# Model Guide

## Lake Mead Water Bank based on the Principle of Divide Reservoir Inflow

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# I**ntroduction**

The purpose of this tool is to give users the opportunity to immerse in water user roles and experiment with a Lake Mead Water Bank. The Bank works on the principles of **A) Divide reservoir inflow**, **B) Subtract evaporation**, and **C) Users withdraw and conserve within their available water**, others choices, and real-time discussion of choices. We see uses of the tool for two purposes:. We see use of the tool for two purposes:

* As researchers we want to learn *Why* basin partners choose assumptions and *how* extreme; *Why* and *how* basin partners articulate their risk of uncertain future water supply and manage their vulnerability; and *Which* new insights they take from a model session.
* Provoke discussion about new alternatives for Colorado River management post 2026 and their possible benefits to:
  + Stabilize and recover reservoir storage under conditions of low storage *and* low inflow, and
  + Give users more autonomy to manage their vulnerability to water shortages.

This document provides context information for each individual and group choice within the immersive model. The document also explains how choices build on existing Colorado River management (Appendix A). The document also suggest potential values to enter for user choices.

Find quick links to this support information -- the sections and subsections of this document -- in the Model file, *Master* worksheet, Column N.

Requirements

* **Session Guide**: 1 person to setup in Google Sheets (see Setup below), invite participants, and organize play.
* **Number of People**: 2 or more (Session Guide may also participate).
* **Time**: 1 to 3 hours.
* **Software**: Session Guide has a Google Account.

# Instructions to Guide a Model Session

Review the main canons of existing Colorado River management (Appendix A; persons not familiar with current Colorado River operations).

Follow the setup and play instructions (Box 1). The rest of the document provides guidance on each step.

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## Types of Use

The model can be used in two modes:

1. Synchronously by multiple participant where each participant manages one or more accounts (in Google Drive).
2. By a single participant (manages all accounts).

Participants can explore:

* Water conservation and consumptive use strategies.
* Scenarios of Lake Mead inflow.
* Joint (political) decisions such as:
  + Split existing reservoir storage among accounts.
  + Split future inflows among accounts.

# Step 1. Assign Accounts, Articulate Vulnerabilities, and Strategies to Manage Vulnerability

The Reclamation, California, Arizona, Nevada, and Mexico accounts represent entities defined in the 1922 Colorado River Compact, US-Mexico Treaty of 1948, subsequent Minutes 319 and 323, Lower Basin drought contingency plans, and pledges to include more accounts (Table 1)(1922; IBWC, 2021; USBR, 2019; USBR, 2020). The Tribal Nations of the Lower Basin users represents Tribal Nations and their settled water rights (Ten Tribes Partnership, 2018).

**Maps of water user areas**

* [Upper Basin, Lower Basin, Mexico](https://www.usbr.gov/lc/images/maps/CRBSmap.jpg) (USGS, 2016)
* [First Nations](http://www.naturalresourcespolicy.org/images/col-river-basin/map-tribes-crb.jpg) (Ten Tribes Partnership, 2018)

**Table 1. Accounts, Reason(s) to include in model, and Potential Strategies**

| **Account** | Reason(s) to Include | **Potential Strategy(s)** |
| --- | --- | --- |
| Reclamation | Article II(c to g) of the Colorado River Compact (1922). Lower Basin Drought Contingency Plan (USBR, 2019). | * Set Lake Mead Protection Elevation of 1,020 feet as defined in the Lower Basin Drought Contingency Plan (USBR, 2019). Lake Mead will not fall below this level. * Lower the protection elevation to allocate more active storage to other users |
| California | Article II(c to g) of the Colorado River Compact (1922). | * Continue mandatory conservation and cutback from 4.4 maf per year as Lake Mead level declines from 1,090 to 1,025 feet (USBR, 2019). See cutback schedule in *MandatoryConservation* sheet. These values exclude 0.95 maf per year of use by First Nations in the Lower Basin. * Cut back an addition amount per year to represent the 500-Plus Plan (Allhands, 2021). * Buy water to reduce mandatory conservation. * Save some water for future years. |
| Arizona | Article II(c to g) of the Colorado River Compact (1922). | * Continue mandatory conservation and cutback from 2.8 maf per year as Lake Mead level declines from 1,090 to 1,025 feet (USBR, 2019). See cutback schedule in *MandatoryConservation* sheet. These values exclude 0.95 maf per year of use by First Nations in the Lower Basin. * Cut back an addition amount per year to represent the 500-Plus Plan (Allhands, 2021). * Buy water to reduce mandatory conservation. * Save some water for future years. |
| Nevada | Article II(c to g) of the Colorado River Compact (1922). | * Continue mandatory conservation and cutback from 0.3 maf per year as Lake Mead level declines from 1,090 to 1,025 feet (USBR, 2019). See cutback schedule in *MandatoryConservation* sheet. These values exclude 0.95 maf per year of use by First Nations in the Lower Basin. * Cut back an addition amount per year to represent the 500-Plus Plan (Allhands, 2021). * Buy water to reduce mandatory conservation. * Save some water for future years. |
| Mexico | 1944 U.S.-Mexico Treaty and subsequent Minutes | * Continue mandatory conservation and cutback from 1.5 maf per year as Lake Mead levels decline (IBWC, 2021). See *MandatoryConservation* sheet. * Conserve more water beyond mandatory targets. * Lease water to get money for non-water projects. |
| Tribal Nations of the Lower Basin | * Include more accounts (USBR, 2020) * Tribal water study (Ten Tribes Partnership, 2018) | * Develop and use 0.95 maf of settled water rights by Tribal Nations in the Lower Basin. * Lease settled, undeveloped water to other users to acquire capital to build new projects. * Save water for future use. |

