Summary of CCRS White Paper 6

Alternative Management Paradigms for the Future of the Colorado and Green Rivers

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Our ability to sustainably manage the Colorado River is clearly in doubt. The Bureau of Reclamation's 2012 Water Supply and Demand Study demonstrated the precarious balance that currently exists between water supply and the amount consumptively used by society. A future with either declining water supplies or additional consumptive uses will undoubtedly upset this balance. This balance is threatened, because:

- **Climate change science predicts that watershed runoff will decline due to increased evapotranspiration from rising temperatures;** *and*
- **Water users, especially in the Upper Basin, aspire to increase consumptive uses by developing new projects.**

This white paper describes how declining runoff and increased consumptive use will impact water supplies and ecosystems, and also considers how these risks can be addressed.

The objective of the White Paper is to encourage wide-ranging and innovative thinking about how to sustainably manage the water supply, while simultaneously encouraging the negotiators of new agreements to consider their effects on ecosystems. To achieve this objective, we introduce a wide variety of *alternative management paradigms* that offer significant modifications or entirely new approaches to the status quo. Because of the magnitude and severity of the impending challenges that the basin faces, we intentionally describe and evaluate approaches that some might consider radical due to existing and assumed physical or management constraints. However, all infrastructural and institutional constraints on the Colorado River have been developed over only the last century, and to assume that decisions must remain bound by such constraints may limit our ability to identify innovative solutions needed to meet the challenges ahead. The goal of this white paper is to encourage conversation and consideration of new management concepts that will better meet future needs.

The Law of the River can and must be adapted to meet the challenges of the future. For a hundred years, the *Law of the River* has defined how the Colorado River is managed and allocated among its multiple uses, however, this *Law* is not static nor singular. The *Law of the River* is comprised of a complex suite of interstate compacts, a bi-national treaty and its minutes (amendments), Supreme Court decrees, federal and state laws, administrative agreements, and records of decision linked to numerous environmental impact statements. Institutional and political divisions, such as state and national boundaries and the distinction between the Upper and Lower Division states that formed the structure of many

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allocation agreements, yet even those divisions are relatively new constructs. Throughout its development, the *Law of the River* has been amended and adjusted to adapt to changing hydrologic conditions, evolving demands for water, political influence, and shifting societal values. Traditionally, the *Law of the River* has been revised in incremental steps that make adjustments driven by immediate crises, as was the case when the onset of the Millennium Drought in 2000 provoked the development of the *Interim Guidelines for Lower Basin Shortages and Coordinated Operations of Lake Powell and Lake Mead* in 2007 and *Minute 319* of the bi-national treaty between the United States and Mexico in 2012. The persistence of the Millennium Drought provoked *Minute 323* in 2017 and the *Drought Contingency Plans* in 2019.

A gradual and incremental approach to adaptation, however, is unlikely to meet the challenges of the future. If the Millennium Drought, which has now persisted for more than two decades, has become the 'new normal', or if the progressive decline of runoff resulting from climate change becomes even more apparent, major structural changes to water management in the basin will be urgently required. As a result of these emerging and uncertain risks, a new discussion about the *Law of the River* has begun to identify a more sustainable and adaptive approach to manage the Colorado River. Sustainability will inevitably require governance that can incorporate such an approach into the *Law of the River*.

Sound planning for the future can only occur by developing management strategies that are applicable or adaptable to a wide range of possible future hydrologic scenarios. The historical record for the Colorado River provides a useful but limited guide for the future. Estimates of flows that occurred between 1906 and 2018 show an average annual natural flow at Lee Ferry of 14.8 million acre-feet per year (maf/year), but this historical window is both short relative to stream flows estimated from tree-rings and unlikely to be indicative of what the future will hold, particularly when considering the implications of a warming and drying climate. Even within this historical record, the variations in watershed runoff have been substantial. For example, a *pluvial period* that was recorded from 1906 until 1930 resulted in an estimated 17.7 maf/year of annual natural flows at Lee Ferry. In comparison, the average natural flows from 2000-2018 are estimated to have been 12.4 maf/year. Today, we recognize that the *pluvial period* was unusually wet, and no indication exists that flows of a similar magnitude will reoccur in the future. Water planners must acknowledge that the recent hot and dry conditions of the Millennium Drought may indeed be much more indicative of the future rather than those that occurred a century ago.

