Colorado River Risk Study
Phase III Final Report

November 20, 2019

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Prepared for the Colorado River District and the Southwestern Water Conservation District

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Disclaimer

Hydros Consulting Inc., the Colorado River District, and the Southwestern Water Conservation District acknowledge that the findings presented herein are based on specific modeling assumptions and are intended for discussion purposes only. Neither this Report, nor any of the findings contained herein, represent an official or final position of the Colorado River District, the Southwestern Water Conservation District or any other entity with respect to the law of the Colorado River or State of Colorado water use, law, administration or policy. This study is a work in progress, and the assumptions and conclusions are subject to future modification based on pertinent developments and/or the intent of the proponents to study risk under different scenarios.

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I. Introduction

A. Background

The Colorado River Basin has experienced significantly lower than average annual flows since 2000. Whether this is the result of a long-term drought or the new "normal" is subject to debate. Regardless, average naturalized flows at Lee Ferry during the period 2000-2017 were approximately 12.6 million acre-feet (Maf)[1]. Storage levels in Lake Powell have remained below 65% full since 2000 (except for 2011; **Error! Reference source not found.**). In spite of a good snowpack in 2019 resulting in an increase in storage from the previous year, Lake Powell remains just above half-full, and is forecast to end 2019 about 58% full[2]. A repeat of the 1988-1993 or 2001-2006 severe drought periods could threaten hydropower generation at Lake Powell and possibly the Upper Basin's ability to meet its obligations under the 2007 Interim Guidelines, the Colorado River Compact, or both. Note that during both of those historical drought events which occurred prior to the 2007 Interim Guidelines, Powell was releasing 8.23 Maf/yr. Under the 2007 Interim Guidelines, releases in non-equalization years have averaged 8.8 Maf/yr.

Drought Contingency Plans (DCP) have been developed and approved for both the Upper and Lower Basins. While those plans, if fully implemented, would reduce the risk of a Compact deficit or critically low storage levels at Lake Powell, they may not completely eliminate the risks 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 potential for an involuntary Colorado River Compact curtailment. That objective, plus concerns voiced by the Colorado River Basin Round Tables (BRTs) in a joint meeting in December 2014, provided the catalyst for the Colorado River Risk Study.

B. Phase III Purpose and Scope of Work

From the original scope: "*The purpose of Phase III of the Risk Study is to build on Phases I and II and continue to answer Colorado River system risk questions asked by the West Slope roundtables in the context of Colorado's Water Plan and the development of the IBCC Conceptual Framework. Most notably the Risk Study Phase III will continue to address the IBCC Conceptual Framework Summary Point No. 4 which states: An insurance policy that protects against involuntary curtailment is needed for existing uses and some reasonable increment of future development in the Colorado River system, but will not cover a new TMD.*"

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[1] http://www.usbr.gov/lc/region/g4000/NaturalFlow/index.html

[2] https://www.usbr.gov/lc/region/g4000/24mo/index.html

Phases I and II set the stage for Phase III by evaluating system-wide risks in the Colorado Basin, and also by developing a new approach to modeling both in-state (Colorado) impacts of potential involuntary curtailment, and/or the development of a demand management program. This modeling approach utilizes the State of Colorado's StateMod water rights simulation model and Reclamation's CRSS (Colorado River Simulation Model). The models share data generated by evaluation of different management, conservation, and administration scenarios, and can be used to better understand the feedback mechanisms and relationships between in-State actions and Basin-wide conditions (particularly at Lake Powell). In Phase III we utilize these tools to revisit current and future risks, and explore some potential approaches to involuntary curtailment.

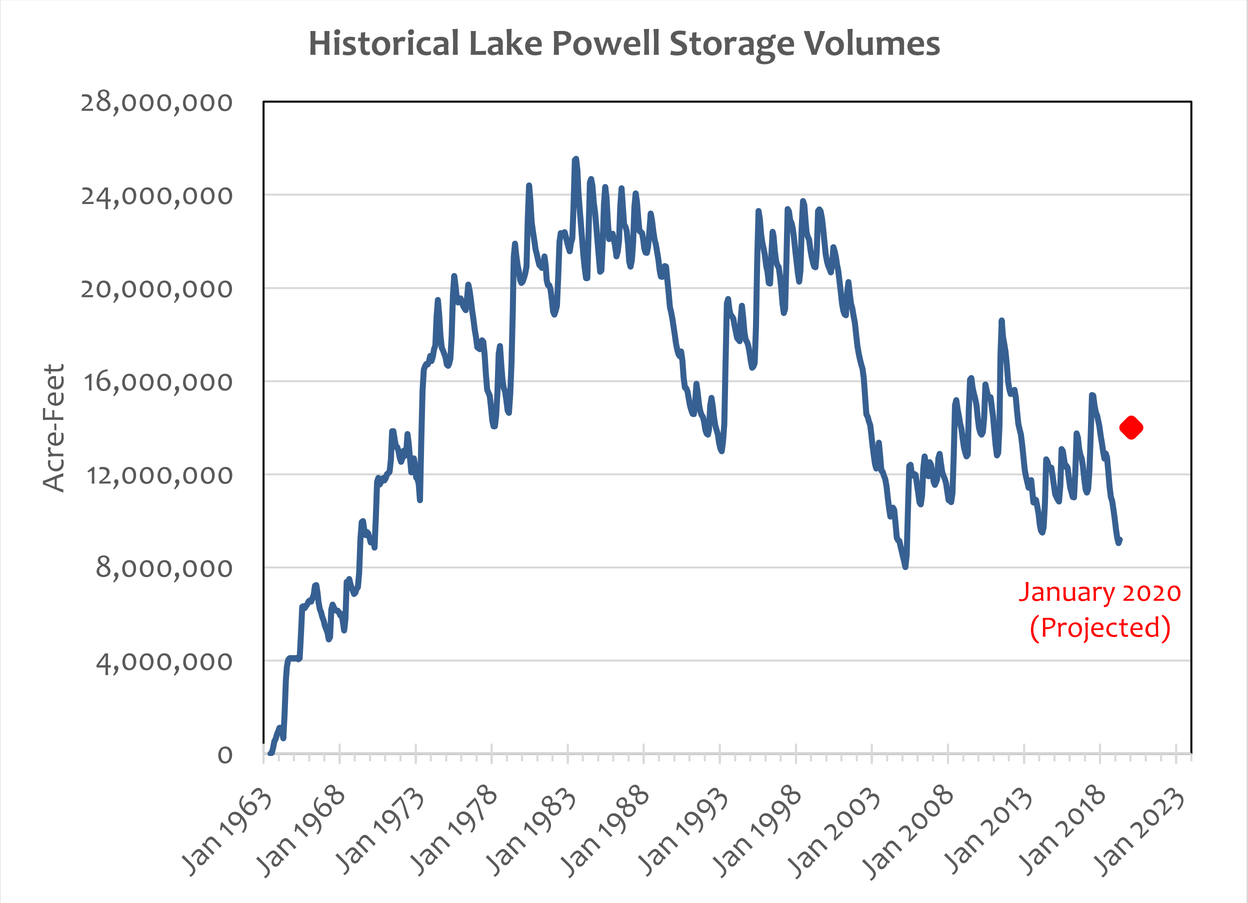

Figure 1. Historical Lake Powell storage with January 1, 2020 projection based on July 2019 24-month study.

The tasks identified for Phase III included:

a. Update the Lake Powell risk analysis (likelihood of dropping below elevation 3525' and likelihood of not meeting the 75 or 82.5 Maf over 10 year obligations) from previous phases to: 1) evaluate levels of risk using current demands as well as a reasonably probable increment of future growth, and 2) evaluate the efficacy of the Lower and Upper Basin Drought Contingency Plans (DCPs) in reducing or eliminating those risks.

b. Obtain, review, and modify as needed the State of Colorado's linked StateMod model. This model version was used for the State's Compact Compliance Study, which is being conducted under the purview of the Attorney General's office and remains confidential. The CWCB made the model publicly available in early 2018 (minus any model assumptions regarding future demands, hydrology, or analyzed approaches to administration of a Compact curtailment).
c. Evaluate a variety of scenarios in which an involuntary curtailment is applied to some or all post-Compact rights. These scenarios include conceptual "allocations" of a Compact shortage across basins and use-types, and include a variety of different deficit assumptions ranging from a full Compact call to different consumptive use reduction target volumes.
d. Evaluate the impacts to Lake Powell levels and risk with a hypothetical 1.0 Maf non-equalized demand management account. Volumes of 100 Kaf and 200 Kaf annually from the four Upper Basin states are assumed to come from voluntary, compensated, and temporary reductions in consumptive use. Colorado is assumed to contribute half of the total annual volume. Also evaluate the recovery time required when using part or all of the non-equalized pool, and the frequency and volumes of water supply deficit that the pool could not fully meet.

While Tasks A-C were completed as written with only minor modifications to scope, Task D will not be completed as part of Phase III and instead may be re-scoped for a future Phase IV. After the original scope and contract were approved, the 7 Basin States finalized, and Congress passed legislation approving the DCPs and their accompanying agreements. Significant to this study is the approval of a 500 Kaf storage account in one or more of the initial CRSP units that could be filled by a (yet-to-be fully defined) demand management program in the Upper Basin. Our initial approach to modifying the scope to align with the DCP was to reduce the volumes of both the demand management storage account and the annual contributions by half, to match the DCP. However, additional uncertainty exists over exactly when and under what circumstances water stored under an Upper Basin demand management program would be released – and hence no specific policy to follow when modeling these operations led us to postpone this task. In lieu of a full analysis of the potential benefits of a demand management account, we provide additional post-processing analysis of the one-time impacts such an account might have on Lake Powell elevations and Lee Ferry volumes (see Section III.c.)

II. Modeling Approach

Phase II of the Risk Study[3] described a new approach to modeling the complexities of both in-state water rights administration (using StateMod) and basin-wide "big river" operations (using CRSS). StateMod[4] is a highly detailed model capable of simulating water rights administration within the State of Colorado, and represents thousands of individual water rights, diversion structures and

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[3] Colorado River Risk Study, Phase II Task 2 Final Report, Hydros Consulting Inc., 2018
[4] https://www.colorado.gov/pacific/cdss/statemod

reservoirs, as well as operating policies that govern numerous exchanges, instream flow requirements, interstate compacts, and other water rights administration actions. StateMod also includes the necessary physical representations of return flow timing and spatial distribution, and naturalized inflows for historical hydrology to enable simulation of the results of the combination of historical hydrology with current or future levels of demand. Herein it is used primarily to examine how possible Compact administration protocols might be implemented, the impacts of those protocols to each basin within Colorado, and the potential amounts of pre-Compact and post-Compact depletions in each of Colorado's west-slope basins.

CRSS is a comprehensive model of the Colorado River system, which simulates the policy-based operations of the major Federal reservoirs as prescribed by the 2007 Interim Guidelines[5] and the modified operations and water deliveries anticipated by the recently signed Drought Contingency Plans[6]. The larger spatial scale of CRSS in comparison to StateMod necessitates a higher level of spatial aggregation in representations both of inflow sources and smaller-scale water users, both of which exist primarily in the Upper Basin. The large contract water users and sparse inflows in the Lower Basin, as well as deliveries to Mexico, are also represented. CRSS simulations illustrate how the operations of the large mainstem reservoirs are affected by basin-scale factors such as regional hydrology and increasing demands due to regional population growth. In this study, CRSS allows for the evaluation of systemic risks such as critically low Lake Powell elevations impacting power generation and possible Compact deficits (flows past Lee Ferry), and is used to quantify the impacts of in-state activities on these metrics.

All of the risk profile analyses for Lake Powell and Lee Ferry in this Phase of the Risk Study use the linked StateMod/CRSS modeling tools previous developed in Phase II. This approach allows us to maintain consistency when modeling Colorado's water uses across both models. Additional information on the synchronization of the two models is provided in Section D below, while details on the model run sequencing and hydrologic trace simulation protocols are in Section E.

Technical details relating to comparisons made between the models are summarized in Appendix A. The versions of each model are listed in Appendix B, along with details on the process for obtaining each model.

A. Common Assumptions

Previous modeling using CRSS utilized demand datasets from the Colorado River Basin Study[7], which all increase over time based on various growth rate assumptions. StateMod uses fixed demands which do not vary over time, except to represent changes in irrigation water requirements due to variations in temperature and precipitation. StateMod models of individual basins within Colorado have differing lengths of hydrology data, and the linked StateMod model has a different hydrologic

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[5] https://www.usbr.gov/lc/region/programs/strategies/RecordofDecision.pdf
[6] https://www.usbr.gov/dcp/
[7] https://www.usbr.gov/lc/region/programs/crbstudy/info.html

dataset than CRSS. Due to these differences, it was necessary to synchronize the demands and hydrology between the two models, so that the coupled simulations used the same data to the greatest extent possible.

All model runs for Phase III were carried out using fixed demand sets representing two different levels of use: "current demands" and "future demands" (described below). Hydrology data is from the years 1988-2015. This period is often called the "Stress Test", due to its lower-than-average flows (although it does include some periods of above average flows that are useful in simulating reservoir recovery), and was used extensively in Reclamation's modeling for the DCPs. Some hydrologic data filling was required in StateMod, because none of the basin models have hydrology extending through 2015.

B. StateMod Assumptions

StateMod simulations are carried out through a set of rules that execute in an order that follows the priority system used for water rights administration in Colorado. These rules include representations of direct diversions from streamflow, reservoir operations, exchanges, return flows, and many more water rights operations.

1. Hydrology

The physical processes simulated in StateMod are incorporated into algorithms that estimate timing and amount of flow, by accounting for the impacts of measured diversions and assumed return flows on observed stream gage flows from the historical record. The process of developing these input hydrologic datasets is described in detail in the modeling dataset documentation for each basin model, which is provided online, along with a detailed description of the assumptions applied for developing the demand dataset[8].

2. Current Demands

Current demands in StateMod are generally based upon historical acreage of irrigated lands, estimated crop water use requirements, and estimated system efficiencies. Historical and Baseline demand datasets exist for each basin model, with the Baseline dataset representing the best estimate of the demand for water by currently existing uses across the historical years of simulation. The Baseline demand dataset was used for this analysis, with adjustments as described below in Section **Error! Reference source not found.**. The total Baseline demand for depletions for the years 1988-2005 for the State of Colorado in StateMod is 2.803 Maf/yr. Annual supply shortages reduce the amount by 0.271 Maf/yr. resulting in an average simulated baseline annual depletion of 2.532 Maf/yr for the years 1988-2005.

