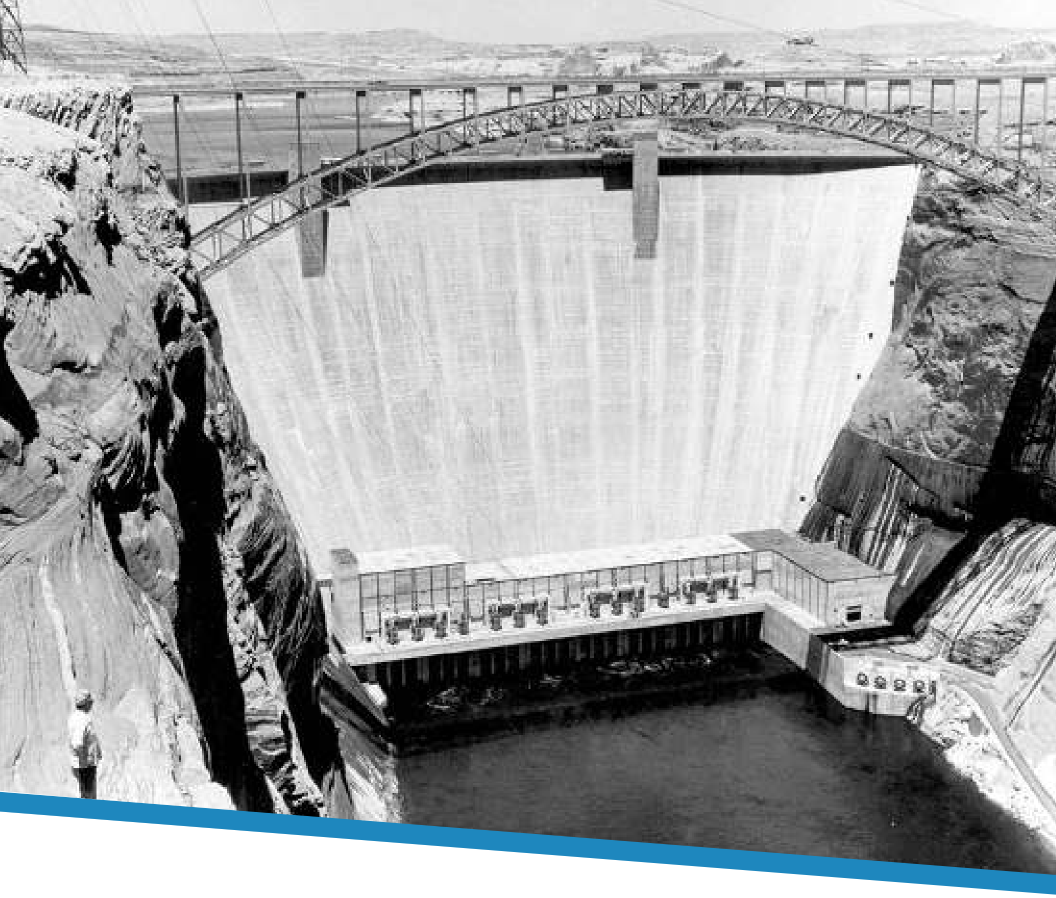

ANTIQUE PLUMBING & LEADERSHIP POSTPONED

HOW THE GLEN CANYON DAM'S ARCHAIC DESIGN THREATENS THE COLORADO RIVER WATER SUPPLY

A recommendation for immediate action from the Utah Rivers Council, Glen Canyon Institute and the Great Basin Water Network

Photo by Dawn Kish

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Photo by Eric Balken

The hydropower penstocks are the primary means of complying with water delivery obligations of the Colorado River Compact, yet they will be unusable at just 45 feet below current water levels.[4]

Executive Summary

The Colorado River Basin is facing a water supply crisis of historic magnitude, a result of water demand far outstripping the climate-change-stricken river's low water flows.[1] This has caused America's two largest reservoirs, Lake Mead and Lake Powell, to drop to their lowest levels since they were both constructed.[2]

The Bureau of Reclamation, the seven Colorado River states, and Mexico have implemented Drought Contingency Plans to address the declining river system, and the Interim Shortage Guidelines will address at least some of how water cuts will be taken in coming years. In June 2022, the Bureau of Reclamation announced the need to cut an additional 2 – 4 million acre-feet of Colorado River water in the system to avoid a serious crisis.[3]

The challenge is that the system will likely crash well before 2026, and it's not about electricity or hydropower generation.

Lots of attention has been given to the loss of hydropower generation when Lake Powell levels drop below minimum power pool, the reservoir elevation at which Glen Canyon Dam can no longer generate electricity through its power turbines. The loss of power generation at Glen Canyon Dam will certainly create challenges for customers who receive its electricity and for the federal programs funded by this revenue stream. But the most serious problems are not about hydropower.

If and when the water levels behind Glen Canyon Dam drop below 3,490 fasl, the facility begins the countdown to the point where it will not be capable of releasing enough water to meet the Upper Colorado River Basin's standard delivery of 7.5 million acre-feet of water to the Lower Basin. This is because the hydropower penstocks are the primary means of complying with the water delivery obligations of the 100-year-old Colorado River Compact, yet they will be unusable at just 45 feet below current water levels.[6] Under current interpretations of the Law of the River, delivering less than this amount of water is a violation of cornerstone agreements, which may bring heavy penalties for the Upper Basin.[7]

Alarmingly, there has been relatively little public dialogue about this problem and its solution.

The climate impacts on the Colorado River hydrology have exposed a major engineering flaw at Glen Canyon Dam, which raises the specter of a serious problem for the desert southwest: How will the Lower Basin deal with dramatically reduced water deliveries from the antique plumbing inside the dam, and will there be consequences to the Upper Basin for delivering reduced quantities of water to the Lower Basin?

This report urges immediate action from Congress to authorize and fund the Bureau of Reclamation to initiate the engineering design studies, permitting actions and construction necessary to retrofit Glen Canyon Dam to allow water delivery obligations to be met on a long-term basis when Lake Powell is below 3,490 fasl. This work must begin immediately to avoid a water delivery crisis since Glen Canyon Dam is effectively becoming an obstacle to delivering water to downstream water users.

A research scientist looks for vegetation in the side canyons of the reservoir.
Photo by Dawn Kish

No Plan, No Public Dialogue

Public officials remain tightlipped about the engineering and operational conundrum at Glen Canyon Dam stemming from its antique plumbing system. If future conditions on the Colorado River System mimic the dry period we have experienced in the 21st Century to date, a significant part of the 40 million people who depend on the water in the river and its tributaries could be in jeopardy. Glen Canyon Dam's inability to deliver minimum Compact water delivery requirements below 3,440 fasl at Lake Powell imposes a threat of violating the Colorado River Compact.

This shocking observation leads observers to rightly ask how we could have found ourselves so unprepared for the future.

