Managing the Uncertainties on the Colorado River System

Welcome Address

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Introduction

Ever since pioneers first diverted water in 1854 from the Blacks Fork of the Green River for irrigation purposes, Colorado River waters were considered available for appropriation and development for beneficial use. Until very recently, the basic assumption has been that if we needed additional water supplies, the water was there. To use it, all we needed to do was to build another dam, diversion structure, pumping plant and canal, or pipeline system. New water rights were perfected through beneficial use.

Today, the focus of our basic approach to the Colorado River has changed from one of development to one of reallocation and risk management. Although a number of projects are still under consideration or being actively permitted in the Upper Colorado River Basin, there is a growing consensus that within the Colorado River system as a whole the existing demand for water now exceeds the available supply.

The projects in the Upper Basin being planned today may be developing the unused apportionment of individual Upper Basin states, but from the system-wide perspective, these projects are reallocating existing supplies. The Upper Basin's "unused" water is currently in use in the Lower Basin.

To properly manage a system as complex as the Colorado River Basin, the numerous Federal, State, local, and private entities charged with managing or using the resources of the Colorado River need a fundamental understanding of the basic uncertainties they face.

The development era of the Colorado River has given us a sound foundation of well-run and efficient governmental agencies, water utilities, and irrigation districts. These water entities have developed advanced management and technological skills and highly trained personnel. These same water entities, by necessity, are now faced with the need to develop new planning and management tools to take on a different set of challenges, but with the same basic objective of delivering reliable and high-quality water to their customers at a reasonable price. These new tools are needed as we transition from the era of development to the new era of risk management.

Within the Colorado River Basin, there are three basic sources of uncertainty: hydrology, future demands, and unresolved legal disputes. To address these uncertainties will require the adoption of three broad management strategies: identifying and avoiding unacceptable outcomes, maintaining effective working relationships among stakeholders, and increasing focus and reliance on the use of science in decisionmaking.

The Basic Assumption Concerning the Law of the River

My list of three management strategies does not include any major changes or revisions to what is referred to as "the law of the river." The term "law of the river" refers to the whole body of international treaties, interstate compacts, Supreme Court decisions and decrees, Federal and State laws, and adjudicated water rights that are used to allocate,

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manage, and distribute the waters of the Colorado River system to its many users.

My view is that while there may be a few "tweaks" here and there, it is highly unlikely that there will be major changes to the law of the river for a long time. My fundamental assumption is that the basic tenets of the law of the river will continue to set the boundaries or bookends that will constrain all future management strategies, traditional or new in scope.

Specifically, the obligation of the United States under the 1944 treaty to deliver to the Republic of Mexico 1.5 million acre-feet (maf) per yr in most years will continue unchanged. The basic apportionments made in Articles III a. and III b. of the 1922 Colorado River Compact to the Upper and Lower Basins will not be changed. The obligations of the states of the Upper Division at Lee Ferry under Articles III c. and III d. of the 1922 Colorado River Compact will remain unchanged. The individual apportionments made to the five states with lands in the Upper Basin will continue to be as defined by Article III of the 1948 Upper Colorado River Basin Compact. The 1964 United States Supreme Court decree in Arizona v. California will continue to control the deliveries of water on the mainstem of the Colorado River in and below Lake Mead. The 1964 decree along with the 1928 Boulder Canyon Project Act, the 1956 Colorado River Storage Project Act, and the 1968 Colorado River Basin Act will remain largely unchanged and continue to give the United States, through the Secretary of the Interior, very broad powers.

Finally, the myriad of Federal environmental laws such as National Environmental Policy Act (NEPA), the Endangered Species Act (ESA) and the Clean Water Act, will continue to constrain, guide, and influence the many Federal agency decisions and actions required for the management of the river.

It is not that I do not believe that targeted changes to individual elements of the law of the river will not be proposed or actively pursued by individual stakeholders or that future Supreme Court decisions will not further interpret the law of the river. These events could happen. I suggest that there will be no major or fundamental changes to the law of the river because it is simply too difficult in today's political and legal environment to make changes. Changes to interstate compacts require approval or ratification by each participant State legislature and Congress. Changes to Federal laws require either a crisis trigger or super majorities in both houses of Congress. Within the Basin States, water rights which define, prioritize, and quantify the amount of water that can be applied to beneficial use are property rights and, except for abandonment for non-use, cannot be easily changed, undone, or ignored.