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[8] https://www.colorado.gov/pacific/cdss/modeling-dataset-documentation

3. Future Demands

Demands for the "future conditions" scenarios were developed through cooperation with Basin Roundtable technical representatives and staff from the two Conservation Districts. The purpose of the future condition demands was solely to examine how an increment of additional depletions could impact the risk profiles at Lake Powell and Lee Ferry. The identified increases in consumptive use were a combination of additional use of existing rights/projects as well as new uses. When available, Programmatic Biological Opinion (PBO) depletion allowances formed the basis for "allowable" growth without any Federal re-consultation requirements. PBO depletion allowances were used to set the future demand data for the Yampa, Gunnison, and Colorado mainstem basins. The southwest basins (San Juan, Dolores, and various tributaries), and the White basin future demands were developed primarily by in-basin BRT representatives with input from River District and Southwestern District staff. A total of 26 new or enlarged water use demands were identified and added to the model, consisting of agricultural, municipal, and industrial uses. The total increase in demands across all Colorado basins under the future growth scenario total 384 Kaf, or an increase of 13.7% over current demand levels. Actual modeled depletions from these demands averaged 11.5%.

C. CRSS Assumptions

The reservoir operational policies that currently guide system operations most significantly are the 2007 Interim Guidelines for Coordinated Operations of Lakes Powell and Mead, and these Guidelines are used as the operational policy throughout the simulation period. We recognize that the guidelines will be replaced by a new agreement after 2026, and that operations from 2027 into the future will likely be somewhat different. Nevertheless, absent a "better" guess at those future operations, the 2007 Guidelines are used throughout.

1. Hydrology

Natural flow hydrology input data for CRSS is developed by the Bureau of Reclamation, based upon the gage records of 20 stream gages in the Upper Basin, and 9 stream gages in the Lower Basin[9]. The streamflow data from these gages are processed along with historical demand datasets to calculate natural inflows. The demand sets used in development of the natural inflow data come from the Consumptive Uses and Losses Reports prepared by Reclamation[10]. The differences between the consumptive use amounts in the demand sets used for flow naturalization, and the scheduled amounts of consumptive use anticipated in the various demand sets used in simulations, are important to note and are discussed in detail in Appendix A.

2. Demands

CRSS contains spatially-aggregated representations of demands for depletions, and these demands were compared to the corresponding demands in StateMod to provide context for differences in simulation results. The basin-specific depletions simulated in CRSS were calculated through addition

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[9] https://www.usbr.gov/lc/region/g4000/NaturalFlow/documentation.html

[10] https://www.usbr.gov/uc/envdocs/plans.html#CCULR

of computational sub-basins and a data object that summarizes depletions within each sub-basin. StateMod depletions were aggregated by basin and compared to the corresponding values in CRSS, and these comparisons are presented in Appendix A. The demands for all Upper Basin users outside of the State of Colorado were set based upon the 2007 UCRC demand schedule, which is the most recent UCRC demand schedule incorporated into CRSS. The demands for the Lower Basin were drawn from the demand schedule provided for the 2007 Interim Guidelines FEIS, with updated demands for Nevada from December 2016.

3. Drought Contingency Plans

The operations of the Upper Basin and Lower Basin DCPs are represented in CRSS as they were implemented for the round of modeling carried out by Reclamation in October of 2017 to support analysis of the impacts of the DCPs. These DCP implementations include re-operations of the Upper Basin CRSP reservoirs, and mandatory contributions in the Lower Basin with progressively greater reductions in use triggered as storage levels in Lake Mead decrease. The voluntary demand management program and corresponding non-equalized storage account that are discussed as potential options in the ratified version of the Upper Basin DCP are not explicitly included in CRSS, but the potential benefits from such programs are considered in the analysis of risk presented in Section III.

D. Model Synchronization

StateMod and CRSS are significantly different in terms of spatial and temporal resolution. The greater resolution of StateMod within the State of Colorado led to implementation of a model linkage where the portion of CRSS representing Colorado was replaced by StateMod.

1. Conceptual Linkage Implementation

The portions of CRSS that represent the State of Colorado were disconnected from the remainder of the model at points corresponding to the gage nearest the State line in each of the West Slope river basins. Table 1 lists these gages for each of the river basins on the West Slope of Colorado, along with the node in StateMod representing that gage, and the link in CRSS where the existing connection to the remainder of the Upper Colorado River Basin was replaced. The outflow simulated by StateMod at each of the nodes in Table 1 was input directly into CRSS as a reach inflow on a monthly timestep.

Table 1. Gages Linking StateMod and CRSS

River Basin	Linking Gage	USGS ID	CRSS Link
Yampa	Yampa River at Deerlodge Park, CO	09260050	YampaAtDeerlodge.GageInflow
White	White River near Watson, UT	09306500	WhiteNearWatson.GageInflow
Upper Colorado & Gunnison	Colorado River near CO-UT State Line	09163500	ColoradoNearCO_UTStateLine.GageInflow
Dolores	Dolores River near Cisco, UT	09180000	DoloresNearCisco.GageInflow
McElmo*	McElmo Creek near CO-UT State Line	09372000	LowerSanJuanRiver: BelowFourCorners.LocalInflow
Mancos*	Mancos River near Towaoc, CO	09371000	
La Plata**	La Plata River at CO-NM State line	09366500	SanJuanSJTribs.Inflow2
Animas**	Animas River near Cedar Hill, NM	09363500	
Los Pinos***	Los Pinos River at La Boca, CO	09354500	Navajo.Inflow
Piedra***	Piedra River near Arboles, CO	09349800	
San Juan***	San Juan River near Carracas, CO	09346400	

* ** *** These outflows were combined using confluence objects in CRSS to enter the system as aggregated flows at the specified links

Figure 2 displays the connections for the Yampa, White, Upper Colorado, Gunnison, and Dolores Rivers, and Figure 3 displays the connections for the San Juan River and its many tributaries. These monthly inflows are re-sequenced as part of the Index Sequential Method trace generation process, along with the rest of the natural inflows in CRSS.

In the White and Dolores basins, the gages used to link the models are downstream of water users in Utah that are not represented in StateMod, which ends at the State Line in each basin, above the River Gages used for linkage. To account for this, the Utah depletions were subtracted from the flows at the basin outflow nodes in StateMod. These Utah depletions total 6,487 AF/yr in the Dolores River Basin, and 3,958 AF/yr in the White River Basin. Depletions of the San Juan River and its tributaries outside of the State of Colorado are represented explicitly in CRSS, due to the implementation of the linkage in those basins, which is depicted in Figure 3. The San-Juan Chama Project depletions were removed from both the demands and the inflows in the linked StateMod model since these uses occur in the Rio Grande basin in New Mexico, and are represented separately within the CRSS model.

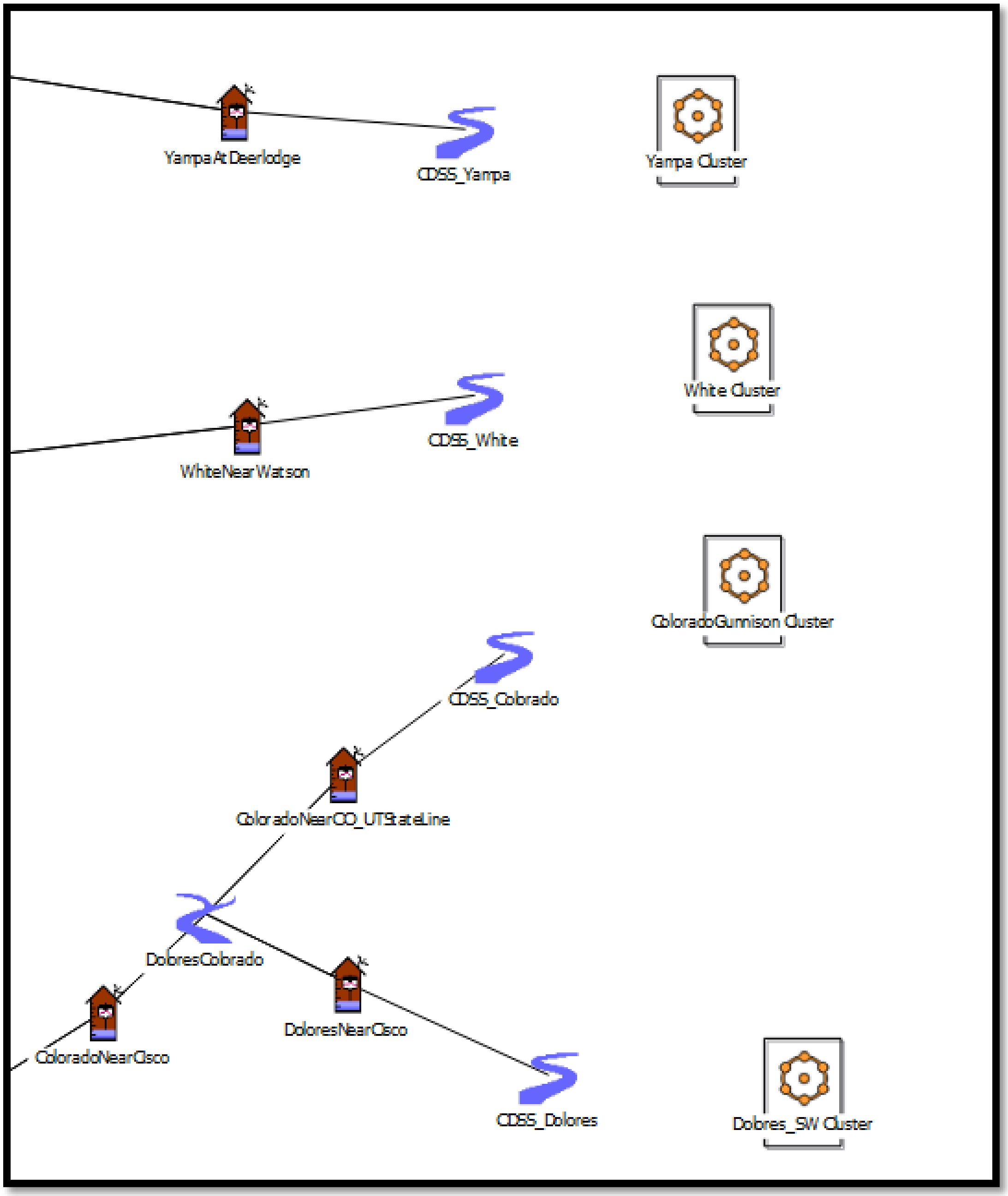

Figure 2. Yampa, White, Upper Colorado/Gunnison, and Dolores Basin Linkages

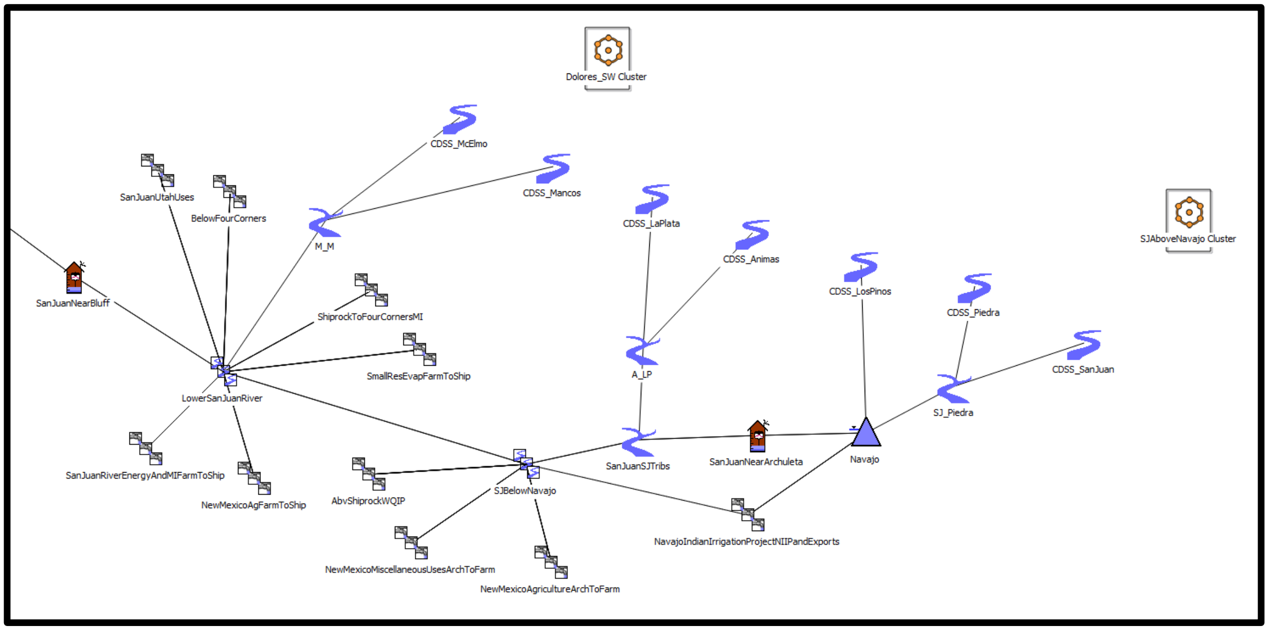

Figure 3. Southwest Colorado Basin Linkages

2. StateMod Surrogate Years

The simulation period for the StateMod linked model ends in 2005, while the Stress Test period used in CRSS covers the period 1988-2015. In order to fill in the years 2006-15 in StateMod, annual flow of the Colorado River at the Colorado-Utah state line for each of the years 2006-2015 was compared to the years 1909-2005, and the year with the closest total annual volume was selected as a surrogate. Table 2 lists the years and percent differences in flow, calculated by subtracting the observed flow in the recent year from flow in the surrogate year. The appropriate year-specific StateMod data from each surrogate year was then appended to the linked model input datasets.

Table 2. Surrogate Years for StateMod Extended Stress Test Simulation

Recent Year	Surrogate Year	% Difference in Flow
2006	1925	-0.7%
2007	1991	0.5%
2008	1938	-0.9%
2009	1971	-0.1%
2010	1991	0.3%
2011	1917	0.0%
2012	1981	3.0%
2013	1940	0.1%
2014	1948	-0.2%
2015	1944	0.1%

E. Simulation Protocols

As discussed above, both CRSS and StateMod were configured to run over the period 1988-2015. CRSS utilizes the Index Sequential Method (ISM) to generate multiple model runs using a single input dataset. In ISM, each year of the simulation period is used once as the first year of a trace (a “trace” as used herein describes one set of hydrology and demands that is run through the model). For the Stress Test period, there are 28 years of data, and thus 28 different traces that comprise a single CRSS scenario simulation. For example, when simulating the current demand schedule with the DCP, CRSS will cycle through the dataset 28 times, each time using a different starting year. Each trace can be thought of as a possible future, and we treat the 28 Stress Test traces as our collection of all possible futures for this analysis. Within a single trace’s run, when the model reaches 2015, it loops back to 1988 and continues. All of the data associated with a given year remain synchronized through all the traces.

