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Technical Memorandum | Final

To:	**Blaine Dwyer / Matt Brown (AECOM)**
Distribution:	**Distribution List**
From:	**Ben Harding / Kevin Wheeler (AMEC Earth & Environmental)**
Subject:	**CRWAS Phase I | Task 8.2 | Colorado River Compact Overview and Analyses | Approach**
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CRWAS Phase I included a public comment period on the draft CRWAS Phase I Report and public outreach workshops to solicit feedback from stakeholders on the Study. CWCB and the CRWAS technical team used these forms of feedback to refine Study deliverables, such as this technical memorandum, which may include content that has been updated. Please refer to the revised CRWAS Phase I Report (posted at http://cwcb.state.co.us) for updated information associated with this technical memorandum. Note that the assumptions in this memorandum cannot anticipate future changes in policy. Thus, they are meant to be illustrative and not definitive.

Introduction

This Technical Memorandum summarizes information developed as part of Task 8 of the Colorado River Water Availability Study (CRWAS or Study).

The objective of Task 8 is to analyze Colorado River Compact provisions based on previous investigations of the current Compact setting and in relation to implementation of recent guidelines.

The activities were initially scoped to include analysis of water available to Colorado but have since been re-scoped, at the direction of the CWCB, to limit the analysis to water availability in the Upper Basin.

This memo is associated with subtask 8.2 (Approach) and provides an assessment of the methods that that might be used to evaluate water availability in the Upper Basin under a range of operating scenarios and hydrologic conditions in which provisions in the Colorado River Compact might be implicated. Subsequent sections of this technical memorandum discuss: 1) the requirements of CRWAS, 2) an evaluation of alternative modeling methodologies, 3) a recommended modeling methodology, 4) a recommended analytical approach, 5) references, followed by an appendix of specific modeling assumptions.

Requirements of CRWAS

CRWAS Task 8 scope of work calls for a quantitative estimate of the amount and timing of any supplementation flows in the Upper Colorado River Basin that would be required under conditions in which provisions in the Colorado River Compact might be implicated. Supplementation flows refer to the additional flows that would potentially be required in the Upper Colorado River Basin to meet projected water demands in that Basin while simultaneously meeting the cumulative flow provisions in the Colorado River Compact. Estimating the amount and timing of supplemental flows will require a basin-wide analytical approach that estimates the quantity of water that would pass from the Upper Basin to the Lower Basin at Lee Ferry and determines the amount of additional water required to meet Compact requirements.

Evaluation of Alternative Modeling Methodologies

The derivation of the amount of water available to Colorado under the provisions in the Colorado River Compact requires a basin-wide analysis that simulates factors in the Colorado River Basin that affect the flows that pass through Lee Ferry. These factors include, but are not limited to, physical properties, such as system inflows, diversions and consumptive use, reservoir storage volumes, and resulting pool elevations. The analysis must also include simulation of the legal framework and operational procedures that govern the management of the reservoirs and the allocation of water among the stakeholders. Such an analysis requires the use of a simulation model.

Current models make assumptions about future hydrologic conditions and water demands, and use management logic that represents actual or assumed legal policies and operational guidelines. These tools have been developed and used by stakeholders to evaluate the impacts of alternative assumptions relative to a baseline condition.

The modeling methodologies available for an appropriate basin-wide analysis include modeling tools that simulate the hydrology and operation of the Colorado River Basin.

- The Colorado River Simulation System (CRSS) model was developed by and is maintained by the Bureau of Reclamation (Reclamation). The CRSS currently exists within the RiverWare modeling framework which was developed at the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) within the University of Colorado. Reclamation maintains the most current naturalized historical hydrologic inflows, future demand schedules, and Reclamation's interpretations of legal and operational policies within the model. The RiverWare framework allows for alternative policies to be incorporated with relative ease while maintaining all other assumptions constant.

- The Colorado River Model (CRM) was developed for the Severe Sustained Drought Project (SSDP) which was completed in 1994 (Sangoyomi and Harding, 1995). This model is based on a network flow archetype and was developed over a 12-year period to emulate Reclamation's Colorado River Simulation Model (CRSM). Similar to the CRSS model, historical hydrologic conditions, future demand schedules and interpretations of legal and operational policies governing the management of the reservoirs are incorporated in the model. This model has not been maintained with current operational policies since the SSDP study was completed.

