



Colorado River Risk Study: Phase II Task 1 Report

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Submitted to the Colorado River District and Project Participants

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Disclaimer

The findings presented herein are for discussion purposes only, and do not represent the official position of any entity with respect to factual or legal matters concerning the Colorado River.

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I. Introduction

A. Background

The Colorado River Basin is in the midst of a drought that began in 2000 and continues today. Average naturalized flows at Lee Ferry during this period are approximately 12.6 maf (million acre-feet), or 4.0 maf annually less than would be needed to meet the full compact allotments of the seven basin states and to the Mexican Treaty obligation to Mexico. Recent droughts have significantly reduced storage levels in Lake Powell. If these droughts were to repeat themselves today, the ability of Lake Powell to satisfy its compact-obligation and power-generation purposes would be threatened (Figure 1). Drought Contingency Plans (DCP) are being developed for both the Upper and Lower Basins (See Hydros 2015 report “Summary Report on Contingency Planning in the Colorado River Basin”). While those plans, if implemented, would reduce the risk of a compact deficit or critically low storage levels at Lake Powell, they do not completely eliminate the risk for the Upper Basin States.

Concurrent with the DCP efforts, Colorado completed its Water Plan (<https://www.colorado.gov/pacific/cowaterplan/plan>), which lays the foundation for a secure water supply for the State. Point #4 of the Plan’s Seven Point Framework is to take actions that minimize the risk of a Colorado River Compact curtailment. That objective, plus concerns voiced by the West Slope Basin Round Tables (BRTs) in a joint meeting in December 2014, provided the catalyst for this work.

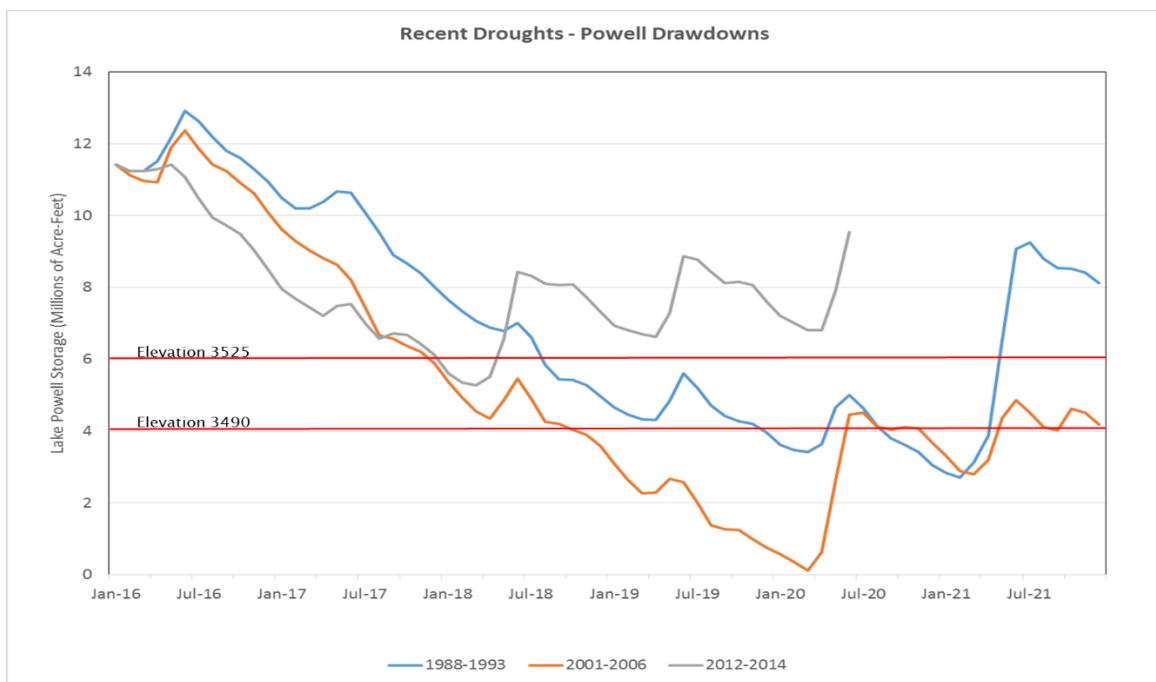


Figure 1. Past Lake Powell drawdowns superimposed on current conditions. A repeat of any of the last three drought events and subsequent drawdown of Powell would threaten the Upper Basin’s ability to meet its

obligations under the 2007 Interim Guidelines. The Upper Basin States and Reclamation have designed a Contingency Plan to keep Powell’s elevation above the 3525’ threshold.

B. Project Phasing

The project has been structured as a multi-phase process. Phase I work was completed in the fall of 2016, and is documented in the (draft) report “Colorado River Risk Study – Phase I Summary Report” dated October 18, 2016. Phase II was initiated in the spring of 2017, consists of two distinct tasks. Task 1 addresses questions that were raised during the Phase I process specific to the modeling performed using CRSS. This document summarizes this additional modeling and analyses, and is intended as a supplement to the original Phase I report.

