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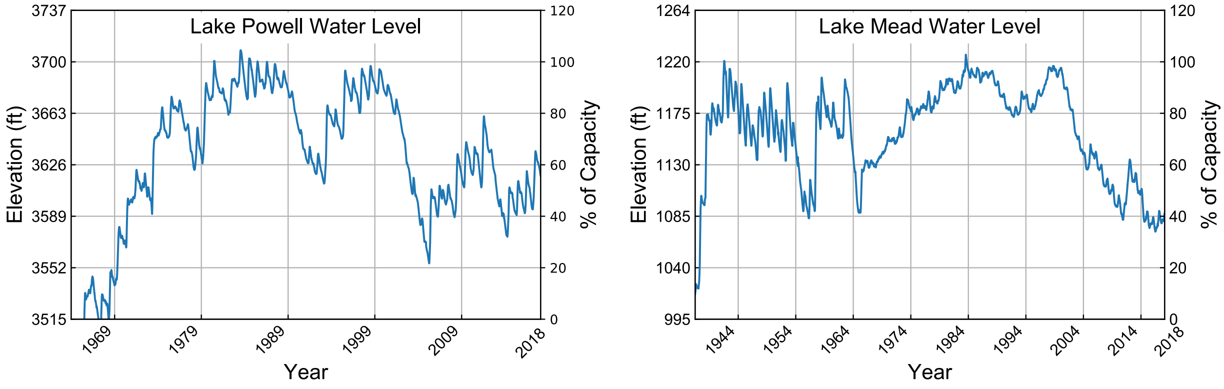
Comprehensive Review of the Fill Lake Mead First Initiative

1. INTRODUCTION

The Colorado River Basin (CRB) has a diverse set of stakeholders that shape basin policy. The management of the CRB and surrounding region is challenging because policy decisions can be in direct conflict with different stakeholders. For example, pulse flow releases from the Glen Canyon Dam that benefit rafters and native fish could also potentially destroy the critically endangered Kanab Ambersnail's habitat (Kennedy et al. 2016). Therefore, any proposed policy change needs to be carefully defined and the impacts understood. One such proposed policy is the Fill Lake Mead First plan, which proposes draining Lake Powell in the upper basin and filling Lake Mead in the lower basin (Kellett 2013).

The Glen Canyon Dam is located at the dividing line between the upper and lower basins of the Colorado River. Lake Powell, impounded by the Glen Canyon Dam, is the second largest man-made reservoir in the United States with a capacity of 24.3 Million Acre Feet (MAF) (Bureau of Reclamation 2007). Only Lake Mead (impounded by the Hoover Dam) is larger, with a capacity of 26 MAF (Bureau of Reclamation 2007). Construction of the Glen Canyon Dam began in 1956, and commissioning occurred in 1966. By 1980, the reservoir reached full pool. Since its commissioning, Lake Powell has served an important role in the Western United States for water storage, power generation, flood control and surface water recreation.

Operation and management decisions are made in tandem for Lake Mead and Lake Powell with an "equalization rule" policy (Bureau of Reclamation 1970). Under the equalization policy, both reservoirs impound roughly equal amounts of water. The rule was enacted to prevent Lake Mead from dropping to critically low levels and maintain hydroelectric power generation at both Glen Canyon and Hoover Dams. However, under this policy both reservoirs have operated at 50% capacity for the last decade. Shown in Figure 1 are the current reservoir levels (as of February 2018) and the percentage of capacity that level represents.



(a) (b)

Figure 1: (a) Lake Powell reservoir elevation and capacity, (b) Lake Mead reservoir elevation and capacity. (Water-data.com 2018)

Recent studies have been conducted to determine how drought in the CRB will affect reservoir levels in the coming decades. Barnett and Pierce (2008) projected that low reservoir levels will continue, impacting the ability of both dams to generate hydroelectric power and provide a stable water source for downstream users. Kirk et al. (2017), who noted that 70% of the annual stream flow of the Colorado River originated as snowmelt, found that hotter, drier conditions will likely persist. Summertime ridge patterns, which have been typically associated with drought, will increasingly dominate the atmospheric conditions in the CRB watershed.

