperature increases could affect winter snow levels and spring runoff timing. Some of these changes appear to have already begun. In some parts of the Western U.S., the fraction of water year runoff coming during the April through July traditional snowmelt season, although highly variable from year to year, seems to have been decreasing during the past 50 years. This effect is more noticeable in the lower elevation northern Sierra-Nevada Mountains than the higher elevation southern Sierras. Figure 3 shows the declining percentages of water year runoff for the four major rivers of the Sacramento River system (Sacramento River near Red Bluff, Feather River, Yuba River and American River). This shift, if it continues, would cause less snowmelt in the late spring, making it more difficult to fill the major foothill reservoirs in California.

Examples of Consequences to Water Resources Systems

There are many potential effects on California water resources infrastructure due to global warming. Much depends on the degree of warming and whether future changes are large or small. As a general rule, a warmer world would mean more evaporation and hence more precipitation overall – but where and when the precipitation falls is all-important and less well-understood. One relatively certain impact is rising snow elevations in the mountains, with a corresponding decrease in the snowpack. A reasonable estimate is about 500 feet of elevation change for every degree of temperature rise. Many early studies used 3 degrees of warming as a reasonable 100-year projection for the western states, meaning a rise of 1,500 feet in snow levels. Historical average snow levels on April 1st (the usual peak of the snow accumulation season) range from 4,500 feet in the northern Sierra to about 6,000 feet in the southern Sierra. Early preliminary DWR estimates suggested that this snow level rise (assuming the amount of precipitation remained the same) would translate to a decrease of nearly 3 million acre-feet of April through July runoff, with a lesser impact in the higher elevation southern Sierra. DWR's preliminary estimates of the combined effects of warming on Sierran snowpack and spring rainfall suggested that reduction on April through July runoff would be on the order of 33 percent. More recent work by Scripps Institute and others has suggested that a 50 percent reduction could be possible. Although global circulation model studies have not produced consistent results for California winter season precipitation amounts, all models have so far shown less snowmelt runoff from the northern Sierra.

Less spring snowmelt could make it more difficult to refill winter reservoir flood control space during late spring and early summer of many years, thus potentially reducing surface water supplies during the dry season. Lower early summer reservoir levels would also reduce hydroelectric power production, adversely affect reservoir-based recreation, and potentially result in late season temperature problems for anadromous fish such as salmon and steelhead.

Another potential impact of warming is sea level rise, which could adversely affect the Sacramento-San Joaquin River Delta, a major water supply hub for California. The IPCC projected that sea level would rise by about 1.6 feet by 2100. The rate of rise in the 20th century appears to have been around 0.7 feet, which is consistent

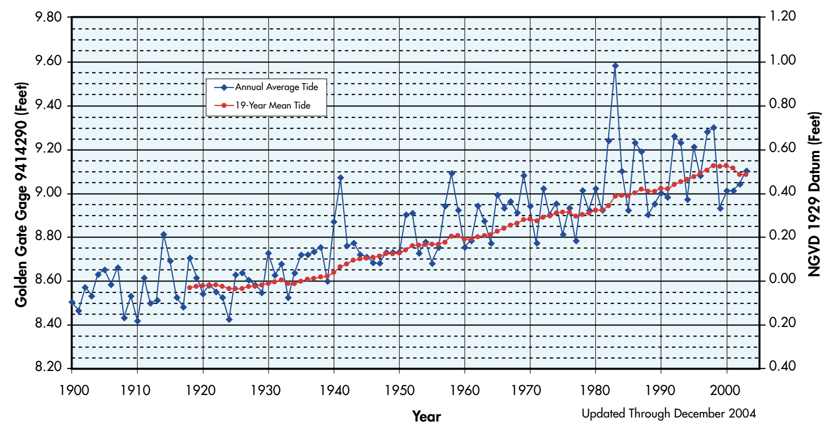


Figure 4. *Golden Gate Annual Average and 19-Year Mean Tide Levels*

with the historical trend at the Golden Gate tide station (Figure 4), although it is possible that tectonic movement may have also influenced tidal stages there. An increase in sea level would increase the flood risk to fragile Delta levees during high tide events; levee failure could compromise the ability of the State Water Project and the federal Central Valley Project to export Sierra Nevada runoff to central and southern California. Similarly, sea level rise could result in increasing salinity intrusion and diminished water quality for water users within the Delta and for the users of exported water.

Adapting and Responding to Climate Change

Interest in climate change and greenhouse gas emission reductions at the state level led Governor Schwarzenegger to issue Executive Order S-3-05 in June 2005, setting goals for reducing California emissions by 2010 to year 2000 levels and by 2020 to 1990 levels. He also directed that a report be completed by January 2006 on potential impacts to California of global warming, including impacts to water supply, public health, agriculture, the coastline, forestry, and reporting on mitigation and adaptation plans to combat these impacts.
From a water resources planning perspective, information and research in a variety of areas is needed to be able to respond to climate change impacts. Foremost among the needs is better long-term hydrologic monitoring. Because weather and hydrology are so inherently variable, many years of consistent and accurate measurements are vital. Monitoring is necessary not only to track quantitative changes, but also for use in calibrating climate models used for future predictions. Currently, for example, there are few good climate data stations in the mountain zones where the most significant impacts are expected.

Southern California & the "Perfect Drought"

Glen MacDonald and Sigrid Rian, *Department of Geography, UCLA*
Hugo Hidalgo, *Scripps Institute, UCSD*

Introduction

The book 'Perfect Storm' by Sebastian Junger recounts meteorological factors that came together in October 1991 to create a devastatingly lethal storm that swept up the eastern coast of the United States. In terms of Southern California water management one might ask if there could be a similar analogy in terms of a devastating 'perfect drought' that would critically strain drought mitigation capacities in the region. One might also consider what the probabilities are of such a perfect drought occurring in the future. In this article we suggest that a perfect Southern California drought occurs when a local drought increases water demand and decreases water supplies and storage at the same time that the Northern California and Colorado River Basin imported water sources are impacted by droughts, and that such conditions persist for several years or longer. We then explore historical climate records for the past century and tree-ring records for the past 500 years to look for evidence of such droughts.