- Trace 1: 1988-2015
- Trace 2: 1989-2015 + 1988
- Trace 3: 1990-2015 + 1988-1989
- Trace 4: 1991-2015 + 1988-1990
- …
- Trace 28: 2015 + 1988-2014

StateMod does not have the ability to perform ISM-type simulations. However, the key outputs from StateMod that feed into the CRSS simulations are flows at the Colorado state line. It is thus straightforward to synchronize the StateMod outputs by year as inputs into the CRSS ISM method.

Model simulations in CRSS were carried out for each of the 28 traces for each scenario (e.g., current demands + DCP, future demands + DCP, etc.). Post processing to develop statistics for the model runs used the first 25 years of each trace, hence a total of 700 years (28 traces x 25 years per trace) is used to generate the frequency data presented in the CRSS results.

For the analysis of curtailment scenarios completed entirely in StateMod, we use both the linked StateMod model as well as the individual sub-basin models. The results presented for the curtailment scenarios (Section IV) are generally developed from model outputs for the period 1988-2005. A comparison of results from this subset of the available StateMod data shows only minor differences in average consumptive use when compared to the full period of simulation.

III. Analysis of "Big River" Risks

We evaluated the likelihood of reaching critically low Lake Powell elevations as part of Phase II of this Risk Study[11]. That analysis used Reclamation's CRSS model and demand schedules A and (a modified version of) D1 from the 2012 Basin Study, which escalate over time. The increasing demands in those data sets made it difficult to discern the impact of increasing demands as compared to changes in hydrology. This modeling builds upon that analysis by examining the increased risk associated with an increment of hypothetical future growth compared to current demands, both of which are simulated at fixed levels throughout their respective simulation periods. In other words, it was assumed that there were no changes in the current demands throughout the Baseline simulation period, and the values for the future demands were fixed and did not escalate over time in the "Future Demands" scenario. In addition, the recently completed and approved DCPs for both the Upper and Lower Basins were re-evaluated, to determine the impact those plans have on the risks associated with both current and future demand conditions. The DCP simulations include the Lower Basin's delivery reductions plus Mexico's contributions under Minute 323. The Upper Basin drought operations of CRSP reservoirs (Initial Units) is simulated, but no modeling of demand management or the corresponding use of the 500 Kaf storage pool as approved by the DCP was undertaken. We do provide a post-modeling analysis of the possible efficacy of a 500 Kaf demand management account, but a more robust evaluation is needed to better understand how and when such an account might be used. For these simulations, the 2007 Interim Guideline rules for Powell and Mead operations as well as Lower Basin shortages persist for the entire duration of the runs (i.e., beyond 2026). January 1, 2019 data are used for Initial reservoir storages.

Four scenarios were evaluated, combining each of the current and future demand sets with river operations both with and without the DCPs in place:

- Scenario 1: Current Demands Baseline (without DCP)
- Scenario 2: Future Demands Baseline (without DCP)
- Scenario 3: Current Demands + DCP
- Scenario 4: Future Demands + DCP

The risks of declining storage at Lake Powell and flow at Lee Ferry were analyzed for each scenario. The risk of flows at Lee Ferry dropping below assumed critical levels is related to the risk of declining storage at Lake Powell, but with the DCPs now in place, the timing of events and relative risks

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[11] Colorado River Risk Study, Phase II Task 1 Final Report, Hydros Consulting Inc., 2018

needed to be revisited. We first address the timing and cumulative frequency of risk at Lake Powell, followed by the Lee Ferry / Compact deficit analysis, and finally a short discussion of potential demand management storage program benefits.

To be consistent with the modeling from previous Phases of the Risk Study, and to maintain consistency with the analysis of the DCPs, this study uses elevations 3525' and 3490' at Lake Powell as the indicators for critically low reservoir elevation. The origin of the use of the 3525' threshold for the DCP analysis is two-fold: 1) it represents the top of the Lower Elevation Balancing Tier from the 2007 Interim Guidelines, and 2) it is only 2.0 Maf above minimum power pool (3490'), and Reclamation staff have indicated that they would get "nervous" about the use of the turbines and power generation if Powell were to drop below 3525, because of possible air entrainment in the turbines and other hydraulic issues. Elevation 3490' is the nominal minimum power pool below at which no generation is possible.

Analysis of risk at Lee Ferry uses 10-year flow targets of 82.5 Maf and 75 Maf, which are the two most commonly cited volumes when defining a potential deficit or measuring compliance under Article III(d) of the Compact. The hydrologic and demand assumptions evaluated in this study, including the runs with additional future demands, did not produce 10-year flows below 75 Maf. Even so, it should be noted that this may not suggest a zero likelihood of such an occurrence, because the hydrologic data assumed for this study do not represent the full range of variability suggested in either the paleo-hydrologic record, or in simulations of the potential impacts of Climate Change. This result is also largely driven by the combined effects of the DCPs and the 2007 Interim Guidelines, which are assumed herein to continue beyond 2026.

Note that exact calculation of the risk of a particular event happening at some point in the future is only possible when the probability associated with all important factors is known. The deep uncertainty evident in the hydrologic record and the extent to which it reflects future conditions, combined with the uncertainty inherent in conflicting interpretations of guiding policy and administrative assumptions necessitates quantification of the relative risk associated with alternative policy actions that are controllable, such as implementation of DCP agreements, and incremental development of additional depletions. The incremental changes to the baseline risk profiles resulting from the modeling assumptions described above are analyzed here, solely to provide guidance in evaluating future policy decisions.

A. Risk Profile for Lake Powell Elevations

The modeled likelihood of Powell dropping below 3525 and 3490 are presented in Figure 4 and Figure 5, respectively. The plots show the cumulative frequency of modeled events. Recall that each scenario consists of 28 different traces. If in a single trace (out of the 28 traces) Lake Powell drops below the target level, that "event" is recorded. The timing of the event can be discerned from the increase in the cumulative frequency, while the total number of traces experiencing the event is shown as the maximum of the cumulative frequency plot.

For example, in Figure 4, Scenario 3 has a maximum (cumulative) frequency of 43% (12 of 28 traces). If our dataset of 28 "futures" are indicative of future hydrology, then there is a 43% likelihood of Lake Powell reaching that critical level at some point in the next 25 years. Because the initial condition for Lake Powell is relatively low (approximately 10 Maf), the majority of events when Powell hits 3525' occur relatively early in the simulation, if at all. Over the 28 year Stress Test period, there are some wetter years, and these wetter periods (particularly the late 1990s) refill the system enough so that the very dry periods that follow do not cause Powell to drop to critical levels. It is interesting to note as well that when the future demands scenarios are simulated (Scenarios 2 and 4), the frequency of hitting 3525' increases dramatically. The additional fixed demands in those Future scenarios is large enough that even through the wetter periods, Powell does not recover sufficiently to be able to make it through the dry years without going below 3525'. Finally, note that the DCPs provide a greater benefit over time under current demand conditions as compared to future demands. This is due to the essentially fixed magnitude of CRSP releases available under drought operations being overwhelmed by the magnitude of shortages under the future demands simulation.

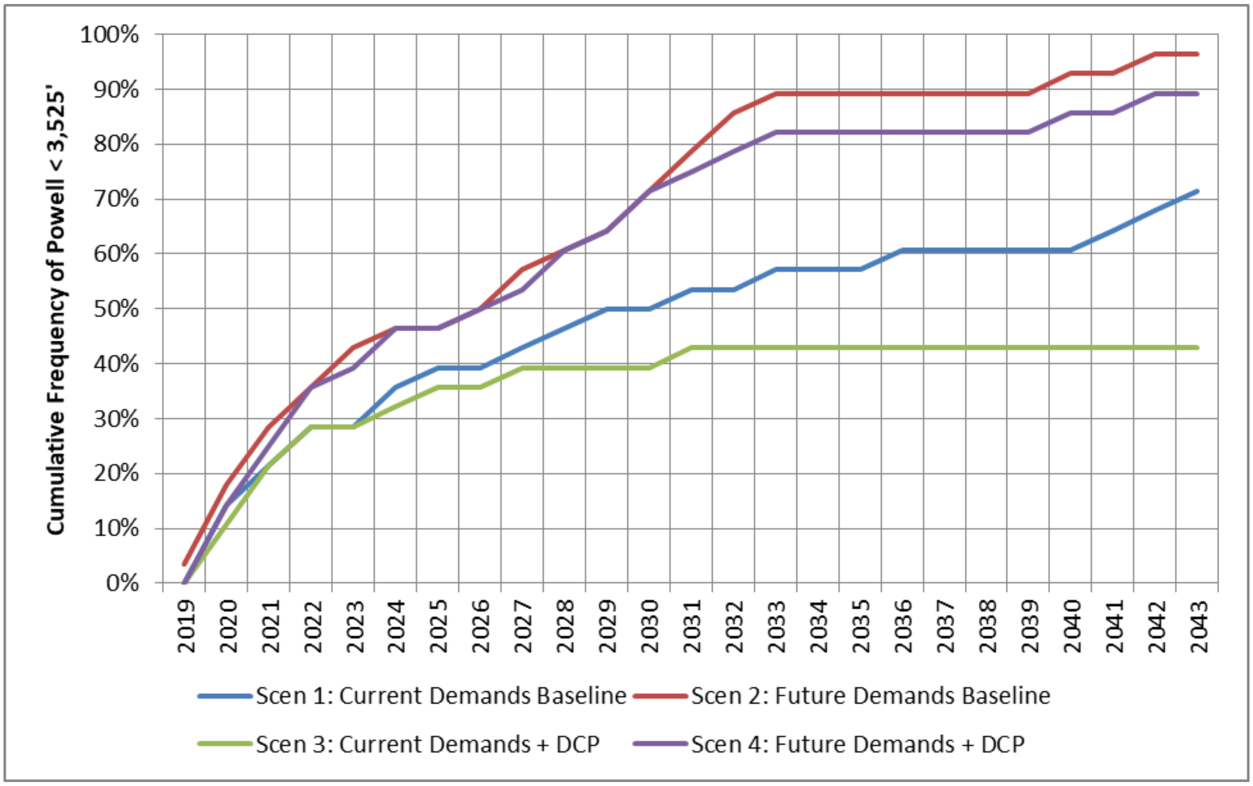

Figure 4. Risk Profile for Lake Powell elevation 3525'.

The benefit of the DCPs is more apparent under future demands when looking at the 3490' elevation power generation threshold (Figure 5). Under the future demand scenario, the DCPs act to significantly reduce the likelihood that Powell would drop below its minimum power elevation. This result is expected, as the CRSP drought operations turn on, and the Lower Basin conservation targets act to stabilize Lake Mead above elevation 1025'. With Mead stabilized above 1025, and

Powell dropping into its Lower Elevation Balancing Tier, releases from Powell are likely to be closer to 7.0 Maf than the 9.5 Maf maximum that is possible under the 2007 Interim Guidelines.

As with the 3525' threshold, the impact of increased demands is also clear. The modeled increase in Upper Basin depletions of ~11.5% roughly doubles the risk (likelihood of Lake Powell reaching that critical level at some point in the next 25 years) at both the 3525'and 3490' thresholds with the DCPs in place.

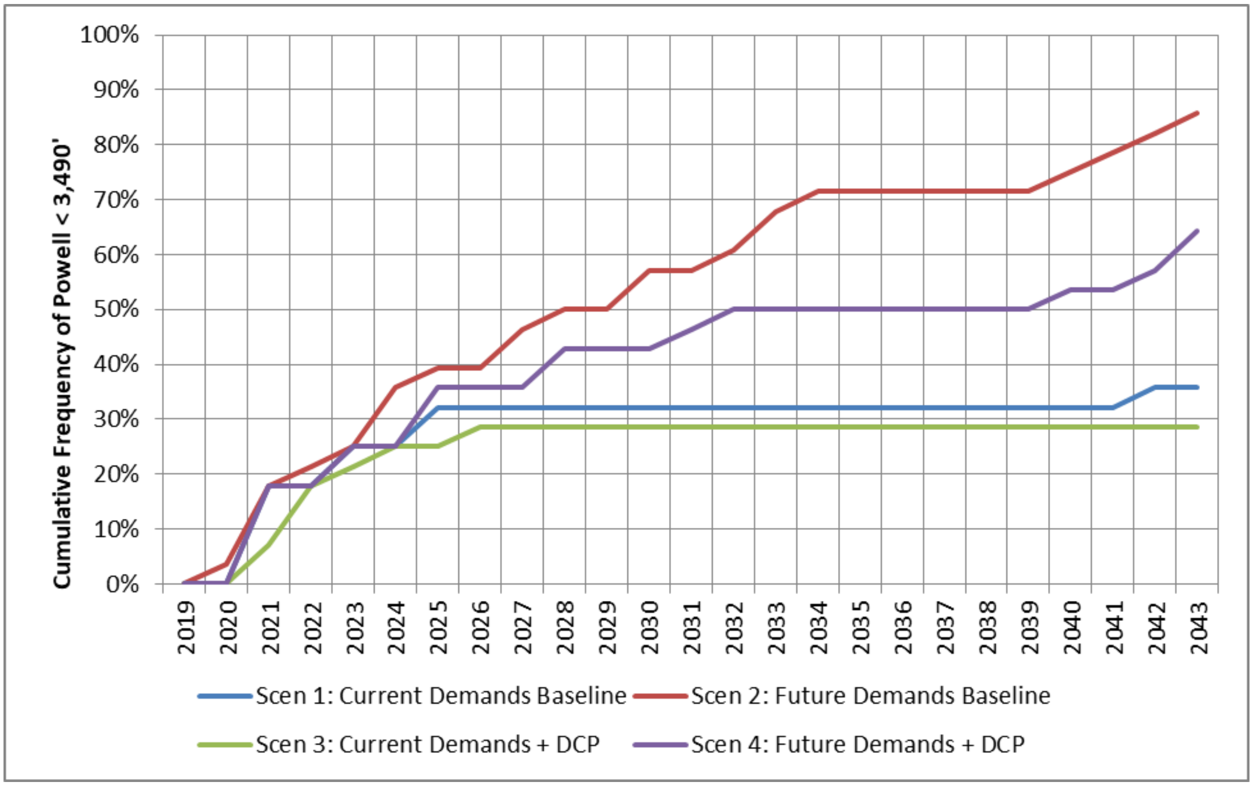

Figure 5. Risk Profile for Lake Powell elevation 3490'.