A participant can play one or more accounts.

The First Nations account allows First Nations of the Lower Basin to manage their water independently from the Basin State in which the First Nation was located. This set up differed from current operations where Basin States administer water rights for the First Nations within their state boundaries.

Delete the entry in Cell A10 to remove the Tribal Nations of the Lower Basin

user. Removing will reallocate 0.95 maf of settled water rights – add 0.48 maf

to the Arizona and 0.48 maf to California.

## 1A. Explain cell types

Four model cell types are defined by fill color (Table 2).

**Table 2. Model Cell Types**



## 1B. Make Assumptions

### **(i) Evaporation rates**

Evaporation rates for Lake Mead are presently entered as the midpoint within reported ranges of measurements (Table 3)(Schmidt et al., 2016). Evaporation rates for Lake Mead are presently measured using state-of-the-art eddy-covariance however there is a several year delay in reporting values (Moreo, 2015). A sensitivity analysis found that the lower and upper bounds on Lake Mead evaporation rates for a five year study for Lake Mead draw down saw variations of 0.25 maf or less in Lake Mead storage volume.

**Table 3. Reservoir evaporation rates (feet per year)**

|  |  |  |
| --- | --- | --- |
| **Reservoir** | **Midpoint** | **Range** |
| Mead | 6.0 | 5.5 – 6.4 |

### (ii) Start storage

Reservoir start storage is taken from the [data portal](https://www.usbr.gov/lc/region/g4000/hourly/mead-elv.html) (USBR, 2021c). Text in Column D lists the date. Figure 1 shows Lake Mead storage over time (Solid black line).

A graph of water and water conservation

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**Figure 1. Lake Mead Storage (solid black line), Water Conservation (ICS) Account Balances (light blue fill), and anticipated lake volume absent the water conservation program (dashed red line). The conservation program kept Lake Mead level above elevation 1,020 feet (5.9 million acre-feet) during low lake levels in 2022.**

### (iii) Protection elevation

The Reclamation user decides the Lake Mead elevation to protect against further drawdown. An elevation of 1,020 feet was defined in the Lower Basin Drought Contingency Plan (Figure 1, dark blue fill labeled Protect)(USBR, 2019). More recently there has been discussion to lower the protect elevation to 1,000 feet (Buschatzke et al., 2024). The Lake Mead Water Bank maintains the protection elevation because the Reclamation user is always assigned a share of inflow that exactly equals the account’s share of evaporation. The protection volume is calculated from the Elevation-Area-Volume curve for Lake Mead. See worksheet *Mead-Elevation-Area*.

### (iv) Storage above Protect Zone

This storage value is the Reservoir start storage (Cell C19) minus the Protection volume (Cell C20)(Figure 1, light and medium blue fills labeled Water Conservation Accounts and Public Pool). The Storage above the Protect Zone represents the active storage that can be assigned to user accounts (see Row 35).

### (v) Water Conservation Program (ICS) Total Balance.

This entry is the sum of all existing water conservation program account balances (Figure 1, light blue fill). These balances are also referred to as the Intentionally Created Surplus (ICS) account balances and are reported at (USBR, 2021b). Figure 2 shows Water Conservation Account balances over time for the three Lower Basin states. Reclamation typically publishes values in Spring for the prior calendar year. Note, Mexico’s water conservation account balance is not shown in Figure 2.

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**Figure 2. Lake Mead Water Conservation (ICS) Account balances over time**

### **(vi)** **Remaining Storage above the Protect and ICS Balances**

This storage is calculated as the Lake Mead storage above the protection zone (Cell C21) minus the total water conservation program balances (Cell C21; Blue Public pool in Figure 2). This storage represents additional storage that may be allocated to the Lower Basin states or other users (see Step 3 Split storage in Row 35).

# Step 2. Specify Lake Mead Inflow

Participants together choose the Lake Mead inflow for the year. This inflow represents the sum of gaged flows for the gages most immediately upstream of Lake Mead (Table 4).

