End of Season Wrap-Up – Holding on to What We've Got

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> **Opportunities to rebuild basin-wide reservoir storage have been rare in the 21st century.**

On April 3 2024, the snow accumulation season in the Colorado River watershed ended and the snow water equivalent of the snowpack of the Upper Basin peaked. Two weeks later on April 17, the watershed's reservoirs[1] dipped to their lowest level of the year. Now runoff is underway, and the watershed's reservoirs are beginning to refill. This is a good time to assess how well water managers did during the past nine months to retain the bounty of 2023's excellent runoff season, an essential part of rebuilding reservoir storage and regaining basin-wide water supply security.

The good news is that **water managers did quite well**, and **reservoirs lost only 26% of the total amount accumulated during the 2023 runoff season**. This was the smallest loss of any year in the last decade. Most of the decrease in storage that followed last year's snowmelt inflow occurred in Upper Basin reservoirs, and Lake Mead and Lake Powell lost only 5% of the storage that accumulated in those two reservoirs. It is imperative that water managers continue to work to reduce consumptive uses, reduce losses, and retain the bounty of the few unusually wet years of the 21st century, as they did following the 2023 snowmelt.

Opportunities to rebuild basin-wide reservoir storage have been rare in the 21st century, and there have been many years in which there is significant risk of basin-wide reservoir storage depletion. Hydrologic and reservoir storage data between 2014 and 2023 indicate that annual snowmelt-derived gains in reservoir storage exceeded losses when natural flow at Lees Ferry exceeded 13.7 million acre feet per year (af/yr). Annual flows less than this amount occurred in 16 years of the 21st century. Opportunities to significantly rebuild basin-wide reservoir storage existed when natural flow exceeded 15.8 million af/yr, which only occurred six times in the 21st century. Development of a sustainable policy for managing Colorado River reservoir storage must focus on reducing consumptive uses and losses in both wet and dry years.

To recap, the natural flow of the Colorado River at Lees Ferry in 2023 was the third highest of the 21st century and was exceeded only in 2011 and 2019 (Table 1). Unregulated inflow to Lake Powell in Water Year (WY) 2023 was ~13.4 million af[2].

Table 1. Natural flow at Lees Ferry in the five years of greatest runoff in the 21st century.

	Total annual natural flow during the indicated water year, in million acre feet
2011	20.2
2019	17.7
2023	17.4
2005	16.9
2017	16.4

In response to this large runoff, the basin's reservoirs recovered a significant amount of storage. The watershed's reservoirs reached their maximum in mid-July (13 July 2023) when total storage was 29.7 million af. The increase in basin storage between mid-April and mid-July was 8.38 million af and was the largest single-year increase in storage in the last decade, and approximately 1 million af more than the increase in storage that had resulted from the inflows of 2019 (Table 2).

Table 2. Natural flow and increase in total watershed reservoir storage in each year of the past decade.

	Total natural flow, in acre feet	Increase in basin reservoir storage, in acre feet	Percentage of the snowmelt season increase in storage subsequently consumed or lost
2023	17,400,000	8,380,000	26
2022	9,850,000	1,080,000	243
2021	7,150,000	170,000	2900
2020	9,890,000	1,300,000	525
2019	17,700,000	7,360,000	38
2018	8,630,000	467,000	1030
2017	16,400,000	5,210,000	75
2016	13,400,000	3,610,000	76
2015	13,400,000	3,540,000	97
2014	14,000,000	3,460,000	74

However, the runoff in 2023 did not eliminate critically low reservoir storage conditions. The increased reservoir storage that peaked in mid-July 2023 recovered storage to the amount it had been in mid-February 2021 in the early stages of the 2020-2022 water crisis (Fig. 1). Based on average annual water consumption[3] 2023's runoff would need to be repeated five more times to refill the reservoir system. Good runoff years rarely occur consecutively. The projected unregulated inflow to Lake Powell in 2024 is estimated to be only 81% of average.

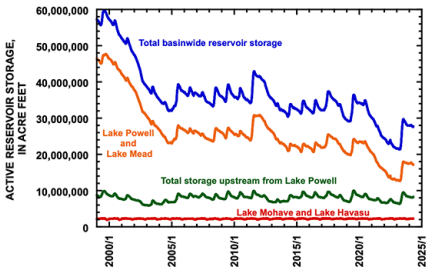

Figure 1. Graph showing reservoir storage in the Colorado River basin between 1 January 1999 and 1 May 2024. Note that at the peak of storage in mid-July 2023, the total stored water supply was the same as it had been in mid-February 2021.