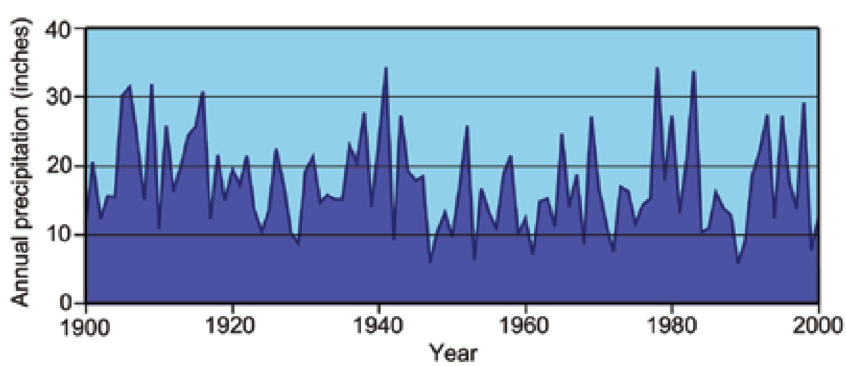


FIGURE 1 *Measured annual precipitation in Southern California*

FIGURE 2 Sources of imported water for Southern California and MWD.

Southern California Water Demand and Sources

Two factors dictate the sensitivity of Southern California to drought. First, Southern California has exhibited wide variability in annual precipitation over the period of historical records (Figure 1). The average annual precipitation for coastal Southern California from 1895 to today is about 17 inches. However, during that time there have been 14 years (about 13% of the time) with precipitation below 10 inches. In some years precipitation has been less than 6 inches. Second, local water supplies are insufficient to meet demands even in normal precipitation years, and the region relies heavily on imported water. The Metropolitan Water District (MWD) is the largest distributor of imported water in southern California. MWD typically wholesales some 1.8 million acre-feet (MAF) of water annually to Southern California's larger urban water suppliers, which serve a

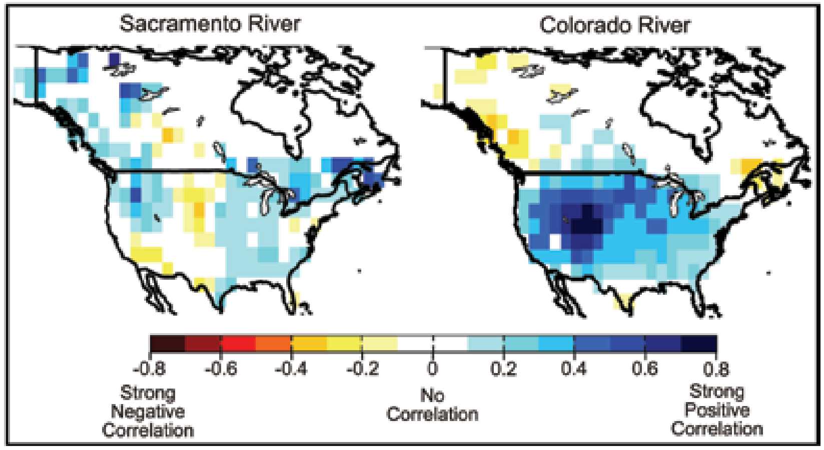


FIGURE 3 *Correlations between river flow and regional geographic patterns of Palmer Drought Severity for the Sacramento and Colorado rivers. High flows on the rivers are most highly correlated with wet years in the blue areas of the maps.*

population totaling about 18 million people. In recent years sources for imported water (Figure 2) include the Colorado River (~1.2 - 0.5 MAF) , the California State Water Project (~ 0.4 - 1 MAF) and the Los Angeles Aqueduct (0.2-0.4 MAF).

Imported Water as a Buffer Against Local Drought

Supplementation of Southern California water supplies with imported water can provide a buffer against the impacts of local drought if the sources of the imported water are unaffected by local drought conditions. Water flowing in the lower Colorado River comes largely from mountain snowpack in the states of Wyoming, Colorado and Utah. Water provided by the California State Water Project and the Los Angeles Aqueduct come largely from Sierra Nevada snowpack that feeds the Sacramento River drainage basin on the western slope of the Sierra and the Owens River drainage on the eastern slope. Analysis of the relationship between Colorado and Sacramento river flow shows that over the past century flows in these rivers are typically most strongly correlated with local conditions in their headwaters areas (Figure 3). High or low flows in either river system are not particularly highly correlated with each other or with precipitation in Southern California, allowing MWD and other state and local authorities to manage resources to take advantage of supply availability. However, a multi-year perfect drought presents greater water management challenges.

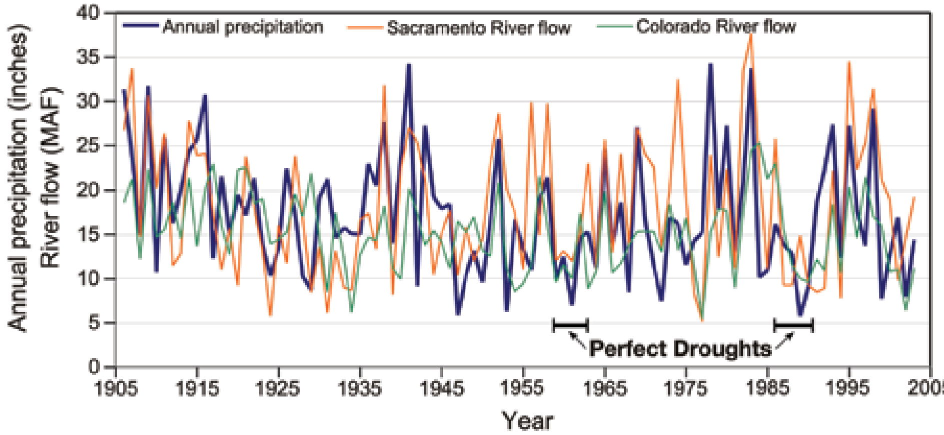


FIGURE 4 *Measured annual precipitation in Southern California compared to measured annual flow of the Sacramento and Colorado rivers. Times of perfect drought impacting all three regions are indicated.*

Perfect Droughts in the Past Century

How often have perfect drought-like conditions occurred during which Southern California, Northern California and the Colorado Basin have all been impacted? A comparison of historical records of Southern California precipitation and flows of the Sacramento and Colorado rivers shows that flows in both river systems and precipitation in southern California were 30% below normal during periods of drought in late 1950s-early 1960s and late 1980s-early 1990s (Figure 4). In both cases, these were periods of multi-year drought in southern California. A map of drought conditions during 1990 shows the presence of severe aridity centered on the headwaters of the Colorado River extending west to eastern California and a second center of drought directly over southern California (Figure 5). During other severe drought episodes in southern California the flows in the Colorado and Sacramento basins were either not as severely depressed or were at average or above conditions.