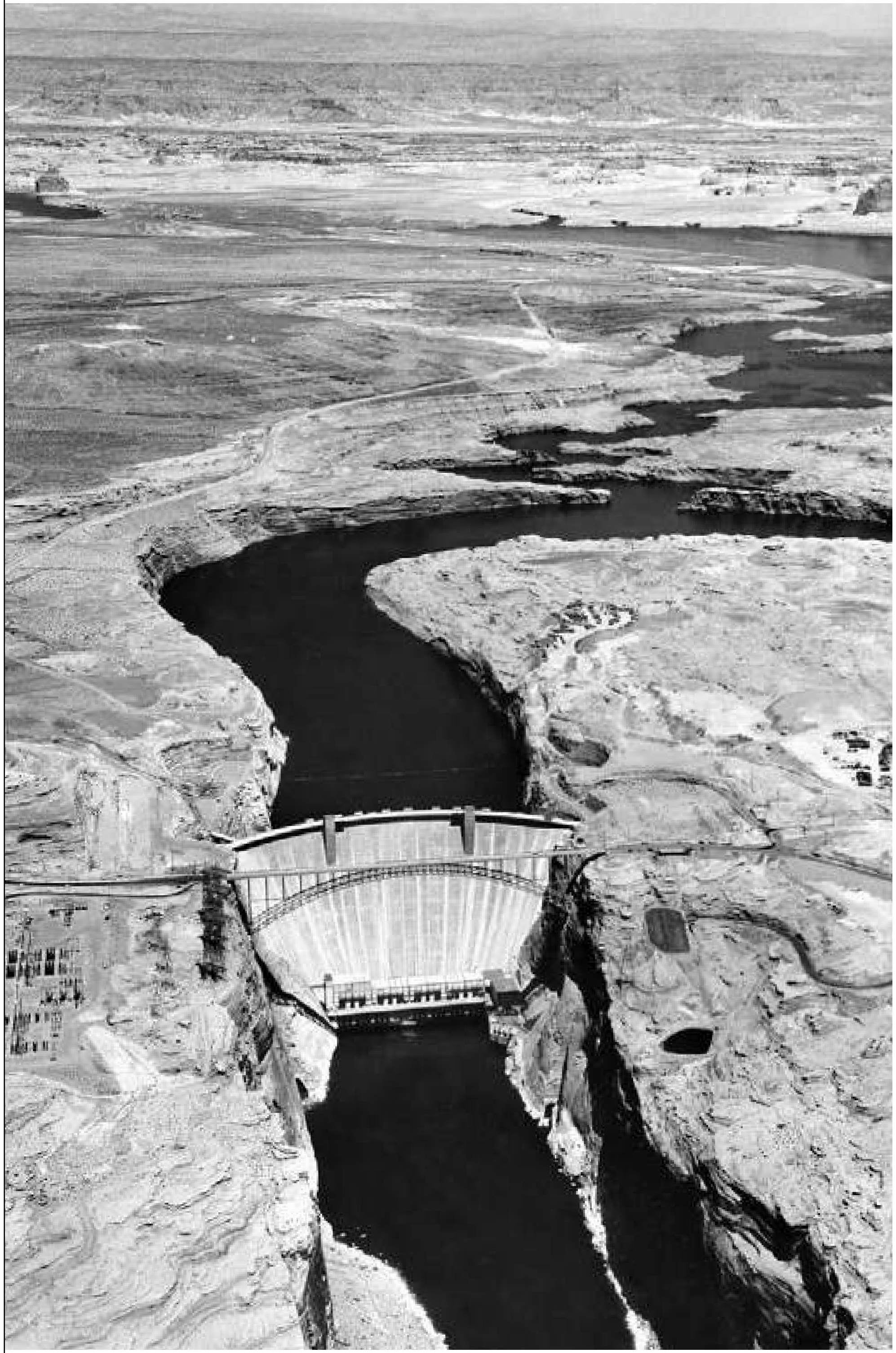
Water managers on the Colorado River have not prepared for this predictable problem, in spite of decades of peer-reviewed published scientific warnings from credible climate scientists. Instead, the Bureau and water managers have been sluggish in responding to the science and failed to understand and address the scope of climate change impacts befalling the water supply in the snowy headwaters of the Colorado River, where most reservoir water originates.

Some water managers and politicians appear to have been crossing their fingers, waiting in vain, or praying for wet winters that didn't arrive. It is also hard to miss the contrast of greater levels of water conservation in the Lower Basin against a lagging conservation ethos in parts of the Upper Basin. There has been a lot of procrastination in recognizing the vagaries of climate change in the Colorado River Basin, and one need to look no further than the many proposed or newly-constructed water diversions which have advanced amidst a declining 21st century Colorado River water supply. The Bureau itself is contributing to this problem by advancing the permitting for the largest new water diversion proposed in the Basin in 2020 – the Lake Powell Pipeline.[8]

In June 2022, the Bureau announced that the seven Colorado River Basin states had just 60 days to devise a plan to cut 2-4 million additional acre-feet of water use from the system.[9] Bureau officials noted that if the states do not identify where these water cuts will be made, the federal government will make its own decision and impose these water cuts on the states.[10] This unprecedented news barely caught the attention of the public, but it is a seismic pronouncement of how unprepared the water users of the Colorado River System truly are, in spite of the long-standing and widely-predicted nature of this problem.

Colorado River water managers are now scrambling to address the compounding results of aridification, overuse and population growth after years of cognitive dissonance regarding climate change. As water managers propose water cuts for farms and cities, there is little public debate about the efficacy of our water delivery infrastructure inside Glen Canyon Dam.

One thing is clear – the Bureau and state officials have failed to properly inform the public about the oncoming infrastructure limitations at Glen Canyon Dam and why it matters.



Glen Canyon Dam during construction. Note Colorado River water flowing around the dam at riverbed level through bypass tubes. *Photograph from Bureau of Reclamation.*

The Engineering of Glen Canyon Dam Threatens Our Water Supply

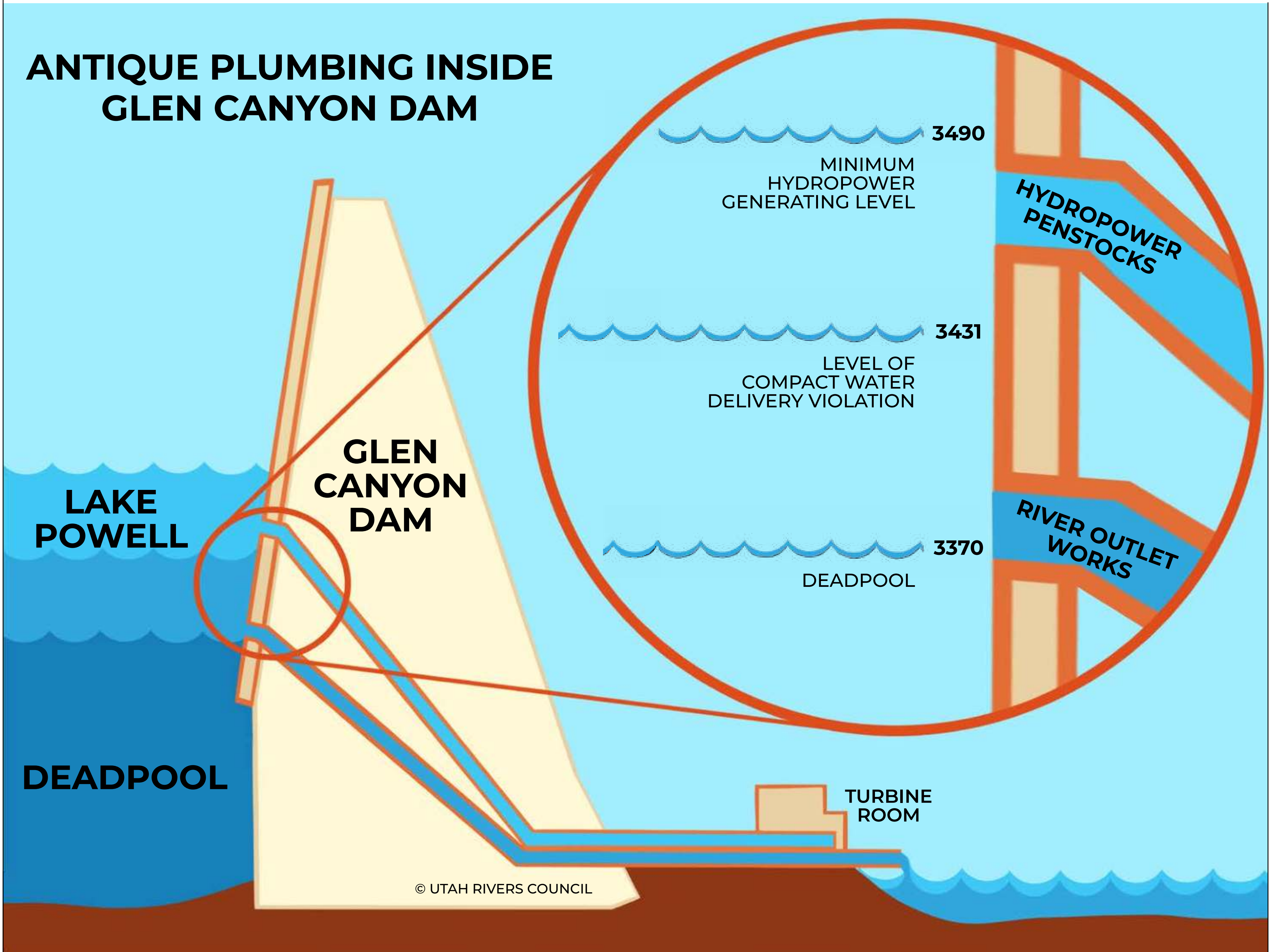
When the Bureau of Reclamation engineered Glen Canyon Dam in the 1950s, it prioritized two things: water storage to help the Upper Basin meet its delivery requirements; and hydropower generation.[11] The notion that anthropogenic carbon emissions would significantly shrink the snowpacks in the headwaters and thereby deplete the flows of the Colorado River (and subsequently the amount of water in Lake Powell) would have sounded like science fiction to most Americans at the time and heresy to western agriculturalists and city planners.