B. Risk Profile for Compact Deliveries

Exactly what the Upper Basin's obligations are with respect to Lee Ferry "non-depletion" volumes under the Colorado River Compact is the subject of much debate and uncertainty, and this study makes no attempt to answer those questions. For this study, we analyzed the two most commonly cited volumes, 75 Maf and 82.5 Maf, both of which are computed using a 10-year running total. These represent the Upper Basin obligation under Article III(d) of the 1922 Compact to "*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*", and an additional 750 Kaf annually, to reflect a conservative (i.e. disadvantageous to the Upper Basin) interpretation of what the Upper Basin's obligation may be under Article III(c). As mentioned above, the simulations in this study produced no instances of 10-year totals dropping below 75 Maf. Minimum Lee Ferry volumes by scenario are shown in Table 3.

Table 3: Minimum 10-year Lee Ferry volumes by scenario.

Scenario	Minimum 10-Year Volume at Lee Ferry (af)
Current Demands Baseline	80,414,547
Future Demands Baseline	78,681,420
Current Demands + DCP	78,650,744
Future Demands + DCP	77,221,987

Figure 6. Cumulative Frequency of Lee Ferry flows < 82.5 Maf / 10-years.Figure 6 shows the cumulative frequency of dropping below the 82.5 Maf threshold at Lee Ferry for each scenario. As with the Powell elevation thresholds, the cumulative frequency statistic increases each time another trace within a given scenario drops below the 82.5 Maf threshold. For example, by the end of the 25 year time horizon, all but three of the Scenario 4 traces (see purple line) has experienced at least one year in which the trailing 10-year total was less than 82.5 Maf. Most of the Lee Ferry "deficits" at the 82.5 Maf threshold do not start occurring until 2024 or later. Because the model uses historical flows as initial conditions, and those flows have generally been in the 9.0 Maf range for the past several years, it takes several years of simulated Powell Releases of 7.48 Maf or lower before the 10- year total drops below 82.5 Maf.

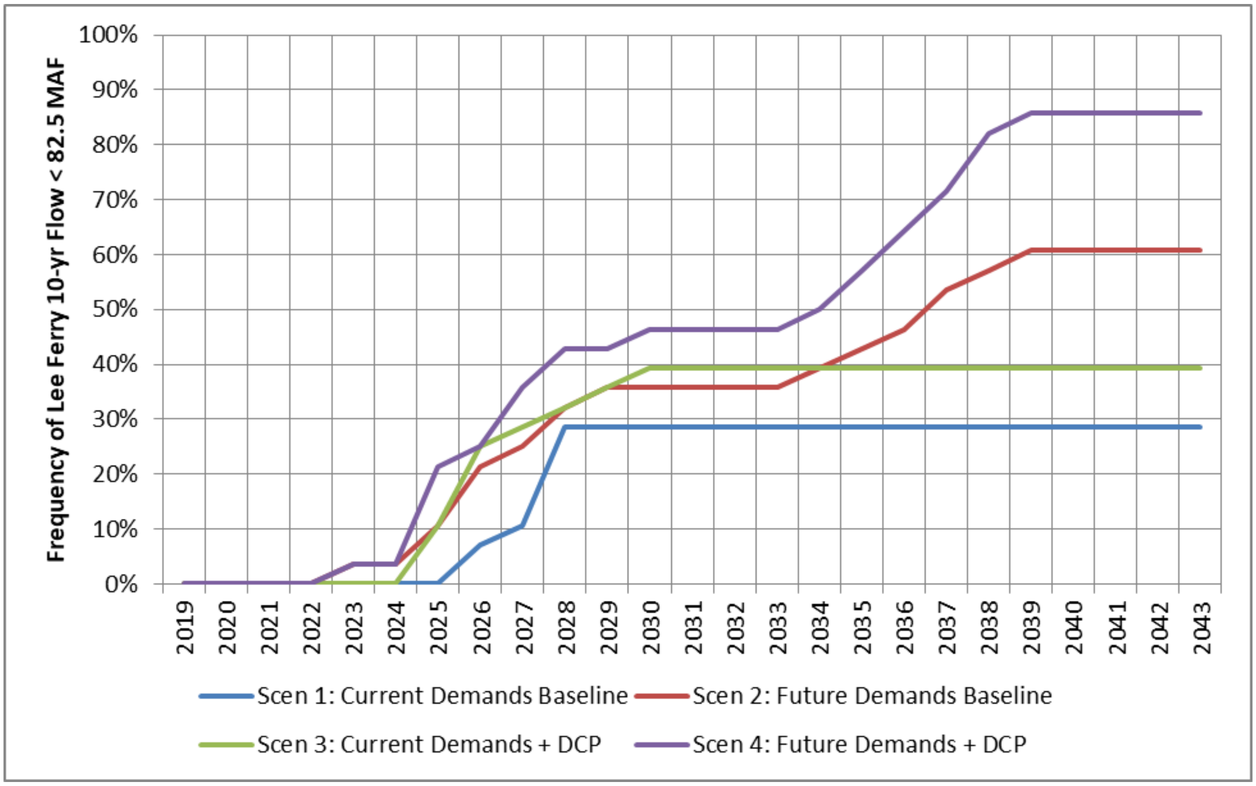

Figure 6. Cumulative Frequency of Lee Ferry flows < 82.5 Maf / 10-years.

The typical pattern of higher risk with the future demands dataset seen in the Lake Powell results carries through to Lee Ferry. However, note that the likelihood of a Lee Ferry deficit at the 82.5 Maf threshold *increases* when the DCPs are implemented. This result is expected, because the DCPs act to increase lake levels at both Powell and Mead. In doing so, the DCPs will tend to push Powell releases into the lower end of the ranges that are prescribed for each operating tier. In particular, DCP operations tend to keep Powell in the Mid-Elevation Release Tier for extended periods of time, by maintaining elevations above 3525' when possible. So instead of getting 9.0 Maf or 8.23 Maf releases, the DCP scenarios tend to result in a lot more 7.48 Maf releases. And if Powell does drop into the Lower Elevation Balancing Tier, it is more likely to have a 7.48 or even 7.0 Maf annual release than 9.0 Maf or 9.5 Maf. This trend towards reduced release volumes at Powell with the DCPs in place is further illustrated by Figure 7 and Figure 8. Under current demands, the likelihood of dropping below 82.5 Maf increases from 28% to 39% when including the DCP. The volumes of deficit increase as well, and the likelihood of a deficit greater than 1.5 Maf increases from 4% to 21%.

As seen above in Figure 4, the DCP operations do not significantly impact the cumulative frequency of maintaining Powell Pool elevations above 3,525' for the entirety of the simulation, but they can prevent the onset of shortfall for long enough, or promote recovery more quickly, such that the minimum elevation in Powell benefits significantly, as seen in Figure 5**Error! Reference source not found.**. This difference in the lowest resulting storage amounts in Powell is seen in reverse at Lee Ferry, as the amount of extra storage at Powell is equal to an amount not flowing past Lee Ferry.

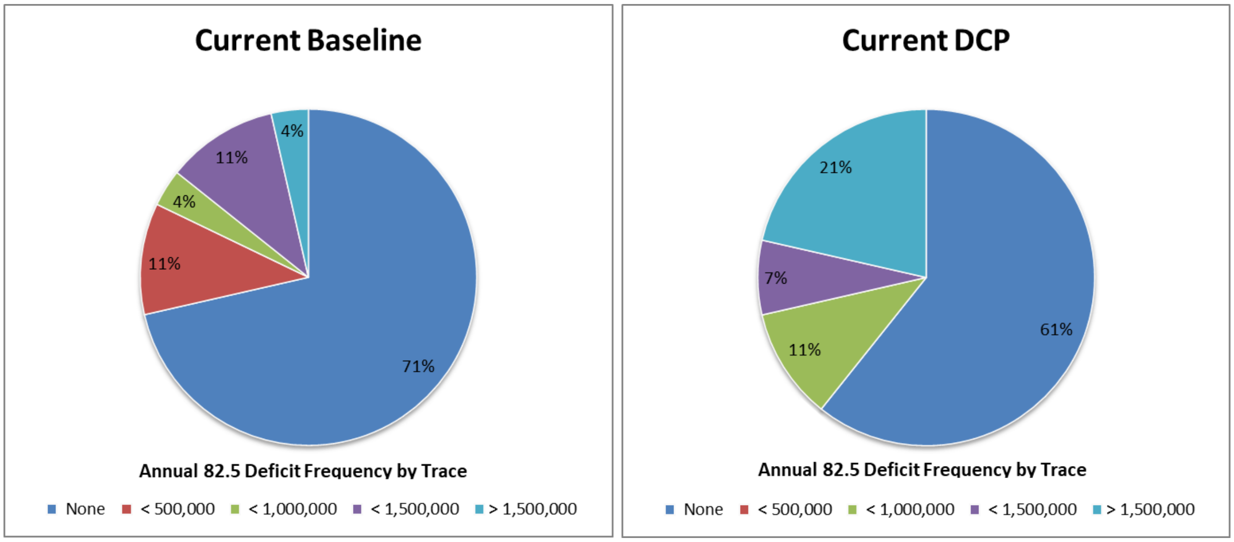

Figure 7. Current Demands Baseline and +DCP Risk Profile for Lee Ferry < 82.5 Maf. The volumes shown are the maximum deficit volumes seen in each trace.

The elevated demands in the Future Baseline scenario result in more traces with simulated Lee Ferry shortfalls, and shortfalls of greater magnitude, as compared to the Current Baseline scenario. Figure 8**Error! Reference source not found.** displays the distribution of maximum shortfall by trace, where it can be seen that 86% of traces which include the DCP experience a shortfall, and the majority of the shortfalls exceed 1.5 Maf.

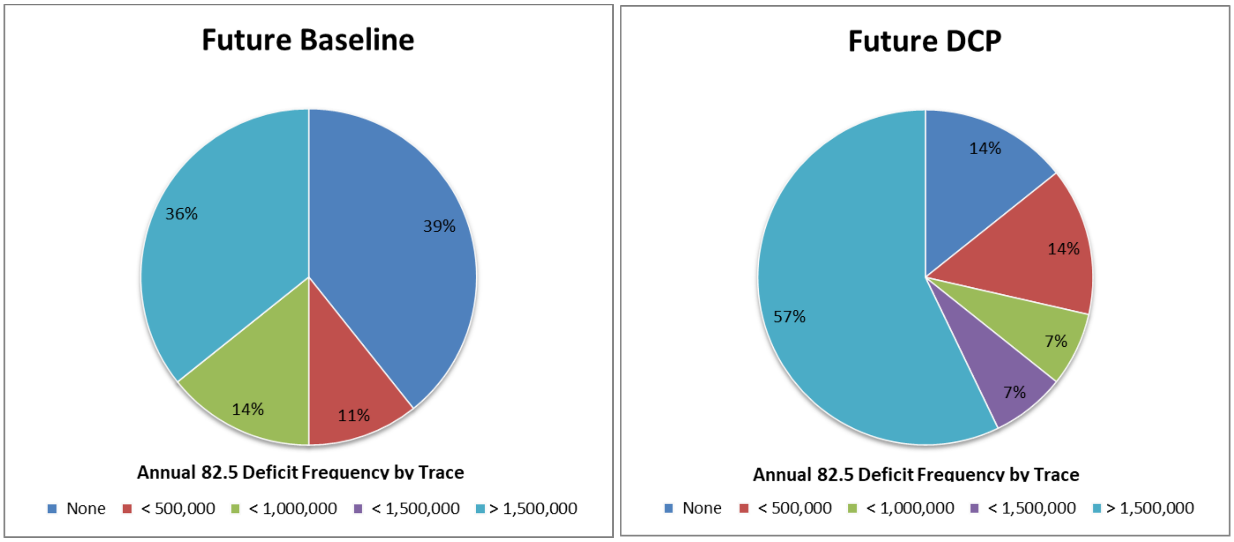

Figure 8. Future Demands Baseline and +DCP Risk Profile for Lee Ferry < 82.5 Maf. The volumes shown are the maximum deficit volumes seen in each trace.

1. Caveat to the Lee Ferry Analysis

As discussed above, the DCPs do a good job of protecting Lake Powell elevations, but actually increase the frequency of 10-year Lee Ferry volumes dropping below 82.5 Maf. When these "deficits" occur, they are often not caused by a lack of water in Powell, but instead by adhering to the policies of the Interim Guidelines. If, as a matter of policy, the Upper Basin decided to ask Reclamation to make additional releases to stay above the 82.5 Maf threshold, it is likely that a significant amount of that deficit could be readily released from Lake Powell. As an example of the intertwined nature of the risks at Lake Powell and Lee Ferry, Figure 9**Error! Reference source not found.** illustrates the simulated pool elevation and 10-year rolling average Compact volume for the hydrologic trace beginning in 2012. The dashed black line in the figure represents both the 82.5 Maf threshold for 10-year flow at Lee Ferry (left y-axis), and elevation 3,525' at Lake Powell (right y-axis). When Powell's elevation crosses the 3525' threshold, both in decline and in recovery, it precedes the 10-year Lee Ferry flow crossing the 82.5 Maf threshold, with a longer lag time between the two events in recovery resulting from the operations dictated by the Interim Guidelines. In this example, by the time the Lee Ferry deficit reaches its maximum in 2029, Powell has approximately 4.0 Maf in storage above minimum power pool.