Recognizing the current low reservoir levels and the chance that levels may decline, The Glen Canyon Institute (GCI) proposed a plan in 2013 to Fill Lake Mead First (FLMF) (Kellett 2013). The FLMF plan would drain the remaining water from Lake Powell and use it to fill Lake Mead. Once drained, any inflows into Lake Powell would pass downstream to the Grand Canyon without impoundment. Lake Powell would then serve as additional flood control in high flow years. The GCI estimated that consolidating water to one reservoir would save 300,000-600,000 acre-feet (AF) annually. The GCI also provides several other goals of the FLMF plan: 1) Restore the Colorado River to a pre-dam flow and sediment regime, 2) Make Glen Canyon, which is currently underwater, accessible again. Glen Canyon Dam would not be removed under this plan due to the extreme cost required to do so. The purpose of this paper is to evaluate the goals of the FLMF plan and determine if they are plausible and based on accurate assumptions. The ecological concerns of the FLMF plan will also be examined.

2. FILL LAKE MEAD FIRST IMPLEMENTATION

With the understanding that no major modifications would be made to the Glen Canyon Dam Schmidt et al. (2016) summarized the most likely potential phases of the FLMF plan. These phases were evaluated to determine if they would restore the Colorado River to pre-dam flow and sediment regimes.

Shown in Figure 2 is a diagram of the three Colorado River outflow elevations at the Glen Canyon Dam. The spillway, located at 3,648 feet, can release 208,000 ft^3/sec. During the lifespan of the dam, the spillway has only been operated once, during the high flow year of 1983. The penstocks, at 3,470 ft, are used for hydroelectric power generation and can release 33,000 ft^3/sec. Finally, the river outflow at 3,374 ft can release 15,000 ft^3/sec; any water lower than this level cannot be released.

2.1. Phase I

Phase I, as shown in Figure 2, of the FLMF plan would lower Lake Powell from its current level of 3,620 ft (Feb 2018 level) to 3,490 ft. During this initial phase, the reservoir can only release 45,000 ft^3/sec. (While technically 48,000 ft^3/sec can be released, under the current operation plan the maximum permitted outflow is 45,000 ft^3/sec.) For much of the year, inflows can be released, with no increase or decrease in reservoir elevation. However, during periods of springtime runoff, the outflow capacity cannot match expected inflows, and the reservoir elevation will increase. For example, in June 2008 the average inflow was roughly 60,000 ft^3/sec (Water-data.com 2018), which averaged over the entire month would produce a net increase of 1.1 MAF of impounded water. The June 2008 Colorado River flows are not abnormal, with some estimates suggesting that prior to the construction of dams the annual peak flows were 50,000 ft^3/sec or higher (Topping et al. 2003).

2.2. Phase II

Phase II of the plan lowers the reservoir to 3,370 ft, the dead pool elevation. At this elevation only 15,000 ft^3/sec can be released through the river outflow conduits. It is difficult to control the reservoir elevation during this phase because inflows routinely exceed the outflow capacity. In Figure 3 Schmidt et al. (2016) presents the recorded 2008 inflows and superimposes the outflows for Phase II. In Figure 3a, the 15,000 ft^3/sec outflow cannot match the recorded inflow into Lake Powell, and the reservoir will begin to rise. Once the reservoir rises to the penstocks (3,490 ft) an additional 30,000 ft^3/sec can be released from the reservoir, which occurs on June 1st for the given example. When the reservoir elevation drops below the penstock intake, water once again can only be released from the 15,000 ft^3/sec river outflow conduits. At year's end, the reservoir elevation does not decrease back to the starting elevation (Figure 3b).

