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Adaptively Managing Lake Powell Releases to Respond to Reservoir Inflow and Evaporation

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Adaptively Managing Lake Powell Releases to Respond to Reservoir Inflow and Evaporation

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Abstract

Across the Western U.S., reservoir levels are declining towards protection elevations because of aridity amplified by long-standing operations that release more water than inflow. This paper has the purpose to sketch the effects of reservoir operations that release less water than inflow and evaporation. We use the case of Glen Canyon Dam/Lake Powell on the Colorado River, U.S.A. We programed a new rule in the trusted basin simulation model maintained by the U.S. Bureau of Reclamation. The rule releases 95% of inflow in each time step. The 5% reduction is typically greater than reservoir evaporation. Lake Powell levels stabilize and recover in a few years across a range of assumptions for hydrology and upstream diversions. There remain challenges technically and politically to implement into existing operations the idea to release less water than inflow and evaporation.

Keywords: Colorado River Simulation System (CRSS), aridification, river basin management, power pool elevation, 3490 feet, drought.

1. Introduction

The Colorado River Basin (CRB) is an important asset to millions of people and farming interests throughout the south-western United States (US), Native American tribal communities, and Northern Mexico (Salehabadi et al., 2022; K. Wheeler et al., 2021). More than 40 million people depend on the Colorado River to secure their municipal and industrial water supplies. The CRB is divided into the Upper Colorado River Basin (UCRB) and the Lower Colorado River Basin (LCRB) based on Colorado River Compact of 1922 (Castle & Fleck, 2019). Water inflows from the UCRB that represent more than 80% of the Colorado River flow are collected downstream in Lake Powell behind the Glen Canyon Dam and then released downstream based on pre-defined schedules to fulfill water requirements of the LCRB. Released water from Lake Powell is collected upstream of the LCRB in Lake Mead that is formed upstream of Hoover Dam. However, the CRB has been experiencing drought conditions since the turn of the century, resulting in significant declines in the Colorado river flows and critically low reservoir storage levels. Unprecedented high temperatures (0.9 °C above the 1906-1999 average) in the CRB were found responsible for at least one-sixth to one-half of the observed loss in the Colorado River water flow (Udall & Overpeck, 2017). Because of that, new ideas and guidelines have been explored by water managers and stakeholders to help mitigate the impacts of the ongoing drought and optimally manage the Colorado River flow and Lake Powell and Lake Mead water storage. For instance, water managers responded with 2007 interim guidelines and 2019 drought contingency plans that tied reductions in historical water allocations to declining Lake Powell and Lake Mead water levels (Castle & Fleck, 2019). Reservoirs continued to draw down towards levels where Glen Canyon and Hoover Dams no longer generate hydropower or safely release water through existing outlet structures. In 2021 (Allhands, 2021; Hager, 2021) and 2022 (Trujillo, 2022), additional emergency operations were carried out to reduce withdraws from Lake Mead by an additional 500,000 acre-feet per year for 2 years. These emergency operations reduced 2022 to 2023 Lake Powell releases by 480,000 acre-feet over the annual volume specified by the interim guidelines and released an additional 500,000 acre-feet from headwaters reservoirs to prop up Lake Powell. In Summer 2022, the U.S. Bureau of Reclamation challenged the 7 CRB states to reduce basin water uses by 2-to-4-million-acre feet to protect system infrastructure from further draw down due to natural and human factors (USBR, 2022). In response to that, the UCRB adapted a water conservation program called the "Pilot System Conservation Program" for testing a wide range of water conservation concepts that may reduce water use in the basin and help maintain the Colorado River flow (UCRC, 2022; USBR, 2021). Discussions continue to identify emergency operations and longer-term, more equitable and sustainable basin water uses that can replace interim guidelines that expire in 2026.

In line with the effort to help mitigate the impacts of the ongoing drought on the Colorado River flow and its reservoirs, this study aims to provide useful insights on the response of Lake Powel water storage to linking Lake Powel outflow with the hydrology (water inflows) of the UCRB as an alternative reservoir operation to using pre-defined discharge schedules. The water balance model shown in Equation 1 explain that the water available to be released from Lake Powell can mainly come from Lake Powell storage and water inflows from the UCRB. As the storage of Lake Powell has been declining over the past years due to drought-caused declines in the natural inflows from the UCRB, water inflows from the UCRB to Lake Powell have become a larger portion of the water available to be released from Lake Powell to the LCRB. These inflows are variable and could draw down Lake Powell reservoir to its dead pool if was not considered when designing future water releases. Controlling Lake Powell's discharge schedules using the hydrology of the UCRB provides useful insights on an alternative reservoir operation especially during intense arid conditions with reduced natural inflows into the Colorado River Basin. The new proposed operation may also help in maintaining the water storage of Lake Powell and maximize the time until the levels of Lake Powell reservoir drop below critical elevations such as its power pool elevation of 3,490 feet. This objective also shows that the CRSS model enables carrying out a simple, but valuable and easily implemented change to provide a lot of insights into certain problems.