Engineers designed Glen Canyon Dam with three sets of water pipes to move water from Lake Powell into the Colorado River and the Grand Canyon. The first set of water conveyance are two spillways set on both sides of the dam near its crest, at an elevation of 3,648 fasl.[12] These spillways are set just below the dam's full pool elevation of 3,700 fasl,[13] to protect the dam from large floods that might spill over the top of the dam and damage or destroy it.

The second set of pipes are the eight hydropower penstocks at an elevation of 3,470 fasl, which is how water is routinely delivered to the Lower Basin.[14] The eight turbines cannot generate hydropower when the reservoir drops below 3,490 fasl, due to a lack of water pressure and potential structural damage, such as cavitation from air entrainment.[15] The elevation difference between the top of the reservoir when Lake Powell is full (3,700 fasl) and the penstocks is about 200 vertical feet, enough room to hold some 19 million acre-feet of water.[16]

The third set of pipes are four smaller tubes known as the River Outlet Works. The intakes for these pipes are located at an elevation of 3,370 feet in elevation, making them the lowest water delivery method in the dam.[17] If water levels drop to 3,370 feet, the outflows from the dam will roughly be the same as water flowing into Lake Powell up to a point. (Once flows exceed 15,000 cfs, the River Outlet Works reach delivery capacity and cannot convey water through the dam at a faster rate.[18])

ANTIQUE PLUMBING INSIDE GLEN CANYON DAM



The River Outlet Works were not designed to permanently deliver large quantities of water,[19] as their main role is to supplement water releases from the reservoir when the hydropower releases are not adequate. In the dam's lifetime, the River Outlet Works have only been used when the dam first filled, during the short-term high flow experiments, and for emergency releases during the 1983-1986 flood years.[20] Since the River Outlet Works were designed for emergency purposes and were not designed to routinely deliver water, serious questions exist regarding whether these outlets are capable of functioning long-term, as will be required when Lake Powell drops below the penstock intake level of 3,490 feet.[21]

At a certain elevation, the River Outlet Works are not physically capable of releasing all the water required to meet the Upper Basin's delivery obligation to the Lower Basin and Mexico, under current interpretations of the Law of the River.[23]

Additionally, the River Outlet Works are limited in the amount of water they are able to convey through the dam. There are fewer outlets than there are penstocks, and the outlets are smaller in diameter.[22] This means that as reservoir levels drop, the amount of water flowing out of Glen Canyon Dam is reduced. A simple thought experiment makes this clear. Imagine swimming to the bottom of a deep pool. The deeper you go, the more pressure you feel build on your body. As you swim lower into the water column the more water there is above you. The more water there is above you the heavier it feels, meaning the pressure is higher the lower you go into the water column. This concept is known as head pressure or hydraulic head and it is the same force that pushes water through Glen Canyon Dam into the river at the eastern end of the Grand Canyon National Park.

As the water level of Lake Powell declines, so too does the water pressure at the intakes of the River Outlet Works at 3,370 fasl. The less water there is above this 3,370-foot elevation, the less pressure there is to push water out of the River Outlet Works. In other words, as the water level of Lake Powell declines, so too does the amount of pressure to push water through the River Outlet Works. At a certain point, the pressure pushing the water out of the River Outlet Works gets so weak that the facility can no longer release 7.5 or 8.3 million acre-feet of water to the Lower Basin.

This phenomenon is well documented in scientific literature. The Bureau of Reclamation's *Technical Record of Design and Construction* for the Glen Canyon Dam shows the discharge capacity curve of the River Outlet Works – or the amount of water that the River Outlet Works are able to convey through the dam at varying Lake Powell elevation levels.[24] It makes clear that below 3,440 the maximum discharge is less than 8.3 million acre-feet and below 3,430 it is less than 7.5 million acre-feet.

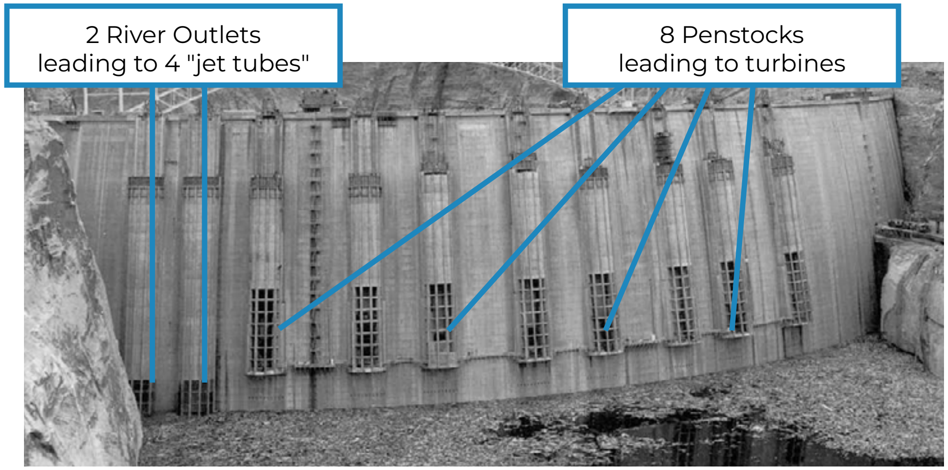
This data is conveniently summarized in *White Paper #1* by John C. Schmidt of Utah State University's Center for Colorado River Studies. Table 1, taken from *White Paper #1*, shows the maximum release capacity of the River Outlet Works for key Lake Powell elevations.[25]

Maximum rate of discharge through the river outlets as a function of Lake Powell elevation[20]

Reservoir elevation, in feet above sea level	Maximum discharge through river outlets, in cubic feet per second	Maximum discharge rates through bypass tubes, in acre feet per year
3,500	15,000	10,900,000
3,490	14,650	10,600,000
3,450	12,600	9,090,000
3,440	11,400	8,280,000
3,430	10,200	7,410,000
3,420	8,800	6,370,000
3,400	4,800	3,470,000

Table 1: Table from White Paper #1 demonstrating limited release capacity of river outlet works

Historic photo from the Bureau of Reclamation of Glen Canyon Dam and its associated sets of pipes



How Did We Get Here?

Rosy Forecasting by the Bureau

Climate change is an immensely challenging problem for water managers and the Bureau has been subject to the varying climate change priorities from very different presidential administrations and congressional leaders. Perhaps this is why the Bureau has missed the chance to lead the American West on climate change and has greatly underestimated the scope of climate change impacts befalling the system in the face of peer-reviewed published science warning everyone about the coming crisis.

The water forecasts used by the Bureau for the Colorado River often present a much rosier picture than what has been observed.[26] Forecasting the long-term future at Lake Powell is very difficult to do with certainty because climate change is upending many previously tried and true modeling practices, a problem the entire world is facing. But as we grapple with climate change, realistic predictive modeling is vital for all who depend on the Basin's water, and peer-reviewed published science must be integrated into planning forecasts.

One of many such critical published findings comes from Utah State University's John C. Schmidt et al. This study evaluated Colorado River projections by the Bureau and found that the agency has consistently underestimated the impacts of climate change and overestimated the amount of water projected to flow in the Colorado River, specifically into Lake Powell.

As described in the Futures of the Colorado River Project's *White Paper #7*, the Bureau's 24-month studies have consistently overestimated runoff of the studies' 2nd year "most probable" projection.[27] The study found that the Bureau's "most probable projected inflows were higher than what actually occurred by as much as ~7 million acre feet (maf) in some years, and predicted reservoir elevations were also higher than what occurred in some years." This is most aptly demonstrated by White Paper #7's Figure 7, which has been reproduced in Figure 2 as a single graph.

As we grapple with climate change, realistic predictive modeling is vital for all who depend on the Basin's water, and peer-reviewed published science must be integrated into planning forecasts.

