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Technical Memorandum | Final

To:	**Ray Alvarado**
Distribution:	**Client and Consultant Team Distribution List**
From:	**Blaine Dwyer and Matt Brown (AECOM)**
Subject:	**CRWAS Phase I | Task 2.2 | Summary Briefs**
Date:	**January 29, 2010**

This Technical Memorandum presents Summary Briefs of select pertinent documents identified as part of Task 2 of the Colorado River Water Availability Study (CRWAS or Study). The objective of Task 2 is to *identify, review, and summarize relevant and readily available previous studies and investigations pertinent to the execution of primary Study tasks*, limited to 20 documents. The selected pertinent documents are organized below by topic: *Alternate Historical Hydrology, Climate Change, Forest Change, and Colorado River Compact*.

Alternate Historical Hydrology

Meko, D.M., C.A. Woodhouse, C.A. Baisan, T. Knight, J.J. Lukas, M.K. Hughs, and M.W. Salzer. "Medieval drought in the Upper Colorado River Basin." Geophysical Research Letters 2007 34(5), L10705, doi: 10.1029/2007GL029988.

CRWAS Relevance: *This document describes the development of the dataset of reconstructed flows of the Colorado River at Lees Ferry, Arizona that was used for CRWAS as the basis for the stochastic model used to generate extended historical hydrology, and describes one part of one methodology that was considered for adoption for generating extended historical hydrology.*

This work investigates extending the Colorado River at Lee Ferry chronology into the Medieval Climate Anomaly. The most extreme low frequency feature of this time period (A.D. 762-2005) is a drought in the mid 1100s characterized by a decrease of more than 15% in mean annual flow averaged over 25 years and the absence of high annual flows over a period of six decades. This drought is consistent with dry conditions in the Great Basin and Colorado plateau at the same time but there are notable regional differences in intensity.

Prairie J., B. Rajagopalan, U. Lall, T. Fulp. "A stochastic nonparametric technique for space-time disaggregation of streamflows." Water Resources Research 2007 Volume 43, W03432, doi: 10.1029/2005WR004721.

CRWAS Relevance: *This document describes one part of one methodology that was considered for adoption for generating the extended historical hydrology for CRWAS.*

A nonparametric method for space-time disaggregation of streamflow is presented in this paper. The disaggregation is a two-step process where temporal disaggregation (e.g., annual to monthly) is followed by spatial disaggregation (e.g., from an index gage to subbasin gages). Streamflow ensembles for each gage are developed using the k-nearest neighbor bootstrap method. This method preserves all space-time co-variability statistics of streamflow, and was demonstrated with an application to the Upper Colorado River Basin. In addition, this method was particularly successful in preserving the multi-modal probability distribution of flow which has been observed in historical streamflow time series.

Prairie, J., K. Nowak, B. Rajagopalan, U. Lall, and T. Fulp. "A stochastic nonparametric approach for streamflow generation combining observational and paleoreconstructed data." Water Resources Research 2008 Volume 44, W06423, doi: 10.1029/2007WR006684.

CRWAS Relevance: *This document describes the methodology that was adopted for CRWAS to generate the extended historical hydrology.*

This work presents a method for generating streamflow scenarios by combining paleohydrologic reconstructions and historical streamflow. A nonhomogeneous Markov chain model developed with the paleo data is used to generate the system state (wet or dry) and a nonparametric k-nearest neighbor time series bootstrap of the historical stream flow data, conditioned on the system state, is used to generate stream flow scenarios.

Woodhouse, C. A., S. Gray, and D. Meko. "Updated streamflow reconstructions for the upper Colorado River Basin." Water Resources Research 2006 42(5), W05415, doi: 10.1029/2005WR004455.