$$\text{Water outflows (t)} \leq \text{available water (t)} = \text{Storage (t)} + \text{Water Inflows (t)} + \text{Precipitation (t)} - \text{Evaporation (t)} \qquad \textit{Equation } 1$$

This study also aims to carry out a vulnerability assessment to investigate Lake Powell pool elevation under more-arid hydrologic conditions coupled with different consumptive use scenarios in the UCRB. The time for Lake Powell to reach its minimum power pool elevation for different combinations of arid hydrologic scenarios and consumptive use will be identified. To achieve this objective, three steady hydrologic scenarios with reduced natural inflows, and two changing demands scenarios including increased consumption and increased conservation in the UCRB were developed and used in a bottom-up vulnerability assessment (Brown et al., 2012, 2016). The developed hydrologic scenarios were formulated to represent the CRB becoming more arid over the coming years due to the ongoing temperature-induced global warming (K. G. Wheeler et al., 2022; Williams et al., 2022). The changing demand scenarios were formulated and examined in this study because of some water conservation projects such as the UCRB's Pilot System Conservation Program (UCRC, 2022; USBR, 2021) that supports that fact that changing water demands through a range of conservation measures could mitigate the impacts of the ongoing drought in the Colorado River Basin. This study was carried out using the Riverware (https://cadswes2.colorado.edu/downloads/riverware/releases/) version 8.2.2 and the CRSS model version Aug2021 (http://bor.colorado.edu/Public_web/CRSTMWG/CRSS/). The CRSS model was previously developed to provide Colorado River Basin managers and policy makers with predictions of flow and reservoir levels in the basin. An analysis period of 32 years (2022-2053) was selected for this study. The estimated future demand of the *UB and LB 2016 demands* CRSS scenario were used in this study to represent the future water demands in the CRB. The UB and LB refers to the Upper Basin and Lower Basin of the Colorado River, respectively.

2. Material and Methods

2.1. Alteration to Existing Lake Powell Ruleset

A new rule that adapts releases to 95% of Lake Powell's inflow was added under the *Powell Rules* Policy Group in the CRSS model (Figure 1). The rule was implemented at the highest priority (17) within the "Powell Rules" Policy Group above equalization and other Powell release rules. As shown in Figure 1, the rule was named "Outflow Hydrology Rule" and expressed as the equation shown in Equation 2. Lake Powell's inflow that is represented by the "Powell.Inflow" variable in the CRSS model is the Lake Powell's gaged flow and is measured by a stream gage with historical reservoir operations and diversions. However, a naturalization process usually takes place to estimate the unregulated flows by numerically removing upstream reservoirs and then numerically removing water diversions to estimate the natural flows needed to run the CRSS model (K. G. Wheeler et al., 2019).

$$\text{Powell Release } (t) = \text{Powell Inflow } (t) * 0.95 \qquad \textit{Equation 2}$$

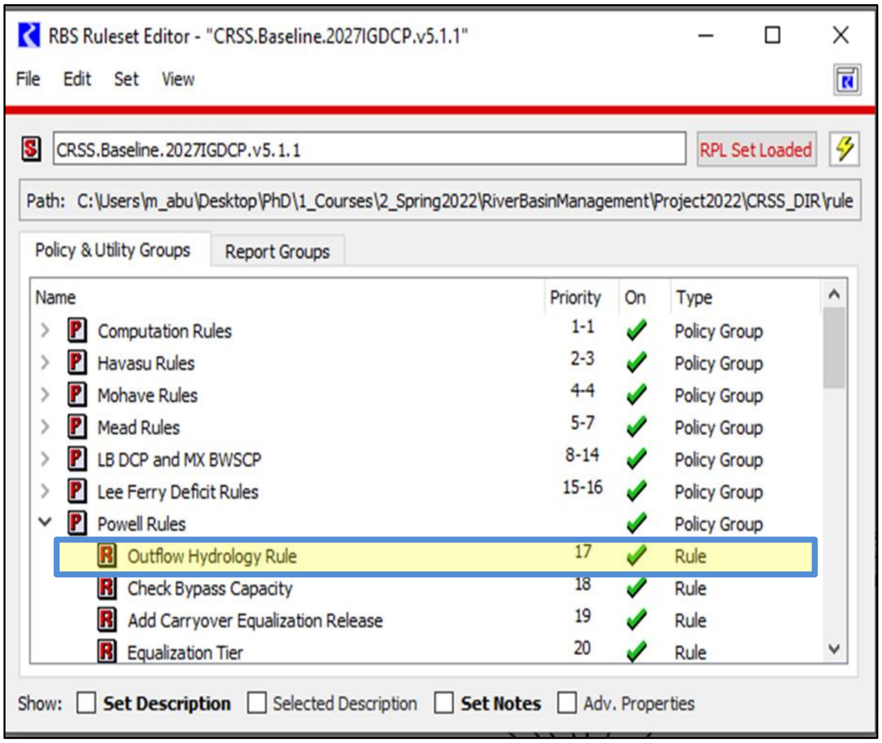

Figure 1. A screenshot showing the "Outflow Hydrology Rule" CRSS rule and its priority within the "Powell Rules" Policy Group