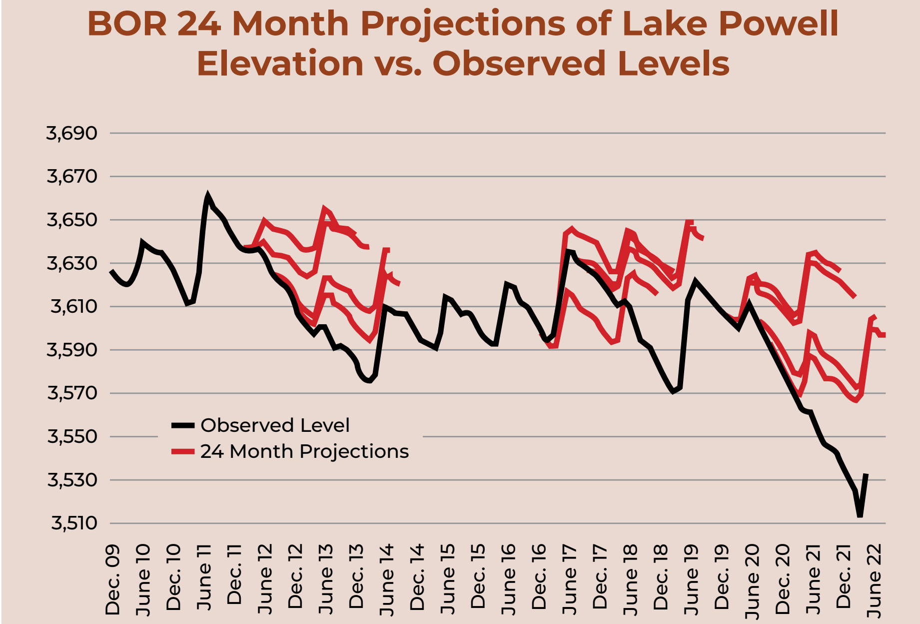


Figure 2. Bureau water level predictions versus reality. The declining levels of Lake Powell between December 2009 and June 2022 demonstrates how far Lake Powell water levels have declined over time, as shown in black. The red lines are Bureau of Reclamation 24 month "most probable" forecasts which demonstrate a bias to overestimating the amount of water that will be in Lake Powell. Reproduced from White Paper #7, Figure 7.

Given current trends in the Basin and the work of numerous climate scientists projecting that the impacts of climate change will worsen in coming years, it is very plausible that Lake Powell water levels may drop much lower than the Bureau is currently projecting. It is clear that many water managers, including the Bureau itself, have chronically underestimated the scope of climate change impacts to the Colorado River water supply. Given the risks associated with Lake Powell declining to compact-violating levels, it is wise to prepare for a much drier future as quickly as possible.

How Likely is it that Lake Powell Will Decline Further in the Future?

While it is difficult to project our future with a high degree of confidence, historical trends and the current scientific literature indicate that the Colorado River System and its reservoirs will continue to decline. Climate change has reduced the Colorado River's average annual flow roughly 20% over the past two decades, compared to the 20th Century average, thereby resulting in dramatic water level declines at Lake Powell.[29] Numerous scientific papers have elucidated the causes of these flow declines, and have modeled what future conditions in the Basin could look like if climate change proceeds unmitigated.[30]

For example, scientists have tracked just how much air temperatures have risen in the American Southwest as a result of anthropogenic carbon emissions,[31] and modelled how these increased air temperatures are reducing snowpacks,[32] shortening the length of winters,[33] shifting precipitation patterns from snow to rain,[34] producing more dust on snow events,[35] and increasing the likelihood and severity of megadroughts.[36] Given the range of impacts, prominent climate scientists have forecast that we are likely not yet at the bottom of Colorado River flow declines and suggest we could see declines up to 40% in water flows by the mid-century.[37]

Table 3 summarizes the range of Colorado River flow declines projected by peer-reviewed scientific papers. This material is reproduced from *A Future on Borrowed Time*, an analysis of Upper Colorado River Basin water budgets. Flow declines are shown as a percent decrease from the 20th Century Average of 15.2 million acre-feet, and both the 20th and 21st Century Averages are included for reference.

Water Flow Scenario

Flow reduction of the Colorado River at Lee Ferry	Naturalized flow at Lee Ferry
20th Century Average (1906-1999)	15.2
5% Decrease	14.4
21st Century Average 19% Decrease	12.4
20% Decrease	12.2
40% Decrease	9.1

Table 3. From 2000 to 2018, the Colorado River flowed at an average 12.4 million acre-feet per year, a roughly 20% drop in flows from the 15.2 million acre-feet experienced for most of the 20th century.

As water flows in the Colorado River System decline, so will reservoir levels. The reservoirs function like a savings account where the rivers are the income stream. When the income stream declines, expenditures must decline as well or else savings will be depleted. This is exactly what has happened to the savings accounts at both Lakes Powell and Mead, and future water flow declines will only exacerbate the issue.

The Bureau recently took steps to prop up Lake Powell, releasing an additional 500,000 acre feet of water from Flaming Gorge and holding back 480,000 acre feet of water from being released to Lake Mead downstream.[40] Even with these efforts, the Bureau projects that, under the most probable scenario, Lake Powell's elevation will drop to approximately 3,505 fasl by April 2023, 17 feet lower than the reservoir's 2022 low point.[41] Under minimum probable inflow projections, the Bureau estimates that Lake Powell could fall as low as 3,491 by September 2023.[42]

To examine what the reservoir's future could look like and provide another possible prediction of what could happen in the years ahead, we conducted a simple analysis where we projected potential future Lake Powell water levels by simply using observed historical data. We chose two historical five-year periods and examined what Lake Powell's water level would be if future conditions resembled those observed in either of these periods.[43] Figure 4 shows the entire history of Lake Powell's water levels and illustrates the two color-coded periods we used to project future Lake Powell levels, from 2000-2004 and from 2017-2021.

Historic Elevation Levels of Lake Powell

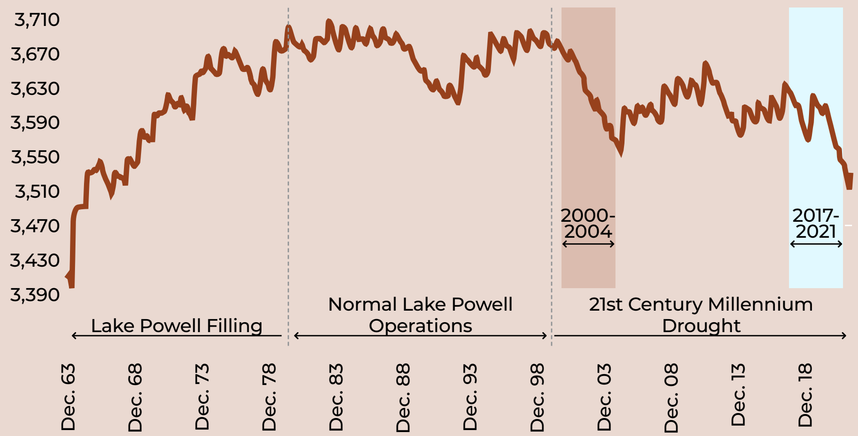


Figure 4. Historic elevations of Lake Powell and highlights for the two historic periods used to forecast possible future declines in Lake Powell for policy consideration of Glen Canyon Dam engineering.

Table 5 provides summary data for the two periods.

	Average unregulated inflow to Lake Powell	Change in Lake Powell Storage	Change in Lake Powell Storage	Average Natural Flow at Lees Ferry	Decline in Natural flow from 20th Century Average
2000-2004	5.8 million ac-ft	-120 feet	-13.8 million ac-ft	9.4 million ac-ft	38%
2017-2021	7.8 million ac-ft	-65 feet	-5.5 million ac-ft	12.2 million ac-ft	20%

Table 5. Summary statistics for two historical time periods used in analysis.

These two periods were chosen because they represent good 'new normal' and 'low end' projections for the Colorado River System. The 2000-04 period roughly lines up with the low end projection of a 40% decline in Colorado River flows predicted by the current scientific literature.[44] The 2017-21 is similar to the 21st century average Colorado River flow of 12.3 million acre-feet and could be thought of the recent new normal. Figure 6 shows Lake Powell's projected elevation level using these two historical periods.

When forecasted into the future using these two historic periods, Lake Powell quickly drops to levels well below the critical elevation thresholds of 3,440 and 3,430 fasl, thereby causing the aforementioned Compact and water supply problems. Our exercise is not meant to be a prediction that Lake Powell will follow either of these paths over this time frame. Projecting Lake Powell's actual water levels over the next five years with a high degree of certainty is very difficult. This exercise merely demonstratesit is plausible that Powell could drop to these critical elevation thresholds in the near future.