CRWAS Relevance: *This document describes several reconstructions of streamflows of the Colorado River at Lees Ferry, Arizona, and describes one part of one methodology that was considered for adoption for generating the extended historical hydrology for CRWAS*

Paleohydrologic reconstructions of streamflow data for four gauges in the Upper Colorado River Basin based on expanded tree-ring data were developed. Reconstructions were done using multiple linear regressions and the results account for 72-81% of the variance in the gauge records. Findings confirm that Colorado River Compact allocations are based on one of the wettest periods in the past 500 years.

Climate Change

Bureau of Reclamation. "Appendix U: Climate Technical Work Group Report. Final Environmental Impact Statement: Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead". October 2007.

CRWAS Relevance: *This document is a compilation of previous work regarding climate science in the Colorado River basin, along with a review of climate and hydrological science relevant to water resources management in the basin.*

The Climate Technical Work Group is part of a program by the Bureau of Reclamation's Lower Colorado Region to investigate climate change in the region and design a more responsive decision support framework. The Climate Technical Work Group investigated potential climate change impacts in the Colorado River Basin and how these changes can be related to reservoir

operation. They determined what should be involved in shorter term and longer term studies and the directions that future research and development should go in.

Christensen, N. S., A. W. Wood, N. Voisin, D. Lettenmaier. The Effects of Climate Change on the Hydrology and Water Resources of the Colorado River basin. Climate Change 62: 337-363. 2004.

CRWAS Relevance: *This document describes hydrology modeling of projected climate conditions in the Colorado River basin using methods that are relevant to the CRWAS.*

This work used simulated hydrologic and water resources scenarios driven by downscaled climate simulations compared to scenarios driven by observed historical climate to determine the potential effects of climate change on the hydrology and water resources of the Colorado River Basin. Three 105 year Parallel Climate Model scenarios were run based on business-as-usual greenhouse gas emissions and static 1995 greenhouse gas emissions. Data from these runs were used in the Variable Infiltration Capacity (VIC) model to simulate streamflow sequences. Results showed on average an increase in temperature of 3.1 ºF, a decrease in precipitation of 6% and a decrease in runoff of 18% by 2040-2069.

Christensen, N. and D.P. Lettenmaier. "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 Discussion. 9 July 2007: 1417-1434.

CRWAS Relevance: *This document describes hydrology modeling of projected climate conditions in the Colorado River basin using methods that are relevant to the CRWAS, some of which were adapted for use in the Study.*

Downscaled and bias corrected output from 11 General Circulation Models (GCMs) was used to drive macroscale hydrology and water resources planning models. Downscaled climate scenarios were used as forcings to the Variable Infiltration Capacity (VIC) macroscale hydrology model, which in turn forced the Colorado River Reservoir Model (CRMM). Ensembles of downscaled precipitation and temperature, and derived streamflows and reservoir system performance were assessed through comparison with current climate simulations for the 1950-1999 historical period. Results showed on average an increase in temperature of 4.5 ºF, a decrease in precipitation of 1% and a decrease in runoff of 6% by 2040-2069.

IPCC (2007), Summary for policy makers in: climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report for the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY USA.

CRWAS Relevance: *This document provides background on climate science and policy, including information on emission scenarios and climate modeling relevant to CRWAS.*

The Report describes the progress in the understanding of the human and natural drivers of climate change, observed climate change, climate processes and attribution, and estimates of projected future climate change. Scientific progress since the Third Assessment Report is based upon large amounts of new and more comprehensive data, more sophisticated analysis of data, improvements in understanding of processes and their simulation in models and more extensive exploration of uncertainty ranges.

Maurer, E.P., A.W. Wood, J.C. Adam, D.P. Lettenmaier, and B. Nijssen. "A long term Hydrologically-based Data Set of Land Surface Fluxes and States for the Conterminous United States." Journal of Climate. 15 Nov. 2002: 3237-3251.