The climatology associated with dry years such as 1990 typically includes development of a particularly extensive and sustained blocking high over western North America with a low developed in the east. The westerly storm track is diverted north and then eastward producing dry conditions across the west with moist conditions often developing eastward of the continental divide. In some cases, depending upon position and extent of the high, the far Pacific Northwest may or may not experience dry conditions at the

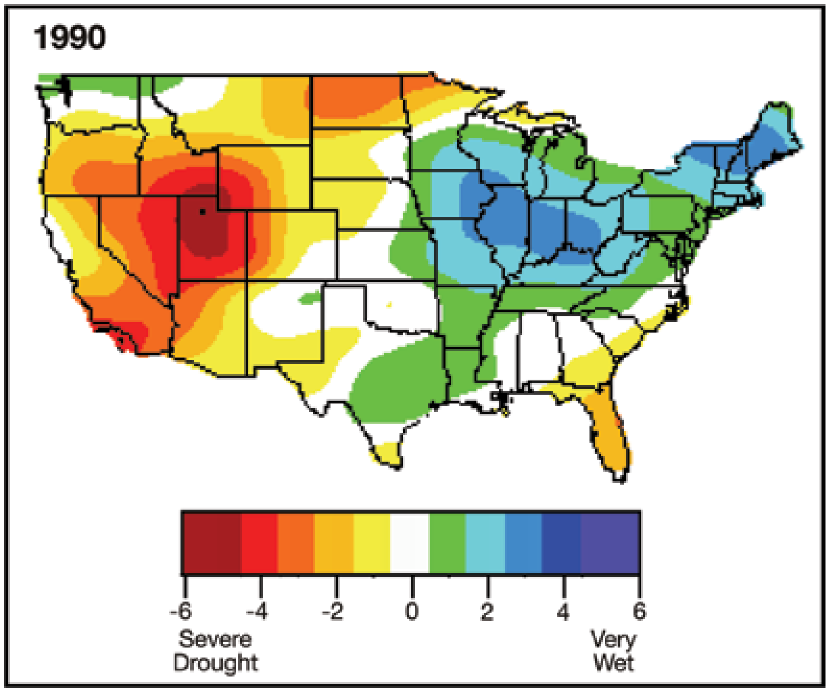


FIGURE 5 *The geographic extent of drought during 1990, measured using the Palmer Drought Severity Index (from http://www.ncdc.noaa.gov/paleo/pdsiyear.html).*

same time. The configuration of dry and wet regions and general climatological conditions during 1990 are typical of some, but not all, periods when synchronous droughts have impacted the Sacramento and Colorado basins. Attempts to find a consistent link between driving factors (such as sea surface temperatures) and this climatic pattern have not yielded a complete answer to their genesis or predictability, and continue to be pursued.

Searching for Evidence of Prehistoric Perfect Droughts

Analysis of historical records indicates that perfect droughts, including severe droughts (decreases in precipitation and river flow of greater than 30%), can indeed occur. However, our instrumental records of precipitation and river flow extend back in time only 100 years or so. This time span is insufficient to capture the full range of natural variability in the climate of California and the west.

Tree-ring analysis (dendrochronology and dendroclimatology) offers a means of extending hydrological records back in time for hundreds to thousands of years (Figure 6). Standard methods of sample collection, processing and analysis are applied in such studies and many tree-

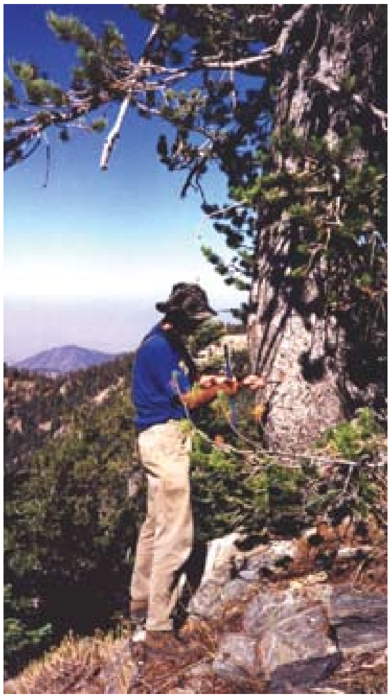


FIGURE 6 *Obtaining a tree-ring core from an ancient pine in the mountains above the Los Angeles basin.*

ring based reconstructions of climate and river flow are available for the West. The rings of trees growing in water stressed locations are typically narrow during years of low precipitation as the lack of water causes physiological stress to the tree. Low precipitation also results in decreased river flow, and this allows tree-rings to be useful in reconstructing both precipitation and the resulting impact of precipitation variability on river flow.

Tree-ring based reconstructions of annual precipitation are available for Southern California. Reconstructions are also available for the Sacramento and Colorado rivers. These reconstructions extend our hydrological records back over 400 years and allow us to look for evidence of prehistoric perfect droughts that might exceed those of the past century. Comparison of the tree-ring records of Southern California annual precipitation and annual flow of the Sacramento and Colorado rivers show several instances in the period 1500 to 1900 when prolonged drought conditions impacted all three regions simultaneously (Figure 7). Examples include the mid-1800s, the late 1700s and a particularly prolonged period of low flow on the Colorado in the late 1500s. Tree-ring based maps of annual drought extent are available for the mid-1800 and late-1700 drought periods and show a geographic pattern (Figure 8) that is similar to the

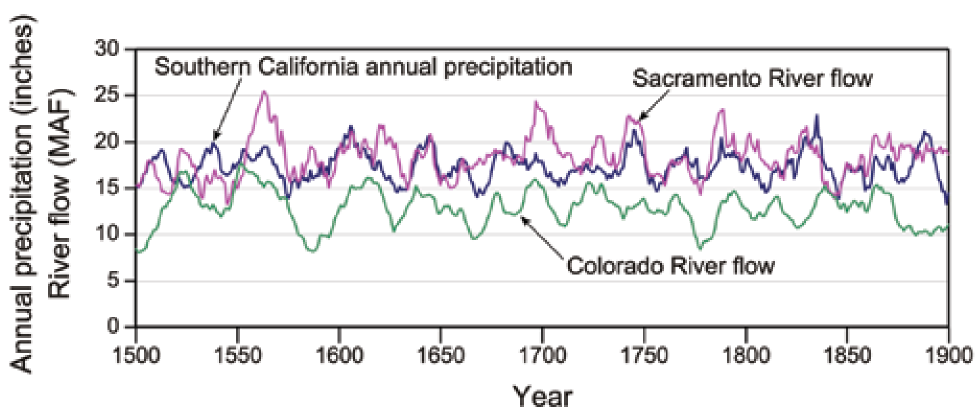


FIGURE 7 *Comparison of tree-ring based reconstructions of Southern California annual precipitation and flow of the Sacramento and Colorado rivers from 1500 to 1900. The series are smoothed with an 11-year running average (data from Rian, S. and MacDonald, G.M. unpublished; Hidalgo H. G., Piechota T C., Dracup J. A., 2000: Alternative Principal Components Regression Procedures for Dendrohydrologic Reconstructions. Water Resources Research, 36, 3241-3249; Meko, D.M., Therrell, M.D., Baisan, C.H., and Hughes, M.K., 2001, Sacramento River flow reconstructed to A.D. 869 from tree rings: J. of the American Water Resources Association, v. 37, no. 4, p. 1029-1040).*