When we entered mid-summer 2023, I expressed concern about water managers' ability to conserve the benefit of 2023's runoff season, because we had not done so in previous years of good runoff. In those years, the benefit of reservoir storage recovery was not retained for more than two years (*see blog post from October 2023*). The benefit of 2011, the largest runoff of the 21st century, had been completely consumed in 19 months, and the benefit of large runoff in 2019 had been consumed in 24 months. I suggested that public understanding about the status of reservoir storage and the need to conserve the bounty of good years would be improved if water managers regularly reported how much of the previous year's inflow benefit was retained. Such a metric could highlight success in rebuilding water storage or could be used to sound a warning of the need for additional conservation.

Throughout winter and early spring 2023 and 2024, I reported on the status of reservoir storage and showed that water managers were successfully conserving reservoir storage. Between mid-July (13 July 2023) and mid-April (17 April 2024), total basin-wide reservoir storage lost only 2.2 million af (Fig. 2) which was 26% of the total "gains" of the 2023 snowmelt season. Most of this decrease in storage occurred upstream from Lake Powell, where reservoirs lost 1.4 million af. In contrast, storage in the Lake Powell-Lake Mead reservoir system decreased by only 0.83 million af.

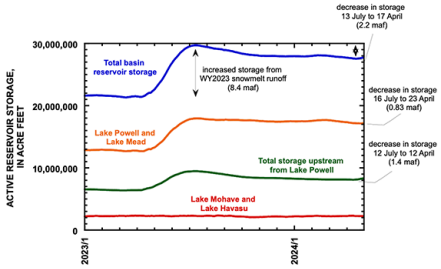

Figure 2. Graph showing reservoir storage in the Colorado River basin between 1 January 2023 and 1 May 2024.

The percentage of the accumulated snowmelt in 2023 that was consumed or otherwise lost from reservoirs in the subsequent months was less than in any other year of the past decade and was less than following the 2019 runoff season and significantly less than the years between 2014 and 2017 when runoff was moderately good (Table 2). I compared the rate and magnitude of decrease of reservoir storage in 2023-2024 with similar data for the previous nine years. The results are presented in a complicated Figure 3. Each line on this graph is the loss in storage in each year, plotted as the cumulative decrease in storage from the peak that had occurred in early summer. Lines that plot higher on this graph reflect smaller decreases in basin storage. The decrease in storage was notably large after the 2020 snowmelt season; total basin storage was nearly 7 million af less in spring 2021 than it had been in summer 2020. There were also large reductions after the snowmelt inflows of 2018 and 2021. In contrast, the reduction in storage after the 2023 runoff season (the thick blue line) was smaller than in the other years; this pattern is reflected by the thick blue line that plots higher on Figure 3 than in most other years.

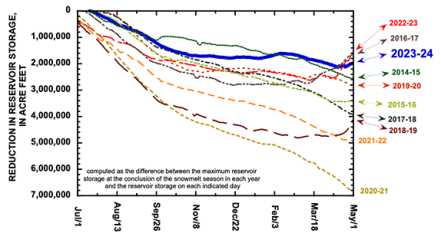

Figure 3. Graph showing the decrease in reservoir storage during late summer, fall, winter, and early spring following each year's snowmelt season.

Although the combined storage contents of Lake Mead and Lake Powell reflect the balance (or imbalance) between basin water supply and consumptive use, the trajectories of individual reservoirs also result from reservoir operational rules specific to each facility. Lake

Powell reached its peak storage of the year in early July (8 July 2023; 9.67 million af) and subsequently lost 2 million af by mid-April, because water was transferred downstream (Fig. 4). Storage began to accumulate again in Lake Powell in mid-April (18 April 2024). In contrast, storage in Lake Mead steadily increased between August 2022 and early March (4 March 2024), gaining 2.7 million af of storage. Lake Mead has been losing storage since early March.

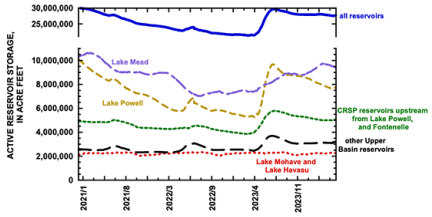

Figure 4. Graph showing the distribution of reservoir storage in different parts of the Colorado River basin between 1 January 2021 and 1 May 2024.

The trajectory of storage in Upper Basin reservoirs differed between those facilities authorized or linked to the Colorado River Storage Project (CRSP)[4] in contrast to other facilities (Fig. 4). Peak storage upstream from Lake Powell peaked in early (facilities unrelated to the CRSP peaked on 5 July 2023 at 3.69 million af) to mid-July (CRSP related facilities peaked on 15 July 2023 at 5.79 million af). Storage in facilities unrelated to the CRSP was quickly reduced to approximately 3 million af by mid-September, and storage was maintained at that quantity until the beginning of the 2024 snowmelt season. In contrast, storage in CRSP related facilities progressively lost storage of approximately 0.8 million af until mid-February 2024 when storage stabilized at approximately 5 million af. The longer period of declining storage in CRSP-related facilities was caused by policies related to transferring water to Lake Powell.