CRWAS Relevance: *This document describes the development of the gridded weather data that was used in CRWAS in simulations of the study period, and as the basis for development of future climate conditions using the perturbation approach.*

This study provides a model-derived dataset of land surface states and fluxes for the conterminous United States and portions of Canada and Mexico spanning from 1950-2000 at a three hour time step with a spatial resolution of 1/8 degree. This dataset is distinct from reanalysis products because precipitation is a gridded product derived directly from observations, and both the land surface water and energy budgets balance at every time step. Simulated runoff is shown to match observations quite well over large river basins and it is argued that other terms in the surface water balance (e.g., soil moisture and evapotranspiration) are well represented at least for the purposes of diagnostic studies.

Ray, A. J., et al. "Climate change in Colorado; a synthesis to support water resources management and adaptation." A report by the Western Water Assessment for the Colorado Water Conservation Board. 2008.

CRWAS Relevance: *This document was developed by CWCB to provide reliable background information about climate science and climate projections relevant to Colorado and CRWAS.*

This report summarizes Colorado-specific findings from peer-reviewed regional studies focusing on observed trends, modeling, and projections of temperature, precipitation, snowmelt and runoff. All recent hydrologic projections show a decline in runoff for most of Colorado's River Basins by the mid-21st century as a result of decreased total water supply combined with temperature increases and related changes in evaporation and soil moisture.

Climate models project Colorado will warm by 2.5ºF by 2025 and 4ºF by 2050 with more warming expected in summers than winters. Winter projections show fewer extreme cold months, more extreme warm months and more strings of consecutive warm winters. Individual model projections do not agree whether annual mean precipitation will increase or decrease by 2050. However runoff is projected to shift earlier in the spring and to decline by 6-20% by the mid-to-late 21st century. The range of individual model projections within a single study can include both increasing and decreasing runoff due to the range of climate model output used to drive the hydrology models, reflecting both model-simulated climate variability and differences in model formulation.

Seager, R., M. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H. Huang, N. Harnik, A. Leetmaa, N. Lau, C. Li, J. Velez, and N. Naik. "Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America." Science. 25 May 2007: 1181-1184.

CRWAS Relevance: *This article describes projected climate conditions relevant to the Colorado River basin.*

This study examined future subtropical drying by analyzing the time history of precipitation in 19 climate models participating in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Emissions scenario A1B was used in which carbon dioxide emissions

increase until about 2050 and decrease modestly thereafter. Results showed a decrease in runoff of 8-25% by 2050.

Forest Change

Bethlahmy, N. 1974. More Streamflow after Bark Beetle Epidemic. Journal of Hydrology 23:185-189.

CRWAS Relevance: *The study described in this article provides empirical data regarding forest change from a large scale disturbance in Colorado, providing context in CRWAS for understanding potential relationship between Colorado beetle epidemic and watershed run-off.*

A beetle epidemic near the Continental Divide in Colorado destroyed the timber in two large drainages but bypassed a third drainage. Long-term streamflow records were available for the three drainages for the periods before and after the onset of the epidemic. Analysis of these records reveals that a major increase in streamflow occurred after the epidemic.

The study provides a description of the correlative method used to determine significance of change in run-off. Bethlahmy reports that the smallest increases in run-off occurred in the first 5-years (as the epidemic got started) and were the most pronounced 15 years later (approximately 7 years after the beetles had run their course). Increase in run-off were tabulated for 5-year periods from 1945 – 1965. The study estimated an increase in Yampa run-off of 23.6 mm for the 25 year period, 1941–1965. An increase of 31.8 mm was estimated in run-off for the White River.

Graham, Russell T., Technical Editor. 2003. "Hayman Fire Case Study." Gen. Tech. Rep. MRS-GTR-114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 396 p. Accessed March 3, 2009.