2.2. More-Arid Hydrologic scenarios

Three steady hydrologic scenarios of 20%, 35%, and 50% reduction in flows compared the average 1988 to 2018 flows were developed to represent the Colorado River Basin becoming more arid over the coming years. The steady flow hydrologic scenarios approach helped describing hydrologic assumptions, allowed for more direct results from CRSS model runs and also created a more transparent way to communicate prolonged effects of intensified arid conditions on Lake Powell pool elevation (Rosenberg, 2022). To develop the three steady hydrologic scenarios, the natural inflow data were first randomly resampled from the data of the second Colorado River dry period (2000-2018), and then decreased further by 20%, 35%, and 50%. For simplification purposes, the variability of yearly inflows was ignored, and it was assumed that the Upper Colorado River Basin received a constant annual flow equivalent to the annual flow of the first year (2022) of the analysis period that extended from 2022 to 2053. This resulted in three hydrologic scenarios with natural inflow rates of 10.1, 8.2, and 6.3 MAF at the Lees Ferry gauge site as presented in Figure 2. The developed more-arid hydrologic scenarios were then saved to *inflow* files and implemented in the CRSS model to simulate the changes in Lake Powell pool elevation due to arid hydrological conditions with reduced natural inflows. The plot shown in Figure 2 also presents the *ISM1988 to Present* hydrologic scenario that represents the natural inflow values projected to mid-century based on the 1988 to present river flow rates. The *ISM1988 to Present* inflow has a minimum, mean, and maximum annual inflow of 6.8, 14.5 and 22.7 MAF, respectively. The ISM refers to "Index-Sequential Method" that was used to model the statistics of Colorado River flow and produce the *ISM1988 to Present* hydrologic scenario.

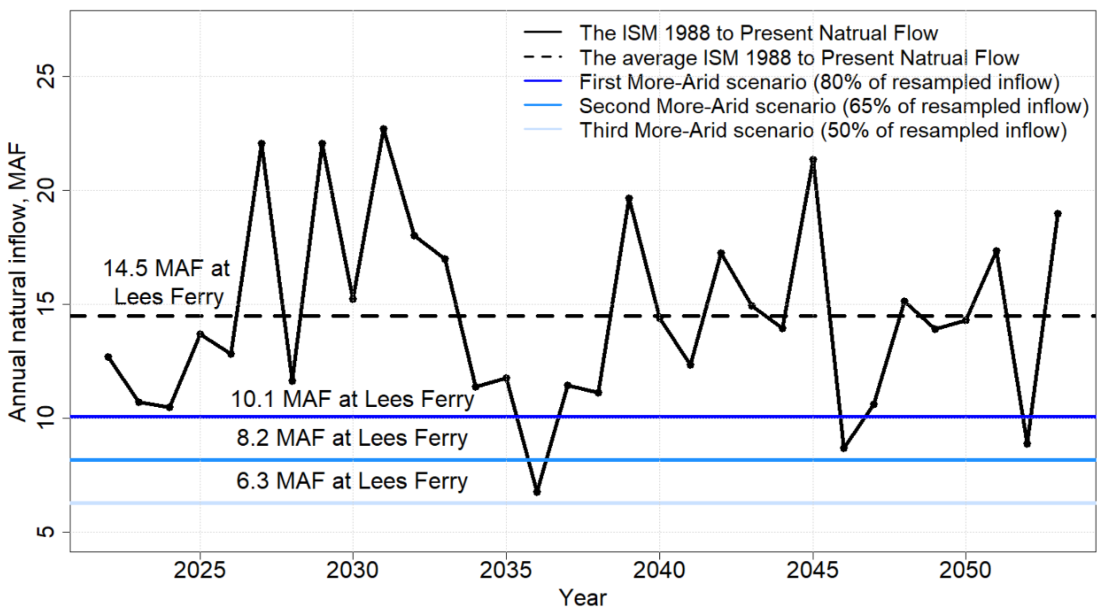

Figure 2. The More-Arid Hydrologic Scenarios and the ISM (Index-Sequential Method) 1988 to Present Natural Inflow