I believe that the changes in management strategies adopted by cooperative efforts will be allowed and implemented through the existing flexibility and perhaps creative reinterpretation of the existing law of the river.

The Basic Uncertainties

Hydrology

When the 1922 Colorado River Compact was negotiated, the collective wisdom was that the Colorado River system had a total yield of well over 20 maf per yr as measured at Yuma, AZ. In fact, the negotiators believed they were only committing a portion of the available system water. Article III f. provided for a future apportionment of the remaining waters.

Of course history has shown that there would be no future apportionment and, in many if not most years, nature has not even provided enough Colorado River water to cover the original 17.5 maf of water committed for consumptive uses to the Upper and Lower Basins under the 1922 Compact and to Mexico under the 1944 Treaty.

Using the metric of natural flow at Lee Ferry, the general rule has been that the longer the period of record examined, the lower the estimated mean flow. The 1922 Compact negotiators had about 20 yrs of gage records. In 1922 the estimated flow of the Colorado River at Lee Ferry was between 17 and 18 maf per yr. At the time the Upper Colorado River Basin Compact was negotiated in 1948, we had over 40 years of gage data and the estimated mean natural flow at Lee Ferry had dropped to 15.7 maf per yr. Today, the Bureau of Reclamation's natural flow estimate, based on the 100- yr period of 1905–2004, is about 15.0 maf per yr.

A number of well known studies using the analysis of tree ring data have been published and have expanded the record back 500 yrs or more. These paleohydrology studies suggest a mean flow at Lee Ferry in the range of 13.5–14.8 maf per yr. These reconstructions also suggest that drought periods have occurred that are far more severe and longer lasting than what we have experienced in the post-1905 gage record.

The prospect of climate change–induced flow changes adds additional uncertainty. While there is a wide range of results in the different published studies, all suggest a future Colorado River with less streamflow. In 2007, a report by the National Research Council of the National Academies (2007, p. 3) concluded that "*the preponderance of scientific evidence suggests that warmer future temperatures will reduce future Colorado River stream-flow and water supplies*". In late 2008, the Colorado Water Conservation Board (Colorado Water Conservation Board, 2008) issued a synthesis report on climate change specifically targeted for water managers. This report warns that "*climate change will affect Colorado's use and distribution of water. Water managers and planners currently face specific challenges that may be further exacerbated by projected climate changes*". The study concludes that "*all recent hydrologic projections show a decline in runoff for most of Colorado's rivers*". Perhaps Greg Garfin of CLIMAS put it best: "*the certainty of the future temperature increase trumps the uncertainty in future precipitation levels*" (Garfin and Lenant, 2007).

My conclusion is that given the current demands on Colorado River water resources, even a small change in the mean natural flow at Lee Ferry will cause serious problems. Among the most optimistic of the climate impact studies published is the 2006 paper by Christiansen and Lettenmeyer. This study suggested modest reductions in the mean flow at Lee Ferry in the range of 6–10 percent. Most recently, a project by the Western Water Assessment to narrow the results of the various studies suggests the floor for the estimated flow reduction is about 10 percent (Brad Udall, personal commun., September 2009).

Are there credible studies that model the current operation of the Colorado River with a sustained 10 percent reduction on natural flow at Lee Ferry? I believe the answer is yes. Reclamation's recent environmental impact statement on the Lower Basin shortage criteria included an alternative hydrology appendix (U.S. Bureau of Reclamation, 2007). The paleohydrology analysis used estimated flows at Lee Ferry (Woodhouse et al., 2006). The paleohydrology-based trace for the period of 1620–1674 is illustrative of my conclusion. This period has an estimated mean flow at Lee Ferry of approximately 13.5 maf per year. The model output shows a number of unacceptable and shocking results. For example, the Central Arizona Project (CAP) would experience 47 straight years of shortages, including a number of individual years when the project would divert no water at all. Lake Mead would drop below and stay below the minimum level for the Las Vegas Valley Water District to pump water to its customers (1000' msl) for a period of close to 20 yrs. California, which has the most senior of the prior perfected rights in the Lower Basin, would experience occasional large shortages.

In the Upper Basin, Lake Powell would operate below the minimum storage level necessary to produce hydroelectric power over 60 percent of the 50-yr period, and there would be two periods, one of 5 yrs and one of 12 yrs, when Lake Powell would be empty and the Upper Basin states would be unable to meet their obligations to the Lower Basin under the 1922 Colorado River Compact.