A separate report has been developed for the Phase II Task 2 work, which focuses on the use of StateMod to address in-state questions related to demand management, resulting yields of conserved water, water banking, and the potential to couple StateMod with CRSS. That report also outlines recommendations for model enhancements and provides a template for simulation of demand management within Colorado coupled to “big river” operations as modeled in CRSS.

C. Basin Roundtable Participation and Communication

The CWCB (Through the four west slope BRTs), Colorado River District, and Southwestern District contributed funding to Phase II. Project guidance and communications were handled through two stakeholder committees. The Technical Advisory Committee (TAC) consisted of Hydros Consulting, representatives from sponsoring roundtables, funding sponsors, and CWCB staff. This committee worked closely with Hydros on refinement of model details, StateMod model investigations, coupling of CRSS and StateMod, and other technical issues.

The Outreach Committee acted as a conduit for dissemination of project status reports, results, and as a conduit for feedback from a broader set of stakeholders. The committee consisted of Hydros staff, representatives from each sponsoring roundtable, representatives of the funding sponsors, CWCB staff, and other interested parties. This committee met 4 times during Phase II, via webinar, and generally had between 30-50 participants.

Presentations of project results were also made to the sponsor agencies in-person, and the final meeting of Phase II was a joint west-slope basin round table meeting in Grand Junction on April 25, 2018.

D. Phase II Task 1 Objectives

Feedback from stakeholders during Phase I resulted in the identification of additional model scenarios for analysis. Budget and time constraints limited our ability to address all questions raised during the public engagement process. A refined list of scenarios from that process formed the basis for the Phase II Task 1 scenarios presented herein. The scenarios and questions to be addressed, as defined in the scope, included:

- a. Water Banking scenarios that include various levels of proactive demand management and storage in a hypothetical reservoir not subject to the 2007 Colorado River Interim Guidelines (which dictates Lake Powell releases based on Powell pool elevations), together with different assumptions about future demand growth.
- b. Additional model runs utilizing paleo-hydrology sequences to understand sensitivity to paleo-events and where those events fit within the spectrum of historical gaged data and climate change (predicted) hydrology.
- c. Evaluation of historic and possible future hydrologic variability and the impacts of that variability on critical reservoir elevations. Comparison of the magnitude of the hydrologic variability to other factors such as demands (as represented by both the Scenario A and 90% of Scenario D1 (“90%D1”) demand schedules, as defined in the 2012 Colorado River Basin Supply and Demand Study).

II. Colorado River Operations under the Interim Guidelines

The Record of Decision on the Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead (The “Interim Guidelines”; Secretary of the Interior, 2007) is the guiding document for “Big River” Colorado River operations through the end of 2026. It dictates under what conditions and in what quantity water stored in Lake Powell will be released to Lake Mead. It also includes criteria for the determination of shortages in the Lower Basin States, and the apportionments to those states in shortage years, as well as criteria for the establishment of Intentionally Created Surplus (ICS) accounts at Lake Mead to encourage water conservation as an additional hedge against prolonged drought.

The operation of Lakes Powell and Mead as described in the Interim Guidelines, as well as the shortage criteria and ICS rules, are implemented within the CRSS model using its embedded rule policy language. Unless otherwise noted, model simulations assume that the Interim Guidelines DO NOT expire in 2026. In CRSS, this is implemented through continuation of the operational policies as described in the Guidelines, including an extrapolation of the upper “equalization curve” to account for ongoing growth in the Upper Basin states. The extrapolation of these operational policies is identical to those used in extending the Interim Guidelines rules in the Basin Study.

Operation of all other reservoirs represented in CRSS are as provided by Reclamation, except in the implementation of Drought Operations rules for the Navajo, Aspinall, and Flaming Gorge Units as described below.

III. Modeling Assumptions

For brevity, only model assumptions that differ from those used in Phase I are discussed in detail here. The core model assumptions regarding river operations under the Interim Guidelines, the proposed Drought Contingency Plans, upper and lower basin demands, and hydrology are unchanged (one notable addition is the inclusion of a paleo-hydrology record, as described below).