In addition to the steady hydrologic scenarios, changing demands scenarios including increased consumption and increased conservation scenarios were also developed and defined in the CRSS model. After that, the steady more-arid hydrologic conditions and changing demands scenarios were used in a bottom-up vulnerability assessment (Brown et al., 2012, 2016) to investigate Lake Powell pool elevation under the more-arid scenarios coupled with increased consumption and conservation scenarios in the UCRB. This would help quantitatively examine how increased consumption and conservation practices in the UCRB would impact Lake Powell pool elevation during arid hydrological conditions. As mentioned earlier, the UCRB was chosen for this analysis because it is where most of the Colorado River inflow comes from. Increased consumption scenarios were defined by making changes to the *Diversion Slot* of Lake Powell object in the CRSS. A 30, 60, and 90 thousand-acre feet per month diversions were used to illustrate three scenarios of increases in demand in the UCRB. Increased conservation scenarios were defined by making changes to the *Return Flow Slot* of the CRSS Lake Powell object. The same 30, 60, and 90 thousand-acre feet per month values were also used to illustrate three scenarios of decreased demand in the UCRB. The more-arid hydrologic scenarios and changing demands (increased consumption and conservation scenarios) were then used in conjunction in the CRSS model. The CRSS outcomes using the more-arid hydrology scenarios coupled with increased consumption and conservation scenarios were then utilized to predict Lake Powell's time to the power pool elevation of 3,490 feet.

3. Results and Discussion

3.1. The Impact of More-Arid Hydrology Scenarios on Lake Powell Water Storage

The results of the CRSS model based on the *ISM1988 to Present* and the more-arid hydrologic scenarios are shown in Figure 3. The power pool elevation of Lake Powell of 3,490 feet is also presented in Figure 3 using a dashed red line. The results of the CRSS model clearly demonstrate that Lake Powell pool elevation will drop below the power pool elevation within the next five to ten years under all four hydrologic scenarios. However, it returns above the power pool elevation under only the ISM1988 to Present hydrology after few years. Contrarily, Lake Powell pool elevation continues to decline to dead pool elevation under all the more-arid hydrologic scenarios. The pool elevation of Lake Powell will fluctuate near 3,421, 3,408 and 3,399 feet under the 10, 8 and 6 MAF drought hydrology, respectively. Little outflow from Lake Powell to the LCRB will be allowed. The plot presented in Figure 3 also shows that the time to power and dead pool is also impacted by the hydrologic scenarios. For instance, the elevation of Lake Powell appears to fall below its power pool within the next two years (2023) under the 6.1 MAF hydrologic scenario, whereas it remains above power pool elevation until the end of 2025 with the 10 MAF hydrology. The data also show that Lake Powell will reach the dead pool faster under the 6 MAF hydrology as compared with other higher inflow scenarios.

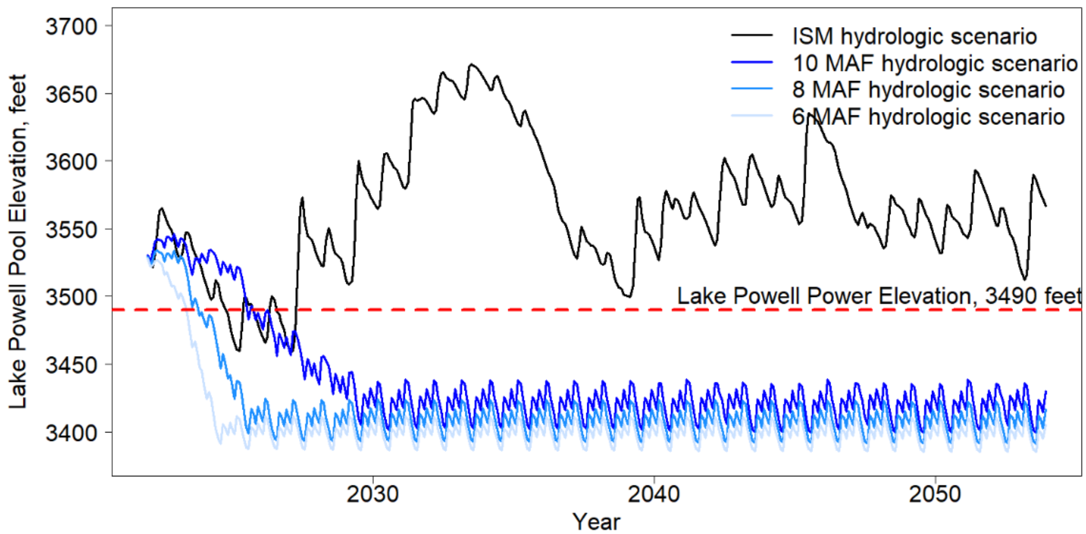

Figure 3. Modeled Lake Powell elevation with existing operations using the more-arid hydrologic scenarios and the ISM (Index-Sequential Method) 1988 to Present Natural Inflow.