The lesson is that without major changes in how we currently manage the Colorado River, even a modest decrease in system streamflows on the order of 10 percent could cause significant unacceptable impacts throughout the Basin.

Unresolved legal disputes

It is not hard to understand that with the intense competition for the waters of the Colorado River system and the complex and often conflicting compacts, treaties, and Federal and State statutes that make up "the law of the river," there are a number of unresolved legal disputes. For the most part, these disputes have been well known for many decades, but until recently there was little incentive to resolve many of them.

However, since the completion and full utilization of the CAP in the mid-1990s, there has been major

effort to reach consensus solutions for a number of previously unresolved matters. The Secretary of the Interior issued interim surplus criteria in 2000 and interim shortage criteria in 2007 for the operation of Lake Mead. The surplus criteria effort included the resolution of major issues in California, including an agreement that quantifies the individual rights of California's senior irrigation users. This agreement is referred to as the QSA, or the Quantification Settlement Agreement. The QSA was a necessary prerequisite to the water transfer agreement between San Diego and the Imperial Irrigation District (IID).

The shortage criteria brought with it a new conjunctive management strategy for the operation of Lake Mead and Lake Powell and the implementation much needed efficiency and conservation projects.

Despite the clear progress, important unresolved legal disputes remain to be addressed. Two sets of related problems are perhaps the most salient. The first set of unresolved issues involves the Republic of Mexico. The second set involves the final quantification and future use of the remaining un-adjudicated Indian water rights within the Basin.

There are a number of unresolved issues with respect to Mexico; two of them are especially important to the Upper Basin, and perhaps they could be considered as the opposite sides of the same coin. Under the 1944 Treaty with Mexico, the United States can reduce its deliveries to Mexico: "*in the event of extraordinary drought or serious accident to the irrigation system in the United Sates making it difficult for the United States to deliver the guaranteed quantity of 1,500,000 acre feet a year, the water allotted to Mexico... will be reduced in the same proportion as consumptive uses in the United States are reduced*."

The obvious question is when are we in an "extraordinary" drought as opposed to an "ordinary" drought? If climate change reduces flows in the Colorado River system, is this a drought or just nature reducing the baseline? Under all reasonable climate change scenarios, there will still be considerable natural variability within the Colorado River Basin.

Currently, a task group of Federal and State water officials is working with counterparts from Mexico to begin a dialogue on Colorado River water issues. This process is promising, but it will take time and the initial efforts will likely avoid the most difficult issues.

The second Mexico issue is internal to the United States and potentially very divisive. Article III c. of the 1922 Compact states:

(c) "*If, as a matter of international comity, the United States of America shall hereafter recognize in the United States of Mexico any right to the use of any waters of the Colorado River System, such waters shall be supplied first from the waters which are surplus over and above the aggregate of the quantities specified in paragraphs (a) and (b); and if such surplus shall prove insufficient for this purpose, then the burden of such deficiency shall be equally borne by the Upper Basin and the Lower Basin, and whenever necessary the States of the Upper Division shall deliver at Lee Ferry water to supply one-half the deficiency so recognized in addition to that provided in paragraph (d).*"

Among the unanswered questions are: (1) when is there a surplus; (2) when there is a surplus, how is it quantified; (3) where in the Basin is the surplus water located; and (4) does the Upper Basin need to cover transit losses from Lee Ferry to the Mexican border. The stakes are high for both Basins. Is the Upper Basin 10-year obligation at Lee Ferry 75 maf, 82.5 maf, something more, or something in between?

Note that the obligation of the United States to Mexico is an annual obligation, not a ten-year moving average. If the Upper Basin's obligation to Mexico was set at 750,000 af every year, then the total 10-yr obligation would be 82.5 maf.

In Colorado, the answer to the Upper Basin's long-term obligation to Mexico could mean the difference between having enough water or not having enough water to support a large new trans-mountain diversion or perhaps meeting the needs of a large future oil shale industry. If there is no water for additional Colorado River water diversion to the Front Range, the only other practical choice may be agricultural conversions in the Platte and Arkansas Basins. Not having enough water for oil shale could

have similar repercussions for West Slope agriculture.

In the Lower Basin, the question is the effect on Lower Basin tributaries, primarily the Gila River. In all but very rare wet years, the Gila River system is fully used and has been for decades. The Gila River has already been the primary driver for several Supreme Court cases. It was the primary reason Arizona refused to ratify the 1922 Compact until 1944. And as a practical matter, because of high transit losses through the desert from Phoenix to Yuma, the Gila River cannot efficiently make deliveries to Mexico.