CRWAS Relevance: *This article provides research findings of an actual Colorado case study (Hayman fire), providing context in CRWAS for understanding potential relationship between drought periods and fire severity. In this particular case, local water quality impacts were the primary issues with respect to water resources in the burned areas.*

The Hayman Fire burned 138,000 acres near Cheesman Reservoir in the South Platte Basin of Colorado in 2002. The report details almost every aspect of the fire and the fight to contain the blaze. The section "Ecological Effects of the Hayman fire" describes the historical and current fire regime, the historical and current forest landscape, succession, aquatic systems and changes in aquatic systems, and soil properties erosion and rehabilitation. The Ecological Effects are explained in a general context, so that the nature of the Hayman fire is placed in context with respect to other forest types, the conditions leading up to the fire, the role of human fire suppression, and other factors.

The Case Study summarizes previous research on fires in the area from Southern Wyoming to Southern Colorado. The analysis concluded that on a regional scale, synchrony of fire years suggests extreme weather increases fire hazard over the area. Tree-ring sampling indicated that major fires correspond with significant drought during the year and/or during the preceding year. There were several large fires in 2002, the tree-ring record of drought and fire occurrence indicates that over the past several hundred years, fire years of similar extent to the year 2002 have occurred numerous times.

MacDonald, Lee H. and Stednick, John D. "Forests and Water: A State of the Art Review for Colorado." CWRRI Completion Report No. 196. Colorado Water Resources Research Institute. 2003.

CRWAS Relevance: *This review is a compilation and description of forest change focused on Colorado's forests and hydrology, providing context in CRWAS for broadly understanding potential relationship between forest management and water quantity and quality.*

The report provides a comprehensive review regarding forest management and how it affects water quantity and quality and identifies key gaps in knowledge. MacDonald takes a "process based" approach stating that understanding the effects of forest change requires a systematic analysis of the underlying processes. He cautions regarding extrapolations of forest change data: "Generalizations and extrapolations can be misleading unless there is a clear linkage to, and understanding of, the underlying processes."

The authors point out the importance of forest change in relation to Colorado's water supply, "most of the runoff in Colorado comes from forest and alpine areas above approximately 9000 ft (2730 m) in elevation. The dominant role of high-elevation areas is due to the increase in precipitation with increasing elevation, the decrease in potential evapotranspiration with increasing elevation, and the concentration of snowmelt in a relatively short period of time. In lower elevation forests the amount of runoff per unit area is greatly reduced because the rainfall and snowmelt inputs are much smaller relative to potential evapotranspiration".

Romme, W.H. et al. "Recent Forest Insect Outbreaks and Fire Risk in Colorado Forests: A Brief Synthesis of Relevant Research," Colorado State University. Accessed February 27, 2009.

CRWAS Relevance: *This reference helps describe, in "layman's" terms, the bark beetle life cycle in Colorado, providing context in CRWAS for understanding how beetle epidemic outbreaks take hold and progress in Colorado.*

The Synthesis presents a question and answer "primer" regarding insect outbreaks in Colorado. Recent bark beetle outbreaks in Colorado are a result of four interacting factors:

- long-term drought, which stresses trees and makes them more vulnerable to insects,
- warm summers, which further stress the trees and may accelerate growth of the insects,
- warm winters, which enhance survival of insect larvae, and
- abundant food (trees) for the insects in Colorado's extensive and often dense forests.

Bark beetles (including mountain pine beetles, spruce beetles, and pinon ips beetles) and defoliators are killing trees in Colorado. The mountain pine beetle feeds on ponderosa, lodgepole, and limber pine. Adult bark beetles bore through a tree trunk and lay eggs within the inner bark. The eggs hatch and the beetle larvae eat the inner bark, killing the tree. After the larvae mature, the new adults fly to new trees, bore through the bark, and continue the cycle. Defoliators are a group of insects having a life cycle very different from the bark beetles. The adult defoliators are tiny moths that lay their eggs in the buds of trees. The eggs hatch into caterpillars that feed on the emerging new leaves in spring and early summer.