3.2. The impact of "Outflow Hydrology Rule" on Lake Powell pool elevation and water release

Figure 4 and Figure 5 presents the CRSS results based on 95% passing inflow for each of the more-arid hydrologic scenarios. Figure 4 presents Lake Powell's pool elevation and Figure 5 presents Lake Powell total annual water releases with Lake Powell outflow equals 95% of Lake Powell's inflow. The annual release of the More-Arid hydrologic scenarios shown in Figure 5 is rather steady mainly because of the steady More-Arid hydrologic scenarios used in the analysis. The results shown in Figure 4 clearly show that the "Outflow Hydrology Rule" rule would help maintain the current pool elevation of Lake Powell. In fact, the plot shows that Lake Powell pool elevation will start to rise under all the ISM1988 to Present, 10 MAF and 8 MAF hydrologic scenarios with only 5% of the inflow stored behind the Glen Canyon Dam. However, having an annual natural inflow of less than 8 MAF would cause Lake Powell pool elevation to keep dropping even if 95 percent passing inflow to reservoir outflow was allowed. Despite that, the plot clearly shows that Lake Powell pool elevation will remain above its power pool elevation throughout the analysis period (2022-2053) even with inflows as low as 6 MAF hydrologic scenario. These outcomes clearly indicate that saving a small portion (e.g., 5%) of water inflows would help maintain Lake Powell’s water storage. This approach may also maximize the time until Lake Powell elevation drops below critical elevations (e.g., the power elevation of 3490 feet) due to reduced inflow hydrologic scenarios such as the 6 MAF hydrologic scenario. Besides maintaining Lake Powell water storage, saving a small portion (e.g., 5%) of the inflows could also help in compensating for Lake Powell’s evaporation losses. According to the CRSS model, the estimated monthly evaporation losses from Lake Powell were less than 5% of the lake’s inflows for 56.5% of the time during the 32-analysis period (2022-2053) under the ISM hydrologic scenario.

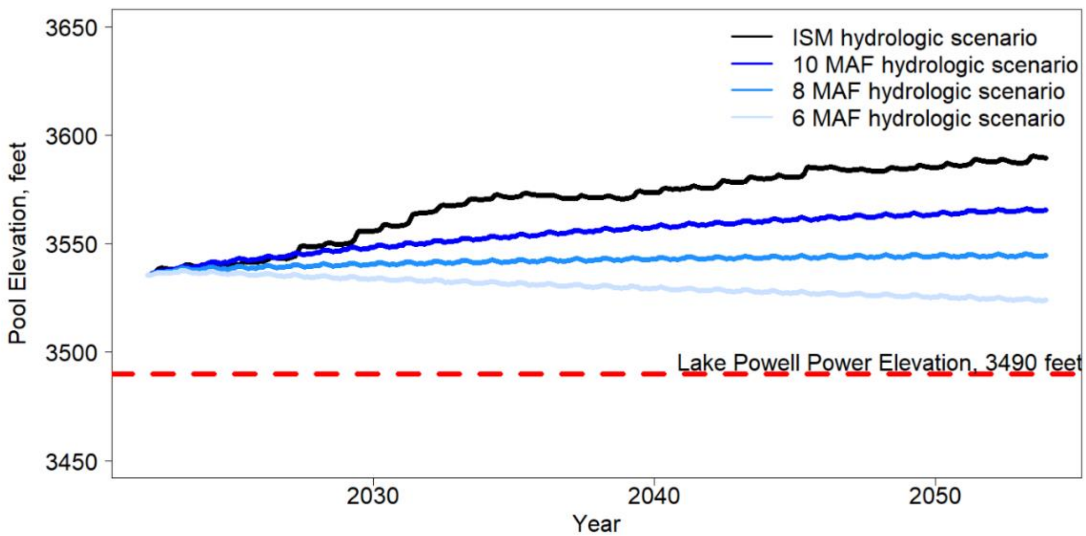

Figure 4. Lake Powell’s pool elevation with Lake Powell outflow set to 95% of its inflow using the more-arid hydrologic scenarios and the ISM *(*Index-Sequential Method*)* 1988 to Present Natural Inflow.