Potential Future Elevation of Lake Powell if Historic Conditions Repeat

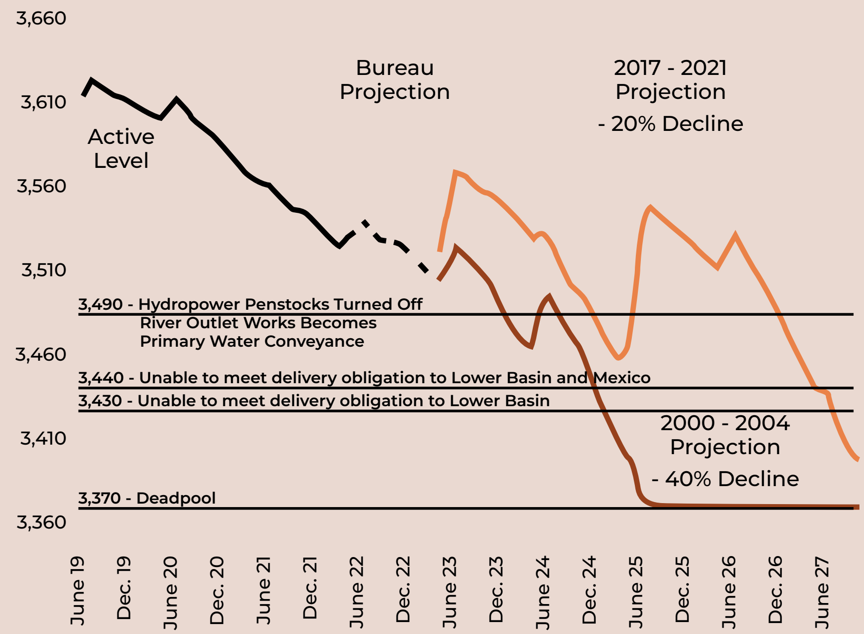
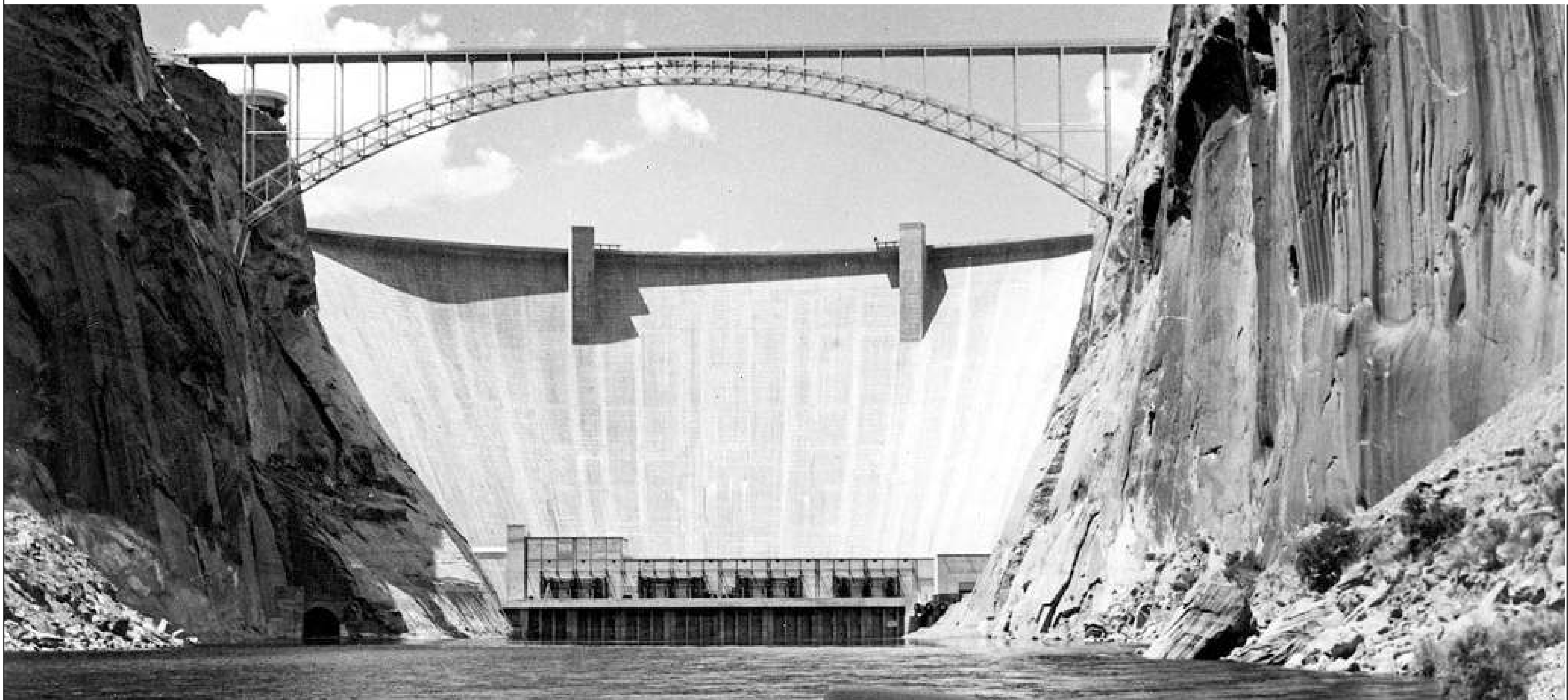


Figure 6. Projected elevation of Lake Powell reservoir levels into the future from March 2023 forward, given observed historical hydrologic periods of both 2000 – 2004 and 2017 – 2021.



SOLUTION

Modernize Glen Canyon Dam for the 21st Century

Given the likelihood of Lake Powell dropping to very low water levels in the future and given the severity of the water delivery problems that will occur, there is an urgent need to implement a permanent solution to address this archaic design. While these problems could be years away, any solution could take several years for approval and perhaps several more years for design and construction, making immediate action essential.

The Bureau recently initiated a preliminary study to examine options for generating hydropower at lower water levels by installing turbines in the River Outlet Works.[45] While this study is a good first step, its scope of research is narrow and it should have been initiated years ago. Installing turbines lower in the dam will not solve the issue of reduced water deliveries from Glen Canyon Dam and could potentially make the problem worse by further restricting the release capacity of the River Outlet Works.[46]

That's why a more expansive study is needed, which includes fixing the archaic engineering of Glen Canyon Dam by considering operating the reservoir at water levels near or below the River Outlet Works while expanding the flexibility to move water through or around the dam. Two possible alternatives to this problem are outlined below along with a cursory discussion of each solution's benefits and drawbacks. Congress should immediately fund the Department of Interior to commission a full-scale analysis of these alternative engineering solutions at Glen Canyon Dam.

ALTERNATIVE 1

Retrofitting the River Outlet Works to Release More Water

One potential solution to Glen Canyon Dam's engineering problems is modifying the River Outlet Works to release more water at low elevation levels, between 3,490 and 3,370 fasl. This could happen by either expanding the diameter of the existing River Outlet Works or by constructing additional outlets to increase the overall release capacity. While the feasibility of this option would need to be studied, preliminary discussions from the Glen Canyon Dam Technical Working Group suggest that it could be possible to create additional intakes for the River Outlet Works. This seems to indicate that structural changes to the face of the dam are possible,[47] and peer-reviewed studies have indicated that the creation of new penstock tubes through existing dams is technically feasible in some circumstances.[48]

Such a modification would solve the immediate water delivery issues described in this report as the maximum amount of water that could be released through the River Outlet Works would be increased to allow the Upper Basin to meet their water delivery obligations down to elevation level 3,370 fasl (the intake point for the River Outlet Works). These modifications could also be paired with the Bureau's ongoing effort to install low-head hydropower turbines in the River Outlet Works,[49] thereby preserving some hydropower generation.

There are many considerations that come from the reduction of Lake Powell water levels, and this report was not written to analyze the benefits or costs associated with different water storage proposals at the reservoir. By having sufficient water delivery functionality and flexibility at the River Outlet Works, the Bureau has the option of operating Lake Powell at a lower elevation level if they chose to do so.