The report discusses the severity of the current insect outbreak in Colorado. "The outbreaks now taking place in Colorado are similar in intensity and ecological effects to previously documented outbreaks in the Rocky Mountains. For example, mountain pine beetle outbreaks

killed millions of lodgepole pine trees over thousands of square miles in the Cascade and Rocky Mountains during the 1960s, 1970s, and early 1980s (Lynch 2006; chapter 4); and a spruce beetle outbreak in the 1940s killed spruce trees over much of the White River Plateau in western Colorado. Historic photos and tree-ring evidence also document extensive insect outbreaks prior to the 20th century (Baker and Veblen 1990, Veblen et al. 1991, Veblen et al. 1994, Swetnam and Lynch 1998, Eisenhart and Veblen 2000, Veblen and Donnegan 2006). Thus, insect outbreaks are a natural occurrence in almost all of the different kinds of forests in Colorado."

"Given the naturally long intervals between recurrent bark beetle outbreaks in Rocky Mountain forests, there is nothing unusual about a hundred-year period of low activity followed by an extensive outbreak."

The report also discusses the potential relationship of insect outbreaks to the risk of severe wildfires: "Although it is widely believed that insect outbreaks set the stage for severe forest fires, the few scientific studies that support this idea report a very small effect, and other studies have found no relationship between insect outbreaks and subsequent fire activity. Theoretical considerations suggest that bark beetle outbreaks actually may reduce fire risk in some lodgepole pine forests once the dead needles fall from the trees...Based on current knowledge, the assumed link between insect outbreaks and subsequent forest fire is not well supported, and may in fact be incorrect or so small an effect as to be inconsequential for many or most of the forests in Colorado."

Whitaker, Younes, and Decker. "Evaluating Peak Flow Sensitivity to Clear-cutting in Different Elevation Bands of a Snowmelt-dominated Mountainous Catchment." Water Resources Research, Vol. 38, No.9, 1172, doi: 10.1029/2001WR000514, 2002.

CRWAS Relevance: *This article describes the relationship between run-off and various assumptions regarding the nature and extent of forest disturbance, providing context in CRWAS for understanding potential relationship between streamflow impacts at different elevations.*

This study evaluated peak flow sensitivity to clear-cutting utilizing a hydrologic model of a mountainous snow-melt dominated catchment in British Columbia. The modeling focused on peak flow and effects of logging at different elevation bands on run-off. Generally, the simulations showed that clear-cutting in the lower elevation bands had less effect on peak flows than clear cutting at the higher elevation bands.

Simulations suggest that peak flow increases may be caused by greater snow accumulation and snow melt in clear-cut areas. Clear-cutting at 'lower" elevations appeared not to influence peak flows because of timing of snowmelt (early and not coincident with peak).

Colorado River Compact

Bureau of Reclamation. Law of the River (focus on *1922 Colorado River Compact, 1944 Treaty between the United States of America and Mexico, 1948 Upper Colorado River Compact*)

CRWAS Relevance: *The 'Law of the River' is the basis for determining the Colorado River Compact Allocations to the State of Colorado, providing basis for assumptions used for CRWAS Compact analysis.*

1922 Colorado River Compact

Relevant provisions of the Compact include:

- Article II (a): *The term "Colorado River System" means that portion of the Colorado River and its tributaries within the United States of America*.

- Article III (a): *There is hereby apportioned from the Colorado River System in perpetuity to the Upper Basin and to the Lower Basin respectively the exclusive beneficial consumptive use of 7,500,000 acre-feet of water per annum, which shall include all water necessary for the supply of any rights which may now exist*.

- Article III (b): *In addition to the apportionment in paragraph [III] (a), the Lower Basin is hereby given the right to increase its beneficial consumptive use of such waters by one million acre-feet per annum*.

- Article III (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 [III](a) and [III](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 of the deficiency so recognized in addition to that provided in paragraph [III](d)*.

- Article III (d): *The States of the Upper Division will not cause the flow of the river at Lee Ferry to be depleted below an aggregate of 75,000,000 acre-feet for any period of ten consecutive years reckoned in continuing progressive series beginning with the first day of October next succeeding the ratification of this compact*.