Other plausible hydrologic future conditions are also considered in this study. The 25-year 'Mid-20th Century' Drought that occurred from 1953-1977 resulted in estimated natural inflows at Lee Ferry of 12.9 maf/year. Even more critical than the Millennium or Mid-20th Century droughts, the reconstructed flows from tree-ring analyses reveals a 'Paleo-tree Ring Drought' that occurred between 1576 and 1600 which resulted in estimated natural flows at Lee Ferry of 11.8 maf/year. Applying the methods of Salehabadi et al. (2020), we simulated future conditions that replicate the Millennium Drought, the Mid-20th Century Drought, and the Paleo-tree Ring Drought. Conditions similar to these historically severe droughts certainly can be expected to reoccur in the future. Furthermore, the situation could be worse when considering the implications of climate change. Flows during 2000-2018 were approximately 18% less than the

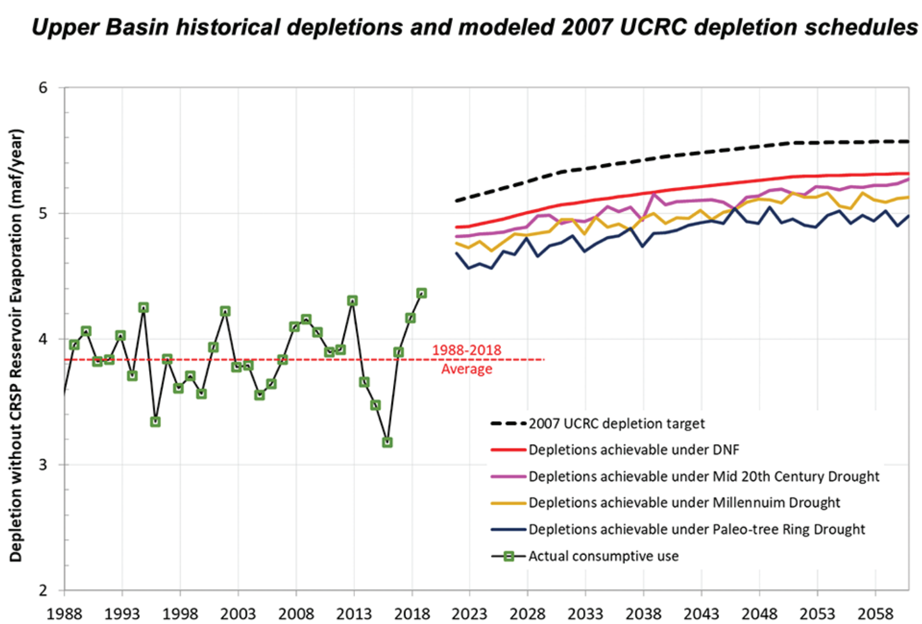

Figure ES-1. The 2007 UCRC future depletion schedule (black dashed line) and predicted average total Upper Basin depletions met which are unconstrained by compact requirements using the current configuration of the CRSS model with different hydrologic scenarios. Historical Upper Basin consumptive uses since 1988 are shown (green squares). The red dashed line shows the stable average Upper Basin Use from 1988 to 2018. The difference between the black dashed line and any of the color lines reflects 'shortages,' in the sense that UCRC future depletion schedules are not achieved. Not even Reclamation's DNF hydrologic scenario based on 1906 to 2018 conditions can be fully satisfied.

20th century average (1906-1999), and this downward trend is likely to continue as increasing temperatures cause more evapotranspiration and the aridification of the landscape.

To evaluate the implications of climate change, we developed hydrologic scenarios based on the proportional reduction in runoff that occurs in response to warming temperatures (Udall, 2020). We considered temperature projections from two well-established Representative Concentration Pathways (RCP 4.5 and RCP 8.5) defined by the Intergovernmental Panel on Climate Change (IPCC), and analyzed reductions of flows ranging from a 3% to a 10% decrease in runoff for each degree Celsius of warming. By doing so, we could evaluate the effects of aridification and its implications on the sustainable management of the Colorado River.