- The Colorado River Reservoir Model (CRRM) implements a simplified version of the CRSS model logic. CRRM was developed at the University of Washington to assess climate change impacts on the Colorado River Basin (Christensen et al., 2004). Similar to the CRSS model, this monthly model represents the hydrologic system and operational policies of the reservoirs, but uses a reduced spatial resolution and a simplified representation of operating rules. It has a limited number of applications by stakeholders throughout the basin.

- Colorado River Open Source Simulator (CROSS) provides a simplified representation of the CRSS model. It runs on an annual time step. CROSS is distributed by On the Colorado (2009).

Recommended Modeling Methodology

We recommend application of the CRSS model for determining a quantitative estimate of the amount and timing of any flow supplementation in the Upper Colorado River Basin that would be required under conditions in which provisions in the Colorado River Compact might be implicated. Although certain assumptions incorporated in the CRSS model are disputed, the CRSS model is the most widely used and accepted modeling tool among the numerous Colorado River stakeholders. This model provides the most comprehensive and current collection of physical, legal, and operational aspects that affect the management of the River. CRSS also provides adequate flexibility for the purposes of CRWAS because of the relative ease with which changes can be made to assumptions about future hydrology, water use, and operating rules.

Recommended Analytical Approach

The recommended analytical approach for estimating the amount and timing of flow supplementation is to use the current CRSS model as maintained by the Bureau of Reclamation to simulate the operation and management of the primary reservoirs in the Colorado River Basin under projected hydrologic conditions and future demands. CRSS simulates the Basin through a network that includes 29 inflow locations, 12 reservoirs and 171 existing or potential demand locations. The operation of the reservoirs and water deliveries is simulated through a set of prioritized logical statements or “rules” that simulate the legal framework and operational policies.

Information about CRSS, the operating rules and system characteristics include:

- Model Access - The current CRSS Model is accessible via the Colorado River Stakeholder Modeling Work Group Website (2009; requires login account).

- Model Description - A general description of CRSS is in Appendix A of the Colorado River Guidelines EIS (Bureau of Reclamation, 2007a).

- Modeling Assumptions - Current Modeling Assumptions are summarized by Reclamation as a document. The version of that document that is current at the time of this writing is attached as Appendix A to this memo.

Assumptions included in the CRSS model regarding the operation of the reservoirs will be maintained as part of CRWAS. This includes, but is not limited to, reservoir characteristics, projected demands, operation assumptions under normal conditions, declared surplus conditions and declared shortage conditions.

The CRSS model does not currently contain functionality to supplement flows to the Lower Basin when the cumulative flow requirement of the Colorado River Compact is not satisfied. However the flexible modeling environment of RiverWare does allow policies to be modified or adapted to assure that these requirements are met.

The following procedure will be used to determine the amount of supplemental flows required.

- CRSS will be run for a set of assumptions representing hydrology and water use, which are described below.
- Outputs from the model include average monthly flow through Lee Ferry. This value will be converted to a volumetric quantity.
- A running 10-year volumetric accumulation of flows through Lee Ferry will be determined for each month by summing the previous 119 months of modeled flows at Lee Ferry with the proposed flow for the current month.
- The 10-year volumetric accumulation of flow through Lee Ferry will be compared to the cumulative flow requirement at Lee Ferry. The required supplemental flows will be determined as the amount of additional water required to assure that the 10-year volumetric accumulation of flows satisfies the cumulative flow requirement as computed on a monthly basis.
- A single value will be used to represent the 10-year cumulative flow requirement of the Colorado River Compact and the 10-year cumulative amount of the Upper Basin's share of the Mexico delivery obligation. This approach assures that deliveries to the Lower Basin under the Colorado River Compact are satisfied in addition to providing sufficient water to meet the Upper Basin's delivery obligation to Mexico under the assumption that any water passing Lee Ferry is first used to satisfy the Upper Basin's obligation to Mexico. This assumption would only be violated if the flow passing Lee Ferry in any year is less than the Upper Basin's obligation to Mexico, but this occurrence is exceedingly unlikely. The combined cumulative flow requirement will be represented by a variable so that the value of the requirement can be changed to evaluate different assumptions regarding the quantification of that requirement. For initial evaluations, the value of the variable will be set at 82.5 maf in order to represent the upper limit of the Upper Basin States obligation. This assumption is for modeling purposes only and does not represent a policy of the state of Colorado.
- The amount of water required to supplement flows at Lee Ferry will be introduced on a monthly basis as additional inflows to the model immediately above Lee Ferry. This will eliminate any effects on the Reservoir Levels of Lake Powell. Actual supplementation projects might introduce water at a location or locations within the Upper Basin, closer to points of use (or distributed throughout the basin as might be the case with weather modification). This analysis is not intended to evaluate specific supplementation proposals for supplementation and therefore assumes the introduction of water at Lee Ferry.
- For each model run, a time series of the annual volumes of required supplemental water will be compiled from model outputs. These results will be analyzed to determine an

empirical probability distribution of expected supplementation requirements for a given set of assumptions.