1944 Treaty between the United States of America and Mexico

Relevant provisions of the Treaty include:

- Article 10: *Of the waters of the Colorado River, from any and all sources, there are allotted to Mexico:*

  Article 10(a): *A guaranteed annual quantity of 1,500,000 acre-feet (1,850,234,000 cubic meters) to be delivered in accordance with provisions of Article 15 of this treaty*.

  Article 10(b): *Any other quantities arriving at the Mexican points of diversion, with the understanding that in any year in which, as determined by the United States Section, there exists a surplus of waters of the Colorado River in excess of the amount necessary to supply uses in the United States and the guaranteed quantity of 1,500,000 [sic] acre-feet (1,850,234,000 cubic meters) annually to Mexico, the United States undertakes to deliver to Mexico, in the manner set out in Article 15 of this Treaty, additional waters of the Colorado River system to provide a total quantity not to exceed 1,700,000 acre-feet (2,096,931,000 cubic meters) a year. Mexico shall acquire no right beyond that provided by this subparagraph by the use of the waters of the Colorado River system, for any purpose whatsoever, in excess of 1,5000,000 [sic] acre-feet (1,850,234,000 cubic meters) annually.*

In the event of extraordinary drought or serious accident to the irrigation system in the United States, thereby making it difficult for the United States to deliver the guaranteed quantity of 1,5000,000 [sic] acre-feet (1,850,235,000 cubic meters) a year, the water allotted to Mexico under subparagraph (a) of this Article will be reduced in the same proportion as consumptive uses in the United States are reduced.

- Article 15 (not reproduced here), defines the schedule of delivery of amounts of water quantified in Article 10.

1948 Upper Colorado River Compact

Relevant provisions of the Compact include:

- Article III (a): *Subject to the provisions and limitations contained in the Colorado River Compact and in this Compact, there is hereby apportioned from the Upper Colorado River System in perpetuity to the States of Arizona, Colorado, New Mexico, Utah and Wyoming, respectively, the consumptive use of water as follows:*

  (1) To the State of Arizona the consumptive use of 50,000 acre-feet of water per annum.

  (2) To the States of Colorado, New Mexico, Utah and Wyoming, respectively, the consumptive use per annum of the quantities resulting from the application of the following percentages to the total quantity of consumptive use per annum apportioned in perpetuity to and available for use each year by Upper Basin under the Colorado River Compact and remaining after the deduction of the use, not to exceed 50,000 acre-feet per annum, made in the State of Arizona.

  State of Colorado, 51.75 per cent; State of New Mexico, 11.25 per cent; State of Utah, 23.00 per cent; State of Wyoming, 14.00 per cent.

- Article III (b): *The apportionment made to the respective States by paragraph (a) of this Article is based upon, and shall be applied in conformity with, the following principles and each of them:*

  (1) The apportionment is of any and all man-made depletions;

  (2) Beneficial use is the basis, the measure and the limit of the right to use;

  (3) No State shall exceed its apportioned use in any water year when the effect of such excess use, as determined by the Commission, is to deprive another signatory State of its apportioned use during that water year; provided, that this subparagraph (b) (3) shall not be construed as:

    (i) Altering the apportionment of use, or obligations to make deliveries as provided in Articles XI, XII, XIII or XIV of this Compact:

    (ii) Purporting to apportion among the signatory States such uses of water as the Upper Basin may be entitled to under paragraphs (f) and (g) of Article III of the Colorado River Compact; or

(iii) Countenancing average uses by any signatory State in excess of its apportionment.

(4) The apportionment to each State includes all water necessary for the supply of any rights which now exist.