**Table 4. Stream gages most immediately upstream of Lake Mead and used to calculate Lake Mead inflow.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Gage Name** | **USGS Number** | **Years** | **Link** |
| A. Colorado River nr Peach Springs | 9404200 | 1990 to Present | [Here](https://waterdata.usgs.gov/monitoring-location/09404200/#parameterCode=00065&) |
| B. Virgin River at Littlefield | 9415000 | 1990 to Present | [Here](https://waterdata.usgs.gov/monitoring-location/09415000/#parameterCode=00065&period=P7D) |
| C. Las Vegas Wash Below LAKE LAS VEGAS NR BOULDER CITY, NV | 9419800 | 2002 to Present | [Here](https://waterdata.usgs.gov/monitoring-location/09419800/) |

Because Lake Mead inflow is uncertain—and likely differing from historical inflows because of climate change—we can only specify inflow as a scenario (Table 5)(Rosenberg, 2022).

**Table 5. Scenarios of Lake Mead Inflow (Rosenberg, 2022)**.

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For reference, historical Lake Mead inflows since 1990 varied from 8 to 16 million acre-feet per year (Figure 3) with the preponderance of inflows between 9 and 10 maf per year (corresponding to a Lake Powell release between 8.23 and 9 maf per year; Figure 4).

A graph showing a line

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**Figure 3. Lake Mead inflow as measured by nearest USGS gages.**

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**Figure 4. Histogram of Lake Mead inflows as measured by the nearest gages.**

Additionally note that Colorado River flow near Peachtree is the annual Lake Powell release plus 600,000 to 1 million acre-feet of gains along Grand Canyon (Rosenberg, 2022; Wang and Schmidt, 2020; Figure 5).



**Figure 5. Mean Grand Canyon tributary flow (Glen Canyon Dam to Lake Mead) for different sequence lengths.**

Further note that different methods to estimate Lake Mead inflow give different values (Figure 6). For example:

* Nearest USGS gages.
* Inflow data downloaded from the Reclamation Application Programming Interface (API; https:
* //www.usbr.gov/lc/region/g4000/riverops/\_HdbWebQuery.html).
* Back calculate from Lake Mead storage, release, Nevada Diversion, and Lake Mead evaporation data also retrieved from the Reclamation API.
* Back calculate from Lake Mead storage, release, Nevada Diversion, and Lake Mead evaporation (1990 to present). Here we use evaporation data from elevation-storage-area relationship from Colorado River Simulation System (CRSS) model.

A graph showing the number of usbs

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**Figure 6. Differing values for Lake Mead inflow as estimated by different methods.**

This work uses gages closest to Lake Mead because these values gave the *largest* annual inflows.

## 2A. Begin of year reservoir storage

In Year 1 (Column C), beginning of year reservoir storage is the Lake Mead volumes specified in Cell B19.

In subsequent years (Columns D, E, …), the Lake Mead storage volume is the is the storage at the end of the prior year (Row 134).

# Step 3. Split existing Lake Mead storage among accounts (year 1 only)

Participants split the starting Lake Mead active storage specified in Row 19 among the users. This split is a joint choice (Orange Cells B36 to B41). There are many possibilities.

However, suggestions for the split can be informed by the prior choice for the Reclamation Protect Elevation (Cell B20) and existing Water Conservation (ICS) Account Balances (Figures 1 and 2; Table 6). When using existing Water Conservation Account balances, users can access **all** of the prior conserved water (rollover) and current account balance at **any time** because the protection volume ensures a minimum storage volume and account balances must always stay zero or positive. In this setup, *there is no trigger to prohibit debits.*

**Table 6. Suggested split of existing Lake Mead storage**

|  |  |
| --- | --- |
| **User** | **Suggested initial volume** |
| Reclamation | Protection volume entered in Row 20. This level is shown as elevation 1,020 feet in Figure 1. |
| California | Water Conservation (ICS) account balance shown in Figure 2 (rollover). |
| Arizona | Water Conservation (ICS) account balance shown in Figure 2 (rollover). |
| Nevada | Water Conservation (ICS) account balance shown in Figure 2 (rollover). |
| Mexico | Water Conservation account balance under Minutes 323 to the U.S.-Mexico Treaty (IBWC, 2021; USBR, 2019). |
| Other users | Remaining water in the Public Pool shown in Figure 1. |

If the Lake Mead active storage minus the Water Conservation Account balances:

* Fall below the Reclamation protect elevation (such as in 2022 in Figure 1), the states will need to negotiate the split. In this case, states will receive less than their water conservation account balance.
* Are above the Reclamation protect elevation (such as in 2008 to 2021 and 2023), the additional water (Public pool in Figure 1) can be assigned to other users such as Tribal Nations of the Lower Basin.

In actuality, the participants will negotiate over a share of the existing reservoir storage. In these negotiations, participants will get the same or more storage water as they get with current operations.