No one can know precisely which hydrologic condition lies ahead in the uncertain future. We find, therefore, that **the Colorado River water-supply system is most appropriately evaluated using both scenarios of prolonged drought and scenarios of climate warming-induced runoff decline, such as undertaken in our study.**

The risks of drought and climate change are both uncertain and potentially severe; however, our ability to control these futures is extremely limited compared to our ability to control the future demands for water. A significant threat to sustainable management of the Colorado River's water supply would occur if current projections of future consumptive uses materialize. Such increases would significantly exceed all projections of available supply. However, **evidence suggests that the projections made by the Upper Colorado River Commission of future water use are unrealistically high** (Kuhn, 2020; Wang et al, 2020).

Virtually all the increase in water consumption in the future is projected to occur in the Upper Basin, where consumptive water use has remained essentially unchanged since 1988 and averaged 3.86 maf/year. Our findings are based both on observations of the past and the likelihood of future expansion of irrigated agriculture, the reduction of coal-fired power production, the capacity of existing trans-basin diversions, and the regulatory impediments to building new trans-basin diversions. The Bureau of Reclamation's Colorado River Simulation System (CRSS) reveals that the 2007 UCRC future depletion schedules cannot be reliably met under any of the hydrologic conditions considered in this study (Figure ES-1), including Reclamation's *Direct Natural Flows* that considers all years from 1906-2018 to be equally probable of reoccurring, despite the 20th century pluvial period and ongoing aridification. Simulations of Upper Basin consumptive use under the drought scenarios suggests additional significant shortfalls.

If the Upper Basin were to not consume additional water beyond that which occurs now, the risks and impacts of future droughts and climate change would be substantially ameliorated. If the 2000-2018 period (i.e. Millennium Drought) is representative of future hydrologic conditions and the increasing 2007 UCRC future depletion schedules are assumed, the combined storage volumes of Lake Powell and Lake Mead will decrease to nearly 5 maf within 25 years. However if Upper Basin water use did not increase, the reservoir storage would decline but stabilize at 15 maf (Figure ES-2). If future hydrologic conditions are similar to the 1988-2018 period and Upper Basin water use did not increase, then the reservoir storage would remain similar to what it is today.

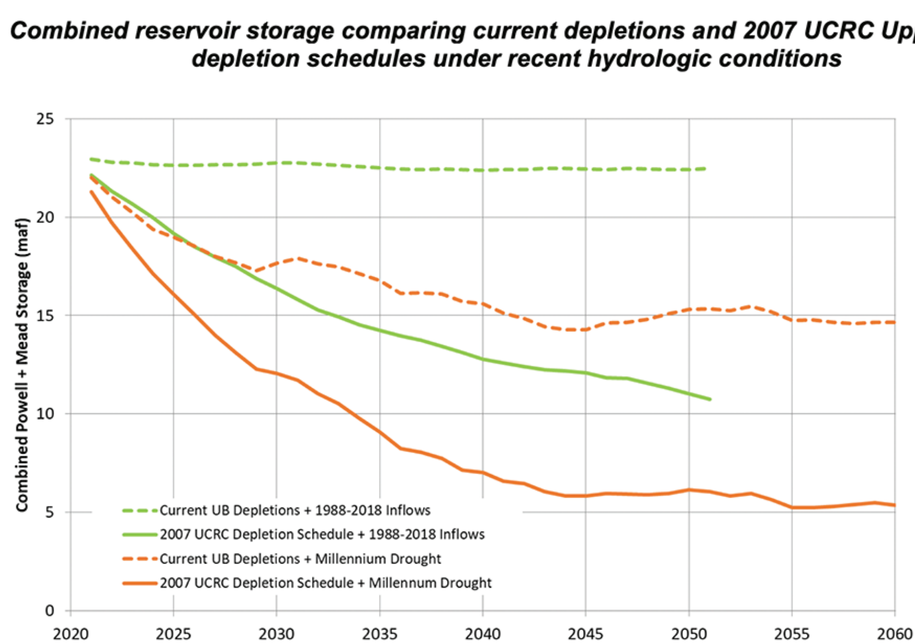

Figure ES-2. End-of-year combined Lake Powell and Lake Mead reservoir storage under the Stress Test (1988-2018) and Millennium Drought (2000-2018) hydrologic conditions, and considering the implications of the 2007 UCRC schedules (solid lines) and no increases in depletions (dashed lines).