A note regarding Lake Powell elevation 3525. Much of this work, and indeed much of the discussion around the Upper Basin DCP, has focused on maintaining Lake Powell's January 1 elevation at or above 3525 (feet elevation above mean sea level) beginning with the analysis of drought operations by the Upper Basin states and Reclamation in 2015 (See Hydros Summary Report on Drought Contingency Planning, Appendix G of Phase I Report, page 16) and as assessed by Reclamation in 2017 in response to Lower Basin inquiries. There are a number of reasons that 3525 is used as the “trigger” elevation for the proposed Drought Operations at the original CRSP reservoirs in the Upper Basin and as the target elevation in this analysis. First, 3525 is the threshold below which Lake Powell would drop into the Lower Elevation Balancing Tier (2007 Interim Guidelines). If Reclamation's August 24-Month Study were to forecast January 1 Lake Powell elevation below 3525, Lake Powell's releases could be increased relative to the middle elevation operating tier, and as much as 9.5 MAF of water could be released in the subsequent year. If that same year experienced below average Lake Powell inflows, the reservoir could very quickly approach elevations at which power production is no longer feasible. If Lake Powell were to lose power production, it would jeopardize funding for a host of necessary environmental programs, Reclamation's operating revenue for the Upper Colorado Region, would force WAPA to buy other power on the spot market to meet its contractual obligations for energy delivery. Beyond those impacts, continued drawdown of Powell could lead to the reservoir being unable to deliver water as dictated by the 2007 Interim Guidelines due to insufficient hydrologic head, which could lead to a “Compact Hole”, whereby releases of less than the compact obligations in one or more years would need to be offset in subsequent years with higher flows (if and when Lake Powell regains sufficient storage) in order to maintain compliance with the compact's 10-year running average obligation.

There has been discussion in several quarters about the use of 3525 as the trigger elevation for upper basin actions, particularly with respect to possible demand management activities that might be implemented to augment the drought operations aspect of the DCP.

A. Demand Management and Water Banking

Results from Phase I (Figure 2) indicated that under certain drought sequences, as seen in the early part of this century, significant volumes of water could be needed to maintain Lake Powell elevations at or above elevation 3525. These volumes would be required even AFTER taking in to account the release of stored water from other CRSP reservoirs as anticipated by the Upper Basin's DCP. In Phase I we treated this water as being created by voluntary and compensated conservation actions by upper basin states that would result in reduced consumptive uses and hence increased flows to

Lake Powell. These actions were modeled as single year reductions (with the possibility of consecutive years of conservation during extended drought), for purposes of identifying required volumes. There appears to be broad consensus, based on feedback from various groups including the Colorado River Water Bank Work Group, the System Conservation Pilot Project, and the UCRC, that single-year conservation volumes of the magnitudes shown in Figure 2 are probably not feasible under a voluntary program.

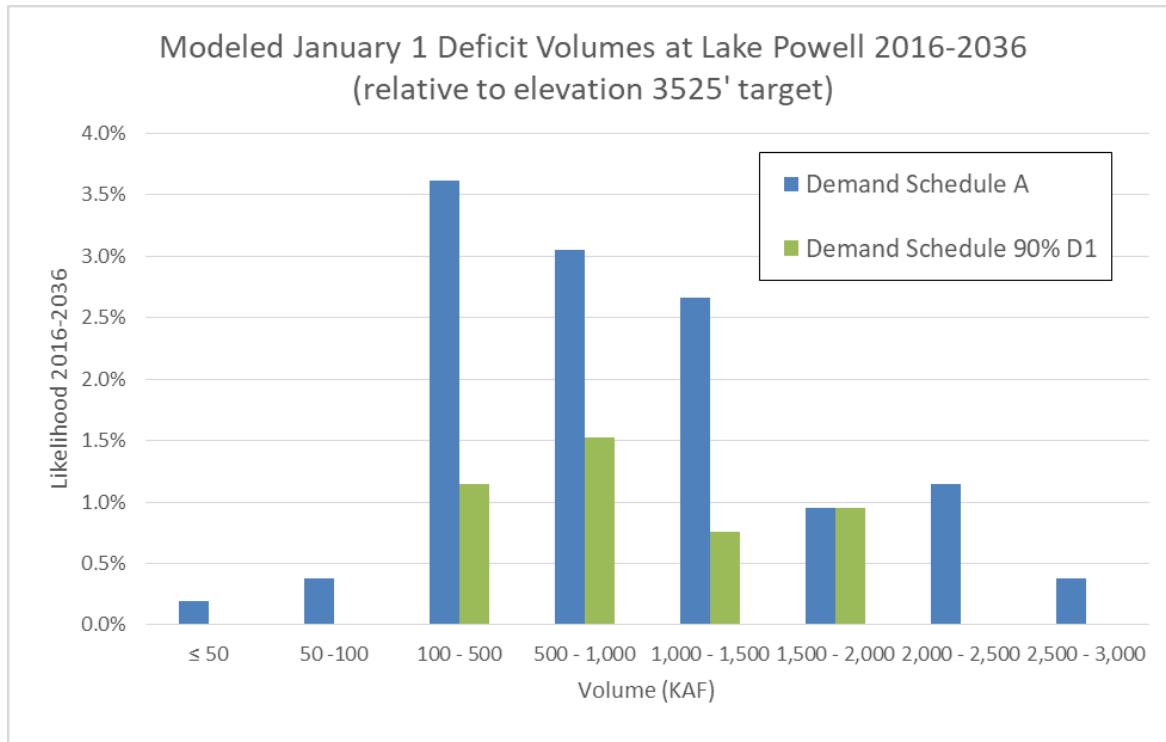


Figure 2. January 1 volumes required AFTER CRSP drought operations to maintain Powell at 3525'. Simulations using Stress Test (1988-2012) hydrology.