## 3B. Calculate Mead Evaporation

Reservoir evaporation volume is the product of (i) annual evaporation rate (see Row 18), and the lake surface area associated with the current reservoir volume. Find the Elevation-Storage-Area relationship on the *Mead-Elevation-Area* worksheets (far right). Data were download from the Colorado River Simulation System (CRSS) model (Wheeler et al., 2019; Zagona et al., 2001).

The total reservoir evaporation is divided among water users in proportion to their account balance (Equation 1, evaporation terms in maf per year, balance and storage terms in maf).



For example, if Lake Mead active storage is 7.2 maf and Lake Mead evaporation is 0.4 maf for the year, and:

* California has an account balance of 0.72 maf (10% of the active storage), then California is assigned 10% of the total evaporation or 0.04 maf that year.
* The Reclamation protect elevation is 1,000 feet (4.5 maf; 62.5%), the Reclamation is assigned 62.5% of the total evaporation or 0.25 maf that year.

# Split Lake Mead inflow among accounts

Participants split the Lake Mead inflow among accounts (See Row 28). There are lots of ways to split inflow among the users.

To maintain the Reclamation protection elevation, this user is assigned *the first block of inflow to* exactly offset to it’s share of the annual reservoir evaporation (Row 46). This volume will vary from year to year as Lake Mead storage and evaporation vary.

Splits of reservoir inflow among the other users can leverage prior shortage sharing agreements, including the recent Lower Basin Alternative (Buschatzke et al., 2024). This proposal allocated user reductions as a percentage of the total mandatory reduction (Table 7). Thus A user’s share of the reservoir inflow is their historical allocation minus the agreed-on shortage volume (Table 8). Several examples follow to illustrate the conversion of share of *shortage* to share of *inflow.*

**Table 7. Prior agreed Lower Basin shortages and shares of shortages (Buschatzke et al., 2024).**



**Table 8. Share of Lake Mead inflow by volume and percentage.**



**Example calculations of share of Lake Mead inflow by volume and percentage (Table A2) are:**

1. Total Lake Mead inflow [B] = 9.0 ─ Total Shortage [A].
   1. For example, a total shortage of 0.4 maf yields a Lake Mead inflow of 9.0 ─ 0.4 = 8.6 maf per year.
2. Share of Reservoir Inflow:
   * Arizona [C] = 2.8 ─ Share of Shortage as Volume in Table A1.
     1. For example, at 8.6 maf of reservoir inflow, Arizona’s share is 2.8 ─ 0.28 = 2.52 maf.
   * Nevada [D] = 0.3 ─ Share of Shortage as Volume in Table A1.
     1. For example, at 8.0 maf of reservoir inflow, Nevada’s share is 0. 3 ─ 0.03 = 0.27 maf.
   * California [E] = 4.4 ─ Share of Shortage as Volume in Table A1.
     1. For example, at 7.5 maf of reservoir inflow, California’s share is 4.4 ─ 0.44 = 3.96 maf.
   * Mexico [F] = 1.5 ─ Share of Shortage as Volume in Table A1.
     1. For example, at 7.5 maf of reservoir inflow, Mexico’s share is 1.5 ─ 0.25 = 1.25 maf.
3. Total Reservoir Inflow [G] = [C] + [D] + [E] + [F]
4. A user’s Percent of Reservoir Inflow is their share by volume divided by the total volume.
   1. Arizona [H] = [C] / [G]
   2. Nevada [I] = [D] / [G]
   3. And so forth.
5. Total Percentage of Reservoir Inflow [L] = [H] + [I] + [J] + [K] = 100%.

**Observations**

1. Nevada and Mexico’s percent shares of the reservoir inflow remain constant at 3.3% and 16.67%, respectively. These percentage shares are the same share of their historical allocations.
2. Arizona’s percentage share of Lake Mead inflow decreases as the inflow decreases whereas California’s share of Lake Mead inflow increases.

# Step 5. Participant Dashboards – Conserve, Consume, and Trade

Each participant has a dashboard where they can trade, conserve, and consume their available water (Figure 8). 

**Figure 8. Upper Basin Dashboard annotated. A Lake Powell natural flow of 9 maf gives the Upper Basin 5.7 maf of available water to sell or consume. No trades or withdraws have been entered.**

### (i) Buy or sell water from other participants(s)

Enter buy amounts as positive (+) and sell amounts negative (-). These are additions and subtractions to the account’s available water. Enter all amounts in maf. If multiple transactions – e.g, buy 0.5 maf from Lower Basin and 0.2 maf from Mexico -- enter as a formula: = 0.5 + 0.2

**These transactions are all temporary – for one year!**

When a buying account requires a selling account to invest financial proceeds in new farm or urban water conservation efforts, the money stays in the local community and the seller can make more water available in future years (Rosenberg, 2021c).