The real question is when and how will the Mexican Treaty delivery obligation issues be resolved. Will the issues be resolved through negotiations or litigation, or perhaps through the negotiated settlement of litigation? Unlike the 1928 Boulder Canyon Act, the 1922 Compact does not give the Federal Government any special status to threaten the States with a Secretarial decision.

Up until now, neither Basin has had a real incentive to press for a resolution of the Mexican Treaty issues, but those days may be ending. The States actually came very close to a showdown in 2005. The current dialogue on Mexican issues could force certain issues to the table, and the effects of climate change may accelerate sustained shortages that cannot be addressed without a resolution of Article III c. of the 1922 Compact.

Compared with other major western rivers, the groups governing the Colorado River Basin have made progress in quantifying the reserved rights of the many Indian tribes with lands in the Basin. However, several challenges remain unresolved. The Navajo Nation covers lands in New Mexico, Arizona, and Utah. The Navajo are in a unique position. The tribe has Upper and Lower Basin water interests in New Mexico and Arizona and Upper Basin water interests in Utah. The State of New Mexico and the Navajo Nation have reached a settlement covering the Nation's claims to the San Juan River. This settlement must still be approved by Congress. There are no guarantees Congress will approve the package, which includes Federal financing commitment.

The proposed settlement includes the construction of a water supply pipeline that will pump water from the San Juan River to the Navajo Nation and to the city of Gallup. Gallup is located on a tributary to the Little Colorado River, a Lower Basin tributary. The pipeline would also provide much needed domestic water to tribal users in Arizona. This project raises a number of messy Compact issues, including the concept of crediting the Upper Basin deliveries for water delivered to Arizona via the pipeline as being delivered at Lee Ferry. In the fall of 2008, the Basin States reached a compromise that allowed the legislation to proceed, but reserves for future battle a number of tough issues.

Within Arizona, is there even enough water to satisfy the minimal Navajo claims? Under the 1948 Compact, Arizona was apportioned 50,000 af of Upper Basin water annually. A major portion of this water is already in use to supply a large coal-fired power plant outside of Page. What happens if the Navajo claims to Upper Basin water, which pre-date both the 1922 and 1948 Compacts, cause Arizona's demands to exceed 50,000 af per year? As a sovereign, can the Navajo Nation use its water anywhere within its boundaries? Can it deliver water diverted on the San Juan in Utah to tribal lands in Arizona? For example, as a sovereign, Utah takes the position that it can use its Upper Basin water in the Virgin River, a Lower Basin tributary. It is seeking Federal permits for the construction of a pipeline from Lake Powell to St. George.

Demand uncertainties

The third set of uncertainties involves the demands for the waters of the Colorado River. This problem is not as simple as it may appear. Planning for and meeting the future water demands in the Basin is much more complicated than the traditional demographic-based approaches. Future water demands will be affected by both events in adjacent basins and by futures that will be dramatically different than what we can imagine. To meet the needs of Southern California's 20 million people on the coastal plain (Santa Barbara to San Diego), the Colorado River is one of only four major sources of water. The four sources are the Colorado River Aqueduct, the California State Water Project, the Owens River Aqueduct, and local in-basin sources.

There are significant challenges and uncertainties with each of these supplies. The largest single supply is the State Water Project. This project diverts water from the Sacramento River system in the Bay-Delta. From the Delta it is delivered hundreds of miles south to Southern California. The project is facing enormous challenges: sea water intrusion, ESA limitations, environmental restoration, and a lack of system storage. Recent court decisions have limited the water yield available to the project. Without a comprehensive solution to the Bay-Delta issue, there could be shortages in average years. If the 2008/2009 winter is dry in the Sierras, Metropolitan Water District (MWD) customers could be facing water rationing.

The bottom line is that the State Water Project water supplies to Southern California are likely to be smaller in the future. This puts more pressure on MWD to firm up its Colorado River supplies. Within California, it has the most junior Colorado River rights. To firm up its Colorado River supply, it needs to transfer existing senior agricultural uses. It has already done so, with some success. When California is limited to its normal year apportionment of 4.4 maf per yr, MWD's senior rights provide about 550,000 af per yr. Its aqueduct has a capacity to pump 1.2 maf per yr. Through agricultural transfer fallowing and conservation programs with Palo Verde and the IID, in 2007 and 2008 the IID pumped over 700,000 af per yr. Will the politics in the Imperial Irrigation District allow more transfers, enough to fill the remaining capacity of the Colorado River aqueduct? If not, where will MWD turn? Will its efforts ultimately lead to the Upper Basin?