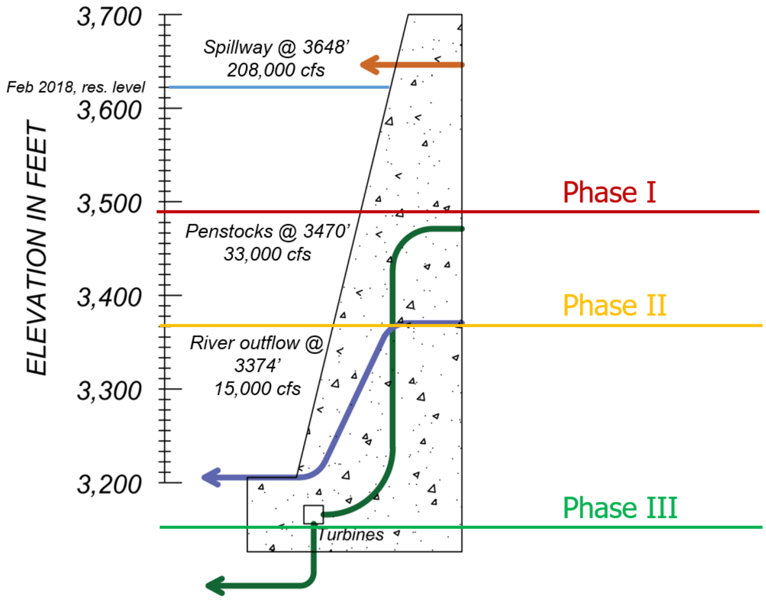


Figure 2: Glen Canyon Dam Colorado River outflow elevations, and proposed Phase I, II, and III drawdown heights. (Figure modified from Vernieu et al. 2005)

Given that the reservoir release capacity during Phase II cannot match reservoir inflows, a pre-dam flow regime is not restored. Outflows into the Grand Canyon are a maximum of 15,000 ft^3 /sec until the elevation of the reservoir reached the penstocks.

2.3. Phase III

Phase III is a hypothetical plan that would modify the existing Glen Canyon Dam and drill new diversion tunnels to release water. Additional lower elevation bypass tunnels would allow the reservoir to drain completely. The diversion tunnels would have to be sized appropriately for the expected flow magnitudes and frequencies. Topping et al. (2003) estimated that prior to Glen Canyon Dam, a flood with a peak flow of 125,000 ft^3/sec was expected on average every 8 years. While designing for the 8-year flood event may not be feasible, it still needs to be considered.

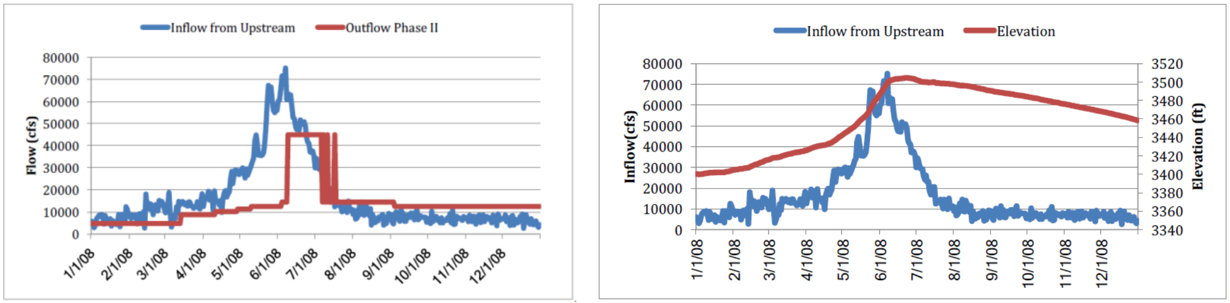
3. WATER SAVING OF FILL LAKE MEAD FIRST INITIATIVE

The water-saving assertion by the GCI primarily comes from the decreases in evaporation and groundwater losses by consolidating water to one reservoir. It is unlikely that FLMF plan or another water storage plan would be implemented unless the plan results in net increases of available water in the CRB (Schmidt et al. 2016).

The change in reservoir storage (ΔS) of Lake Powell can be expressed with a water budget shown in Equation 1 (Schmidt et al. 2016):

$$\Delta S = I + P - E \pm G - R - D \qquad \text{Eq. 1}$$

where *I* is the surface water entering the reservoir, *P* is the precipitation that falls directly onto the reservoir area, *E* is the evaporation of the reservoir, *G* is the ground water moving into or away from the reservoir, *R* is the surface water released from the reservoir and *D* is the direct withdrawal (or pumping) from the reservoir. Of the terms in Equation 1, the estimations of evaporation (E) and ground water (G) are the most poorly known because they cannot be directly measured.