### (ii) Compensation

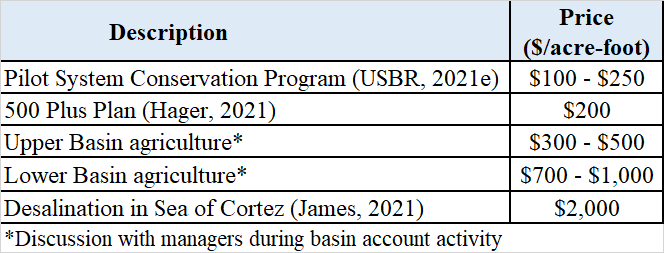
Enter compensation – payments for buying, receipts for sales – in $ millions. Enter as a formula. Multiply the sale price in $/acre-foot by the buy or sell volume in maf. Table 7 shows rough Colorado River water prices. Table 8 shows example compensation for different water prices and target water volumes.

* For example, a purchase of 0.5 maf at $500 per acre-foot is (0.5)(500) = $250 million.
* If a participant buys 0.5 maf at $500 per acre-foot from one participant and 0.2 maf at $1,200 per acre-foot from a second participant, the compensation formula is:

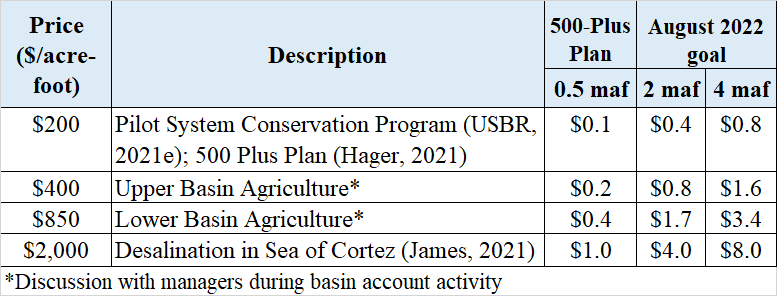
Compensation = (0.5)(500) + (0.2)(1,200) = $850 million.

The recently proposed 500-Plus plan seeks to reduce Lower Basin water use by 0.5 maf per year (Allhands, 2021). Potential compensation amounts are shown in green fill in Table 8.

**Table 7. Approximate Colorado River water prices**



**Table 8. Compensation at different water prices to purchase different target water volumes ($ billion)**



### (iii) Net Trade Volume all Participants

Confirm the net trade volume for all participants is zero. A zero balance indicates there is a buyer for every seller.

### (iv) Available Water

Available water is the water available to a participant to consume, conserve, or sell to another account. Sales decrease and purchases increase available water (Eq. 2).

|  |  |
| --- | --- |
|  | (Eq. 2) |

### (v) Enter Withdraw within Available Water

Account withdraws are consumptive use. This consumptive use occurs by a participant physically withdrawing from the combined Lake Powell-Lake Mead system at Hoover dam (Lower Basin, Mexico, or Delta). Consumptive use can also occur by diverting instream flow before that flow enters the combined system (Upper Basin). In the later case, the Upper Basin diverts the water and its basin account is deducted the corresponding consumptive use.

Enter withdraws and consumptive use according to the strategy identified in Step 1 or modifications to that strategy based on current conditions.

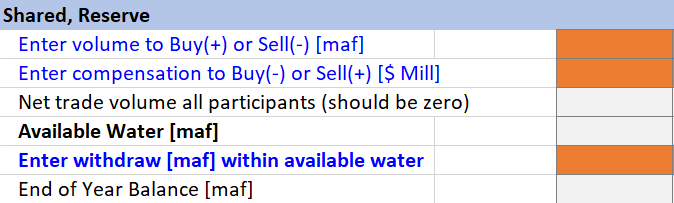
Check that other participants do not withdraw more water than is available to them!

### (vi) End of Year Balance

The account balance at the end of the year after deducting withdraws and consumptive use. End of Year balance = Available Water – Withdraw.

## 5A. Shared, Reserve Dashboard

The dashboard for the shared, reserve account is orange fill – all accounts must agree to a purchase or sale (Figure 9).



**Figure 9. Shared, Reserve account choices are a joint decision by all participants.**

The current recommendation is keep the shared, reserve account balance steady – no sales or gifts to participants in distress.

Selling or gifting water from the shared, reserve account to other accounts will lower Lake Powell and/or Lake Mead levels:

* Reduce storage in Lake Powell, heat the water temperature of Lake Powell storage (less stratification), increase the release water temperature, and push native, endangered fish of the Grand Canyon into unchartered territory -- more susceptible to prey by non-native fish. Higher Lake Powell levels and colder releases maintain the status quo for endangered fish. The worksheet *PowellReleaseTemperature* provides a table and figure of the impacts on fish of less water storage in Lake Powell.
* Reduce the head available for hydropower generation, and speed the time that reservoirs reach their minimum power pools (where they can no longer generate energy). When energy generation declines, power customers must go on the spot energy market to purchase the energy shortfall. The model of Colorado River basin accounts not quantify the impacts of reduced hydropower generation.