- Article IV: *In the event curtailment of use of water by the States of the Upper Division at any time shall become necessary in order that the flow at Lee Ferry shall not be depleted below that required by Article III of the Colorado River Compact, the extent of curtailment by each State of the consumptive use of water apportioned to it by Article III of this Compact shall be in such quantities and at such times as shall be determined by the Commission upon the application of the following principles:*

  (a) The extent and times of curtailment shall be such as to assure full compliance with Article III of the Colorado River Compact;

  (b) If any State or States of the Upper Division, in the ten years immediately preceding the water year in which curtailment is necessary, shall have consumptively used more water than it was or they were, as the case may be, entitled to use under the apportionment made by Article III of this Compact, such State or States shall be required to supply at Lee Ferry a quantity of water equal to its, or the aggregate of their, overdraft of the proportionate part of such overdraft, as may be necessary to assure compliance with Article III of the Colorado River Compact, before demand is made on any other State of the Upper Division;

  (c) Except as provided in subparagraph (b) of this Article, the extent of curtailment by each State of the Upper Division of the consumptive use of water apportioned to it by Article III of this Compact shall be such as to result in the delivery at Lee Ferry of a quantity of water which bears the same relation to the total required curtailment of use by the States of the Upper Division as the consumptive use of Upper Colorado River System water which was made by each such State during the water year immediately preceding the year in which the curtailment becomes necessary bears to the total consumptive use of such water in the States of the Upper Division during the same water year; provided, that in determining such relation the uses of water under rights perfected prior to November 24, 1922, shall be excluded.

- Article V (a): *All losses of water occurring from or as the result of the storage of water in reservoirs constructed prior to the signing of this Compact shall be charged to the State in which such reservoir or reservoirs are located. Water stored in reservoirs covered by this paragraph (a) shall be for the exclusive use of and shall be charged to the State in which the reservoir or reservoirs are located.*

  (b) All losses of water occurring from or as the result of the storage of water in reservoirs constructed after the signing of this Compact shall be charged as follows:

  (1) If the Commission finds that the reservoir is used, in whole or in part, to assist the States of the Upper Division in meeting their obligations to deliver water at Lee Ferry imposed by Article III of the Colorado River Compact, the Commission shall make findings, which in no event shall be contrary to the laws of the United States of America under which any reservoir is constructed, as to the reservoir capacity allocated for that purpose. The whole or that portion, as the case may be, of

reservoir losses as found by the Commission to be reasonably and properly chargeable to the reservoir or reservoir capacity utilized to assure deliveries at Lee Ferry shall be charged to the States of the Upper Division in the proportion which the consumptive use of water in each State of the Upper Division during the water year in which the charge is made bears to the total consumptive use of water in all States of the Upper Division during the same water year. Water stored in reservoirs or in reservoir capacity covered by this subparagraph (b) (1) shall be for the common benefit of all of the States of the Upper Division.

(2) If the Commission finds that the reservoir is used, in whole or in part, to supply water for use in a State of the Upper Division, the Commission shall make findings, which in no event shall be contrary to the laws of the United States of America under which any reservoir is constructed, as to the reservoir or reservoir capacity utilized to supply water for use and the State in which such water will be used. The whole or that proportion, as the case may be, of reservoir losses as found by the Commission to be reasonably and properly chargeable to the State in which such water will be used shall be borne by that State. As determined by the Commission, water stored in reservoirs covered by this subparagraph (b) (2) shall be earmarked for and charged to the State in which the water will be used.

- Article VI: *The Commission shall determine the quantity of the consumptive use of water, which use is apportioned by Article III hereof, for the Upper Basin and for each State of the Upper Basin by the inflow outflow method in terms of man-made depletions of the virgin flow at Lee Ferry, unless the Commission, by unanimous action, shall adopt a different method of determination.*

Bureau of Reclamation. Hydrologic Determination 2007, Water Availability from Navajo Reservoir and the Upper Colorado River Basin for Use in New Mexico. Washington D.C., April 2007.