(a) (b)

Figure 3: (a) 2008 inflow to Lake Powell and proposed outflow under Phase II, (b) 2008 inflow to Lake Powell and reservoir elevation under Phase II.

3.1. Evaporation Losses

Evaporation cannot be directly measured, and the methods used to estimate evaporation often do not accurately represent a large reservoir, requiring significant simplifications. Evaporation is expressed as a rate per unit surface area and total evaporative losses are the rate multiplied by the reservoir surface area.

Typical approaches to measure evaporation include evaporation pans, where the time it takes to evaporate a known quantity of water is measured. Using a water budget, like Equation 1, evaporation can be estimated, often by ignoring the ground water (G) term (Bedient et al. 2008). Eddy Covariance directly measures the water vapor emitted from a water body surface to estimate evaporation (Bedient et al. 2008). Significant year-to-year variations can be expected with any method to determine evaporation due to changes in air and reservoir temperatures, wind speed, and exposure to solar radiation (Davenport 1967).

Multi-year studies have been conducted measuring evaporation rates of both Lake Mead and Powell. Anderson and Pritchard (1951) conducted one of the earliest studies to determine evaporative losses using an energy budget method and estimated Lake Mead would be lowered 5.3 ft annually. Using mass transfer relationships, Harbeck et at. (1953) estimated that between 1941 to 1953 the annual gross evaporation rate was 7.0 ft/ yr. Recently, Westernburg et al. (2006) generated a hybrid estimate using four barges on Lake Mead to measure rates of evaporation and fed those observations into an energy budget method to estimate 7.5 ft of annual evaporation. The annual rate selected herein is proposed by Moreo (2015) who used the Eddy Covariance method described above and estimated between 2010 -2015 the annual evaporation was 6 ft/yr.

The evaporative losses at Lake Powell have not been extensively studied like Lake Mead. Jacoby et al. (1977), using a mass balance approach with wind and temperature data from 4 locations on the reservoir, estimated an annual evaporation rate of 5.7 ft between 1962-1975. The USBR reprocessed the Jacoby et al. (1977) data and found the annual evaporation rate was closer to 5.8 ft/yr, and is the selected evaporation rate for Lake Powell used herein for comparative purposes (Bureau of Reclamation. 1986).

Table 1 summarizes the evaporation losses for Lake Mead and Powell for Phases I and II by Schmidt et al. (2016). Under current conditions, the combined evaporative losses from both reservoirs is roughly 1.1 MAF/yr. Under Phase I of the plan there is no net change in evaporative losses, which is due to how evaporation is measured: Lake Powell will decrease in surface area when it is lowered, but that will cause an increase in surface area of Lake Mead, offsetting changes in evaporation. Phase II has a net decrease of 100,000 AF of evaporative losses, validating the claim that filling Lake Mead First will save water.

Table 1: Estimated evaporation losses for current conditions and Phase I and II of the Fill Lake Mead First Plan. Bounds given in parentheses. (From Schmidt et al. (2016)

	Current Conditions	**Phase I**	**Phase II**
Lake Powell (AF)	570,000 (±80,000)	280,000 (±40,000)	120,000 (±15,000)
Lake Mead (AF)	560,000 (±40,000)	820,000 (±60,000)	870,000 (±70,000)
Total (AF)	**1,100,000** (+200,000) (-100,000)	**1,100,000** (±100,00)	**1,000,000** (+100,000) (-200,000)