This could produce ancillary benefits like daylighting many of Glen Canyon's previously-inundated rivers – thereby creating new aquatic and wildlife habitat and recreational opportunities. Prior to its inundation, Glen Canyon was considered by many, including western writers like Wallace Stegner, to be a National Park-caliber landscape. Since the decline of the reservoir, many of the canyon's tributary rivers and side canyons have experienced ecological rebound[50] and new recreational opportunities associated with free-flowing tributary rivers.[51] We recognize that other kinds of reservoir recreation would be impacted from lower water levels and this will impact nearby communities and businesses engaged in these economic activities, although newly revealed features and the prospect of a river recreation economy have recently been touted by the superintendent of Glen Canyon National Recreation Area.[52]

While initial discussions by the Glen Canyon Dam Technical Working Group suggest modifications to the face of the dam may be feasible – and while new penstocks have been retrofitted into existing dams before – it is unclear if the specific design of Glen Canyon Dam would allow for such modifications. Thorough study is needed to determine the technical feasibility of this solution.

More troubling is that this solution would only work so long as Lake Powell remains above 3,370 fasl. If drying conditions continue to worsen in the Colorado River headwaters as they have for the past 22 years, Lake Powell could quickly fall to water levels near the River Outlet Works, rendering the newly-installed turbines obsolete. Fixing the archaic engineering flaws at Glen Canyon Dam should be implemented in a manner to ensure that future generations have as much operational flexibility as possible.

THE PROBLEMS WITH DEADPOOL AT LAKE POWELL

Glen Canyon Dam is only capable of releasing water down to 3,370 fasl, the intake point for the River Outlet Works.[53] These water intakes sit nearly 240 above the bottom of the dam, meaning that a large pool of approximately 1.7 million acre-feet of water is effectively 'stranded' behind the dam.[54] This large pool of water, commonly referred to as deadpool, could become a common occurrence in the near future at Lake Powell without significant changes at Glen Canyon Dam. In addition to the inability to access to 1.7 million acre-feet of water, operating near deadpool at Lake Powell would create a number of problems for the reservoir's managers, Colorado River Basin water users, and a range of other constituencies. Not the least would be a stagnant body of water sitting in a desert environment that would be conducive to harmful algal blooms and other water quality problems.

At deadpool, the reservoir is subject to rapid changes in elevation, due to the martini glass-like shape of Lake Powell's vertical cross section. Nearly half of the reservoir's capacity resides

continued on page 24

Glen Canyon Dam during construction. Note Colorado River water flowing around the dam at riverbed level through bypass tubes. *Photograph from Bureau of Reclamation.*

above 3,600 fasl,[55] meaning that when water levels drop to deadpool elevation ranges, even moderate inflows can cause water levels to rise over 100 feet in one season.[56] This could create numerous problems for both reservoir visitors and the National Park Service – the federal agency tasked with managing the recreational facilities at Lake Powell.

These rapid elevation changes would force the Park Service to move marinas and extend boat ramps, which can be extremely costly. Already, the majority of Park Service and Tribal supported launch ramps are unusable. Current plans to adapt to declining reservoir levels include abandoning the current Bullfrog Marina site and moving marina facilities into the main channel at an estimated cost of $25 million dollars.[57] With the significant cost of extending boat ramps, walking ramps and marina utility infrastructure, there will come a point of diminishing returns on increasingly large and frequent taxpayer investments. After such investments are made to adapt to deadpool elevations, a subsequent medium or large water runoff year could lead to significant damage to this new infrastructure. This could create infrastructure challenges for the National Park Service, which is already suffering from a large backlog of maintenance projects.

In a scenario where the reservoir nears deadpool without subsequent engineering modifications to Glen Canyon Dam, its lifespan would dramatically decrease due to its storage volume being displaced with sediment. The Colorado River has the second largest natural sediment load of any large river in North America, moving an estimated 54-60 million metric tons of sediment per year into Lake Powell.[58] When the reservoir is full, this amount of sediment displaces a relatively small portion of the reservoir. But when the reservoir is low, that proportion of sediment displacement will more quickly diminish the reservoir's smaller storage volume as sediment moves closer to the dam. According to the findings of Schmidt et al. (2016), if the reservoir were to remain at levels between power pool and deadpool, sedimentation will eventually affect flow into the River Outlet Works.[60]

Sediment has been accumulating in the upper reaches of the reservoir for nearly 60 years, totaling a loss of 6.8% reservoir storage capacity since 1963.[60] As the reservoir and its volume of stored water has declined, the rate of siltation has already increased relative to its overall size.

As Lake Powell water levels drop down to deadpool, the maximum water flow release capacity out of Glen Canyon Dam drops from 15,000 cfs to below 5,000 cfs.[61] The reduction in water release capacity has adverse effects on the Grand Canyon ecosystem, Below elevation 3,440 fasl, downstream releases would need to be maximized to meet delivery obligations, meaning flows in the Grand Canyon would be constant over long periods of time. These reduced flow capacities would limit the ability to conduct High Flow Experiments downstream and aggravate restoration efforts to improve sediment deficits in Grand Canyon Nation Park. Under these flow conditions, the fate of the Grand Canyon's ecosystem is unknown.

One of the most troubling threats to the Grand Canyon ecosystem from low water levels is the introduction of smallmouth bass from Lake Powell, notorious predators of the Colorado River's native fish. Lake Powell's low water levels are now allowing bass – which stay in the upper, warm layers of water in the reservoir – to pass through the dam's penstocks into the Grand Canyon.[62] If water levels continue to decline, more bass will likely pass into the Grand Canyon and establish a permanent population there.[63]

ALTERNATIVE 2

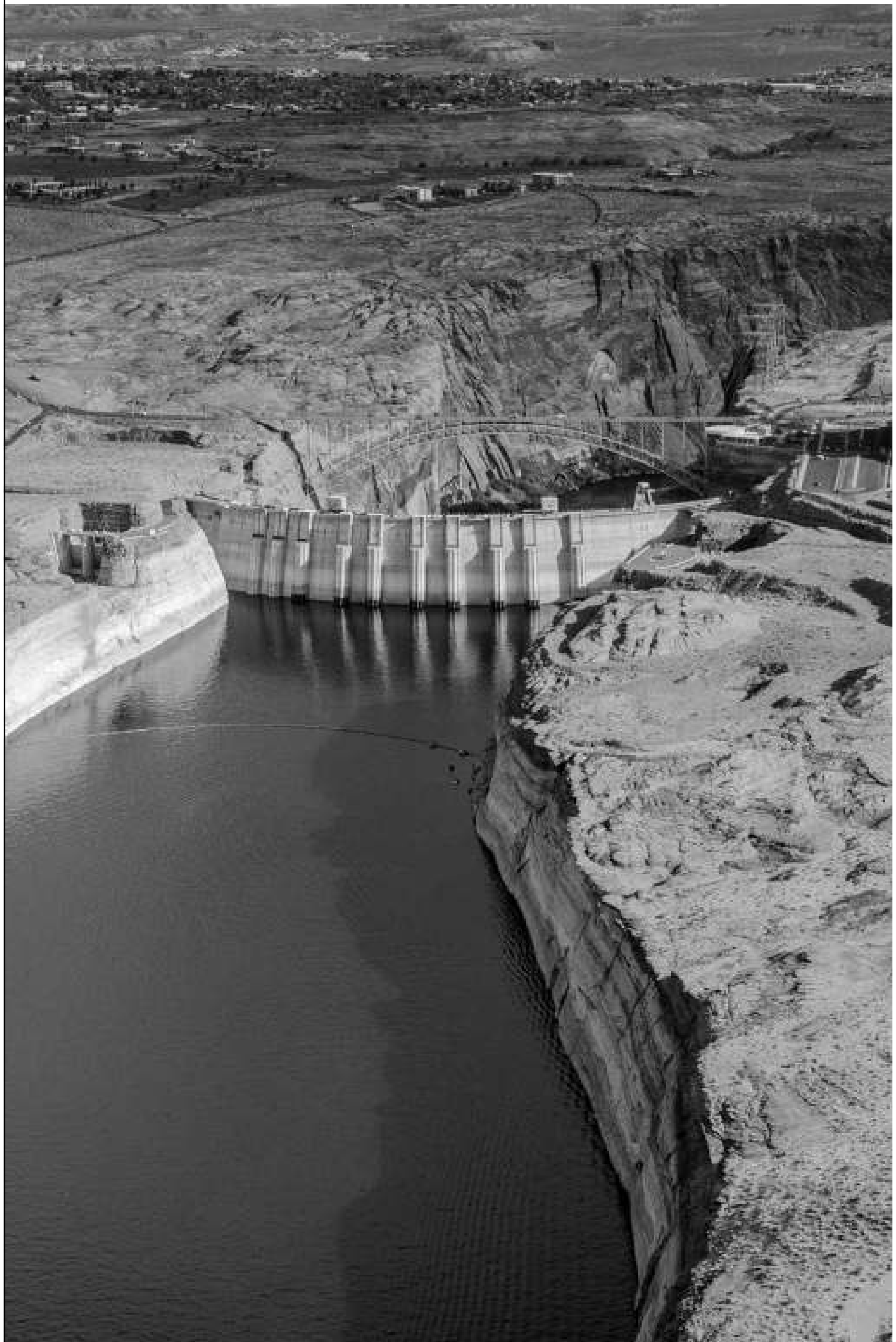
Installing New Bypass Tubes at the Base of Glen Canyon Dam