Insights about the Future

The data and analyses presented above provide insight about the likely trajectory of future Colorado Basin reservoir storage if no changes are made in policies concerning consumptive use and reservoir operations. During the past decade, the increase in basin-wide reservoir storage is well predicted by a power function based on the natural flow at Lees Ferry[5](Fig. 5).

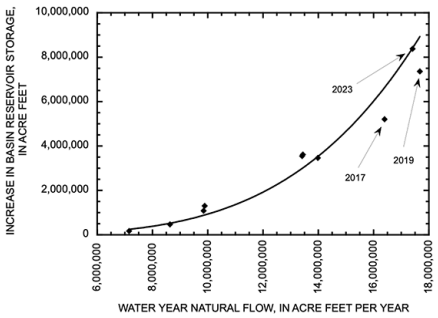

Figure 5. Graph showing the relationship between annual natural flow at Lees Ferry and increase to basin-wide total storage during the snowmelt inflow season between 2014 and 2023.

The proportion of snowmelt-derived gain in storage subsequently lost during the following nine months is well predicted as an inverse power function[6] of the increase in storage. The greater the increase in storage, the smaller the proportion of that increase subsequently lost. In years when there is little increase in storage, basin-wide consumptive uses and losses far exceeded the annual increase in storage (Fig. 6). Such was the case in 2018 and between 2020 and 2022.

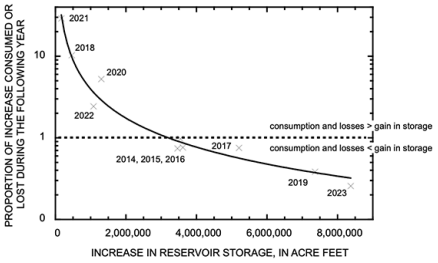

Figure 6. Graph showing the proportion of the annual accumulated reservoir storage consumed or lost during the following nine months prior to the beginning of the next runoff season.

These correlations indicate that annual consumption and losses in excess of annual storage gains occurred when gains were less than approximately 3.2 million af. Between 2014 and 2023, storage gains were less than this amount when natural flows were less than approximately 13.7 million af, which occurred in 16 years of the Millennium Drought. Significant retention of reservoir storage, defined as retention of at least 50% of the annual accumulation, occurred when storage increased by at least 5.7 million af. Such an increase of storage only occurred when natural runoff exceeded 15.8 million af (Fig. 5), which only occurred six times between 2000 and 2023.

Take-Home Messages

The essential purpose of negotiating new reservoir operational guidelines for the Colorado River basin is to maintain sufficient reservoir storage to provide a reliable and secure water supply. At the beginning of the 2024 snowmelt season, basin-wide reservoir storage is comparable to what it was in late spring 2021, demonstrating that the Millennium Drought water crisis persists. The opportunity for significant retention of the benefits of significant increases in reservoir storage exist when natural flow exceeds approximately 15.8 million af, a situation that has rarely occurred since 2000. When natural flow is less than approximately 13.7 million af, there is significant risk of depletion of basin-wide storage. Development of a sustainable policy for managing Colorado River reservoir storage must focus on reducing consumptive uses and losses in both wet and dry years.

1. *In this post, "total watershed reservoir storage" or "total basin storage" are defined as the total storage in 46 reservoirs reported by the Bureau of Reclamation in its hydrologic database at https://www.usbr.gov/uc/water/hydrodata/reservoir_data/site_map.html. These reservoirs do not include those in Lower Basin tributary watersheds and do not include a few smaller reservoirs in the Upper Basin.*

2. *The estimated natural flow at Lees Ferry is greater than the estimated unregulated inflow to Lake Powell, because natural flow is an estimation of what the river flow would be in the absence of humans, whereas unregulated inflow is the estimation of inflow in the absence of upstream reservoirs but with existing consumptive uses and losses.*

3. **Average annual consumptive uses and losses in the Colorado River, including reservoir evaporation and use in Mexico was 15.0 million af/yr between 2001-2020, based on Bureau of Reclamation reports. Between 2016 and 2020, consumptive uses and losses averaged 14.5 million af/yr.**

4. Facilities authorized by or linked to the CRSP include Flaming Gorge, Navajo, Blue Mesa, Fontenelle, Morrow Point, and Crystal reservoirs.

5. y = (1.5699 * 10-22) (x3.9677); R2 = 0.96, where y is increase in basin reservoir storage during the snowmelt season and x is the annual natural flow at Lees Ferry in the same year.

6. y = (4.7903 * 107) (x-1.1806); R2 = 0.99, where y is the proportion of the increase in storage consumed or otherwise lost in the subsequent nine months and x is the increase in storage during that snowmelt season.