3.2. Groundwater Losses

Lake Powell is underlain by porous Navajo sandstone, which is speculated to have significant groundwater losses (Schmidt et al. 2016). Several studies have been performed to estimate the amount of groundwater that leaves Lake Powell and does not return to the reservoir. Using a water budget like Equation 1, Jacoby et al. (1977) estimated that between 1963-1966, 1968-1971, and 1971-1976 Lake Powell lost 0.85 MAF, 0.69 MAF, and 0.68 MAF to groundwater respectively. Using groundwater observation wells and a 2D numerical model, Thomas (1986) estimated the seepage from Lake Powell was 0.37 MAF between 1963-1983, and 0.05 MAF between 1983-2033. While both groundwater studies acknowledge that more water loss occurred during the initial filling of Lake Powell, Thomas (1986) speculated that by 1983 the rock surrounding Lake Powell was about 50% saturated. 100% saturation would occur in the following 80-700 years, with Thomas suggesting 400 years (i.e. year 2383) as the most reasonable estimate. The rate at which water is lost to the surrounding bedrock would decrease with time. The direct measurements and simulations of groundwater losses by Thomas (1986) provide a more compelling argument for the rate of groundwater losses, and therefore 0.05 MAF is assumed to be loss to groundwater.

In contrast to Lake Powell, no modern groundwater studies have been conducted for Lake Mead. The lake is composed of unconsolidated alluvium and bedrock, which have different hydraulic conductivities. Schmidt et al. (2016) estimated the zone of saturation surrounding Lake Mead may be as little as 1 mile to greater than 10 miles depending on the underlain rock.

The total net increase in annual water to the CRB by filling Lake Mead is 150,000 AF. The groundwater estimates proposed by Thomas (1986) will only decrease with time and therefore decrease the potential water savings of the FLMF plan. The 300,000-600,000 AF yearly water saving estimated by the GCI is predicated on very similar evaporation rates, but groundwater losses of 300,000 AF. The GCI argued the groundwater losses would not decrease with time and are the same today as they were during first filling of Lake Powell. Prior to the implementation of any water relocation plan, additional studies should be performed to estimate the evaporation and groundwater losses of both reservoirs, reducing the uncertainty of estimated losses and providing better information to policy makers.

4. SEDIMENT REMOBILIZATION

Sediment that was once transferred down the Colorado River and through the Grand Canyon is now being impounded in Lake Powell. There are no present-day estimates of the amount of fine sediment being deposited into Lake Powell, although Topping et al. (2000) did estimate that 54-60 million metric tons per year of fine sediment was transported through Glen Canyon to Lees Ferry between 1949-1962. Sediment that enters the reservoir is deposited in the upper reaches of the Colorado and San Juan deltas. Shown in Figure 4 are the bathymetry profiles of Lake Powell measured between 1963 to 2005. Majeski (2009) estimated that 410,000 AF of fine sediment has been deposited in the area between 240-300 km upstream of the Glen Canyon Dam on the Colorado delta between 1963-1999. An adverse effect of lowering Lake Powell to Phase I or II elevations would be the remobilization of sediment deposited at the river inflow deltas. Fine sediment would be remobilized closer to Glen Canyon Dam and into Glen Canyon.

Past drawdowns of Lake Powell provide some insight into expected sediment remobilization. Between 1999-2005, Lake Powell was lowered 55 m (Figure 1). Majeski (2009) showed that 84,000 AF of fine sediment in the Colorado River delta was remobilized downstream. 35% of the sediment was remobilized directly in front of the delta, while the remaining sediment was transported closer to the dam (and into Glen Canyon). Pratson et al.

(2008) studied the same remobilization process by looking at changes in reservoir bathymetry profiles (i.e. Figure 4) and observed similar trends with large volumes of sediment moving closer to the dam.