Despite the fact that the “Outflow Hydrology Rule“ CRSS rule would help maintain Lake Powell’s water storage, it will limit Lake Powell water releases to water inflows coming from the UCRB. As presented in Figure 5, the CRSS outcomes show that Lake Powell annual release had an average of 7.75, 6.14, 4.64 and 3.37 MAF, under the ISM1988 to Present, 10 MAF, 8 MAF and 6 MAF, respectively. Based on these outcomes, Lake Powell can’t maintain the scheduled water releases of 8.23 or even the 7.48 MAF under 10 MAF, 8 MAF and 6 MAF hydrologic scenarios or under similar arid conditions. Also, it will be challenging to maintain the scheduled water releases in all years under the ISM1988 to Present hydrologic scenario as presented in Figure 5. This may further suggest that downstream beneficiaries including the LCRB, and the State of Mexico may experience water shortages in dry years. In addition to the 7.48 and 8.23 water release operational schedules, the “Outflow Hydrology Rule“ CRSS rule in its current formulation and priority level contradict other Lake Powell operations such as the equalization rule. In fact, Lake Mead elevation would be under the risk of falling due to decreased water inflows coming from Lake Powell. Hence, the “Outflow Hydrology Rule“ CRSS rule needs to be modified and further improved to achieve the intended goals of considering water inflows from the URRB for maintaining Lake Powell storage without contradicting existing operations and water releases schedules.

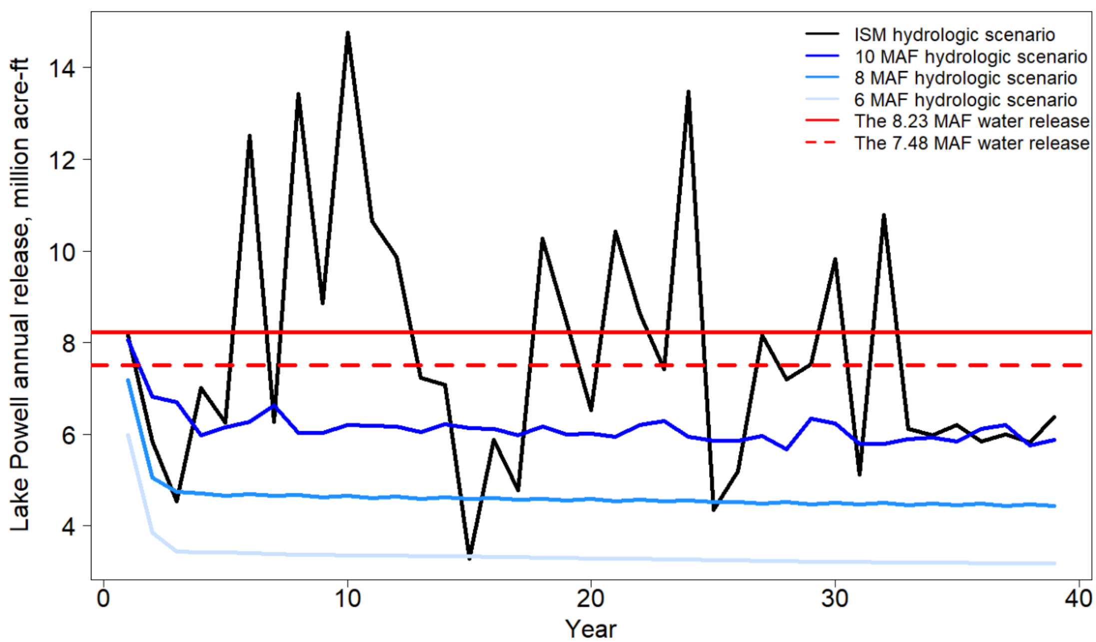

Figure 5. Lake Powell total annual release with Lake Powell outflow set to 95% of its inflow *using the m*ore-*a*rid *h*ydrologic *s*cenarios and the ISM *(*Index-Sequential Method*)* 1988 to Present Natural Inflow.

3.3.The Impact of More-Arid Hydrologic Scenarios Coupled with Conservation and Consumption Scenarios on Lake Powell pool elevation

Figure 6 portrays Lake Powell pool elevation under the more-arid hydrologic scenarios coupled with increased conservation and consumption scenarios in the UCRB. As illustrated in the figure, values in the matrix represent the time in years to Lake Powell power elevation of 3,490 feet.

Changes in basin hydrology are shown on the y-axis, while annual consumption and conservation values are plotted across the x-axis. Based on these results that were obtained from CRSS model show that the time to power elevation of Lake Powell is highly impacted by the changes in hydrology and demand. With future increases in consumption due to increased population growth and development projects, all more-arid hydrologic scenarios will force Lake Powell pool elevation to reach the power elevation faster. Increasing water consumption volumes in the UCRB decreases water inflows to Lake Powell and causes its pool elevation to decline and reach alarming levels faster. The plot shown in Figure 6 also shows that increased conservation initiatives and the assumed more-arid hydrologic scenarios, as outlined in this report, will keep Lake Powell pool elevation above the power pool elevation for a longer time, suggesting that conservation programs may play an important role in maintaining Lake Powell storage. Increasing water conservation volumes in the UCRB increases water inflows to Lake Powell and causes its pool elevation to decline and reach alarming levels slower.