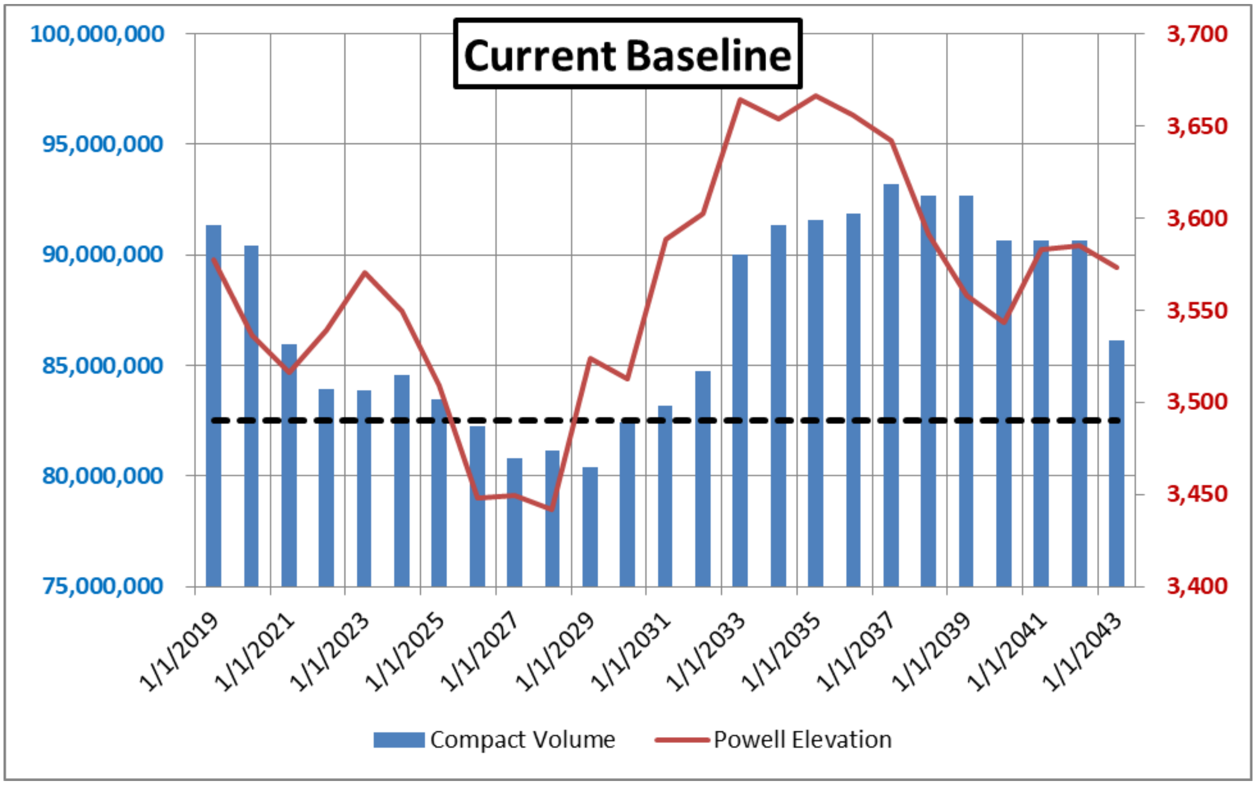

Figure 9. Illustration of the linkage between Powell elevation and Lee Ferry 10-year volumes when operating under the 2007 Interim Guidelines and Drought Contingency Plans

To investigate this phenomenon further, the 82.5 Maf deficit magnitudes were compared to the amount of storage in Lake Powell above minimum power pool (3490') that existed when those deficits occurred. This analysis was carried out as a post-processing step for all four scenarios. The analysis indicates that release of additional water from Lake Powell above the amounts dictated by the Interim Guidelines could eliminate all but one of the Lee Ferry assumed 82.5 Maf shortfalls under the Current Demands Baseline scenario. That single trace would require an additional 1.46 Maf to maintain flows of at least 82.5 Maf. The Current Demands +DCP scenario would also have one scenario in which the existing storage volumes above minimum power pool are unable to eliminate the 82.5 Maf deficit. However, with the DCP in place, the volume of that remaining deficit is only 108,000 AF.

When looking at the Future Demands scenarios, a significant number of the 82.5 Maf deficits can be eliminated by utilizing remaining Powell storage above 3490' elevation. For the Future Demands scenario, use of that water would leave 25% of the traces with a remaining deficit (compared to the original 61%). The maximum remaining deficit from those traces is about 2.1 Maf. The Future Demands +DCP scenario experiences shortfalls remaining in only 29% of traces, as compared to the original deficit frequency of 84%. The maximum volume of those remaining shortfalls is 1.38 Maf.

The exact operational modifications at Powell that would result in release of these additional amounts of water, above or below elevation 3490', were not represented in the modeling, and the development of operational policy that could achieve such deliveries in compliance with existing operational requirements was not considered as part of this analysis.

C. Effectiveness of a 500 Kaf Demand Management Account

The DCP legislation provides for the creation of a 500 Kaf account in one or more of the CRSP Initial Units to be used, if needed, for Compact compliance. Because of uncertainty over the location and operating policy for such an account, we did not attempt to model a comprehensive demand management program in this study. In lieu of that, we analyzed how effective an existing 500 Kaf account would be in offsetting the modeled deficits relative to the 82.5 Maf threshold for compact accounting. This approach greatly simplifies the analysis by assuming that a full 500 Kaf account is available at the onset of each event, and does not reflect the reality that longer term events or events that occur more frequently would reduce the overall effectiveness of the program because of the time needed to refill an account once it has been depleted.

Current Demands Baseline: 8 of 28 traces had at least one instance of the 10 year running total dropping below 82.5 Maf. If a 500,000 AF demand management storage account were available for use at Lake Powell as contemplated in the Upper Basin DCP, it could be used to eliminate the shortfalls in 3 of the 8 traces with deficits. Recall from the previous section that this does not include the possible use of the additional storage below 3525’ and above the minimum power pool (3490’). If additional storage above the minimum power pool is used, the deficits in all but one of the traces can be eliminated. The amount of the remaining assumed shortfall at Lee Ferry in the one trace where the shortfall could not be eliminated by release of the remaining water above power pool in Powell would be approximately 962 Kaf.

Current Demands +DCP: 11 of 28 traces had at least one instance of the 10 year running total dropping below 82.5 Maf. (As noted above, the DCP increases the number of traces below 82.5Maf because it generally reduces the average release from Powell). A 500,000 af demand management storage account in Lake Powell would not fully offset the deficit in any of these traces. However, use of remaining storage above minimum power pool would eliminate deficits in all of the traces.

Future Demands Baseline: 17 of 28 traces had at least one instance of the 10 year running total dropping below 82.5 Maf in the future demands baseline. A 500 Kaf demand management storage account would fully eliminate deficits in 3 of these 17 traces. Use of remaining storage above minimum power pool would eliminate deficits in another 9 traces. 5 traces would contain shortfalls after using both the demand management storage account and remaining storage above minimum power pool, with a maximum shortfall of 1.6 Maf. The reduced effectiveness of the demand management storage account in the Future Baseline, as compared to the Current Baseline, is the result of the difference between Future and Current demands greatly exceeding the size of the account when the annual demand difference (and hence reduced Lake Powell inflows) accumulates over a ten year period.

Future Demands +DCP: 24 of 28 traces had at least one instance of the 10 year running total dropping below 82.5 Maf in the future demands plus DCP scenario. A 500,000 af account would eliminate the deficit in 4 of these 24 traces. Use of remaining stored water above minimum power pool would eliminate deficits in all but 5 of the remaining traces. The maximum remaining deficit after use of Powell storage above minimum power pool is about 881 Kaf.

IV. Colorado River Depletion Analysis

The purpose of Tasks B and C was to develop a comprehensive understanding of the linked StateMod model provided by CWCB, and then implement and analyze a variety of potential curtailment scenarios for the Colorado River basins. StateMod represents in detail the water rights, diversion structures, reservoirs, instream flow rights, exchanges, and numerous other processes that characterize water administration in Colorado. Depletions in StateMod are summarized for the structures included in the model, such as diversion ditches and reservoirs, and for aggregations of structures, such as water districts, but depletions are not summarized in model output by water right. Because of this, determination of the amount of depletions that are senior or junior to key dates requires additional careful consideration.

A. Calculating Depletions at Specified Priorities

The methodology applied here for determination of amounts of depletions senior to key dates required modification of the structure of existing StateMod models. An instream flow water requirement was inserted above the downstream-most node of each StateMod model with a decreed flow rate of 9,999,999 cfs, which is a sufficient amount to call out all water use junior to the administration number of the instream flow requirement. Varying the administration number of the instream flow requirement, and analyzing the resulting depletions was carried out to determine amounts of depletions senior to dates of interest. Depletions were calculated using TSTool scripts that retrieve results directly from the StateMod binary output files. Depletions simulated in StateMod include consumptive use, reservoir evaporation, and transit losses.

This method of determining senior depletion amounts was tested by setting the call date to be senior to all water rights on the Western Slope. The administrative date used for this confirmation run was January 1, 1850. The only depletions simulated at this call date resulted from evaporation of stored water that is present as an initial condition for each of the reservoirs in the model.

B. Depletions of Colorado River Water in Colorado

The first analysis undertaken with StateMod was to simply estimate the amount of consumptive use of Colorado River water currently occurring in Colorado. Figure 10 shows minimum, average, and maximum depletion values for the period 1988-2005. Variations in depletions are caused primarily by changing hydrologic conditions from year-to-year, which in turn changes the frequency, timing, and depth of administrative calls in each basin. Total estimated depletions of Colorado River water average just over 2.5 Maf for the simulation period.

	Annual Depletions (acre-feet)		
Basin	Minimum	Average	Maximum
Yampa	173,547	196,982	215,193
White	48,550	62,060	70,397
Colorado	1,117,487	1,220,386	1,345,192
In-Basin	*650,747*	*669,257*	*692,193*
TMDs	*466,740*	*551,129*	*652,999*
Gunnison	480,358	551,150	599,762
Southwest	335,365	500,717	556,627
Total	2,155,307	2,531,296	2,787,171

Figure 10. Depletions of Colorado River water. From the StateMod Baseline model.

C. Pre-Compact Depletions

Of the roughly 2.5 Maf of depletions, we then quantified the proportion that could be attributed to "pre-Compact" water rights. The depletions senior to two possible Compact administration dates were quantified using administration numbers (aka Holt Numbers, developed by the Colorado Division of Water Resources) and appropriation dates. The more senior of the two potential dates of Compact administration is November 24, 1922, which is the date on which six of the seven Basin States signed the Compact. The more junior of the potential dates is June 25, 1929 (administration # 29030), which is the date on which the Boulder Canyon Project act was signed into law by President Hoover. The depletion amounts senior to these dates are displayed in Figure 11Figure 11, using both the administration numbers and appropriation dates of each water right:

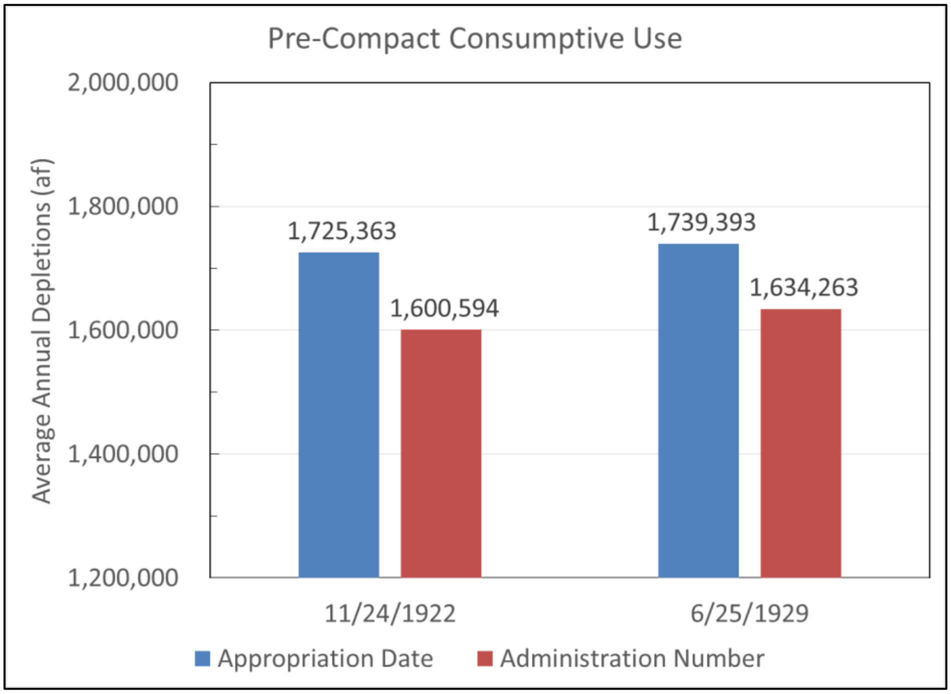

Figure 11. Pre-Compact Depletion Volumes

These depletions are different from the historical depletions associated with water rights senior to the Compact, due to historical use of water rights with priorities both senior and junior to the Compact to irrigate the same lands. These levels of pre-Compact depletions are notably elevated in comparison to some previous estimates, such as the estimate listed in the minutes of the 6th meeting of the Colorado River Commission, where an average total for the State of Colorado's irrigation of lands in production since 1920 was listed as 1,110,000 AF/yr. One of the sources of this difference is the improvement in quantification of potential consumptive use in high altitude irrigation, and another source of the difference is the enhanced efficiency with which pre-Compact water rights are simulated to be used in times of a persistent call.

For the remainder of this report, the term "pre-Compact" will be used to refer to uses with administration numbers senior to the 1922 date. Using the administration number approach will yield the lower of the two volumes of pre-Compact usage, and hence is a conservative assumption for this analysis. The lowest estimate of the amount of pre-Compact use is considered conservative because it corresponds to the highest estimate of the amount of "post-compact" use that would be subject to curtailment under the Compact. The average amounts of pre-Compact depletions by basin for each basin in Colorado are listed in Table 4, along with the proportions each basin represents in terms of total pre-Compact depletions. The Colorado main stem depletions in Table 4 are further differentiated between in-basin uses and trans-mountain diversions (TMDs).[12]

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[12] The TMDs referred to in this Report divert water from the Colorado River main stem Basin into the South Platte and Arkansas River Basins. There are a number of smaller post compact trans-mountain diversions that divert from the San Juan and Gunnison Basins into the Rio Grande and Arkansas River Basins. These smaller

Table 4. Pre-Compact Depletions by Basin

Basin	Pre-Compact Depletions (AF/yr)	As Percentage of Statewide Total
Yampa	138,544	8.7%
White	50,173	3.1%
Colorado	594,169	37.2%
In-Basin	574,997	36.0%
TMDs	19,173	1.2%
Gunnison	493,879	30.9%
Southwest	322,561	20.2%
Total	1,599,327	100.0%

D. Post-Compact Depletions

The difference between depletions simulated with and without a Compact call are depletions which rely at least in part on post-Compact rights to meet their consumptive use needs. These depletions are different from the historical depletions associated with post-Compact rights for reasons similar to those that differentiate the pre-Compact depletions described in the previous section from the historical depletions attributable to pre-Compact water rights. Average annual post-Compact depletions for each basin are listed in Table 5, both as volumes and as the percentage they represent of the statewide total. The percentages of total post-Compact use are used as the basis for proportional distribution of curtailment volumes in some of the scenarios evaluated in Section V.