CRWAS Relevance: *The Hydrologic Determination estimates reasonably available depletions by the Upper Basin given a proposed contract for the Navajo-Gallup Water Supply Project, providing basis for assumptions and approach used for CRWAS Compact analysis.*

This hydrologic investigation was performed to determine the availability of water from New Mexico's Upper Basin allocation and Navajo Reservoir to service a proposed contract for the Navajo-Gallup Water Supply Project and the Navajo Indian Irrigation Project through at least 2060. The determination found that Upper Basin states' depletions could reasonably be allowed to rise to an annual average of 5.76 million acre-feet per year. This depletion amount is exclusive of Colorado River Storage Project reservoir evaporation from Lake Powell, Flaming Gorge, and the Aspinall Unit.

The hydrologic determination assumed the use of "the CRSS natural flows at Lee Ferry, minimum releases from Lake Powell of between 7.48 MAF and 8.23 MAF annually, an allowable overall shortage of no more than 6 percent for a critical period, either maintenance or use of the minimum power pools at CRSP units, reduced storage capacity in Lake Powell due to sedimentation, and inclusion of bank storage."

Bureau of Reclamation. Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead: "Final Environmental Impact Statement", November 2007; "Record of Decision", December 2007.

CRWAS Relevance: *The Interim Guidelines are relevant to the CRWAS as they provide institutional basis that could impact the availability of water to the State of Colorado.*

This Record of Decision (ROD) of the Department of the Interior is related to the Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations of Lake Powell and Lake Mead (Guidelines). These guidelines were developed as the Preferred Alternative in the Final EIS. The Final EIS was prepared by Reclamation to evaluate the specific interim guidelines and to identify potential associated environmental effects. The ROD reiterates from the FEIS the definition of Normal, Surplus, and Shortage Conditions as to be determined by the Secretary of the Interior in relation to 7.5 MAF of consumptive use by the Lower Division states (Arizona, California, and Nevada).

The ROD recommends approval of the adoption of specific interim guidelines based on the Preferred Alternative, summarized as:

- Defining discrete shortage volumes based on corresponding elevations in Lake Mead.
- Coordinated operations of Lake Powell and Lake Mead as determined by specified reservoir conditions.
- Process to account for augmentation and conservation known as Intentionally Created Surplus (ICS).
- Modification and extension of the Interim Surplus Guidelines through 2026.

Specific guidelines are detailed in Section XI of the ROD.

Colorado Water Conservation Board, Colorado River Compact Water Development Projection. Endangered Fish Flow and Colorado River Compact Water Development Workgroup. CO, 1995.

CRWAS Relevance: *This evaluation establishes an estimate of remaining available Compact Allocation to the State of Colorado given instream flows for endangered fish species, providing basis for assumptions used for CRWAS Compact analysis.*

The Workgroup established and recommended a range of development allowance for each subbasin to determine how much water can be appropriated for endangered fish recovery instream flow purposes without impairing Colorado's ability to fully develop its compact apportioned waters. A review of the 1922 Colorado River Compact, the 1948 Upper Colorado River Compact, and other provisions of the "Law of the Colorado River" was used in the review. The workgroup reviewed the contribution to Colorado River flows generated within the state (10.8 MAF), Colorado's potential apportionment under various interpretations of the "Law of the River" and varying hydrologic conditions (between 3.079 and 3.855 MAF), and Colorado's current consumptive use (2.6 MAF). The workgroup determined the remaining apportionment to Colorado given the same uncertainties as between 0.45 and 1.2 MAF. The Workgroup assumes new or future water rights to be junior to the endangered species instream flow rights and the development of senior water rights should not be impaired by junior CWCB instream flow rights (conforming to the "no injury" standard). The hydrologic information only includes waters originating in Colorado and does not include tributary flows to the Little Snake and San Juan Rivers originating in Wyoming and New Mexico, respectively. The review recognizes an increased risk to "compact calls" if Colorado chooses to develop more than 3.079 MAF.