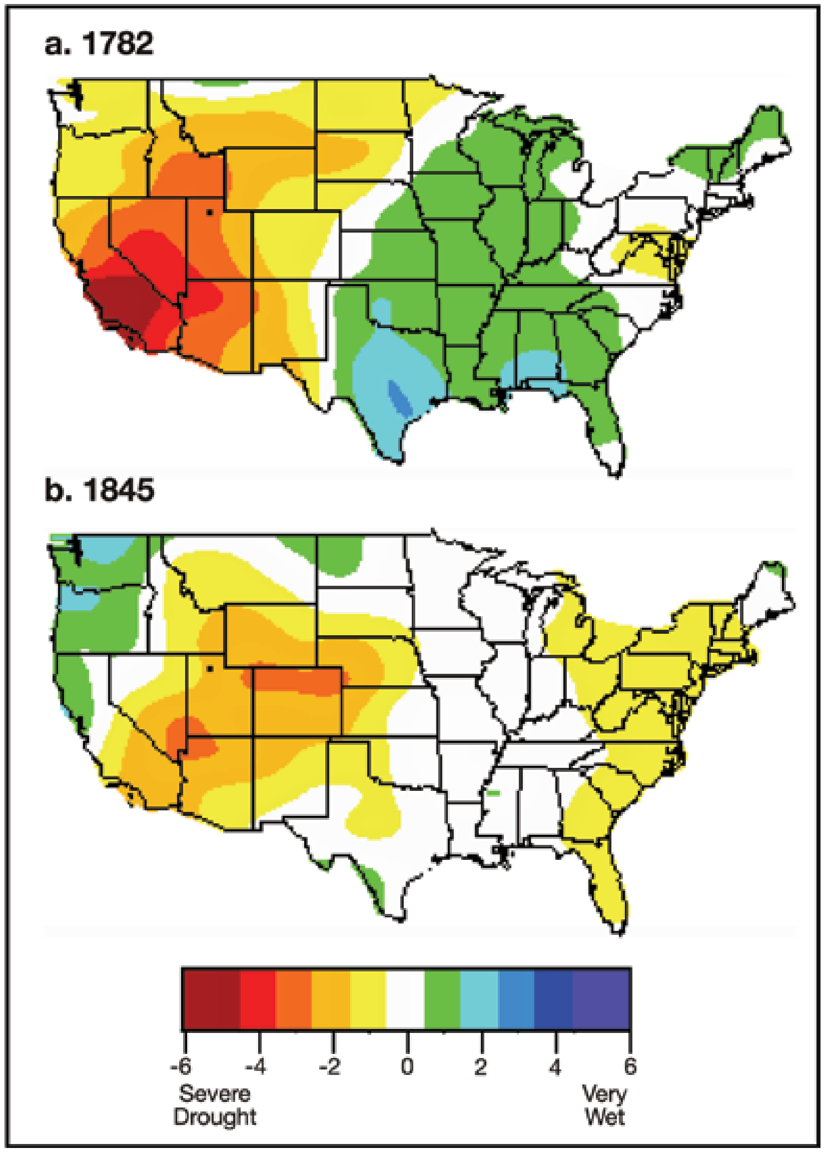


FIGURE 8 *The geographic extent of drought during the perfect drought of 1782 and 1845 measured using the Palmer Drought Severity Index (from http://www.ncdc.noaa.gov/paleo/pdsiyear.html).*

1990 example. In all cases a broad band of aridity extended from California northeastward to the headwaters of the Colorado. The spatial patterning of the pre-historic drought is similar to that recorded in the historical period and substantiates the conclusion that perfect droughts are a natural and expected phenomenon in the West. In addition, the tree-ring records indicate that generally dry conditions may persist in all three regions for lengths of time ranging from several years to well over a decade.

Conclusions

Instrumental climate and hydrological records for the past 100 years and tree-ring based reconstructions for the past 500 years show that multi-year perfect droughts simultaneously impacting Southern California, the Sierra-Sacramento system and the Colorado River have occurred. Such perfect drought episodes should be considered a normal part of the long-term climatic regime in the western United States. Fortunately, water management strategies and storage capacities on the Colorado and in southern California and the state in general have allowed for significant mitigation of the impacts of relatively short perfect droughts, such as during the early 1990s. In addition, both the instrumental and tree-ring records suggest that perfect droughts may only occur once or twice each century. However, the tree-ring record also provides a cautionary note through evidence of more prolonged severe events, such as the multi-decadal drought on the Colorado in the late 1500's.

Future water use planning for southern California is complex, having to account for increasing population size coupled with decreasing availability of water for import as Northern California waters are drawn upon for ecological functioning in areas such as the San Francisco Bay and Owens Valley, or Colorado River waters are fully used by the Lower Basin States. In addition, the possible impact of global climate change remains an open question. However, it is also important to at least consider the potential impacts and mitigation strategies for prolonged multi-year episodes (greater than 5 to 10 years) of widespread drought that would impact local supplies, storage capacity and demands, while at the same time limiting water available for import from Northern California and from the Colorado River Basin due to simultaneous prolonged droughts in those regions.

Further Reading

Meko D. M. and Woodhouse C. A., 2005, Tree-ring footprint of joint hydrologic drought in Sacramento and Upper Colorado River Basins, western USA. Journal of Hydrology 308: 196-213.

REFERENCES FOR FURTHER INFORMATION

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California Climate Change Portal: http://www.climatechange.ca.gov/

Climate Assessment of the Southwest:
http://www.ispe.arizona.edu/climas/

National Weather Service Climate Prediction Center:
http://www.cpc.ncep.noaa.gov/index.html

National Weather Service Colorado Basin River Forecast Center:
http://www.cbrfc.noaa.gov/

NOAA climate timeline information tool: http://www.ngdc.noaa.gov/paleo/ctl/

NOAA Colorado River paleoclimatology information:
http://www.ncdc.noaa.gov/paleo/streamflow/

U.S. Geological Survey fact sheet on Colorado River Basin climatic fluctuations
http://water.usgs.gov/pubs/fs/2004/3062/

Western Water Assessment: http://wwa.colorado.edu/

Western Regional Climate Center: http://www.wrcc.dri.edu/

or faxed comments should be submitted by October 17, 2005.

John W. Roberts,

Acting Chief, National Register/National Historic Landmarks Program.