Likewise, central Arizona has three major sources of supply: the Central Arizona Project (CAP), the Gila/Salt River System, and groundwater. Groundwater is already over-tapped and aggressively managed. The CAP is the most junior project in the Lower Basin and potentially subject to prolonged periods of shortage. The Gila River system, including its major tributaries the Salt and Verde Rivers, is a vital supply that has historically provided approximately 1.5–2.0 maf per yr of water for irrigation and municipal purposes. The Salt/Verde system drains the Mogollon Rim and the White Mountains. Compared with the Colorado Rockies, this watershed is at a low elevation, 7,000–10,000 ft. The current climate science suggests that the southwestern United States and lower elevation watersheds will be the most susceptible to climate change.

Thus, Arizona faces a future of its local supplies reduced by climate change and its CAP subject to prolonged shortage; its groundwater basins are already over-tapped. What are Arizona's options? Are strategies such as the construction of large desalination facilities in Mexico on the shores of the Gulf of Baja California politically or economically feasible? Strategies such as aggressive re-use, the desalinization of local brackish groundwater, and the lease of senior Indian agricultural rights from the Arizona side of the mainstem appear more likely. At the 2008 Colorado River Water Users Convention in Las Vegas, a water planner from the CAP suggested that in the future Arizona might build a pipeline from the Mississippi River (or maybe Lake Michigan) to the Colorado Front Range so that Arizona could exchange the Mississippi River water for the approximate 600,000 af of Colorado River water used on the Front Range.

In the Upper Basin, the major demand uncertainty is energy, specifically oil shale development. With the recent cost of oil and geopolitical concerns, there has been a surge of interest in developing oil shale, primarily at the political level. The development of oil shale will potentially require the consumptive use of large amounts of water for oil shale processing, reclamation, necessary electrical power generation, and the associated municipal use by the supporting communities.

The River District, in cooperation with the State of Colorado, and the Colorado River and Yampa/White Roundtables are sponsoring an energy water needs assessment. The first phase final draft report has been issued (URS Inc., 2008) Efforts to complete a second phase study are now underway.

The first phase results shocked many in Colorado's water community. The bottom line is that a large oil shale industry (greater than 1,000,000 bpd) could require the use of all or perhaps more than all of Colorado's remaining unused Colorado River Compact entitlement. Of course, the study authors had to make numerous assumptions concerning technology and where and how the electrical power needed to supply an in-situ technology-based industry will be produced. If the ultimate oil shale

extraction technology is new and different than what is currently under development, the resulting water demands could be smaller.

This issue presents Colorado with a difficult policy challenge. Do we reserve a major portion of our unused water (if we have any) for a future oil shale industry? If we do not, are we willing to live with the consequences of the industry turning to the market (agriculture) to meet its future supply needs? The situation is complicated because the energy companies already hold valid conditional water rights (rights not yet perfected by use). If the industry develops its relatively senior rights, the results could be an unacceptable reduction in the yield of existing perfected water systems, including many trans-mountain diversions.

Three Strategies to Help Manage Uncertainty

To help manage these uncertainties I suggest three broad strategies.

1. Early identification, acceptance, and prioritization of unacceptable outcomes

The compilation of a list of unacceptable outcomes is probably very easy. Every stakeholder will have its own list. The problems and challenges are reaching a consensus on prioritizing the list and identifying a plan to meet priority needs.

Within the Basin, we all know that there are events we accept as model output but really understand will never happen. For example, would a future Secretary of the Interior ever let Lake Mead drop below the minimum level necessary to deliver water to Las Vegas? The answer is almost certainly no. However, unless Arizona, California, the Upper Basin, and the other parties get something they want in return, will they publicly acknowledge this reality? I believe that most parties acknowledge that human health and safety is the top priority. What happens if there is insufficient water to meet all identified health and safety needs? What if the cost of meeting this top priority is considered unacceptably high for the other uses and resources? At what point can the Basin no longer support human health and safety, critical environmental uses, and minimal quality of life needs such as urban trees and parks? What happens if the owners of the most senior rights say "no more"?

2. Maintain positive relationships among the stakeholders

Again, this task is probably easier said than done. In the Upper Basin, the 1948 Compact created an Upper Basin Commission. This Commission has served a bonus role of fostering good relations and effective communications among the Upper Basin States. However, no similar organization exists in the Lower Basin or the Basin as a whole.