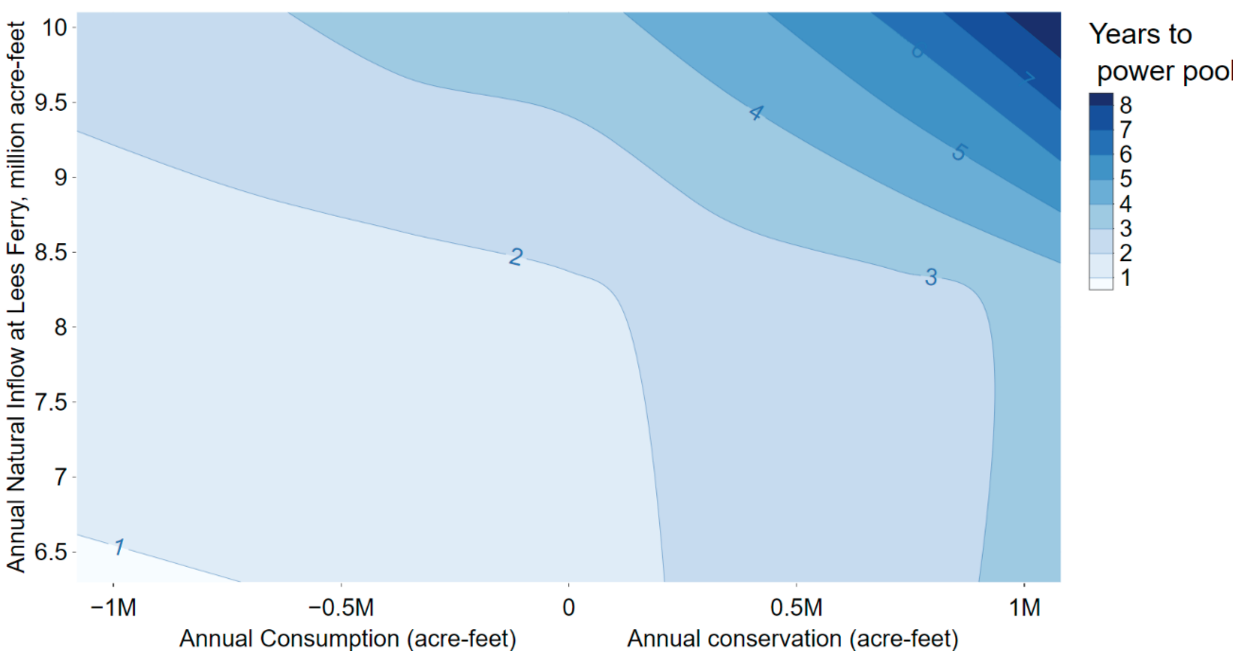

Figure 6. Percent of Time Lake Powell Pool Elevation is under Power Pool (3490 feet)

4. Conclusion

The Colorado River Simulation System (CRSS) has been used in this study provide useful insights on the response of Lake Powel pool elevation to linking Lake Powel outflow with the hydrology of the Upper Colorado River Basin instead of following discharge schedules. For this purpose, a new rule that adapts releases to 95% of Lake Powell's inflow was added under the *Powell Rules* Policy Group in the CRSS model's ruleset. The new rule was implemented at the highest priority within the "Lake Powell" Policy Group. Besides, three steady hydrologic scenarios with reduced natural inflows were developed based on the natural inflow data of the second Colorado River dry period (2000-2018). Two additional changing demands scenarios including increased consumption and increased conservation scenarios were also developed and then used along with the steady hydrologic scenarios in a bottom-up vulnerability assessment to investigate Lake Powell pool elevation under more-arid hydrologic conditions coupled with different consumptive use scenarios in the UCRB. The time for Lake Powell to hit its minimum power pool elevation for different combinations of arid hydrologic scenarios and Upper Basin consumptive use was identified. Increased consumption and conservation scenarios were defined by making changes to the *Diversion Slot* and the *Return Flow Slot* of the CRSS Lake Powell object, respectively. Lastly, the CRSS model was also used to discuss the effects of more-arid hydrologic scenarios in the Colorado River Basin on Lake Powell pool elevation through the next 32 years.

The CRSS outcomes demonstrated that linking Lake Powell's outflow to its inflows would save its pool elevation from reaching alarming levels. Saving some water as low as 5% would also stabilize the existing reservoir elevation. The outcomes of this study also showed that the more-arid scenarios used in analysis have large impacts on the future of Lake Powell pool elevation. Without timely management action to curb decreasing reservoir levels, Lake Powell storage will fall below the power pool elevation within the next decade. Model results also show that increased consumption in the UCRB could force Lake Powell pool elevation to decline below its power elevation pool faster. Conservation measures, however, could significantly help Lake Powell pool elevation to remain above the power elevation for a longer time, especially under more-arid intense drought scenarios.