ARKANSAS

Faulkner County

Lee, Carl and Esther, House, (Mixed Masonry Buildings of Silas Owens, Sr. MPS) 17493 US 65S, Damascus, 05001170

Tyler—Southerland House, (Mixed Masonry Buildings of Silas Owens, Sr. MPS) 36 Southerland, Conway, 05001168

Ward, Earl and Mildred, House, (Mixed Masonry Buildings of Silas Owens, Sr. MPS) 1157 Mitchell St., Conway, 05001169

Webb, Joe and Nina, House, (Mixed Masonry Buildings of Silas Owens, Sr. MPS) 2945 Prince, Conway, 05001171

Washington County

Prairie Grove Battlefield (Boundary Increase II), N of US 62, E of Prairie Grove, Prairie Grove, 05001167

COLORADO

Montrose County

North Rim Road, Black Canyon of the Gunnison National Park, Black Canyon of the Gunnison National Park, Crawford, 05001181

GEORGIA

Bartow County

ATCO–Goodyear Mill and Mill Village Historic District, Roughly bounded by Sugar Valley Rd., Cassville rd. and Pettit Creek, Wingfoot Trail and Litchfield St., Cartersville, 05001172

MAINE

Androscoggin County

Keystone Mineral Springs, Keystone Rd., Poland, 05001175

Cumberland County

Battery Steele, Florida Ave., Peaks Island, Portland, 05001176

Lakeside Grange #63, Main St., jct. of Main St. and Lincoln St., Harrison, 05001173

Hancock County

Garland Farm, 1029 ME 3, Bar Harbor, 05001174

MINNESOTA

Cook County

Grand Portage National Monument, Off US 61 within the area of the Grand Portage Indian Reservation, Grand Portage, 05001180

MISSOURI

Madison County

St. Louis, Iron Mountain and Southern Railroad Depot, Allen St., 150 ft. No of Jct. of Allen and Kelly Sts., Fredericktown, 05001178

MONTANA

Park County

Hepburn, John, Place, 626 E. River Rd., Emigrant, 05001177

New Mexico

Santa Fe County

Kelly, Daniel T., House, (Buildings Designed by John Gaw Meem MPS) 531 E. Palace Ave., Santa Fe, 05001182

OREGON

Multnomah County

Harrison Court Apartments, 1834 SW. 5th Ave., Portland, 05001179

[FR Doc. 05–19526 Filed 9–29–05; 8:45 am]

BILLING CODE 4312–51–P

DEPARTMENT OF THE INTERIOR

Bureau of Reclamation

Colorado River Reservoir Operations: Development of Lower Basin Shortage Guidelines and Coordinated Management Strategies for Lake Powell and Lake Mead Under Low Reservoir Conditions

AGENCY: Bureau of Reclamation, Interior.

ACTION: Notice of intent to prepare an environmental impact statement (EIS) and notice to solicit comments and hold public scoping meetings on the development of Lower Basin shortage guidelines and coordinated management strategies for the operation of Lake Powell and Lake Mead under low reservoir conditions.

SUMMARY: Pursuant to the National Environmental Policy Act (NEPA), the Bureau of Reclamation (Reclamation) proposes to conduct public scoping meetings and prepare an EIS for the development of Lower Colorado River Basin Shortage Guidelines and Coordinated Management Strategies for Operation of Lake Powell and Lake Mead Under Low Reservoir Conditions. The Secretary of the Interior (Secretary) has directed Reclamation to develop additional Colorado River management strategies to address operations of Lake Powell and Lake Mead under low reservoir conditions.

The proposed action is to develop these guidelines and strategies. Through the NEPA process initiated by this **Federal Register** notice, Reclamation is considering development of: (1) Specific guidelines that will identify those circumstances under which the Department of the Interior (Department) would reduce annual water deliveries from Lake Mead to the Lower Basin States below the 7.5 million acre-feet (maf) Lower Basin apportionment and the manner in which those deliveries would be reduced, and (2) coordinated management strategies for the operation of Lake Powell and Lake Mead.

Alternatives to be analyzed in the EIS have not been developed at this time and will be developed through the NEPA process, including through the upcoming EIS scoping meetings.

DATES AND ADDRESSES: Four public meetings will be held to solicit comments on the scope of specific shortage guidelines and other coordinated management strategies and the issues and alternatives that should be analyzed. Oral and written comments will be accepted at the public meetings to be held at the following locations:

- Tuesday, November 1, 2005—6 p.m. to 8 p.m., Hilton Salt Lake City Center, Topaz Room, 255 South West Temple, Salt Lake City, Utah.
- Wednesday, November 2, 2005—6 p.m. to 8 p.m., Adam's Mark Hotel, Tower Court D, 1550 Court Place, Denver, Colorado.
- Thursday, November 3, 2005—6 p.m. to 8 p.m., Arizona Department of Water Resources, Third Floor, Conference Rooms A&B, 500 North Third Street, Phoenix, Arizona.
- Tuesday, November 8, 2005—6 p.m. to 8 p.m., Henderson Convention Center, Grand Ballroom, 200 South Water Street, Henderson, Nevada.

Written comments on the proposed development of these strategies may be sent by close of business on *Wednesday, November 30, 2005*, to: Regional Director, Bureau of Reclamation, Lower Colorado Region, Attention: BCOO–1000, PO Box 61470, Boulder City, Nevada 89006–1470, faxogram at (702) 293–8156, or e-mail at *strategies@lc.usbr.gov*; and/or Regional Director, Bureau of Reclamation, Upper Colorado Region, Attention: UC–402, 125 South State Street, Salt Lake City, Utah 84318–1147, faxogram at (801) 524–3858, or e-mail at *strategies@uc.usbr.gov*.

FOR FURTHER INFORMATION CONTACT: Terrance J. Fulp, PhD., at (702) 293–8500 or e-mail at *strategies@lc.usbr.gov*; and/or Randall Peterson at (801) 524–3633 or e-mail at *strategies@uc.usbr.gov*. If special assistance is required regarding accommodations for attendance at any of the public meetings, please call Nan Yoder at (702) 293–8495, faxogram at (702) 293–8156, or e-mail at *nyoder@lc.usbr.gov* no less than 5 working days prior to the applicable meeting(s).

SUPPLEMENTARY INFORMATION: In recent years the Colorado River Basin experienced the worst five-year drought in recorded history. Drought in the Basin has impacted system storage, while demands for Colorado River water supplies have continued to increase. In the future, low reservoir conditions may not be limited to drought periods as additional development of Colorado River water occurs. The Colorado River is of strategic importance in the southwestern United States for water supply, hydropower production, recreation, fish and wildlife habitat, and other benefits. In addition, the Republic of Mexico has an allocation to the waters of the Colorado River pursuant to a 1944 treaty with the United States.