It is unwise to develop water-supply management plans based on unrealistic assumptions for future consumptive water use in the Upper Basin. Use of these aspirational projections create the impression that Compact delivery violations, very low Lake Powell and Lake Mead storage contents, and greater Lower Basin shortages are inevitable. Such estimates mislead the public about the magnitude of the impending water supply crisis and make identifying solutions to an already difficult problem even harder.

To provide a menu of provocative ideas, we briefly describe 24 alternative management paradigms. These ideas represent major changes in the management of the Colorado River's water supply which can be broadly grouped into three categories:

- **Changes in the rules of water-supply allocation and/or accounting**
- **Changes in the operating rules of existing infrastructure**
- **Changes in the infrastructure**

Some alternatives represent relatively simple adaptations of management practices, while others suggest major changes to the way water is accounted for and allocated. Still others reflect physical changes to the system that would require a substantial amount of time and investment to implement. These ideas are presented so that water-supply stakeholders, scientists, engineers, non-government organizations, and tribal interests might consider them for further analysis, and we hope that our analyses of these alternatives provoke others to identify many more alternative paradigms and management strategies.

In this study, we analyzed the effectiveness of five alternative management paradigms using the CRSS modeling tool, and when appropriate, a reservoir temperature release model. The combination of these tools allowed us to evaluate the potential implications of these alternatives on existing water supplies, power production, and key ecosystem drivers of river flow regimes and temperature conditions.

The combined storage contents of Lake Powell and Lake Mead should be the primary metric for water management in the Colorado River. Presently, the pool elevations of Lake Powell and Lake Mead are the primary metrics used to manage the river and convey information to the public regarding the status of water supplies. Progressively more severe curtailments in consumptive water use in the Lower Basin are initiated at progressively lower elevations of Lake Mead. The magnitude of water released from Lake Powell is based on the elevations of Lake Powell and Lake Mead. The institutional divisions in accounting for and reporting water conditions between the Upper and Lower Basin and the non-linearity of relationships between pool elevation and storage volume obscure the public's understanding of the current condition in the basin and convolutes management responses to critical situations. The use of a new metric of **total water stored in Lake Mead and Lake Powell focuses attention of the public and of managers on the status of the actual resource being managed – the stored available water supply.** While this approach may challenge existing perspectives of Compact obligations between the Upper and Lower Division States, it recognizes that all water which enters the Lake Powell and Lake Mead system is effectively used for the same purpose – supplying water to the Lower Basin – and these two water storage sites are essentially