5. Data Availability

The raw, processed and analyzed data, the CRSS model files and the R code scripts used in this study to analyze the data and the results of this study have been shared in an open-access HydroShare online repository (https://www.hydroshare.org) to promote data availability and reproducibility among the research community. The HydroShare resource can be found at (Abualqumboz & Chamberlain, 2023). A detailed narrative that would help the research community to reuse, reproduce, or replicate the work of this study is provided in the HydroShare resource.

References:

Abualqumboz, M., & Chamberlain, B. (2023). *The Response of Lake Powell Pool Elevation to Alternative Hydrological and Demand Scenarios in the Upper Colorado River Basin* [dataset]. https://doi.org/10.4211/hs.773626e9b84248bc8d431da795ee1a16.

Allhands, J. (2021). *It could take at least 500,000 acre-feet of water a year to keep Lake Mead from tanking*. The Arizona Republic. https://www.azcentral.com/story/opinion/op-ed/joannaallhands/2021/11/08/lake-mead-could-get-extra-water-from-lower-basin-annually/6306601001/

Brown, C., Ghile, Y., Laverty, M., & Li, K. (2012). Decision scaling: Linking bottom-up vulnerability analysis with climate projections in the water sector. *Water Resources Research*, *48*(9), 2011WR011212. https://doi.org/10.1029/2011WR011212

Brown, C., Weatherly, J., Mearns, L., Steinschneider, S., Wi, S., Case, M., Hayden, T., Koster, A., Bukovsky, M., & McCrary, R. (2016). Decision-scaling: A decision framework for dod climate risk assessment and adaptation planning. *Strategic Environmental Research and Development Program (SERDP)*.

Castle, A., & Fleck, J. (2019). The risk of curtailment under the Colorado River compact. *Available at SSRN 3483654*.

Hager, A. (2021). *Lower basin states sign deal to put water back in Lake Mead amid dropping levels*. KUNC. https://www.kunc.org/environment/2021-12-15/lower-basin-states-sign-deal-to-put-water-back-in-lake-mead-amid-dropping-levels

Rosenberg, D. E. (2022). Adapt Lake Mead Releases to Inflow to Give Managers More Flexibility to Slow Reservoir Drawdown. *Journal of Water Resources Planning and Management*, *148*(10), 02522006. https://doi.org/10.1061/(ASCE)WR.1943-5452.0001592

Salehabadi, H., Tarboton, D., Kuhn, E., Udall, B., Wheeler, K., Rosenberg, D., Goeking, S., & Schmidt, J. C. (2022). *The Future Hydrology of the Colorado River Basin* [dataset]. https://doi.org/10.4211/hs.d3efcf0c930646fd9ef4f17c56436d20

Trujillo, T. (2022). *2022 Glen Canyon Dam Operations Decision Letter*. https://www.usbr.gov/uc/DocLibrary/Plans/20220503-2022DROA-GlenCanyonDamOperationsDecisionLetter-508-DOI.pdf

UCRC. (2022). System Conservation Pilot Program (SCPP) in 2023. *Upper Colorado River Commission*. http://www.ucrcommission.com/system-conservation-pilot-program-for-2023/

Udall, B., & Overpeck, J. (2017). The twenty-first century Colorado River hot drought and implications for the future. *Water Resources Research*, *53*(3), 2404–2418. https://doi.org/10.1002/2016WR019638

USBR. (2021). Pilot System Conservation Program (Pilot Program). *U.S. Bureau of Reclamation*. https://www.usbr.gov/lc/region/programs/PilotSysConsProg/pilotsystem.html

USBR, B. of. (2022). *Interior Department Announces Actions to Protect Colorado River System, Sets 2023 Operating Conditions for Lake Powell and Lake Mead*. Newsroom. https://www.usbr.gov/newsroom/

Wheeler, K. G., Rosenberg, D. E., & Schmidt, J. C. (2019). Water resource modeling of the Colorado River: Present and future strategies. *White Pap*, *2*.

Wheeler, K. G., Udall, B., Wang, J., Kuhn, E., Salehabadi, H., & Schmidt, J. C. (2022). What will it take to stabilize the Colorado River? *Science*, *377*(6604), 373–375. https://doi.org/10.1126/science.abo4452

Wheeler, K., Kuhn, E., Bruckerhoff, L., Udall, B., Wang, J., Gilbert, L., Goeking, S., Kasprak, A., Mihalevich, B., & Neilson, B. (2021). Alternative management paradigms for the future of the Colorado and Green Rivers. *Cent. Colo. River Stud. White Pap*, *6*, 1–85.

Williams, A. P., Cook, B. I., & Smerdon, J. E. (2022). Rapid intensification of the emerging southwestern North American megadrought in 2020–2021. *Nature Climate Change*, *12*(3), 232–234. https://doi.org/10.1038/s41558-022-01290-z