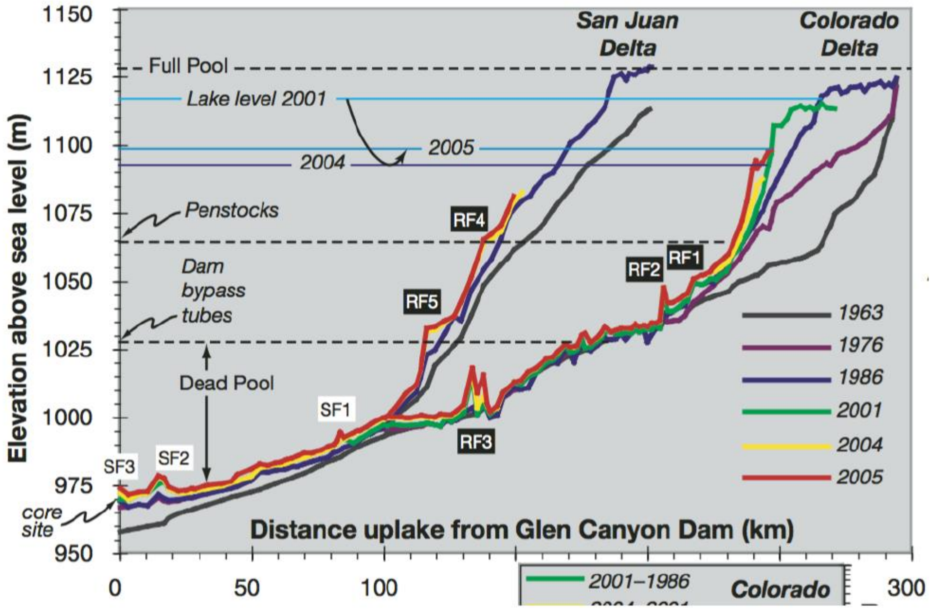


Figure 4: Lake Powell bathymetry profiles upstream from the Glen Canyon Dam (Pratson et al. 2008)

Sediment will be remobilized during each phase of the FLMF plan. It is reasonable to expect that similar movement of sediment may occur like the 1999-2005 drawdown, because Phase I of the plan reduces the reservoir by a similar height. The newly disturbed sediment would then occupy the low-lying areas within Glen Canyon, hindering efforts to restore Glen Canyon to pre-dam conditions.

5. ECOLOGICAL IMPACTS

If implemented, the FLMF plan would be the largest ecological disturbance to the CRB since the construction of the Glen Canyon Dam. Each phase of the proposal would alter the amount of flow released to the Grand Canyon. Restoration to the natural flow regime would only occur when the Phase III diversion tunnels are constructed. Impoundment of water in Lake Powell during Phases I and II will cause the Colorado River to remain sediment deficient, since downstream flow velocities in the reservoir will slow and sediment will drop out of suspension. A sediment deficient Colorado River is favorable for non-native fish (Yard et al. 2007) and without sediment replenishment, natural sandbars and beaches will continue to erode (Dolan et al. 1974).

If water that enters Lake Powell in Phase II is immediately released into the Grand Canyon, the river temperatures in the Colorado River will return to more natural conditions. Currently water released from the penstocks is from 150 ft beneath the surface of the reservoir and is typically 7-13 ℃ throughout the year (Vernieu et al. 2005). By releasing surface reservoir water, the temperature of the water entering Grand Canyon would be restored to pre-dam conditions of 2-24 ℃ (Vernieu et al. 2005) since it would be exposed to air temperature fluctuations.

6. CONCLUSION

In the next several decades decisions will need to be made about the long-term use of Lake Powell and Mead. Under the current equalization rule both reservoirs are at half capacity, with predictions that water levels will continue to decline. The Fill Lake Mead First plan is a proposed plan to consolidate the water from Lake Powell into Lake Mead. This plan is estimated to save 300,000-600,000 AF annually, but the actual saving is closer to 150,000 AF. Additional studies should be performed to better estimate water losses from both reservoirs.

The Fill Lake Mead First plan presented other benefits to the Colorado River Basin that may not be achievable under the current iteration of the proposal. Current capacity of the Glen Canyon Dam penstocks and river outflow inhibit restoration to pre-dam river flows or sediment regime. Unless new diversion tunnels are constructed, the Colorado River will not return to pre-dam flows. Glen Canyon, which is currently beneath Lake Powell would reemerge once the reservoir was drained, but it is likely the draining of the reservoir will remobilize millions of tons of fine sediment currently deposited in the upstream reaches of the reservoir closer to Glen Canyon Dam and into Glenn Canyon.

There is no doubt that future water relocation decisions in the Colorado River Basin will be controversial. Decisions will be made that may not be the best for all basin users, but goals of the proposed project should be critically evaluated to at least determine if they are feasible.

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