In 2001, the Department adopted Interim Surplus Guidelines (66 FR 7772) that are used by the Secretary in making annual determinations regarding ''Normal'' and ''Surplus'' conditions for the operation of Lake Mead. Since adoption, these Guidelines have, among other operational and management benefits, allowed the Department and entities in Arizona, California, and Nevada that rely on the Colorado River greater predictability in identifying when Colorado River water in excess of 7.5 maf will be available for use within these three States. In contrast, at this time the Department does not have detailed guidelines in place for annual determinations of releases from Lake Mead of less than 7.5 maf to water users in the three Lower Division States of Arizona, California, and Nevada (often referred to as a ''shortage'' condition on the lower Colorado River). Therefore, water users who rely on the Colorado River in these States are not currently able to identify particular reservoir conditions under which the Secretary would release less than 7.5 maf for use on an annual basis. Nor are these water users able to identify the amount of any potential future annual reductions in water deliveries.

Over the past year, the seven Colorado River Basin States have been proactively discussing strategies to address the recent period of system-wide drought in the Colorado River Basin. In addition, Reclamation has conducted detailed briefings for stakeholders in the Colorado River Basin and other interested entities regarding future scenarios for Colorado River operations.

Currently, each year, the Secretary establishes an Annual Operating Plan (AOP) for the Colorado River Reservoirs. The AOP describes how Reclamation will manage the reservoirs over a 12-month period, consistent with the Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs Pursuant to the Colorado River Basin Project Act of September 30, 1968 (Long-Range Operating Criteria), the Decree entered by the U.S. Supreme Court in the *Arizona* v. *California* litigation, and other provisions of applicable Federal law. Reclamation consults annually with the Colorado River Basin States, Indian tribes, and other interested parties in the development of the AOP. Further, as part of the AOP process, the Secretary makes annual determinations under the Long-Range Operating Criteria regarding the availability of Colorado River water for deliveries to the Lower Division States. To meet the consultation requirements of Federal law, Reclamation also consults with the Colorado River Basin States, Indian tribes, and other interested parties during the five-year periodic reviews of the Long-Range Operating Criteria.

During the mid-year review of the 2005 AOP conducted this past spring, the Department received conflicting recommendations from the Colorado River Basin States regarding operations of Glen Canyon Dam for the remainder of the 2005 water year. In a May 2, 2005, letter to the Governors of the Colorado River Basin States, issued to complete the 2005 AOP mid-year review, the Secretary directed Reclamation to develop additional strategies to improve coordinated management of the reservoirs in the Colorado River system. Pursuant to that direction, Reclamation conducted a public consultation workshop on May 26, 2005, in Henderson, Nevada; issued a **Federal Register** notice soliciting public comments on June 15, 2005; and conducted public meetings on July 26 and July 28, 2005, in Henderson, Nevada, and Salt Lake City, Utah, respectively. Reclamation received a broad range of public comments and suggestions from these discussions, not all of which can be addressed in this proposed process. In addition, some suggestions may be part of ongoing or future efforts.

In order to assure the continued productive management and use of the Colorado River into the future, Reclamation is now soliciting public comments on the development of Lower Basin shortage guidelines and coordinated management strategies for the operation of Lake Powell and Lake Mead under low reservoir conditions. Reclamation will utilize a public process pursuant to NEPA. By this notice, Reclamation provides notice of its intent to prepare an EIS on this action, and provides notice of its upcoming EIS scoping meetings. Reclamation invites all interested members of the general public, including the seven Colorado River Basin States, Indian tribes, water and power contractors, environmental organizations, representatives of academic and scientific communities, representatives of the recreation industry, and other organizations and agencies to present oral and written comments concerning the format and scope of specific shortage guidelines and coordinated management strategies, and the issues and alternatives to be considered during the development of these proposed guidelines and strategies. Reclamation anticipates publishing a ''scoping report'' after completion of the public scoping meetings identified in this **Federal Register** notice.

All comments received will be considered as Reclamation develops formal alternatives under NEPA. Similar to the surplus guidelines referenced above, it is likely that these shortage guidelines will be interim in nature. It is the Department's intent that these guidelines and coordinated management strategies will provide guidance to the Secretary's AOP decisions, and provide more predictability to water users and the public throughout the Colorado River Basin, particularly those in the Lower Division States. The Department does not intend to evaluate the decommissioning of Glen Canyon Dam.

Public Disclosure

Written comments, including names and home addresses of respondents, will be made available for public review. Individual respondents may request that their home address be withheld from public disclosure, which will be honored to the extent allowable by law. There may be circumstances in which respondents' identity may also be withheld from public disclosure, as allowable by law. If you wish to have your name and/or address withheld, you must state this prominently at the beginning of your comment. All submissions from organizations, business, and from individuals identifying themselves as representatives or officials of organizations or businesses, will be made available for public disclosure in their entirety.

Dated: September 22, 2005.

Rick L. Gold,

Regional Director—UC Region, Bureau of Reclamation.

Dated: September 22, 2005.

Jayne Harkins,

Deputy Regional Director—LC Region, Bureau of Reclamation.

[FR Doc. 05–19607 Filed 9–29–05; 8:45 am]

BILLING CODE 4310–MN–P

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Bureau of Land Management lands, inquiries may also be directed to Taylor Brelsford, Subsistence Coordinator, Alaska State Office, 222 West 7th Avenue, #13, Anchorage, Alaska 99513; phone (907) 271–5806.

SUPPLEMENTARY INFORMATION: Regional Council discussion during the meeting will be devoted to the review and recommendation of the East Alaska Draft Resource Management Plan and Environmental Impact Statement.

Dated: June 7, 2005.

Henri R. Bisson,

State Director.

[FR Doc. 05–11774 Filed 6–14–05; 8:45 am]

BILLING CODE 4310–JA–P

DEPARTMENT OF THE INTERIOR

Bureau of Reclamation

Colorado River Reservoir Operations: Development of Management Strategies for Lake Powell and Lake Mead Under Low Reservoir Conditions

AGENCY: Bureau of Reclamation, Interior.

ACTION: Notice to solicit comments and hold public meetings on the development of management strategies for Lake Powell and Lake Mead, including Lower Basin shortage guidelines, under low reservoir conditions.

SUMMARY: The Secretary of the Interior (Secretary) has directed the Bureau of Reclamation (Reclamation) to develop additional Colorado River management strategies to address operations of Lake Powell and Lake Mead under low reservoir conditions. It is anticipated that, among other potential elements, these strategies could identify those circumstances under which the Department of the Interior (Department) would reduce annual water deliveries, and the manner in which annual operations would be modified.