A more long-term and operationally flexible solution to Glen Canyon Dam's engineering problems in this era of aridification would be to install a new set of bypass tubes at the base elevation of the dam. These tubes could be constructed to have a large water flow release capacity and would include slide gates that the Bureau could open and close to control when and how much water is released. This solution would likely be technically feasible, as the bypass tubes would be relatively similar to the original bypass tubes the Bureau built when it first constructed Glen Canyon Dam.[64] Feasibility studies for other dams in the United States have found that retrofitting dams with large bypass tubes is technically feasible.[65]

This solution would solve Glen Canyon Dam's water delivery problem, and could also afford the Bureau maximum operational flexibility at Lake Powell. Having a way to release water from the very bottom of the dam would allow the Bureau to pursue a wider range of reservoir management alternatives, from operating just below 3,370 fasl down to operating Glen Canyon Dam as a "run of river" facility. This flexibility could prove vital in our climate change future of lower water flows, where Lake Powell may need to be managed at much lower levels.

Constructing bypasses at the base of the dam would also allow Basin water users to access all of the water currently in Lake Powell, ensuring that stranded deadpool water can flow downstream to help satisfy Lower Basin water-delivery obligations. This alternative would allow for sediment to move through the dam and protect the Grand Canyon. It is unclear just how expensive it would be to construct bypasses at the base of the dam, but determining this dollar value would be worthwhile. We should at least know how much it would cost to install new bypass tubes at the base of the dam so as to have a more informed policy discussion regarding solutions to the Colorado River's water supply issues.

Management options available with bypass tubes could also address siltation in Lake Powell and Glen Canyon, and even allow for sediment distribution into the Grand Canyon. Any management choices involving a low reservoir or a completely phased out reservoir would have significant effects downstream in the Grand Canyon, including the trout fishery at Lee's Ferry, invasive fish populations, native fish populations, archeological and cultural resources, as well as river recreation. It should be noted that many of the effects on the Grand Canyon could be at least partially controlled by the Bureau's decisions on how and when to release water.



CONCLUSION

The aridity of the millennium drought continues to grip the West with no end in sight. A few big winters or monsoon seasons will not alleviate the problems that climate change and regional aridification pose for the Basin. The archaic plumbing inside Glen Canyon Dam is an obstacle to satisfying Colorado River Compact obligations in this era of aridification at low reservoir levels. The need for ingenuity, collaboration and swift action are paramount for the future of the entire Colorado River Basin, home to 1 in 8 Americans.

For the past two decades, the Bureau of Reclamation has underestimated the scope of water flow reductions on the Colorado River from climate change aridification in the Basin's headwaters. These underestimates stem from the challenges of incorporating peer-reviewed published science into complicated data sets and forecasting methodologies. This leaves us understandably wondering about the validity of federal modeling that has, time and again, been overly optimistic.

The Bureau is not excused from failing to disclose to the public the risks stemming from the 1950's era engineering inside Glen Canyon Dam. The antiquated plumbing system inside Glen Canyon Dam represents a liability to Colorado River Basin water users who may quickly find themselves in legal jeopardy and water supply shortfalls because Glen Canyon Dam and Lake Powell was designed by engineers to operate with more water storage than Mother Nature is currently providing.

A financial manager has an affirmative obligation to disclose financial risks to a client, regardless of how displeasing the bad news may be to hear. So too does the Bureau have an affirmative obligation to disclose to the entire public the risky nature of the stranded asset posed by the high elevation of Glen Canyon Dam's hydropower penstocks. These penstocks are the primary means of complying with the water delivery obligations of the 100-year-old Colorado River Compact, yet they will be unusable at just 45 feet below current water levels.

Lake Powell is quickly approaching the point at which it may soon become physically impossible to pass enough water through the dam to meet the Upper Basin's water delivery obligations. Such an event would likely be the most calamitous in the Colorado River System's history, causing legal complications, economic harm, and a water supply crisis across the seven states and Mexico. Understanding the severity and urgency of this crisis is a first step to finding common ground among a diverse set of Basin constituents.

We call upon Congress to fund an emergency study by the Bureau of Reclamation to assess and address the engineering shortcomings of Glen Canyon Dam. This study should evaluate, at a minimum, the two alternatives of using the River Outlet Works and/or of using a constructed base-of-the-dam-level bypass at Glen Canyon Dam to satisfy the Upper Basin's water delivery obligations. The study should investigate long-and short-term solutions to address what could be a disastrous scenario on the Colorado River.

The complexity and impacts of using these lower elevation engineering features inside Glen Canyon Dam are far-reaching and will impact many constituents. These impacts are exactly why such a study should commence immediately and be conducted in a transparent fashion.

For the sake of our future, the time to act is now.

How Much Water Must the Upper Basin Deliver through Glen Canyon Dam?

Under current interpretations of the Law of the River, two cornerstone agreements establish that the Upper Colorado River Basin states are required to deliver minimum amounts of water to the Lower Colorado River Basin States and Mexico. Failure to deliver these agreed upon amounts could result in technical, legal, engineering, and environmental problems for all members of the Basin.

The 1922 Colorado River Compact created a framework for the states of the Colorado River Basin to share the water amongst themselves. This agreement is interpreted to mean that the four Upper Basin states of Wyoming, Colorado, New Mexico and Utah should deliver 75 million acre-feet of water every ten years to the three Lower Basin states of Arizona, California and Nevada (an average of 7.5 million acre-feet per year).

In addition, a 1944 treaty requires the United States to deliver 1.5 million acre-feet of water to Mexico each year. There is no consensus on exactly which states need to contribute water to meet Mexico's 1.5-million-acre-foot delivery. Most interpretations of the Law of the River state that the Upper and Lower Basin should split the delivery evenly (meaning each provides Mexico with 750,000 acre-feet), while other interpretations pin the entire 1.5-million-acre-foot delivery obligation on the Lower Basin. Depending on the interpretation, the Upper Basin may need to deliver 750,000 acre-feet of water to Mexico – in addition to its 7.5 million acre-foot requirement – for a total of 8.3 million acre-feet per year. Failure to deliver these water volumes could violate these provisions of the Law of the River, potentially triggering a cascade of impacts commonly referred to as a compact call or curtailment.

Curtailment brings with it a number of negative consequences, chief of which could be forcing the Upper Basin states to sacrifice water supplies. Lower Basin states could incite litigation, demand water from Upper Basin reservoirs, and force curtailment of Upper Basin usage. A compact call would have economic impacts on Upper Basin communities ranging from reduced agricultural production, limited urban growth, and restricted recreation. Communities could be pressured to augment supplies with costly and potentially destructive water importation schemes, buy-and-dry efforts of working farmland and increased groundwater pumping — none of which are sustainable silver bullets. Curtailment should be avoided at all costs, and retrofitting Glen Canyon Dam to avoid such a crisis is clearly warranted.

The 1922 Colorado River Compact is interpreted to mean that the four Upper Basin states of Wyoming, Colorado, New Mexico and Utah should deliver 75 million acre-feet of water every ten years to the three Lower Basin states of Arizona, California and Nevada

It should be noted that the descriptions of the Colorado River Compact and the 1944 Treaty presented here rely on long-standing and commonly accepted interpretations of both agreements. However, the Law of the River is an evolving doctrine in which modifications are often discussed and recent, climate-change-induced stresses in the Colorado River Basin have lead some experts to call for new interpretations that better respond to the Basin's current issues.