Both impacts will depend on how combined storage is split between Lake Powell and Lake Mead (see next section).

# Step 6. Summary of Participant Actions

Shows participant actions grouped by Purchases and Sales, Account Withdraws, and Account end-of-year balances. These groupings can help see whether sales balanced purchases and also overall water consumption for the year.

## 6A. Combined Storage – End of Year

The combined storage – end of the year is the combined storage in Lake Powell and Lake Mead at the end of the year after all account withdraws and consumptive use. This volume is the sum of the end-of-year- balances in all accounts.

# Step 7. Assign Combined Storage to Powell and Mead

All participants together assign the end-of-year combined storage to Lake Powell and Lake Mead. Enter as percent where 50% splits the combined storage equally between the two reservoirs and 75% places more storage in Lake Powell.

After entering a percent split, the following items will calculate:

### (i) Powell and Mead storage volumes and levels

The model uses the elevation-area-volume relationships for the reservoirs to calculate storage level from volume. See the left and right hand side of Figure 11 for critical levels and volumes such as dead pool (0 maf storage) and minimum power pool (penstock elevations) to avoid.

### (ii) Lake Powell release to achieve Powell and Mead storage volumes

This is the annual release from Lake Powell to achieve the specified storage volumes in Lake Powell and Lake Mead. Compare to numbers such as 7 to 9 maf per year that are the target of equalization releases (Figure 13)(USBR, 2007). Note that as combined storage declines, it will become harder to achieve the 7-9 maf targets. This Powell release is calculated as (all terms maf):

Powell Release = -[Powell end storage] + [Powell start storage] + [Powell natural inflow] – [Upper Basin consume] – [Powell evaporation] (Equation 3)

A negative release is infeasible and means too much water is already in Lake Mead. Specify a lower percentage in Step 7 – lower Powell end storage.

### (iii) Turbine release water temperature

The temperature of water released through the Lake Powell penstocks to generate hydropower. This data is pulled from observations of release water temperature and temperature profiles at Wahweap (Wheeler et al., 2021, Appendix 1).

### (iv) Suitability for native, endangered fish of the Grand Canyon

As Lake Powell release water temperature rises, outcomes become more uncertain for endangered, native fish of the Grand Canyon. The endangered, native fish become more susceptible to competition and prey by introduced non-native fish. Colder releases preserve the status quo. Table 9 shows the breakpoints of temperature suitability for native fish (Wheeler et al., 2021, Appendix 1).

### (v) Suitability for tailwater trout

The tailwater trout are an introduced species, require colder water, and live in the Colorado River reach from Glen Canyon Dam to Lee Ferry (and possibly below). Table 9 shows the breakpoints of temperature suitability for tailwater trout (Wheeler et al., 2021, Appendix 1).

Box 2 shows an example of the impacts of 13.8 maf of combined storage if assign 65% of that storage to Lake Powell.



## 7A. Consider four issues to split the combined storage between the two reservoirs:

### (i) Preserve status quo for endangered, native fish of the Grand Canyon

As Lake Powell water storage drops to the turbine release elevation of 3,490 feet (4 maf), the water stored in Lake Powell heats (less stratification), increases release water temperature through the hydropower turbines, and increases uncertainty in outcome for endangered, native fish of the Grand Canyon. The endangered, native fish become more susceptible to prey by non-native fish (Figure 10, left). Higher Lake Powell levels and colder water releases preserve the status quo. Table 9 summarizes the important Lake Powell elevation break points for fish. To delay these negative impacts on fish, managers can forego release and hydropower generation through the turbines and instead release water through the low elevation river outlets (elevation 3,370 feet; 0 maf; Figure 11). For example, an 18oC release through the river outlets requires 5.9 maf less storage than an 18oC release through hydropower turbines (elevation 3,600 feet on Figure 11 left plot compared to 3,525 feet on right plot). This information is also presented on the *PowellReleaseTemperature* worksheet.

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**Figure 10. Lake Powell release water temperatures through the hydropower turbines (elevation 3,490 feet; left) and river outlets (elevation 3,370 feet; right) for different water surface elevations (Wheeler et al., 2021). Dashed black line represents Nov 16, 2021 storage.**

**Table 9. Effects of Summer Lake Powell Elevation on Fish**





Figure 11. Glen Canyon Dam river outlets (red) are ~ 100 feet below the penstocks (blue)

### (ii) Reduce Hydropower Generation

Reduced water surface elevation reduces hydropower generation and speeds the time that reservoirs reach their minimum power pools (elevations 3,490 and 955 feet in Lake Powell and Lake Mead) where the reservoirs can no longer generate energy. When energy generation declines, Lake Powell and Lake Mead energy customers must go on the spot energy market to purchase the energy shortfall. The model of Colorado River basin accounts does not quantify the impacts of reduced hydropower generation.