An alternate approach to conserving large volumes of water over a short period of time to mitigate the risk to Lake Powell is to create an upper basin water bank or other type of storage account, into which conserved consumptive use water could be deposited pro-actively over a span of many years. This water bank would then be available if and when needed, as additional water supply to preserve critical elevations at Lake Powell. This conceptual bank would be used only if the drought operation of CRSP reservoirs was insufficient to meet the target elevation at Lake Powell.

For modeling purposes, the water bank is simulated as a separate accounting pool of water at Lake Powell. It is important to reiterate that our modeling of the water bank is a *proof-of-concept model*, and that the actual implementation of a water bank could take on any number of different physical constructs, at Lake Powell or elsewhere. As part of the Colorado River Basin Study (Reclamation, 2012), CRSS was modified to allow simulation of a separate water bank pool at Lake Powell. We utilize that model construct in these simulations with the following constraints and assumptions:

1. A maximum storage volume of 1.0 maf. The simulations begin with bank storage = zero.
2. If Powell spills, the banked volume spills first.
3. The water bank volume is not subject to equalization, nor inclusion in storage accounting for purposes of determining Lake Powell operations under the Interim Guidelines.
4. If the January 1 Lake Powell elevation is below 3525, and after any drought operations have occurred at the other CRSP reservoirs and that water has been credited at Lake Powell, banked water would be released into the system water pool, up to the maximum of the amount required to bring Powell back above 3525, or the volume available in the bank.
5. The bank would be filled with an assumed 100 kaf of water each year until full. Because of complexities in modeling reduced consumptive use, and lacking any guidance as to which users might actually participate in such a program, the model does not simulate reduced consumptive use by upstream water users. Instead, 100 kaf of water is immediately credited to the water bank account.
6. In years when a release is made from the bank, the assumed consumptive use reduction is doubled to 200 kaf. This water is then available at the end of the year in which a release is made. The 200 kaf contributions continue until Lake Powell is above 3525 on January 1, at which time they revert to 100 kaf per year until the bank refills.

WATER BANK RESULTS

The hypothetical demand management and water banking scenario described above was simulated in CRSS, using the stress test hydrology (1988-2012) and the two previously-used demand scenarios (A and 90%D1). Results (Table 1) indicate that the hypothetical bank can reduce the likelihood of Powell dropping below 3525. As demands are reduced, and with the inclusion of the DCP components, the frequency of bank usage and the total deficit volume at Powell are both decreased. The remaining shortfall after the bank operation is also significantly reduced by lower demands and the DCP.

Scenario	% Years requiring bank release	Bank success rate (Powell > 3525 after bank release)	Average remaining shortfall after Bank release
Baseline + Water Bank (Sc. A demands)	24%	11%	2,035,526
Baseline + Water Bank (Sc. 90%D1 Demands)	12%	18%	1,570,560
DCP + Water Bank (Sc. A demands)	12%	26%	1,270,984
DCP + Water Bank (Sc. 90%D1 Demands)	5%	50%	607,293

Table 1. Modeled likelihood of water bank releases under two demand scenarios, with and without Drought Contingency actions, using the stress test hydrology (1988-2012).

Figure 3 shows the binned distribution of release volumes from the bank by scenario. Note the preponderance of bank releases in the 100-200 kaf range, particularly for the high demand scenario with no DCP actions. This is indicative of multi-year events where the first release from the bank would be insufficient to keep Powell above 3525, and additional releases are required in subsequent years. There are also relatively higher frequencies of releases between 100-400 kaf than in the 400 – 900 kaf range. This is due primarily to the initial conditions at Powell being relatively low, and the fact that it takes 10 years for the bank to fill based on our 100 kaf annual contribution. Many of the stress test hydrology sequences result in low storage conditions at Lake Powell within 3-4 years, so when the bank is needed, it has not yet filled. This results in higher frequency of releases in those lower-volume ranges. We would expect different distributions using different hydrology data, but would still expect to see the high frequency of 100-200 kaf releases with multi-year events.