The supplementation flows will be quantified for eleven cases. Those cases consist of one baseline case (using extended historical hydrology), five cases using alternate hydrology for the 2040 time frame and five cases using alternate hydrology for the 2070 time frame. All eleven cases will use a representation of depletions at the current time frame, which will be those values in the CRSS depletion schedule for 2009.

References

Bureau of Reclamation. “Final Environmental Impact Statement: Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead”. Boulder City Nevada, November 2, 2007. (a)

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Colorado River Stakeholder Modeling Workgroup. 2009. United States Bureau of Reclamation. April 30, 2009. http://bcportals.com/usbr-crs/

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On the Colorado, 2009. CROSS model information. August 5, 2009. http://www.onthecolorado.com/cross.cfm

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Appendix A: CRSS Modeling Assumptions

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All modeling assumptions, except for those listed in this document are identical to the FEIS Basin States Alternative. Appendix A of the FEIS describes the detailed modeling assumptions. Upper and Lower Basin demand schedules are contained in Appendices C and D, respectively. Appendix M describes the modeling assumptions specific to the ICS mechanism. Appendix N describes techniques relating to the generation of hydrologic inflow scenarios.

- January 2009 initial conditions (historical) for all modeled reservoirs
  - Powell: 3617.89 ft
  - Mead: 1110.97 ft
- Run duration 2009 - 2026
- Future inflows are represented through 3 different hydrologic scenarios
  - Index Sequential Method (ISM) used on observed historic period of record (1906-2006) – Direct Natural Flow
  - ISM used on tree-ring reconstructed streamflow (762-2005) – Direct Paleo
  - Nonparametric conditioning re-sampling technique that blends observed historic and tree-ring reconstructed streamflows – Non-parameteric Paleo Conditioned
- Maximum total ICS of 2.1 maf

Lake Powell Coordinated Operation

The Lake Powell operation consists of 4 operational tiers:

- Equalization (above the Equalization Line)
- Upper Elevation Balancing (between 3,575 feet and the Equalization Line)
- Mid-Elevation Releases (between 3,525 feet and 3,575 feet)
- Lower Elevation Balancing (below 3,525 feet)

The operational tier is determined annually based on the Lake Powell January 1 elevation. Because the determination is based on the January 1 elevations, the Lake Powell operational tier may not shift within the water year (two exceptions – see Upper Elevation Balancing Tier below). However, during Equalization and balancing operations, the release amount for the water year is still adjusted monthly based on the end-of-water year (EOWY) forecast.

Equalization Tier

- If the forecasted Lake Mead EOWY storage drops below 1,105 feet, the release from Lake Powell is adjusted until the first of the following three conditions occur: 1) the forecasted Lake Mead EOWY storage comes above 1,105 feet, 2) the forecasted Lake Powell EOWY storage drops below 20 feet under the Equalization Line, or 3) Lake Powell and Lake Mead are equalized.

Upper Elevation Balancing Tier

- If the January 1 Lake Mead elevation is below 1,075 feet, balancing releases are made from Lake Powell with a minimum and maximum release of 7.0 maf and 9.0 maf.
- If the January 1 Lake Mead elevation is at or above 1,075 feet, the Lake Powell release is 8.23 maf. Two exceptions are listed below.
  - If, in April, the forecasted Lake Mead EOWY elevation is less than 1,075 feet and the forecasted Lake Powell EOWY elevation is at or above 3,575 feet, balancing releases are made from Lake Powell with a minimum and maximum release of 8.23 maf and 9.0 maf.
  - If, in April, the forecasted Lake Powell EOWY elevation is above the Equalization Line, releases from Lake Powell are made according to the Equalization Tier.

Mid-Elevation Release Tier

- If the January 1 Lake Mead elevation is at or above 1,025 feet, the release from Lake Powell is 7.48 maf.
- If the January 1 Lake Mead elevation is below 1,025 feet, the release from Lake Powell is 8.23 maf.

Lower Elevation Balancing Tier

- If the January 1 Lake Powell elevation is below 3,525 feet, balancing releases are made from Lake Powell with a minimum and maximum release of 7.0 maf and 9.5 maf.