In recent years, the States have done reasonably well in working out consensus solutions, but the States have been criticized for excluding other stakeholders. Additionally, the motivation has most often been the threat of a unilateral decision by the Secretary. The future challenges may overwhelm voluntary cooperation among the States. Based on history, we need to acknowledge that the courts, primarily the United States Supreme Court, have provided a useful dispute resolution forum, but using the courts for dispute resolution is both expensive and time consuming. The 1964 Arizona v. California decision took over a decade to resolve. The recent Arkansas River dispute between Colorado and Kansas was almost two decades long. Finally, courts can make decisions and interpret laws and compacts, but they cannot provide practical and long-lasting solutions. At the end of any future litigation on the Colorado River, the parties would still have to work out cooperative and practical solutions.

3. Better integration of science into decisionmaking

Again, this is a goal that can be readily agreed to by most stakeholders. The real challenge is implementation.

In recent years we have made some progress. For example, Reclamation's shortage criteria Environmental Impact Statement (EIS) included a nontraditional hydrology appendix. The analysis examined how the system would operate based on the long-term reconstructed gage record at Lee Ferry and stochastic hydrology techniques. While the data were made available, I am not sure it became a part of the dialogue among the States or of the policy decisionmaking process.

In Colorado, we are aggressively pursuing new science-based studies. A number of major water providers are conducting a Front Range climate change vulnerability assessment. The Colorado Water Conservation Board is conducting a Colorado River water supply availability study that will look at vegetation changes, paleohydrology, and climate change. Again, the big question is how will we use this information?

I believe that the reality is that we now must consider two new concepts into our water system planning and management. First, we should not assume that the future will look like the past. In fact, we should plan for a number of reasonably foreseeable alternate futures. Reasonable futures include a Colorado River with reduced streamflows from climate change, a future with a significant oil shale industry, a future where there is a huge worldwide demand for U.S. agriculture, a future where public health requires ultrapure drinking water, and a future with many or all of the above. Can we develop a strategy that does not result in unacceptable outcomes under any of the possible futures?

Second, there is no such thing as the once hallowed concept of system firm yield. We must assume that natural water systems are dynamic and we must consider a range of possible outcomes in terms of probabilities.

When I refer to water system planning and management, I include ecosystem management, fisheries, wildland fire strategies—not just the traditional water systems for human purposes.

To accomplish this task, we need more effective communications among the science community, the water management professionals, and policy makers. Since these three groups have different goals and do not always candidly speak the same language, effective communication will require continued work. We have had some major some recent successes: the efforts of the Western Water Assessment and CLIMAS are examples.

Finally, I want to suggest that we cannot forget the basics, primarily good water system data collection and access, but also streamflow measurements, stream temperature, water quality, basic watershed weather data, consumptive use data, and changes to the vegetation within our watersheds. The collection and analysis of basic data will be fundamental to our understanding of the Colorado River system and for future management decisions. If we do not know the baseline, how can we understand the effects of climate change? How can we evaluate the effects of augmentation plans, such as cloud seeding? There is no substitute.

References

Christiansen, N., and D. Lettenmaier. 2006. A multimodel ensemble approach to assessment of climate change impacts on the hydrology and water resources of the Colorado River basin. Hydrology and Earth System Sciences Discussions 3:3,727–3,770.

Colorado Water Conservation Board. 2008. Climate change in Colorado—A synthesis to support water resources management and adaptation. Report for the Colorado Water Conservation Board.

Garfin, G., and M. Lenant. 2007. Climate change effects on southwest water resources. Southwest Hydrology Magazine 6(1):16–17, 34.

National Research Council. 2007. Colorado River Basin Water Management—Evaluating and Adjusting to Hydroclimatic Variability. National Research Council of the National Academies.

URS, Inc. 2008. Final Draft Energy Water Needs. Report prepared for the Yampa/White and Colorado Mainstem Roundtables, September 2008.

U.S. Bureau of Reclamation. 2007. Draft Environmental Impact Statement: Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead—Appendix N: Analysis of Hydrologic Variability Sensitivity. [Data obtained from direct paleo trace, 1620 to 1674]. U.S. Department of the Interior, Bureau of Reclamation, Lower Colorado Region.

Woodhouse, C.A., S.T. Gray, and D.M. Meko. 2006. Updated streamflow reconstructions for the Upper Colorado River Basin. Water Resources Research 42:W05415.