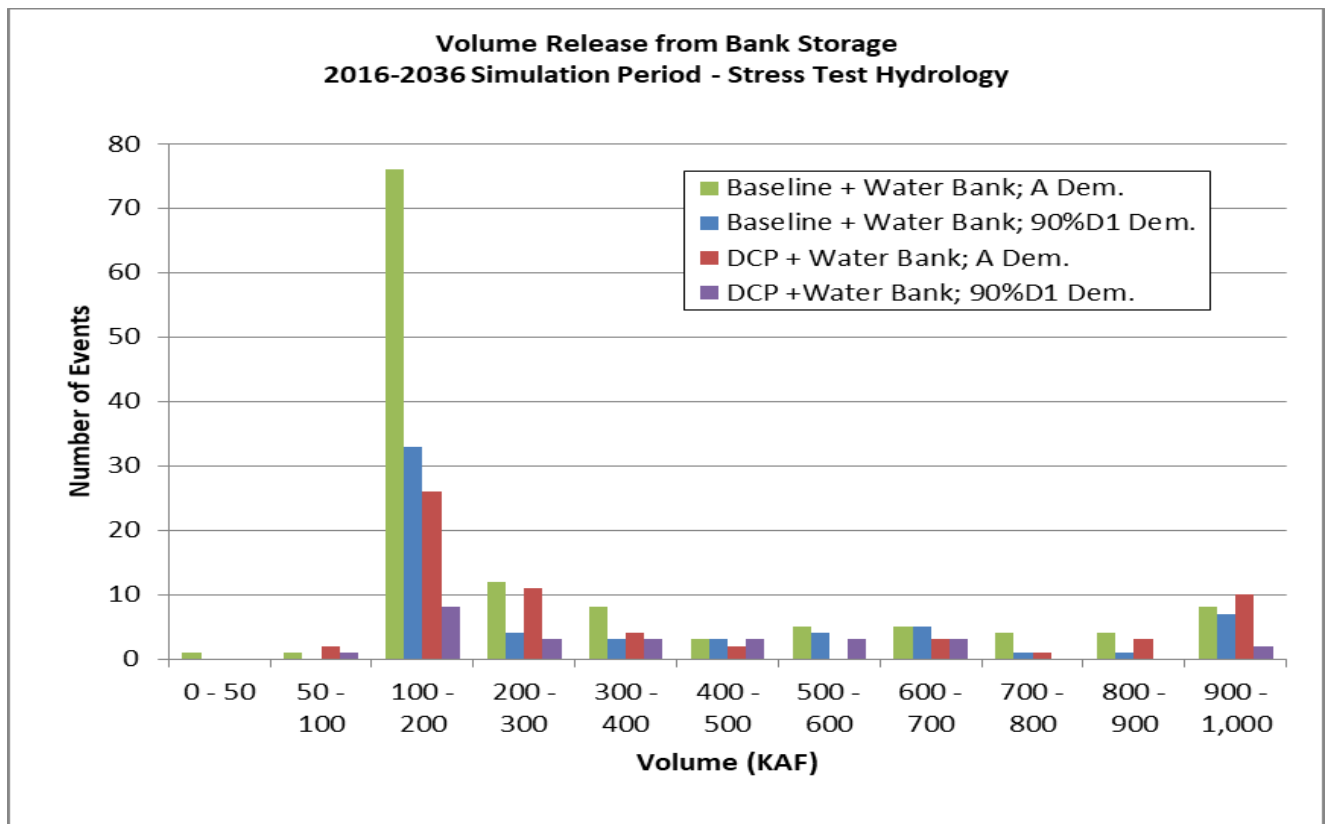


Figure 3. Distribution of water bank release volume by scenario.

It is clear from the modeling that a water bank can reduce the risk of Powell reaching critical elevations. Its effectiveness is limited over the near-term, because of the (assumed) length of time required to conserve and fill a large (1.0 maf) bank. Once filled, a bank could offset significant risk, especially when paired with the Lower Basin’s DCP and the proposed Drought Operations of Upper Basin CRSP facilities.

B. Paleo-Hydrology

Phase I model simulations utilized historical hydrology data developed for CRSS from the period 1950-2012, and climate change hydrology developed for the Colorado River Basin Study (Reclamation, 2012). The historical data set was used for both period-of-record simulations (1950-2012) as well as the stress test subset of that data (1988-2012 period; denoted as the “25-year ISM” below). An additional hydrologic data set using the Paleo-Resampled data from the CRBS was evaluated as part of Task 2. The purpose of this analysis was to understand how the drought events simulated using the paleo dataset compared to the other data sets used in Phase I. An additional baseline scenario run was performed using the paleo data set, and statistics for drought events compiled as shown below. At first glance the paleo- hydrology appears to result in fewer severe drought events than any of the other hydrology sets (Figure 4). However, the number of traces in the paleo hydrology (1,244) makes it difficult to discern the severe drought periods from that data set. A separate analysis showing the duration of the longest drought events for each hydrologic data set (as measured by persistence of critically low elevations at Lake Powell) is shown in Table 2.