### (iii) Reduce evaporation loss

The combined evaporated volume changes less than 0.12 maf to preferentially store water in Lake Mead or Lake Powell (Figure 12, red numbers). These volumes are inside the margin of error of the evaporated volumes (Figure 12, black bars) calculated from the evaporation rates (Section 1Bi). This analysis suggests there is no water supply or evaporation benefit to preferentially store combined storage in Lake Powell or Lake Mead.



**Figure 12. Combined evaporated volume changes little (red numbers) to preferentially store water in Lake Mead or Lake Powell.**

### (iv) Current operations

Since 2007, the current operations sought to equalize storage in Lake Powell and Lake Mead (enter 50%)(USBR, 2007). Prior to 2007, managers kept more storage in Lake Mead (Figure 13).



**Figure 13. Lake Powell-Lake Mead coordination rules (blue fill) and historical lake levels before and after the 2007 interim guidelines (pink and purple lines)(Wheeler et al., 2019).**

# Step 8. Move to next year

Move to next year. Move to Step 2 Specify natural inflow to Lake Powell in the next year (next column). Repeat Steps 2 to 7 for each year.

The purpose of the Colorado River basin accounts activity is to provoke thought and discussion about new Lake Powell and Lake Mead operations. So continue to play years so long as the discussion provokes new insights.

# Step 9. Finish

Congratulations. You finished! If you wish to provide feedback – things you liked, things to improve – please send an email to david.rosenberg@usu.edu.

# Data, Model, and Code Availability

The data, code, and directions to generate figures in this post are available on Github.com at Rosenberg (2021b).

# Requested Citation

David E. Rosenberg (2021). "Model Guide: Colorado River Basin Accounts." Utah State University. <https://github.com/dzeke/ColoradoRiverCoding/tree/main/ModelMusings>.

# Appendix 1. Summary of Current Colorado River Operations

The Colorado River basin has a long history. The parties do not get along. There is much written material. This appendix summarizes key pieces and provides links to the actual documents:

1. [**Map**](https://www.usbr.gov/lc/images/maps/CRBSmap.jpg) shows Upper Basin, Lower Basin, Glen Canyon Dam/Lake Powell, Hoover Dam/Lake Mead, and diversions inside and outside the hydrologic basin (USBR, 2012).
2. **Compacts, treaties, and agreements** in 1922, 1928, 1944, 1956, 1964, and 1968 -- <https://www.usbr.gov/lc/region/g1000/lawofrvr.html>.
3. **2007 Interim Guidelines**. Lower Basin states increase mandatory conservation as Lake Mead level falls from 1,075 to 1,025 feet; Intentionally created surplus (aka conservation) accounts in Lake Mead for Lower Basin states (Section 3); Equalize storage in Lake Powell and Lake Mead (Section 6). <https://www.usbr.gov/lc/region/programs/strategies/RecordofDecision.pdf>.
4. **2012 and 2017. Minutes 319 and 323 to the 1944 US-Mexico Treaty**. Mexico increases mandatory conservation as Lake Mead’s level falls from 1,090 to 1,025 feet. <https://www.ibwc.gov/Treaties_Minutes/Minutes.html>.
5. **2018 Ten Tribes Partnership Water Study.** Quantified 2.0 million acre-feet (maf) rights in Upper and Lower Basins and 0.8 maf claims. https://www.usbr.gov/lc/region/programs/crbstudy/tws/finalreport.html.
6. **2019 Upper Basin Drought Contingency Plan.** Protect Lake Powell elevation of 3,525 feet (5.9 maf). Prevent Lake Powell to fall to minimum power pool elevation of 3,490 feet (4.0 maf). https://www.usbr.gov/dcp/finaldocs.html.
7. **2019 Lower Basin Drought Contingency Plan.** Increase mandatory conservation targets as Lake Mead’s level falls from 1,090 feet to 1,025 feet. See current mandatory conservation schedule in (Castle and Fleck, 2019). Protect Lake Mead from falling below elevation 1,020 feet. <https://www.usbr.gov/dcp/finaldocs.html>.
8. **2021 Lower Basin 500 Plus Plan.** The Lower Basin states and Federal government agree to pay $200 million to conserve 0.5 maf each year for two years (Allhands, 2021).
9. **2026.** **Interim Guidelines and Drought Contingency Plans expire.**
10. **Castle and Fleck (2019)**:
    1. Summarize current Colorado River operations in more detail than Items #1-9.
    2. Describe what happens when the Upper Basin is unable to deliver 8.23 million acre-feet (maf) of water per year to Lower Basin as required in the 1922 Compact and 1944 US-Mexico Treaty.
11. **Kuhn and Fleck (2019)** give a well written history of Colorado River management. Read this piece for fun or to go in depth on a particular piece of management.