Table 5. Post-Compact Depletions by Basin

Basin	Post-Compact Depletions (AF/yr)	As Percentage of Each Basin's Total Use	As Percentage of Statewide Total
Yampa	58,438	29.7%	6.3%
White	11,887	19.2%	1.3%
Colorado	626,216	51.3%	67.2%
In-Basin	94,260	14.1%	10.1%
TMDs	531,956	96.5%	57.1%
Gunnison	57,271	10.2%	6.1%
Southwest	178,157	35.6%	19.1%
Total	931,969	36.8%	100.0%

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trans-mountain diversions were not split from the San Juan and Gunnison Basin values as was done for the Colorado River mainstem.

V. Curtailment Scenario Analysis

The State of Colorado, through the CWCB and AG office, has undertaken a Compact compliance study, which remains confidential. The questions of how and under what conditions a Compact call might be implemented are numerous and highly uncertain. Absent any known path forward if such a situation arose, the WSBRTs wanted to have explored a variety of "what if" scenarios for curtailment. These limited scenarios are not proposals for how to implement a call, but are instead background information across a broad range of possibilities to allow for better understanding of where the impacts may be and how those impacts may vary. The risk analysis presented in the previous section indicates that evaluation of potential curtailment scenarios is a worthwhile step to prepare for future negotiations. It should also be noted that additional potential administrative scenarios are possible, but were beyond the scope of this phase of the modeling effort.

Note also that this analysis of curtailment scenarios is different from and should not be confused with the ongoing discussions and activities related to demand management. Demand management generally refers to the intentional conservation of water to be used to ensure Compact compliance while avoiding the need for water administration to meet the Upper Basin's obligations. A central concept behind any demand management program is that it should be voluntary, temporary, and compensated. The State of Colorado, through the CWCB and AG's office has proceeded with its "2019 Work Plan for Intrastate Demand Management Feasibility Investigations". See http://cwcb.state.co.us/water-management/Pages/DemandManagement.aspx for more details.

A. Scenario Definitions and Rationale

A Compact call is different from a typical administrative call in terms of the time scale associated with the upstream depletions that result in the shortfall addressed by the call, and this difference in time scale suggests that the mechanism for most equitably distributing the cutbacks required by the call could potentially be different for a Compact call, in comparison to a typical real time administrative call. In most cases, for a typical administrative call, the diversions causing the shortfall are occurring upstream of, and at the time of the call, by water users with priority junior to the water user experiencing a shortfall.

A notable exception to this in current administrative practice relates to the administration of out-of-priority upstream storage, which is codified in C.R.S § 37-80-120. Administration of out-of-priority upstream storage is handled by allowing diversions by upstream water users that have a contingency allowing the diversions to be retroactively called out, if the downstream senior right is unfulfilled at a later date. This is conceptually similar to a Compact call, which would result from upstream use junior to the Compact date that occurred at a time prior to the shortfall. The temporal disconnection between the timing of shortfall and the timing of the water use that results in a Compact call is greater than the disconnection involved in out-of-priority upstream storage, which indicates that administration of a Compact call could be based upon long-term patterns of use.

The scenarios evaluated here represent potential methods for distributing the risk of future curtailment inherent in the exercise of rights junior to a right not based upon instantaneous flow availability. Note that these scenarios were developed through multiple meetings and conversations with various BRT groups, and are not intended in any way to represent a full set of "preferred" approaches to possible Compact administration. They are illustrative of a range of possible approaches to reducing consumptive use in an involuntary manner.

1. Direct Priority Administration

One method through which Compact administration might be carried out would be through direct priority administration applied at the same level across all basins. In the direct priority administration scenarios, a single administrative date was determined where uniform application of a call at that date across all basins would result in an average depletion reduction of a specified amount. The most stringent version of this scenario involves application of a call date equal to the date of the Compact, because users senior to the date of the Compact are explicitly exempted from curtailment by Article VIII of the Compact.

2. Basin-Specific Proportional Administration

Another hypothetical scenario for distributing the depletion reductions might be based upon proportional amounts of post-Compact depletions by basin on a long-term average basis. This method is conceptually equivalent to treating each of the basins' group of post-Compact water users as a single entity and assigning equal priorities to the entity representing each basin. So if a particular basin depletes 10% of the State's post-Compact water, it would be responsible for 10% of the state-wide target volume for reduced use.

3. Export-Differentiated Proportional Administration

A second possible variant of the basin-specific method for distributing reductions in depletions was to split the depletion reductions based on percentages of west-slope versus out-of-basin (TMD) depletions. This differentiation groups the trans-basin post-Compact users as an administrative entity separate from the post-Compact water users in the Colorado mainstem, from which the vast majority of post-Compact trans-basin diversions in Colorado occur.

B. Targeted Yield Scenarios

A call amount less than full curtailment could result from a small shortfall at Lee Ferry, or through negotiations that allow for multi-year curtailment which distributes the impacts of the call temporally in a manner similar to the temporal distribution of the depletions that caused the call. These scenarios were compared to the results of a full curtailment scenario, so that the relative reductions in the impact of the call in the targeted scenarios could be assessed. The administrative date of the call for each of the targeted yield scenarios was determined at a monthly resolution, by identifying the month in which the yield of the call switched from yielding less than the targeted amount to more than the targeted amount. Yields exactly matching the targeted amount would require partial curtailment of individual rights, and this analysis focuses on monthly call dates in recognition of the complexity of administration to target yields at single-acre-foot precision. The Targeted Yield Scenarios would result in different impacts to specific water rights compared to a full curtailment, as certain junior rights may be curtailed for longer periods while other more senior post-compact rights might not be impacted at all.

1. Full Curtailment

The most straightforward scenario is that all post-Compact depletions would be curtailed. For this scenario, a call was placed in each of the individual models at an 11/24/1922 priority, and the amount of reduction in depletions compared to a no-call scenario was calculated on an annual basis for each basin. The depletion calculations in the Gunnison were adjusted to remove the simulated depletions associated with evaporation from the Aspinall Unit, which average approximately 23,000 AF/yr. Evaporation from the Aspinall Unit is charged to each of the Upper Basin states on a pro-rata basis of each state's percent of total Upper Basin use, and so should not be counted as part of the Gunnison basin's depletion.

Table 6. Yield of Full Curtailment by Basin

Yield (AF)	Yampa	White	Upper Colorado	In-Basin*	TMD*	Gunnison	Southwest	Total
Minimum	50,440	10,262	527,154	84,234	437,510	42,522	137,840	804,133
Average	58,438	11,887	626,216	94,264	531,952	57,271	178,157	931,969
Maximum	68,468	14,146	722,609	104,681	633,182	87,150	232,037	1,056,021

*Sub-groups of Upper Colorado

The average yield of additional water flowing out of the basin under full curtailment for each basin is essentially equal to the average amount of post-Compact use in each basin (with some minor discrepancies due to evaporative losses, return flows, etc.), and the proportional amounts of post-Compact depletions in each basin to the total were computed for use as the basis of the basin-specific administration scenarios. These proportional amounts are displayed in Figure 12.

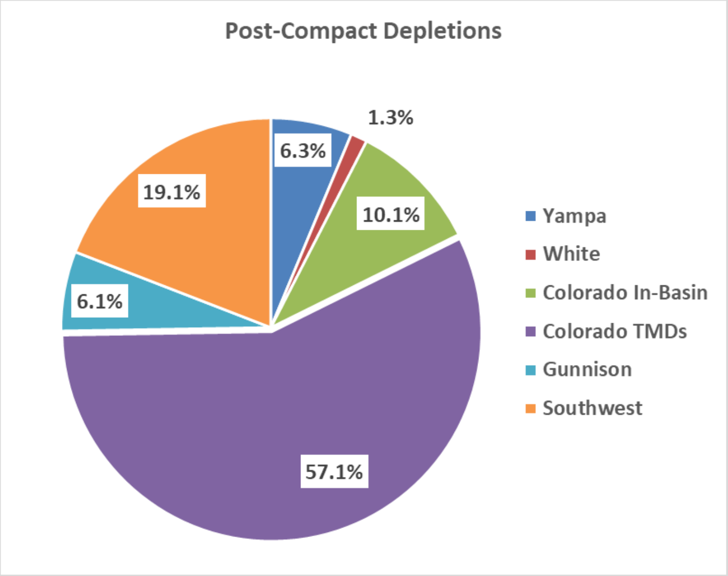

Figure 12. Distribution of Post-Compact Depletions by basin. The total Colorado mainstem portion (67.2%) is split into TMDs and in-basin uses.

2. State-Wide Target Volume Curtailments

As seen in Table 6, a full curtailment of all post-Compact water yields on average about 930 Kaf annually. The next analysis was to look at partial curtailments implemented using single state-wide call dates. For this exercise, we assumed three different target volumes (100 Kaf, 300 Kaf, 600 Kaf), and determined the seniority of the call that would be required, basin-wide, in order to yield that amount of reduced depletions. Using the linked StateMod model, calls were implemented for the duration of the run period, and refined through iteration, until the call dates shown in **Error! Reference source not found.** yielded the target volumes when averaged over 1988-2005. Note that the call dates presented throughout this report are only determined to the month and year, as described above. Refinement to estimate a specific day or even within a day was deemed unnecessary for this level of analysis.

Table 7. State-wide call date to generate a given (average) reduction in annual consumptive use.

Target Volume (acre-feet/yr)	All Colorado River Rights
100,000	Jul 1957
300,000	Sep 1940
600,000	Aug 1935
932,000	**Nov 1922**

Table 8 shows how those volumes would be distributed across the Colorado sub-basins. Note that the distributions change with different target volumes, and are in some cases considerably different than the distribution of all post-Compact rights seen in Figure 12 (and shown in the last rows of this table). This is yet again an indication of how the timing of adjudication and development of water varies across the basins. Basins that have a higher percentage at a given target volume as compared to their Full curtailment percentage developed relatively more slowly than the state-wide average rate of development between the Compact date and the date that produced the target volume, and the converse is true for basins with lower percentages as compared to their Full curtailment percentage. As an example of this type of interpretation of the results, the Gunnison basin developed more quickly than average between November of 1922 and August of 1935, but more slowly than average between November of 1922 and September of 1940.

As before, note that these are average values, and in any given year the volumes and percentages may be higher or lower. The percentage and volume of each sub-basin's post-Compact total water use is also shown for comparison, listed as "Full" in the bottom rows of Table 8.

Table 8. Impact of a state-wide partial call by sub-basin and target volume. Percentages represent the fraction of the target volume that would be curtailed in each sub-basin.

Target Volume (acre-feet/yr)	Yampa	White	Colorado	*In-Basin*	*TMDs*	Gunnison	Southwest
100,000 (Jul 1957)	28%	3%	59%	*22%*	*37%*	6%	8%
	27,627	2,753	59,124	*22,309*	*36,815*	5,925	7,528
300,000 (Sep 1940)	16%	2%	59%	*20%*	*39%*	7%	13%
	47,987	5,325	177,976	*59,918*	*118,058*	20,862	40,233
600,000 (Aug 1935)	8%	1%	55%	*12%*	*44%*	4%	19%
	49,679	8,478	331,556	*69,452*	*262,105*	26,163	113,862
Full	6%	1%	67%	*10%*	*57%*	6%	19%
	58,440	11,888	626,171	*94,403*	*531,834*	57,273	178,163

3. Target Volume Curtailments based on a Pro-Rata Distribution

Another possible approach to curtailing a specific volume annually is to distribute the target volume across the sub-basins based on each sub-basin's share of post-Compact consumptive use. Using the percentages from Figure 12, each sub-basin would be required to curtail the amounts shown in Table 9. For each of these volumes, for each sub-basin, a call date can be developed. Again, these dates represent the call date that would be required across the years 1988-2005 to generate an average annual volume of reduced depletions in the amount shown.

Table 9. Sub-basin target volumes for a given state-wide target, based on pro-rata distribution of post-Compact depletions.

Target Volume (acre-feet/yr)	Yampa	White	Colorado	*In-Basin*	*TMDs*	Gunnison	Southwest
	6.3%	1.3%	67.2%	*10.1%*	*57.1%*	6.1%	19.1%
100,000	6,270	1,276	67,186	*10,129*	*57,064*	6,145	19,116
300,000	18,811	3,827	201,557	*30,387*	*171,191*	18,436	57,348
600,000	37,622	7,653	403,114	*60,774*	*342,382*	36,871	114,697
932,000	58,440	11,888	626,171	*94,403*	*531,834*	57,273	178,163

Results of this exercise are shown in Table 10. Comparing the pro-rata by sub-basin approach to the state-wide curtailment approach reveals significant differences in the impact to individual basins, and is again reflective of the differences in the timing and magnitude of water development across the basins (**Error! Reference source not found.**Figure 13). The dates listed for the 100,000 AF scenario roughly correspond to the date to which 1/9 of that basin's depletions are junior, roughly 1/3 of each basin's depletions are junior to the date listed for the 300,000 AF scenario, and roughly 2/3 are junior to the 600,000 AF dates.

Table 10. Individual Sub-Basin call dates to yield the pro-rata volumes shown. Values shown represent the average reduced depletion over the period of simulation.