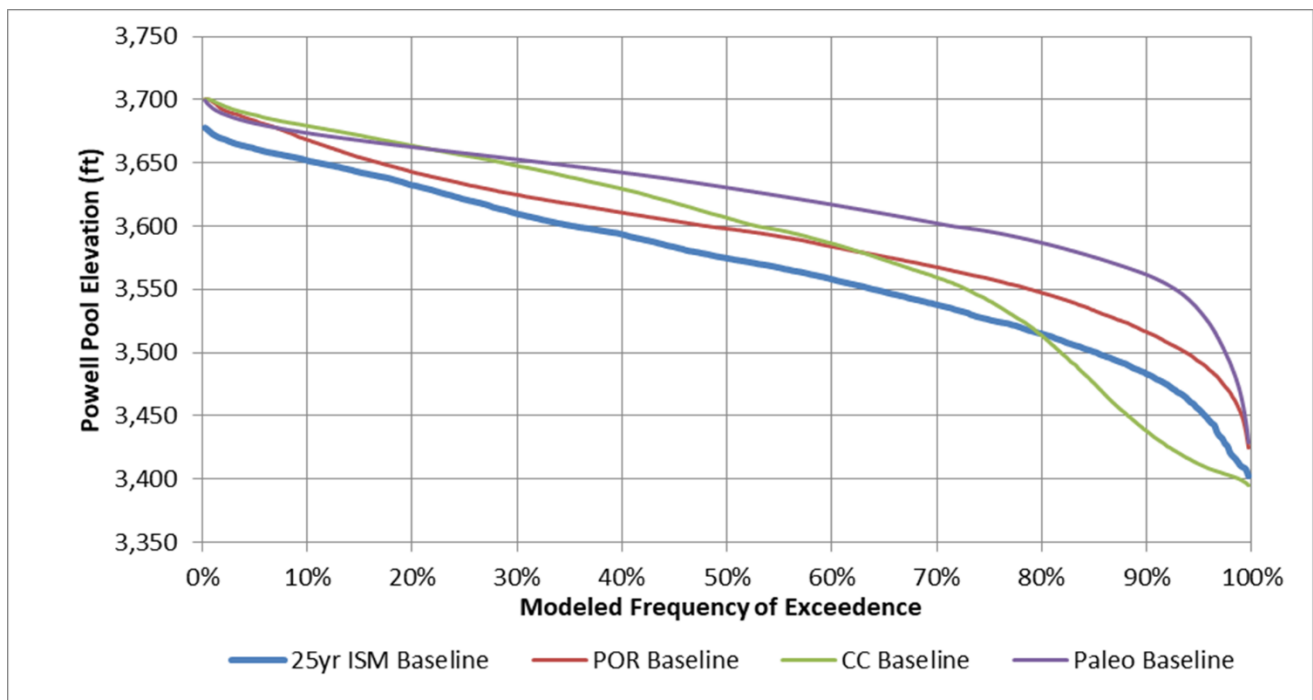


Figure 4. Exceedance curves for the simulation period 2016-2026 for four different hydrologic data sets. All scenarios shown are for the baseline model policy set (no Lower Basin DCP, no Upper Basin CRSP Drought Operations, no demand management, Scenario A demands)

Longest continuous period of months when Powell is below	3490'	3525
Stress Test (1988-2012)	55	78
Period of Record (1950-2012)	34	84
Paleo Record (764-2004)	81	155
Climate Change	222	228

Table 2. Maximum duration of critically low Lake Powell elevations for each hydrology set. Simulated in CRSS for the 2016-2026 period using the baseline model.

Results of this analysis indicate that the paleo-hydrology dataset results in generally wetter modeled conditions than those seen in the other hydrologic datasets. However, the paleo record does produce instances of severe drought that are worse than the stress test period (1988-2012) being used for development of the DCPs, but not as severe as the climate change dataset.

C. Sensitivity Analysis

Phase I of the Risk Study began in early 2016. At that time, Lake Powell held approximately 11.5 maf of water. By the time Phase II began, in mid-2017, Lake Powell had added approximately 2.5 maf. Several participants in both the Technical and Outreach Committees expressed an interest in better understanding how initial conditions in the system changed the risk profile for Lake Powell. In particular, there was concern about how initial conditions might change the long-term likelihood of deficits at Powell, and how short-term risks might change.

To investigate this question, we ran multiple simulations of CRSS using different combinations of starting elevations for Lakes Powell and Mead. The initial conditions used in the analysis were taken from the maximum and minimum end-of-year elevations observed during the period of the Interim Guidelines (2007 – 2016) for Powell and Mead. This resulted in four sets of initial conditions for the simulation (Powell low / Mead low; Powell high / Mead low; Powell low / Mead high; Powell high / Mead high). Figure 5 and Figure 6 show modeled mean values and 95% exceedance values for Lake Powell pool elevations using these initial condition combinations. These combinations would be considered outliers under normal operation (2007 Interim Guidelines) of the reservoirs, as one purpose of those guidelines was to minimize large differentials between the two (i.e., prevent “see-sawing”). The results indicate that even when starting the system in a state that is unlikely under the guidelines, the mean reservoir elevations do converge within the first 5 years. At that point, the elevations are all clustered within the same operating tier. For the 95% exceedance plot (Figure 6), convergence happens more slowly, but the various traces are all back within the same operating tier after 10 years of simulation. The longer time to re-convergence is due to low starting elevations combined with severe drought (the traces starting in 2000 and 2001). Even under these adverse initial conditions, the resiliency of the system is apparent *with both DCPs in place*.