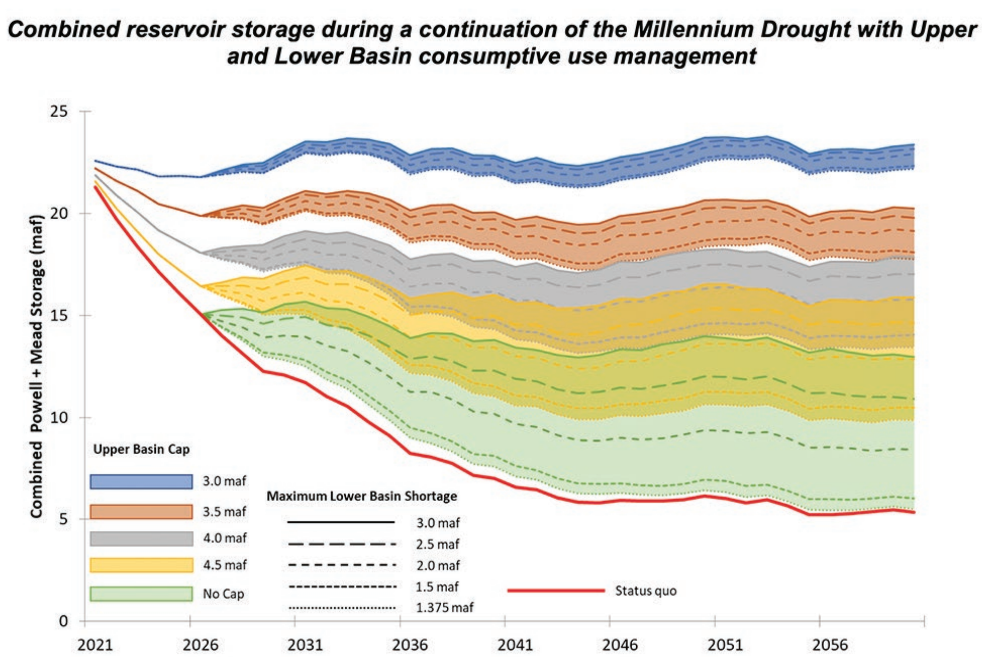

Figure ES-3. End-of-year combined Lake Powell + Lake Mead storage using hydrologic conditions sampled from the Millennium Drought (2000-2018) demonstrates the effects of a range of Upper Basin demand 'caps' along with a range of Lower Basin maximum shortages triggered when the combined storage falls below 15 maf. The status quo uses the 2007 UCRC Upper Basin schedule and elevation-based shortage triggers.

one facility divided into two parts by a 255-mile long bedrock gorge – the Grand Canyon.

To illustrate the critical role the metric of combined storage could play in guiding future management of the Colorado River, we examine the sustainability of the river under a range of hydrologic scenarios and a range of future consumptive water use. The combined storage metric allowed us to define sustainable water-supply management as the maintenance of relatively constant storage volume in the two reservoirs. We used CRSS to evaluate sustainability under different assumptions of future Upper Basin consumptive water use (called 'caps') and future reductions in Lower Basin water uses (called 'shortages').

The Colorado River can be sustainably managed only if consumptive water uses are matched to available supplies, which will require Upper Basin limitations and substantially larger Lower Basin reductions than are currently envisaged. Sustainability is illustrated using two very realistic future hydrologic scenarios of 1) a continued persistence of the Millennium Drought (i.e. a 'new normal' in Figure ES-3) and 2) an increased warming according to the RCP4.5 with a 6.5% decrease in runoff for each degree Celsius of temperature increase (i.e. a 'new abnormal' in Figure ES-4). Each figure demonstrates a range of different limits of Upper Basin consumptive water use, alongside an increasing range of possible Lower Basin shortages.

The Upper Basin uses range from the 2007 UCRC consumptive use projections to a 'cap' of 3.0 maf/year. The Upper Basin 'caps' of 3.5 maf/year and 4.0 maf/year bracket the average consumptive water use in the Upper Basin since 1988. In this analysis, we assumed a range of reductions in Lower Basin water use between 1.375 and 3 maf/year, invoked as the combined reservoir storage reaches a critical remaining volume of 15 maf. The relatively flat color bands beyond 2026 suggest the ability to maintain water storage in Lake Powell and Lake Mead during a 40-yr period under these hydrologic conditions. The sloping color bands suggest that a magnitude of future water use that would not be sustainable. The status quo represents the result of current operations, the aspirational Upper Basin demand projections, and the existing commitments for Lower Basin shortages.

If the conditions of the Millennium Drought become the 'new normal' (Figure ES-3), the Upper Basin maintains its recent usage patterns with a maximum withdrawal of 4.0 maf/year, and the Lower Basin does not increase their commitment to reducing shortages, the combined reservoir storage would fall to approximately 13 maf during the next 25 years, however, the combined reservoir storage would plateau around 17 maf if the Lower Basin increased their shortage volumes to 3 maf/year.