Target Volume (acre-feet/yr)	Yampa	White	Colorado	Gunnison	Southwest
	6.3%	1.3%	67.2%	6.1%	19.1%
100,000	6,270	1,276	67,186	6,145	19,116
	Jul 1972	Jul 1962	Jul 1957	Nov 1957	Sep 1940
300,000	18,811	3,827	201,557	18,436	57,348
	Aug 1962	May 1955	Nov 1935	Apr 1955	Sep 1940
600,000	37,622	7,653	403,114	36,871	114,697
	Jun 1952	Jan 1938	Aug 1935	Dec 1933	Nov 1935

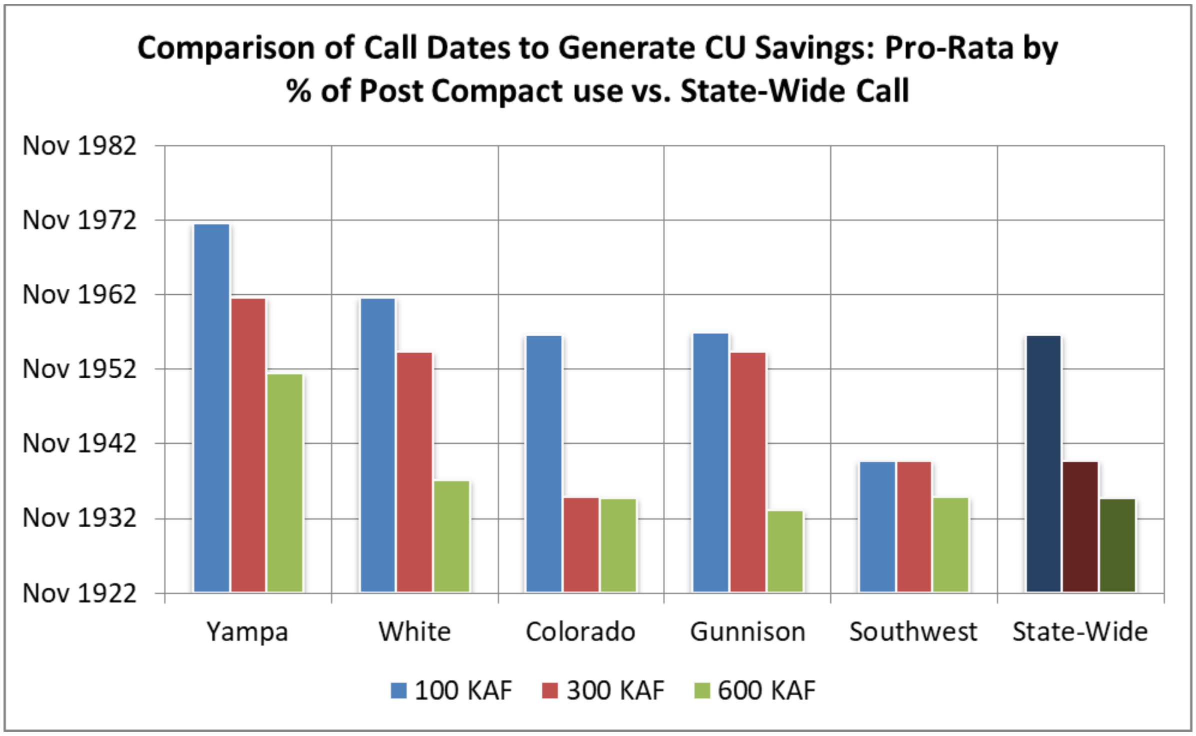

Figure 13. Graphical representation of data from Table 10.

4. Target Volumes on the Colorado Mainstem Pro-rata by in-basin and trans-mountain diversions (TMDs)

The Colorado mainstem accounts for 67.2% of post-Compact depletions, and the necessary call dates to achieve pro-rata curtailment volumes are shown above in Table 10 and Table 11. The timing of development of in-basin uses versus TMDs in this basin vary considerably, and most large TMD developments have rights dating from the mid-1930s to the late 1950s, which puts the pace of proportional development of post-Compact TMDs significantly ahead of the pace of development for in-basin post-Compact uses. For this analysis the target volume obligation of the Colorado mainstem is split into pro-rata volumes based on in-basin and TMD percentages of post-Compact use. This approach does not significantly change the call dates for the TMDs, but does provide some relief to in-basin users by allowing more of the junior in-basin uses to continue diverting.

Table 11. Required call dates and volumes when splitting the Colorado Mainstem obligation between in-basin and TMD uses.

Target Volume (acre-feet/yr)	Colorado	*In-Basin*	*TMDs*
	67.2%	*10.1%*	*57.1%*
100,000	67,186	*10,129*	*57,064*
	Jul 1957	Jan 1981	Jul 1957
300,000	201,557	*30,387*	*171,191*
	Nov 1935	Jul 1957	Aug 1935
600,000	403,114	*60,774*	*342,382*
	Aug 1935	Jul 1941	Aug 1935

Note that due to the large volumes diverted by the TMDs, one of those rights is typically the swing right during these targeted volumetric calls (i.e. it is partially called out in order to yield the target volume).

5. State Wide Target Volumes and call dates split by in-basin and trans-mountain diversions

This last analysis examines how a pro-rata distribution of curtailment would occur if the total volume of Colorado River water use is split between all in-basin uses – regardless of sub-basin – and all TMDs. Recalling that TMDs use 57.1% of all post-Compact water, the remaining 42.9% is consumed by in-basin post-Compact users.

Table 12. Required call dates and volumes when splitting total state-wide post-Compact obligations between in-basin and TMD uses.

Target Volume (acre-feet/yr)	West Slope	TMDs
	42.9%	57.1%
100,000	42,900	57,100
	Nov 1957	Jul 1957
300,000	128,700	171,300
	Jul 1952	Aug 1935
600,000	257,400	342,600
	Nov 1935	Aug 1935

The TMD call dates to yield their target volumes remain the same as when allocating volumes just within the Colorado mainstem (because their percent of the total does not change). The in-basin users are now all aggregated back together. As compared to the Colorado mainstem split above, the in-basin call would be deeper for mainstem users. Compare these in-basin call dates to the individual sub-basin call dates in Table 10 to see how this state-wide in-basin call compares to pro-rata calls. Basins that have more junior call dates in Table 10 than the West Slope call dates in Table 12 developed proportionally more slowly than the rest of the West Slope from the Compact date through the date listed in Table 12.

VI. Summary

This work refines and expands on previous Phases of the Risk Study. The results are intended to inform and support ongoing conversations regarding risk management opportunities in the Colorado River basin. The specific scenarios evaluated should not be viewed as the preferred or only approaches to a possible curtailment or any type of voluntary demand management allocation.

VII. Technical Appendices

A. Model Comparisons

As a first step towards developing the methodology for linking StateMod and CRSS, a series of comparisons between the demand and hydrology datasets of each model was made. Comparisons were also made between the Linked StateMod west-slope model and the individual basin models, to ensure that model results for the Linked Model were sufficiently representative of the individual model results.

1. StateMod Linked Model vs. Individual Basin Models

The Linked Model contains the vast majority of the components of each of the individual basin models, but array size limitations for inputs to StateMod required that some of the reservoir nodes, free river rights, and instream flow rights in the individual basin models be removed during the process of model linkage. Additionally, there were numerous undocumented differences apparent between the input settings of structures in the Linked Model as compared to the individual basin models, such as altered return flow percentages and locations. Rather than attempting to assess the impact of the individual differences between the models, the basin-wide results for simulated depletions were compared to assess the results of the aggregation of all differences in model input settings.

Average percent differences in depletions were found to be small, and the differences reflected higher levels of depletions in the individual models in most cases. Higher depletions in the individual models were expected, due to the removal of numerous reservoir nodes that was a documented part of the linkage process. The percent differences between the Linked Model and the individual models are listed in Table A- 1, where it can be seen that depletions in the individual Gunnison and Southwest models were sometimes lower than the depletions for those basins in the linked model. It was considered possible that these differences resulted from altered return flow percentages and locations. All of the other differences between the Linked Model and the individual models reflected higher depletions in the individual models, but the magnitude of the differences was low enough on average that the linked model was determined to be sufficiently similar to the individual models for use in analysis of state-wide calls. The changes made in support of linking the models were not considered to be improvements, so the individual model results are used in this study for all analyses not involving state-wide calls.

Table A- 1. Percent Differences in Depletions between Linked and Individual Models

Year	Yampa	White	Upper Colorado	Gunnison	Southwest	Total
1988	-1.4%	-2.1%	-1.0%	-0.3%	-2.3%	**-1.2%**
1989	-1.5%	-1.9%	-1.0%	-0.4%	-1.6%	**-1.1%**
1990	-1.7%	-2.0%	-1.1%	-0.5%	-6.1%	**-2.0%**
1991	-1.2%	-2.3%	-1.0%	-0.6%	-4.0%	**-1.6%**
1992	-1.5%	-2.2%	-1.1%	-0.5%	-0.7%	**-0.9%**
1993	-1.2%	-2.1%	-1.1%	-0.5%	0.3%	**-0.7%**
1994	-1.1%	-1.9%	-1.1%	-0.1%	-0.7%	**-0.8%**
1995	-1.6%	-2.5%	-1.1%	-0.5%	0.8%	**-0.6%**
1996	-1.5%	-2.1%	-1.3%	-0.2%	-2.0%	**-1.2%**
1997	-1.5%	-2.7%	-1.1%	-0.5%	0.2%	**-0.7%**
1998	-1.3%	-2.1%	-1.2%	0.1%	-2.1%	**-1.1%**
1999	-1.5%	-2.3%	-1.3%	-0.5%	-0.1%	**-0.9%**
2000	-1.6%	-2.0%	-1.2%	-0.4%	-5.5%	**-1.9%**
2001	-1.6%	-2.1%	-1.0%	-0.5%	-4.5%	**-1.7%**
2002	-2.9%	-2.0%	-0.9%	0.4%	4.3%	**-0.1%**
2003	-1.5%	-2.1%	-1.3%	-0.4%	-7.7%	**-2.3%**
2004	-1.3%	-2.1%	-1.2%	-0.5%	-7.1%	**-2.2%**
2005	-2.3%	-2.2%	-1.5%	-0.5%	0.2%	**-0.9%**
Minimum	-2.9%	-2.7%	-1.5%	-0.6%	-7.7%	**-2.3%**
Average	-1.6%	-2.2%	-1.2%	-0.3%	-2.2%	**-1.2%**
Maximum	-1.1%	-1.9%	-0.9%	0.4%	4.3%	**-0.1%**

2. StateMod vs. CRSS

Comparisons made between StateMod and CRSS consisted of both comparisons of simulated depletions by basin and comparison of simulated basin outflows. The CRSS results were summarized by basin for a model run carried out using the 2019 UCRC demand schedule for each year in an ISM simulation covering the years 1988-2015. Depletions in CRSS were slightly higher than those in StateMod, with an average difference of 112 Kaf/yr, as evident in Table A- 2, which compares the average annual depletions from the StateMod individual basin models to the average annual depletions from CRSS.

Table A- 2. StateMod vs CRSS Depletions (1988-2015, average, AF/yr)

Basin	StateMod	CRSS	% Difference
Yampa	196,982	214,908	9%
White	62,060	40,289	-35%
Upper Colorado	669,397	668,459	0%
Front Range	550,989	757,643	38%
Gunnison	575,267	616,105	7%
Southwest	500,717	383,259	-23%
StateWide	2,555,413	2,667,671	4%

Comparison of the basin outflows between the models revealed greater differences, and the differences in basin outflow have a more direct impact on the risk profile at Lake Powell, so tracking down the source of those differences was considered an important step in development of the model linkage. As a first step in tracking down the source of the differences, the model-simulated inflows to Powell for the Baseline Current Conditions simulation were compared to the CRSS model run that used repeating 2019 UCRC scheduled demands. Both sets of model-simulated inflows to Powell were compared to historical observations, which are calculated by USBR based upon releases from Powell and changes in storage. Exceedance frequencies for historical and simulated annual inflow to Lake Powell are presented in Figure A- 1.

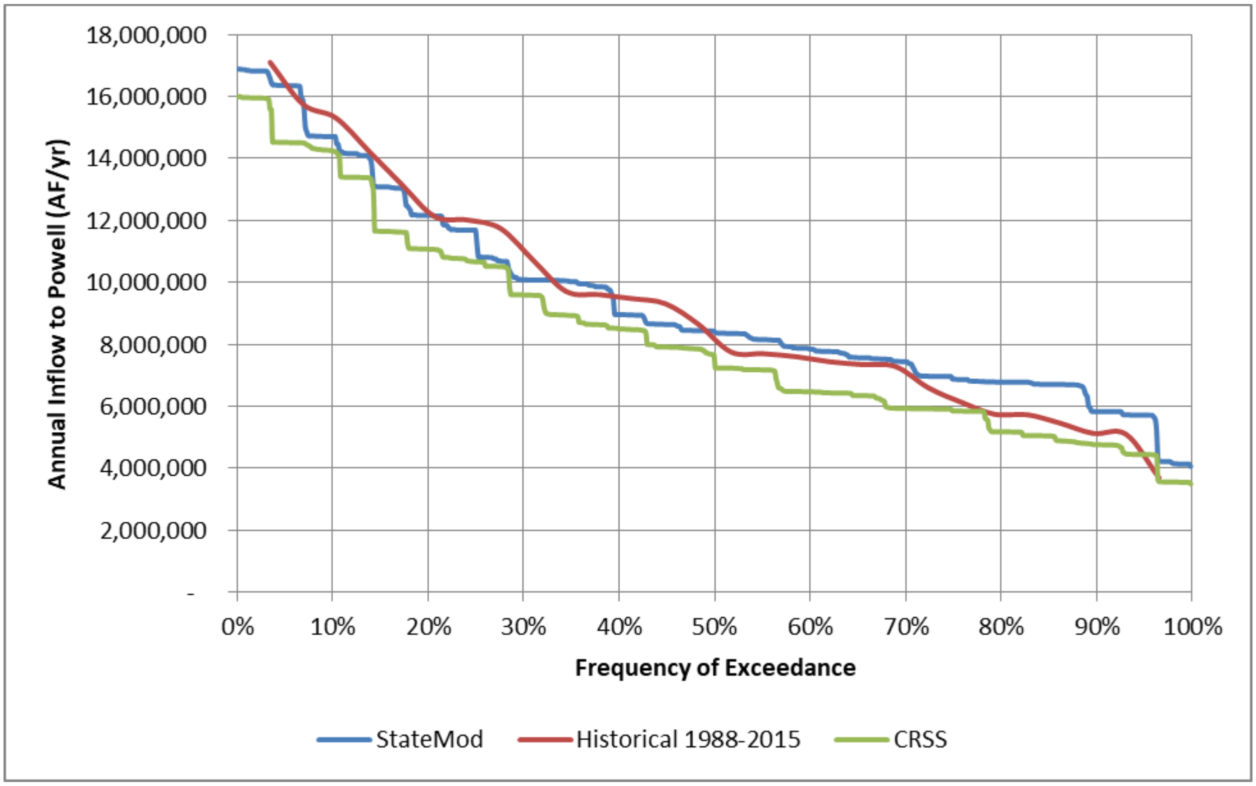

Figure A- 1. Exceedance Frequencies for Annual Powell Inflows, 1988-2015

The historical record includes higher high flows and lower low flows than the StateMod flows, and the flows from the CRSS simulation are consistently lower than both the historical observations and StateMod. The average annual inflows to Powell in the StateMod-linked Baseline Current Conditions simulation exceeded historical observations by 1.8% on average, while the inflows simulated through CRSS alone were 9.7% lower on average than historical observations. The StateMod and CRSS flows both include the CRSS representations of all components of the Upper Basin outside of the State of Colorado, but suitable modeling platforms to represent the other states of the Upper Basin other than CRSS were not available, so the remainder of the comparative analysis of basin outflows focused on gages at or near the Colorado State Line. Comparison of gage flow for the Southwest basins other than the Dolores was carried out through comparison at the San Juan near Bluff gage, which is outside of the state of Colorado, but was chosen for this analysis because its location downstream of the confluence of all seven major tributaries to the San Juan simplified the analysis significantly. Modeled CRSS depletions by New Mexico and Utah in the San Juan basin were subtracted from the gage data before comparing the gage data to StateMod simulation of state line flows.