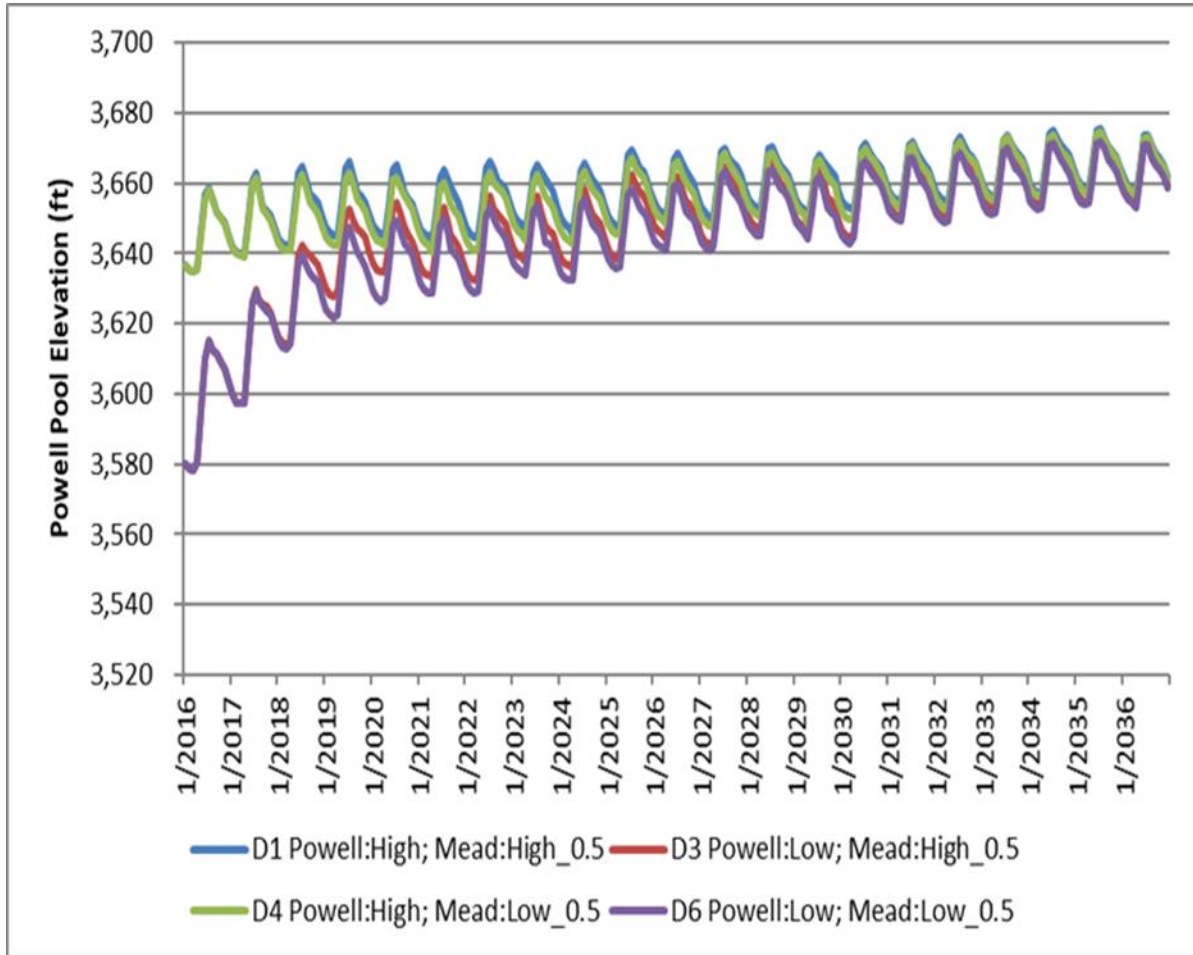


Figure 5. Mean pool elevations for Lake Powell using four different initial condition permutations (Powell and Mead).