However, if flow declines of 6.5% for each degree of warming were to occur (Figure ES-4), the decline in average reservoir storage would persist downwards and unabated at approximately 0.25 maf/year under all demand management strategies. **In the case of these reasonable and probable climate change conditions, aggressive commitments to water conservation by both the Upper and Lower Basins will become critical in the next 25 years to maintain the combined reservoir storage greater than 15 maf.** With this alternative management paradigm focused on the use of combined storage as metric for shared demand

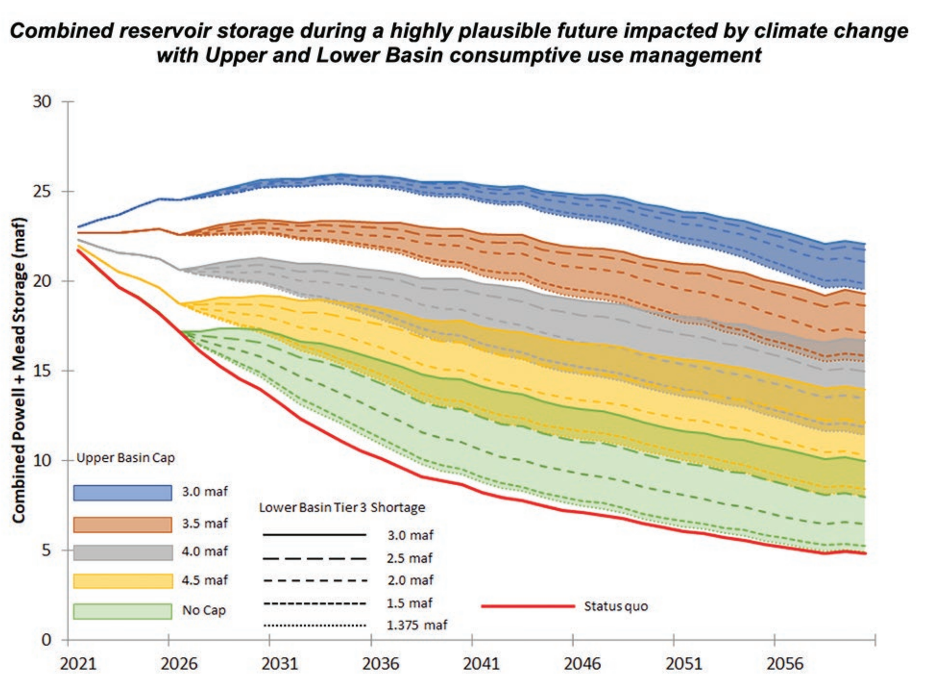

Figure ES-4. End-of-year combined Lake Powell + Lake Mead storage using the RCP45_065 hydrology (i.e. IPCC Representative Concentration Pathway 4.5 with 6.5% decrease of flow with each degree Celsius of warming) demonstrates the effects of a range of Upper Basin demand 'caps' along with a range of Lower Basin maximum shortages triggered when the combined storage falls below 15 maf. The status quo uses the 2007 UCRC Upper Basin schedule and elevation-based shortage triggers.

management, the figures explicitly do not consider the implications of an element of the 1922 Colorado River Compact that may require the Upper Basin to release additional water for the Lower Basin (i.e. a *Compact Call*). Other portions of this White Paper do however address this topic in detail and **reveal substantial risks to the Upper Basin resulting from a Compact Call under decreasing water supplies and increasing consumptive uses.**

Additional analyses of *alternative management paradigms* reveal critical findings regarding some management solutions that have been popularized. Policies that preferentially store water in one reservoir over another – i.e. a *Fill Mead First* or a *Fill Powell First* management paradigm – would not make a significant impact on downstream water supply security. The savings in evaporation would be minimal. The results also indicate that river temperatures in the Grand Canyon would be substantially higher using the Fill Mead First management alternative, and the Fill Powell First alternative would not significantly reduce the likelihood of higher water temperatures released from Powell during drought conditions.

This report also demonstrates that reoperation of Glen Canyon Dam to better match the natural pattern of a spring snowmelt flood is possible, but the reliability of stable hydropower generation would be significantly affected. Such a plan could only be implemented if matched by sediment augmentation, because sediment loss in the Grand Canyon would be a substantial concern. Furthermore, we also show the relatively minimal impact that increased backup releases from Flaming Gorge Dam would have on the sustainability of the water supplies for the Lower Basin.

All these alternative management paradigms point to a common result. **Changes in reservoir operations will not solve the supply-demand imbalance.** To sustainably manage the Colorado River, water managers will have to **match demands to continuously changing supplies** using new forms of demand management. The *Law of the River* will need to be adapted more dynamically than ever before.

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