DATES AND ADDRESSES: Two public meetings will be held to solicit comments on the content, format, mechanism, and analysis to be considered during the development of management strategies for Lake Powell and Lake Mead under low reservoir conditions. Oral and written comments will be accepted at the public meetings to be held at the following locations:

- *Tuesday, July 26, 2005*–10 a.m. to 12 noon, Henderson Convention Center, Grand Ballroom, 200 South Water Street, Henderson, Nevada.
- *Thursday, July 28, 2005*–10 a.m. to 12 noon, Hilton Salt Lake City Center, Topaz Room, 255 South West Temple, Salt Lake City, Utah.

Written comments on the proposed development of these strategies may be sent by close of business on *Wednesday, August 31, 2005,* to: Regional Director, Bureau of Reclamation, Lower Colorado Region, Attention: BCOO–1000, P.O. Box 61470, Boulder City, Nevada 89006–1470, fax at 702–293–8156, or e-mail at *strategies@lc.usbr.gov;* and/or Regional Director, Bureau of Reclamation, Upper Colorado Region, Attention: UC–402, 125 South State Street, Salt Lake City, Utah 84318–1147, fax at 801–524–3858, or e-mail at *strategies@uc.usbr.gov.*

FOR FURTHER INFORMATION CONTACT: Terrance J. Fulp, Ph.D., at 702–293–8500 or e-mail at *strategies@lc.usbr.gov;* and/or Randall Peterson at 801–524–3633 or e-mail at *strategies@uc.usbr.gov.* If special assistance is required regarding accommodations for attendance at either of the public meetings, please call Nan Yoder at 702–293–8495, fax at 702–293–8156, or e-mail at *nyoder@lc.usbr.gov* no less than 5 working days prior to the applicable meeting(s).

SUPPLEMENTARY INFORMATION: In recent years the Department has undertaken a number of initiatives to improve the efficient and coordinated operation and management of the Colorado River. For example, a number of Indian water rights settlements have been enacted and implemented, while additional settlements are under active negotiation. Important programs have been developed in the Upper and Lower Basins to address conservation of endangered species. Scientific investigations are proceeding under the framework of the Glen Canyon Adaptive Management Program to study the impacts to and improve the values for which the Grand Canyon National Park and the Glen Canyon National Recreation Area were established. In 2003, water users in California executed agreements that will assist California to limit its use of water from the Colorado River to its normal year apportionment of 4.4 million acre-feet (maf).

More recently a new management challenge has emerged on the Colorado River. The Colorado River Basin has experienced the worst five-year drought in recorded history. Drought in the Basin has impacted system storage, while demands for Colorado River water supplies have continued to increase. During the period from October 1, 1999, to October 1, 2004, storage in Colorado River reservoirs fell from 55.7 maf to 29.7 maf.

In the future, low reservoir conditions may not be limited to drought periods as additional development of Colorado River water occurs. The Colorado River is of strategic importance in the southwestern United States for water supply, hydropower production, recreation, fish and wildlife habitat, and other benefits. In addition, the Republic of Mexico has an allocation to the waters of the Colorado River pursuant to a 1944 treaty with the United States.

In a May 2, 2005, letter to the Governors of the Colorado River Basin States, issued in the context of the 2005 Annual Operating Plan mid-year review, the Secretary directed Reclamation to develop additional strategies to improve coordinated management of the reservoirs in the Colorado River system. Pursuant to that direction, Reclamation conducted a public consultation workshop on May 26, 2005, in Henderson, Nevada, and has prepared this **Federal Register** notice. In order to assure the continued productive use of the Colorado River into the future, Reclamation is soliciting public comments on, at a minimum, the development of management strategies for the operation of Lake Powell and Lake Mead under low reservoir conditions.

It is the Department's intent that the development of additional management strategies, including Lower Basin Shortage Guidelines, will provide guidance to the Secretary's Annual Operating Plan decisions, and provide more predictability to water users throughout the Basin, particularly those in the Lower Division States of Arizona, California, and Nevada. For example, in 2001 the Department adopted Interim Surplus Guidelines (66 FR 7772) that are used by the Secretary in making annual determinations regarding ''Normal'' and ''Surplus'' conditions for the operation of Lake Mead. Among other provisions, these Guidelines have allowed the Department and entities in Arizona, California, and Nevada that rely on the Colorado River greater predictability in identifying when Colorado River water in excess of 7.5 maf will be available for use within these three states. In contrast, at this time the Department does not have detailed guidelines in place for annual determinations of releases from Lake Mead of less than 7.5 maf to water users in the three Lower Division States (often referred to as a ''shortage'' condition on the lower Colorado River). Therefore, water users who rely on the Colorado River in these states are not currently able to identify particular reservoir conditions under which the Secretary would release less than 7.5 maf for use

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on an annual basis. Nor are these water users able to identify the amount of any potential future annual reductions in water deliveries. By developing additional management strategies, these users would be better able to plan for periods of less than full water deliveries. Additional operational tools may also facilitate conservation of reservoir storage, thereby minimizing the adverse effects of long-term drought or low-reservoir conditions in the Colorado River Basin.

Over the past year, the seven Colorado River Basin States have been proactively discussing strategies to address the current system-wide drought in the Colorado River Basin. In addition, Reclamation has conducted detailed briefings for stakeholders in the Colorado River Basin and other interested entities regarding future scenarios for Colorado River operations. Reclamation will integrate available technical information in the upcoming development of additional management strategies for Colorado River operations.

Reclamation intends to utilize a public process during the development of management strategies for Lake Powell and Lake Mead under low reservoir conditions. By this notice, Reclamation invites all interested members of the general public, including the seven Colorado River Basin States, Indian Tribes, water and power contractors, environmental organizations, representatives of academic and scientific communities, representatives of the recreation industry, and other organizations and agencies to present oral and written comments concerning the content, format, mechanism, and analysis to be considered during the development of these proposed strategies.

Reclamation has not yet determined the appropriate level of National Environmental Policy Act (NEPA) documentation for the upcoming development of additional management strategies. However, to ensure timely consideration of technical information and public comment, Reclamation is proceeding, at this time, as if the development of additional management strategies would require preparation of an Environmental Impact Statement. Information received by Reclamation pursuant to this **Federal Register** notice and the upcoming public meetings will be analyzed in order to define the nature of any proposed federal actions, the level of appropriate NEPA documentation, and the need, if any, for additional scoping activities. In addition to NEPA documentation, other compliance activities, as appropriate, will be undertaken pursuant to applicable Federal law.

Public Disclosure

Written comments, including names and home addresses of respondents, will be made available for public review. Individual respondents may request that their home address be withheld from public disclosure, which will be honored to the extent allowable by law. There may be circumstances in which respondents' identity may also be withheld from public disclosure, as allowable by law. If you wish to have your name and/or address withheld, you must state this prominently at the beginning of your comment. All submissions from organizations, business, and from individuals identifying themselves as representatives or officials of organizations or businesses, will be made available for public disclosure in their entirety.