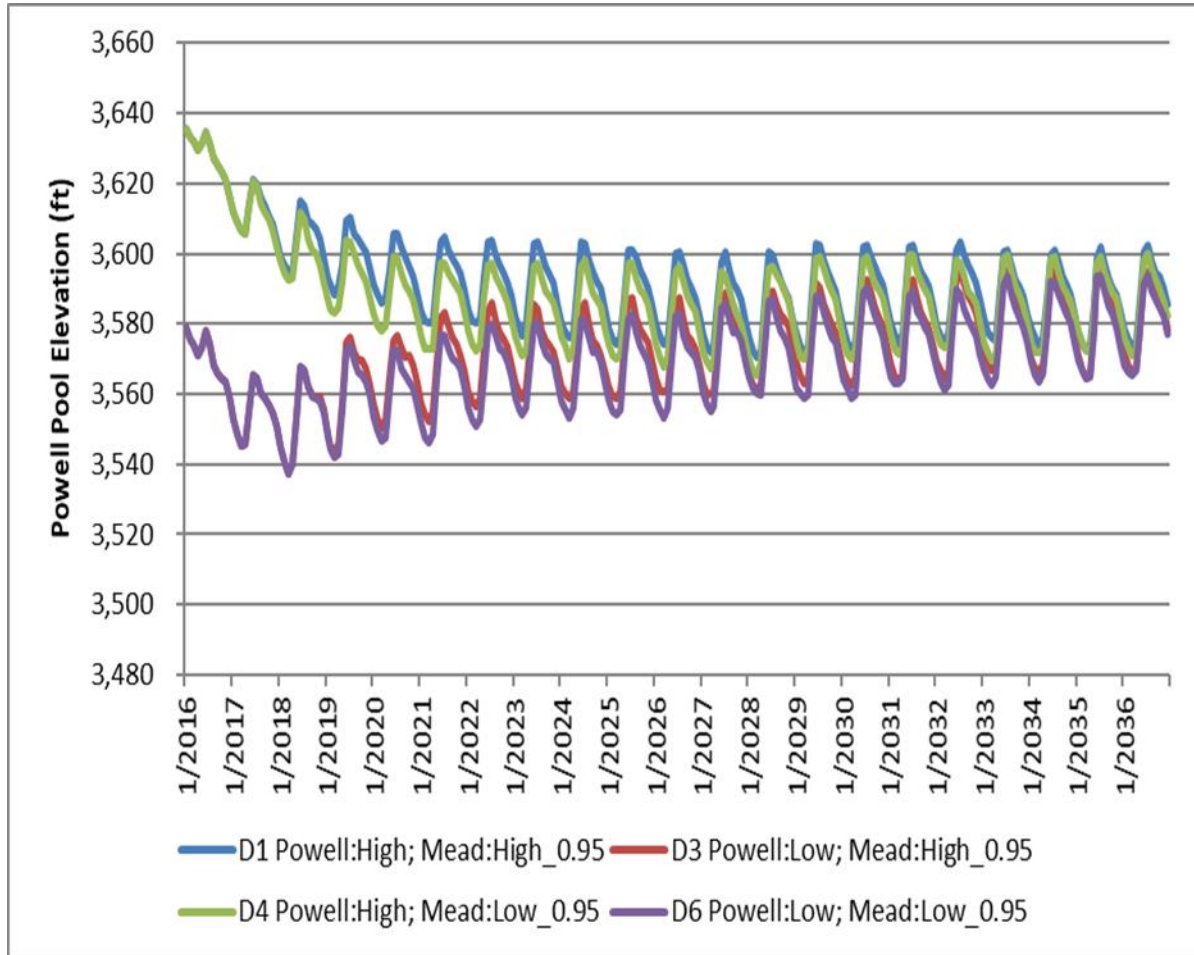


Figure 6. 95th Percentile exceedance elevations for Lake Powell using 4 different initial condition permutations (Powell and Mead).

IV. Summary Discussion

Phase II Task I revisited certain aspects of the Phase I CRSS modeling, based on suggestions and feedback gathered through public presentations and webinars. The additional analyses indicate that:

Water Banking:

- Can serve to reduce the risk of Powell dropping below critical elevations
- Is likely to require many years to fill (depending on size and annual contributions), and as a result may not be as effective in addressing near-term events (within the next 5-10 years)

Paleo Hydrology:

- Is generally wetter than the other hydrologic traces used in Phase I, but

- Has drought periods that are worse than the stress test period (when measured by length of time Powell is below critical elevations), and
- It could provide additional drought periods to further evaluate contingency plans, conservation activities, and other system behaviors under different patterns of stress.

Sensitivity Analysis:

- Initial conditions can alter the risk of Powell reaching critical elevations in the near-term. If Lakes Powell and Mead enter a severe drought at already low elevations, the likelihood of hitting 3525 is increased.
- Over time, and for purposes of longer-term planning exercises, the initial conditions of the reservoirs are less important, as effects of initial conditions largely disappear after the first 5 years of model simulation.
- Previous work from Phase I provides some insight as to the sensitivity of the system to different hydrology and demand assumptions. Variations in hydrology will tend to overwhelm demand and initial condition assumptions over time. However, demands (consumptive uses) are generally the only assumption that can actually be controlled, and as Figure 2 illustrates, under the stress test hydrology, a 10% increase in upper basin consumptive use roughly doubles the frequency and average magnitude of deficits at Lake Powell.

V. References

U.S Department of the Interior. **Record of Decision: Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead.** December 2007. Washington, D.C.

U.S Department of the Interior, Bureau of Reclamation. **Colorado River Basin Water Supply and Demand Study.** December 2012. Denver, CO.