For example, Jeffrey Kightlinger – former general manager of the Metropolitan Water District of Southern California – stated that having the Upper Basin deliver fixed amounts of water downstream in the face of declining flows may be unreasonable: "most (experts) don't think the Lower Basin can take all the water in the river without adjustment. Most believe that the Lower Basin states will also have to share in the reductions."

Similarly, Eric Kuhn – former general manager of the Colorado River District – and John Fleck – director of the University of New Mexico's Water Resources Program – have argued that the Law of the River may need to undergo substantial changes to remain effective in the face of declining flows.

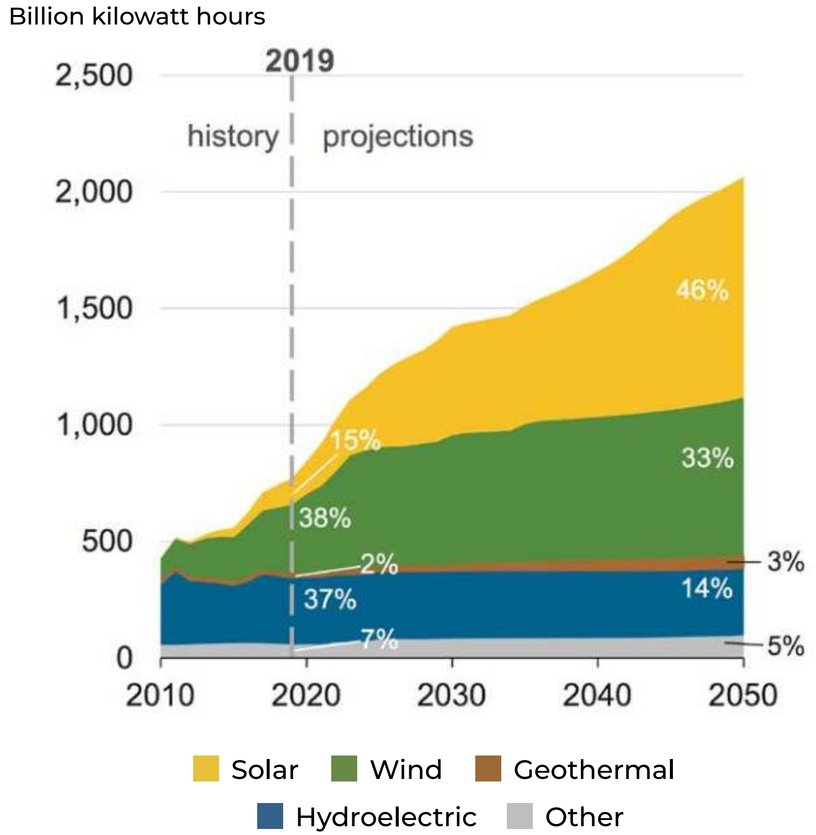
Nevertheless, it is unclear what changes the Law of the River may undergo in the future, and it's likely that Glen Canyon Dam's structural limitations are hindering the system's ability to adapt to those changes. Implementing options to reduce risk and increase operational flexibility is what's needed now.

How important is Glen Canyon Dam hydropower to the American Southwest?

When it comes to low water levels at Lake Powell, much of the attention has been focused on the impacts of losing hydropower generation. The electricity generated by Glen Canyon Dam is used by residents in the intermountain area and the revenues generated by the sale of that electricity fund important federal programs.

To date, we are aware of only one study that examines what effects losing hydropower at Glen Canyon Dam would have on the American Southwest: The Impact of the Loss of Electric Generation at Glen Canyon Dam by Power Consulting and Aesir Consulting. The study found that "the average annual value of Glen Canyon Dam's electric energy represents less than one half of one percent of the sales value from electric generation in the western grid, and that the grid could readily absorb the loss of hydropower from the dam" and that "average yearly cost increases would be $.08 per month for residential customers, $.59 per month for commercial customers, and $6.16 per month for industrial customers of Glen Canyon Dam electricity." In other words, the study found that losing electricity generation at Glen Canyon Dam would not have a significant effect on the electrical grid of the Western US or on individual consumer's power bills.

Renewable electricity generation, including end us
(AEO2020 Reference case)



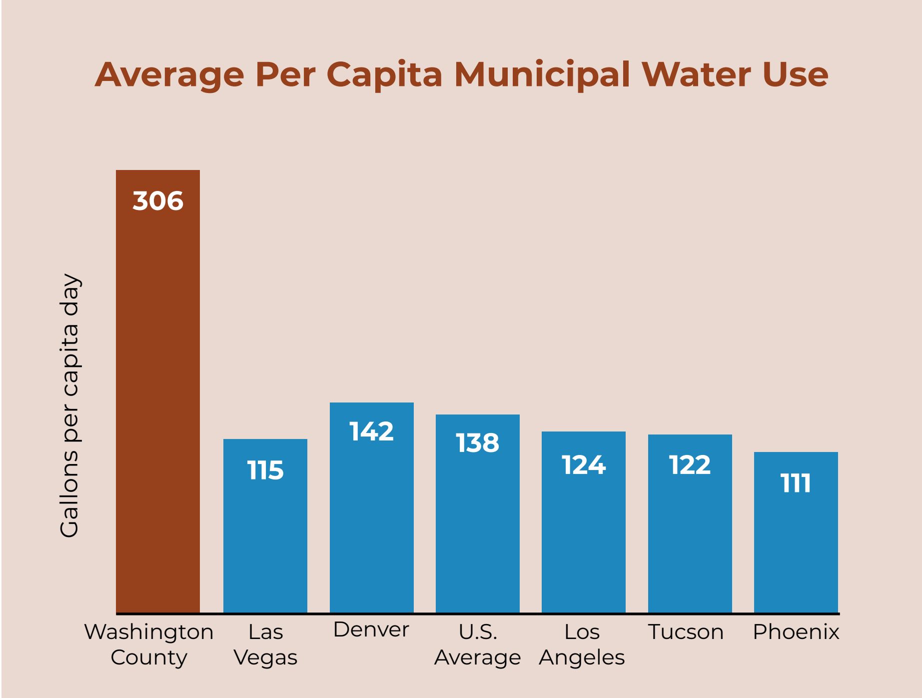
Furthermore, as the United States continues to move into the future, hydropower is expected to play a smaller and smaller role in the nation's overall energy portfolio as renewable energy sourcing increases over time. The US Energy Information Administration projects that by 2050 hydropower will fall from 7.03% of the US's energy portfolio to 5.32%. The administration projects that other renewables will more than fill in the gap, with solar increasing from 2.85% to 17.48% and wind increasing from 7.22% to 12.54% of the nation's portfolio.

While losing hydropower Glen Canyon Dam is a challenge, it is not as dire as some make it out to be. The electricity generated by the dam could be readily replaced by other sources, and future growth in renewable energy supplies is expected to more than make up for any loss of hydropower.

Bureau of Reclamation Permitting Largest New Water Diversion in Colorado River Basin

The Provo Office of the Bureau of Reclamation is currently permitting the largest new water diversion in the entire Colorado River Basin: the proposed Lake Powell Pipeline. Coming in the midst of the current millennial drought, many have criticized the State of Utah for failing to acknowledge the declining water supply of the Colorado River and the impact this water diversion poses to other water users across seven states and Mexico.

Many also have criticized both the State of Utah and the Bureau of Reclamation for justifying the construction of the proposed 140-mile-long pipeline by citing the need for water in Washington County, Utah. According to the Draft Environmental Impact Statement prepared in 2020 by the Bureau, Washington County's water use is 306 gallons per person per day, more than twice the per person municipal water use of residents in Las Vegas, Los Angeles, Denver, Tucson, Phoenix and the U.S. national average. Washington County is believed to have an existing water supply as large as Tucson and Albuquerque, each of which has a population nearly three times the size of Washington County's current population.



Source: U.S. Geological Survey 2015; Bureau of Reclamation LPP DEIS 2020; Individual Cities

As other communities across the Basin contemplate more aggressive water conservation efforts and taking water cuts of the Colorado River water supply, it seems out of place for the federal agency managing a crashing system of dams and reservoirs on the Colorado River to propose poking another straw into an over-allocated water supply for one of the nation's most-wasteful water users.

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