Dated: June 6, 2005.

Darryl Beckmann,

Deputy Regional Director—UC Region, Bureau of Reclamation.

Dated: June 7, 2005.

Robert W. Johnson,

Regional Director—LC Region, Bureau of Reclamation.

[FR Doc. 05–11776 Filed 6–14–05; 8:45 am]

BILLING CODE 4310–MN–P

DEPARTMENT OF JUSTICE

Office of Community Oriented Policing Services, Agency Information Collection Activities: Proposed Collection; Comments Requested

ACTION: 60-day notice of information collection under review: Annual Report to Congress—Expired COPS Awards Exceeding $5 Million.

The Department of Justice (DOJ) Office of Community Oriented Policing Services (COPS) has submitted the following information collection request to the Office of Management and Budget (OMB) for review and approval in accordance with the Paperwork Reduction Act of 1995. The proposed information collection is published to obtain comments from the public and affected agencies. The purpose of this notice is to allow for 60 days for public comment until August 15, 2005. This process is conducted in accordance with 5 CFR 1320.10.

If you have comments especially on the estimated public burden or associated response time, suggestions, or need a copy of the proposed information collection instrument with instructions or additional information, please contact Rebekah Dorr, Department of Justice Office of Community Oriented Policing Services, 1100 Vermont Avenue, NW., Washington, DC 20530.

Written comments and suggestions from the public and affected agencies concerning the proposed collection of information are encouraged. Your comments should address one or more of the following four points:

—Evaluate whether the proposed collection of information is necessary for the proper performance of the functions of the agency, including whether the information will have practical utility;

—Evaluate the accuracy of the agency's estimate of the burden of the proposed collection of information, including the validity of the methodology and assumptions used;

—Enhance the quality, utility, and clarity of the information to be collected; and

—Minimize the burden of the collection of information on those who are to respond, including through the use of appropriate automated, electronic, mechanical, or other technological collection techniques or other forms of information technology, *e.g.*, permitting electronic submission of responses.

Overview of This Information Collection

(1) *Type of Information Collection:* New Collection.

(2) *Title of the Form/Collection:* Annual Report to Congress—Expired COPS Awards Exceeding $5 Million.

(3) *Agency form number, if any, and the applicable component of the Department sponsoring the collection:* Form Number: None. Office of Community Oriented Policing Services.

(4) *Affected public who will be asked or required to respond, as well as a brief abstract:* Primary: State, Local, or Tribal Government. Law enforcement agencies that are recipients of COPS grants over $5,000,000 that are programmatically and financially closed out or that otherwise ended in the immediately preceding fiscal year.

(5) *An estimate of the total number of respondents and the amount of time estimated for an average respondent to respond/reply:* It is estimated that approximately 10 respondents annually will complete the form within one hour.

(6) *An estimate of the total public burden (in hours) associated with the collection:* There are approximately 10 total annual burden hours associated with this collection.

EXECUTIVE ORDER S-3-05

by the Governor of the State of California

WHEREAS, California is particularly vulnerable to the impacts of climate change; and

WHEREAS, increased temperatures threaten to greatly reduce the Sierra snowpack, one of the State's primary sources of water; and

WHEREAS, increased temperatures also threaten to further exacerbate California's air quality problems and adversely impact human health by increasing heat stress and related deaths, the incidence of infectious disease, and the risk of asthma, respiratory and other health problems; and

WHEREAS, rising sea levels threaten California's 1,100 miles of valuable coastal real estate and natural habitats; and

WHEREAS, the combined effects of an increase in temperatures and diminished water supply and quality threaten to alter micro-climates within the state, affect the abundance and distribution of pests and pathogens, and result in variations in crop quality and yield; and

WHEREAS, mitigation efforts will be necessary to reduce greenhouse gas emissions and adaptation efforts will be necessary to prepare Californians for the consequences of global warming; and

WHEREAS, California has taken a leadership role in reducing greenhouse gas emissions by: implementing the California Air Resources Board motor vehicle greenhouse gas emission reduction regulations; implementing the Renewable Portfolio Standard that the Governor accelerated; and implementing the most effective building and appliance efficiency standards in the world; and

WHEREAS, California-based companies and companies with significant activities in California have taken leadership roles by reducing greenhouse gas (GHG) emissions, including carbon dioxide, methane, nitrous oxide and hydrofluorocarbons, related to their operations and developing products that will reduce GHG emissions; and

WHEREAS, companies that have reduced GHG emissions by 25 percent to 70 percent have lowered operating costs and increased profits by billions of dollars; and

WHEREAS, technologies that reduce greenhouse gas emissions are increasingly in demand in the worldwide marketplace, and California companies investing in these technologies are well-positioned to profit from this demand, thereby boosting California's economy, creating more jobs and providing increased tax revenue; and

WHEREAS, many of the technologies that reduce greenhouse gas emissions also generate operating cost savings to consumers who spend a portion of the savings across a variety of sectors of the economy; this increased spending creates jobs and an overall benefit to the statewide economy.

NOW, THEREFORE, I, ARNOLD SCHWARZENEGGER, Governor of the State of California, by virtue of the power invested in me by the Constitution and statutes of the State of California, do hereby order effective immediately:

1. That the following greenhouse gas emission reduction targets are hereby established for California: by 2010, reduce GHG emissions to 2000 levels; by 2020, reduce GHG emissions to 1990 levels; by 2050, reduce GHG emissions to 80 percent below 1990 levels; and

2. That the Secretary of the California Environmental Protection Agency ("Secretary") shall coordinate oversight of the efforts made to meet the targets with: the Secretary of the Business, Transportation and Housing Agency, Secretary of the Department of Food and Agriculture, Secretary of the Resources Agency, Chairperson of the Air Resources Board, Chairperson of the Energy Commission, and the President of the Public Utilities Commission; and

3. That the Secretary shall report to the Governor and the State Legislature by January 2006 and biannually thereafter on progress made toward meeting the greenhouse gas emission targets established herein; and

4. That the Secretary shall also report to the Governor and the State Legislature by January 2006 and biannually thereafter on the impacts to California of global warming, including impacts to water supply, public health, agriculture, the coastline, and forestry, and shall prepare and report on mitigation and adaptation plans to combat these impacts; and

5. That as soon as hereafter possible, this Order shall be filed with the Office of the Secretary of State and that widespread publicity and notice be given to this Order.

IN WITNESS WHEREOF I have here unto set my hand and caused the Great Seal of the State of California to be affixed this the first day of June 2005.

Arnold Schwarzenegger
Governor of California