Differences between historical observations and StateMod-simulated flows are listed in Table A- 3, where it can be seen that some basins have higher outflow in the simulations than historically observed flow, and some basins have lower simulated outflow than historical observations, with total simulated outflows from the State falling below historical observations by an average of 3%. The CRSS model tends to underestimate flows into Lake Powell when looking at the recent historical period. By using StateMod results for the State of Colorado's depletions, and CRSS for the other basin states, we are able to more closely replicate historical flows into Lake Powell. *Given the current data available for both models*, using them in this linked method appears to produce the most realistic results for Powell inflows, and hence is likely a better approach for basin-wide risk analysis.

Table A- 3. Historical Observed and Simulated State-Line Gage Flows (1988-2015, average, AF/yr)

Basin	Historical Gage	StateMod	% Difference
Yampa	1,380,056	1,317,973	-4%
White	465,817	502,395	8%
Upper Colorado	4,139,701	4,089,025	-1%
Dolores	399,015	416,278	4%
San Juan	1,292,928	1,139,437	-12%
Total	**7,677,516**	**7,465,108**	**-3%**

B. Index of Model versions, Website links, and Datasets

The modeling platforms used for this study include the following:

- Colorado River Simulation System RiverWare Model (CRSS)

    - CRSS version dcp_cmb_20171031
        - Version 2.9.0 of CRSS, modified to include the DCP
        - Modified as described below in Section **Error! Reference source not found.**
    - RiverWare version 7.4.3
    - Latest CRSS Model and Datasets Available Here:
        - http://bor.colorado.edu/Public_web/CRSTMWG/CRSS/
- CRDSS Linked Water Rights Allocation Model (StateMod Linked Model)
    - StateMod version 15.001
        - https://www.colorado.gov/pacific/cdss/statemod
- Individual West-Slope Basin Water Rights Allocation Models (StateMod Individual Models)
    - StateMod version 15.001
    - Baseline 2015 models for Yampa, White, Gunnison, and San Juan
        - https://www.colorado.gov/pacific/cdss/surface-water-statemod
    - Baseline 2009 CRWAS model for Upper Colorado
        - http://cwcb.state.co.us/technical-resources/colorado-river-water-availability-study/Pages/CRWASSupportingDocuments.aspx

C. Future Demands Dataset Development

Demands for the "future conditions" scenarios were developed through cooperation with Basin Roundtable technical representatives and the staff from the two Conservation Districts. The purpose of the future condition demands was solely to examine how an increment of additional depletions could impact the risk profiles at Lake Powell and Lee Ferry. The identified increases in consumptive use were a combination of additional use of existing rights/projects as well as new uses. When available, Programmatic Biological Opinion (PBO) studies formed the basis for "allowable" growth that could be achieved without any Federal re-consultation requirements. PBO data were used to develop future demand data for the Yampa, Gunnison, and Colorado mainstem basins. The southwest basin (San Juan, Dolores, and various tributaries), and the White basin future demands were developed primarily by in-basin BRT representatives with input from River District and Southwestern District staff. A total of 26 future uses were identified, consisting of agricultural, municipal, and industrial uses. The total increase in demands across all Colorado basins under the future growth scenario total 384 Kaf, or an increase of 13.7% over current demand levels. Actual modeled depletions from these demands averaged 11.5%. Note that Upper Basin and Colorado's consumptive uses have remained relatively flat for the last 25+ years. The demands identified for the future conditions scenario are not an endorsement of, or proposal for, any specific future use. They are simply illustrative of a range of possible future use scenarios and are intended to illustrate the risks associated with increased consumptive use. Actual growth in demand should it occur, and the timing of that development, may look very different than the future demands postulated for this modelling exercise.

The demand for these future use depletions was not always fully satisfied, resulting in shortages in some cases, and some of the future depletions resulted in shortages to existing uses, where the future uses corresponded to conditional water rights with senior priorities relative to some existing uses. The average depletions simulated for these future uses, and the average change in depletions by basin are listed in Table C- 1**Error! Reference source not found.**, along with the corresponding input demands, for the years 1988-2015.

Table C- 1. Future Use Demands and Depletions

StateMod Linked Model	Future Use Depletions (AF/yr)		
	Average Yield of New Depletions	**Average Increase in Basin Depletions**	**Input Demand**
Yampa	29,506	29,485	30,104
White	61,839	61,787	65,000
Upper Colorado & Front Range	86,077	82,425	120,450
Gunnison	31,053	31,100	37,900
Southwest	81,104	82,355	130,084
StateWide	**289,578**	**287,153**	**383,538**

The input demand of these future uses represents a 13.8% increase over current demands, and the resulting depletions averaged 11.4% higher than current levels over the years 1988-2015. Refinements in implementation of the future demands could raise the simulated depletions closer to the increase in demand, but the simulated increase in depletions of 287,153 AF already exceeds the maximum increase from 2019 demands included in the 2007 UCRC demand schedule by 170,000 AF, so further refinement was considered to be beyond the scope of Phase III and unnecessary for this analysis.

1. Future Demand Monthly Distributions

Depletion amounts specified by the PBOs and by BRT/District representatives were provided in annual amounts, which were disaggregated through application of typical monthly patterns to develop realistic model inputs for StateMod. Future demands in each basin were categorized as one of the following classifications, and a unique monthly disaggregation pattern was developed for each classification:

1. **Industrial Direct Diversion**
2. **Agricultural Direct Diversion**
3. **Municipal Direct Diversion**
4. **Trans-Basin Export**

The pattern of monthly demands used to disaggregate annual demands for Type 1, Industrial Direct Diversion demands, was a uniform monthly pattern that reflects typical diversions for industrial uses such as power production and manufacturing. This uniform monthly distribution of demands also reflects the uncertainty associated with the water use patterns of industrial uses, which do not necessarily follow a predictable seasonal pattern.

The pattern of monthly demand for Type 2, Agricultural Direct Diversion demands, was developed through analysis of diversion records for the Red Top Valley Ditch, which has a long and continuous record of direct diversions for irrigation of pasture grass from the Upper Colorado basin. Diversions by the Red Top Valley Ditch have historically spanned the months of May – August, with an average of 9.1% of the annual diversions occurring in May, 52.2% occurring in June, 38.3% occurring in July, and 0.3% occurring in August, and those percentages were used to disaggregate annual demands for the future uses classified as Type 2), Agricultural Direct Diversion demands.

The pattern of monthly demand for Type 3), Municipal Direct Diversion Demands, was set using a combination of the Type 1) and Type 2) demand patterns, to represent the conceptual understanding that municipal demands consist of both relatively-steady indoor demands, and seasonally-varying demand for outdoor water use. The total amounts of indoor and outdoor water use were assumed to be equal on an annual basis.

Monthly demands for future uses associated with trans-basin diversions were all set according to a uniform pattern extending only across the months of April-July. The pattern for these demands did not correspond with the eventual use, as did the direct diversion demands for types 1-3, because the trans-basin diversion demands include significant regulation through storage in East-Slope reservoirs. The uniform pattern across the months of May-July was selected in recognition of the typically higher flows in those months, during runoff.

2. Basin-Specific Future Demand Details

The future demands in each basin are listed in Table C- 2 through Table C- 6. The total annual demand for each future use is listed, along with the use type, priority date, and notes about implementation in StateMod, including the node on which the future use demand was placed. Some future use demands were implemented on nodes that were added to the river network, and these additional nodes are identified by asterisks, which reference table footnotes that describe the location of the new node in the river network of that basin.

Table C- 2. Yampa Basin Future Use Demand Details

Use Type	Annual Demand (AF)	Priority Date	Notes
Municipal	9,899	10/1/2013	District 44 Future Depletions (44_FDP001) node
Industrial	15,403	9/30/1961	Hayden Station (440522) node
Agriculture	4,802	9/30/1961	Oxbow Agriculture (44_Oxbow*) node
Total	30,104		Future Uses based upon PBO

* 44_Oxbow is a direct diversion node that was added between the 442214 and 440694 nodes of the Linked Model

Table C- 3. White Basin Future Use Demand Details

Use Type	Annual Demand (AF)	Priority Date	Notes
Municipal	2,707	10/1/2013	District 43 Future Depletions (FUD001) node
Industrial	62,293	10/1/2013	District 43 Oil Shale Direct (43_OilDem) node
Total	65,000		Future Uses based upon YWG-BRT Modeling

Table C- 4. Upper Colorado Basin Future Use Demand Details

Use Type	Annual Demand (AF)	Priority Date	Notes
Trans-mountain	28,500	6/24/1946	Roberts Tunnel (364684) node: Denver Water Blue River System Buildout
Trans-mountain	25,500	6/6/1969	Adams Tunnel (514634) node: Windy Gap Firming Project
Trans-mountain	14,450	7/9/1934	Moffat Tunnel (514655) node: Denver Water Moffat System Expansion
Trans-mountain	14,000	2/7/1956	Homestake Tunnel (374614) node: Eagle River MOU Project (Homestake Partners)
Municipal	7,000	12/14/1987	New WS_FDaGS* node: W.S. depletions above Glenwood Springs
Municipal	28,000	7/29/1957	New WS_FDbSP** node: W.S. M&I depletions below Shoshone
Trans-mountain	3,000	6/24/1946	Roberts Tunnel (364684) node: CRCA Next Steps Project
Total	120,450		Future Uses Estimated by Colorado River District Staff

*WS_FDaGS is a direct diversion node that was added between the 09070500 and 950500 nodes of the Linked Model

** WS_FDbSP is a direct diversion node that was added between the 530584 and 09072500 nodes of the Linked Model

Table C- 5. Gunnison Basin Future Use Demand Details

Use Type	Annual Demand (AF)	Priority Date	Notes
Agriculture	12,200	11/1/1905	East Canal (410520) node: Dallas Creek Project
Municipal	22,200	11/12/1957	District 62 Subordination (62USUB_M) node: Upper Gunnison Subordination
Municipal	3,500	10/1/2013	District 62 Yield (62U_MY) node: New Depletions
Total	37,900		Future Uses from Gunnison PBO

Table C- 6. Southwest Basins Future Use Demand Details

Use Type	Annual Demand (AF)	Priority Date	Notes
Municipal	1,100	4/19/1962	(WS_SJRHP*) node: San Juan River Headwaters Project
Municipal[12]	1,856	10/1/2013	(78_ADS004) node: Piedra Basin Incremental Development
Municipal[12]	14,597	10/1/2013	(31_ADS006) node: Pine Basin Incremental Development
Municipal	8,205	3/21/1966	(CO_ALP) node: Animas La Plata Project Future Uses
Municipal	16,234	12/31/2006	(WS_ARiD**) node: Animas Recreational In-channel Diversion
Agriculture	24,226	3/21/1966	(WS_SWCD***) node: SWCD Project Water Rights
Municipal[12]	26,976	10/1/2013	(71_ADS019) node: Dolores Basin Incremental Development and Reservoir Expansion
Agriculture	21,250	1/16/1967	(WS_SMP****) node: San Miguel Project
Agriculture	4,502	1/1/1985	(34_UMU) node: 2060 Scenario A Demands[13]
Agriculture	11,138	3/2/1868	(31_SUIT) node: 2060 Scenario A Demands[13]
Total	130,084		Future Uses Estimated by Southwest District Staff

* WS_SJRHP is a direct diversion node that was added between the 29_ADS002 and 09342500 nodes of the Linked Model
** WS_ARiD is a direct diversion node that was added between the 301902_Dwn and 30_ADS007 nodes of the Linked Model
*** WS_SWCD is a direct diversion node that was added between the four upstream nodes (09357500, 304662, 09359000, and 300523) and downstream node 09359500 of the Linked Model
**** WS_SMP is a direct diversion node that was added between the 601381 and 601381_Dwn nodes of the Linked Model

3. Other Upper Basin Future Demands

It was also necessary to develop future demands data for Wyoming, Utah, and New Mexico for use in CRSS. The intent was to increase those states' demands by the same percentage that those in Colorado were increased within the StateMod Model. To achieve this, the percentage increase in demands computed for Colorado and used in StateMod (13.8%) was compared to the increases in demands over current conditions from the 2007 UCRC demand schedule for Wyoming, Utah, and New Mexico. Forecast demands from that schedule show an increase of 13.6% for 2037. The 2037

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[13] These demands were modeled using uniform monthly demand across April-July, which was found through calibration to increase yield in comparison to the typical municipal pattern

[14] Demands for the Southern Ute and Ute Mountain Ute nodes were set as the difference between Current and 2060 Scenario A demands from the Colorado River Basin Ten Tribes Partnership Tribal Water Study (https://www.usbr.gov/lc/region/programs/crbstudy/tribalwaterstudy.html)

demands for those States were then fixed for all simulations in CRSS as the “future demands” condition.

D. 2006-2015 Data Extension for StateMod

In order to fill in the years 2006-15, annual flow at the Colorado-Utah state line in the mainstem of the Colorado River was compared to the years 1909-2005, and the year with the closest total annual volume was selected. Table 2 lists the years and percent differences in flow, calculated by subtracting the observed flow in the recent year from flow in the surrogate year.

Table 13. Surrogate Years for StateMod Extended Stress Test Simulation

Recent Year	Surrogate Year	% Difference in Flow
2006	1925	-0.7%
2007	1991	0.5%
2008	1938	-0.9%
2009	1971	-0.1%
2010	1991	0.3%
2011	1917	0.0%
2012	1981	3.0%
2013	1940	0.1%
2014	1948	-0.2%
2015	1944	0.1%

The data from each surrogate year was then appended to the linked model input datasets, using a script developed in the R computing language. The following files were extended in this manner:

- Wslope.ddm
- Wslope.iwr
- Wslope.ifm
- Wslope.tar
- Wslope.rim
- Wslope.ipy