# References

Allhands, J. (2021). "It could take at least 500,000 acre-feet of water a year to keep Lake Mead from tanking." *Arizona Republic*, November 8, 2021. <https://www.azcentral.com/story/opinion/op-ed/joannaallhands/2021/11/08/lake-mead-could-get-extra-water-from-lower-basin-annually/6306601001/>.

Buschatzke, T., Hamby, J. B., and Entsminger, J. (2024). "Lower Basin Alternative for the Post-2026 Coordinated Operation of the Colorado River Basin." <https://www.snwa.com/assets/pdf/lower-basin-alternative-letter-march2024.pdf> [Accessed on: August 14, 2024].

Castle, A., and Fleck, J. (2019). "The Risk of Curtailment under the Colorado River Compact." *SSRN eLibrary*. <http://dx.doi.org/10.2139/ssrn.3483654>.

Colorado River Compact. (1922). <https://www.usbr.gov/lc/region/pao/pdfiles/crcompct.pdf> [Accessed on: October 5, 2021].

IBWC. (2021). "Minutes between the United States and Mexican Sections of the IBWC." United States Section, <https://www.ibwc.gov/Treaties_Minutes/Minutes.html> [Accessed on: July 22, 2021].

Kuhn, E., and Fleck, J. (2019). *Science Be Dammed: How Ignoring Inconvenient Science Drained the Colorado River*, University of Arizona Press.

Leeflang, B. (2021). "Colorado River Coding: Pre 1922 Compact Water Use." <https://doi.org/10.5281/zenodo.5501466>.

Moreo, M. T. (2015). "Evaporation data from Lake Mead and Lake Mohave, Nevada and Arizona, March 2010 through April 2015." U.S. Geological Survey Data Release. <http://dx.doi.org/10.5066/F79C6VG3>.

Prairie, J. (2020). "Colorado River Basin Natural Flow and Salt Data." U.S. Bureau of Reclamation. <https://www.usbr.gov/lc/region/g4000/NaturalFlow/current.html>.

Rosenberg, D. E. (2021a). "Colorado River Coding: Grand Canyon Intervening Flow." GrandCanyonInterveningFlow folder, <https://doi.org/10.5281/zenodo.5501466>.

Rosenberg, D. E. (2021b). "Colorado River Coding: Intentionally Created Surplus for Lake Mead: Current Accounts and Next Steps." ICS folder, <https://doi.org/10.5281/zenodo.5501466>.

Rosenberg, D. E. (2021c). "Invest in Farm Water Conservation to Curtail Buy and Dry." *Submitted to Journal of Water Resources Planning and Management*, 3. <https://digitalcommons.usu.edu/water_pubs/169/>.

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., E.Rosenberg, D., Goeking, S., and Schmidt, J. C. (2020). "Stream flow and Losses of the Colorado River in the Southern Colorado Plateau." Center for Colorado River Studies, Utah State University, Logan, Utah. <https://qcnr.usu.edu/coloradoriver/files/WhitePaper4.pdf>.

Schmidt, J. C., Kraft, M., Tuzlak, D., and Walker, A. (2016). "Fill Mead First: a technical assessment." Utah State University, Logan, Utah. <https://qcnr.usu.edu/wats/colorado_river_studies/files/documents/Fill_Mead_First_Analysis.pdf>.

Ten Tribes Partnership. (2018). "Colorado River Basin Ten Tribes Partnership Tribal Water Study." U.S. Department of the Interior, Bureau of Reclamation, Ten Tribes Partnership. <https://www.usbr.gov/lc/region/programs/crbstudy/tws/finalreport.html>.

USBR. (2007). "Record of Decision: Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lakes Powell and Mead." U.S. Bureau of Reclamation. <https://www.usbr.gov/lc/region/programs/strategies/RecordofDecision.pdf>.

USBR. (2012). "Colorado River Basin Water Supply and Demand Study." U.S. Department of Interior, Bureau of Reclamation, Washington, D.C., <https://www.usbr.gov/lc/region/programs/crbstudy.html>.

USBR. (2019). "Agreement Concerning Colorado River Drought Contingency Management and Operations." U.S. Bureau of Reclamation, Washington, DC. <https://www.usbr.gov/ColoradoRiverBasin/dcp/index.html>.

USBR. (2020). "Review of the Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead." U.S. Bureau of Reclamation, U.S. Department of Interior. <https://www.usbr.gov/ColoradoRiverBasin/documents/7.D.Review_FinalReport_12-18-2020.pdf>.

USBR. (2021a). "21st Century Colorado River: Hydrology and Risk of Lake Mead Reaching Critically Low Elevations." U.S. Bureau of Reclamation. <https://github.com/dzeke/ColoradoRiverCoding/raw/main/500PlusPlan/MeadRisk-LBActionsWebianr11-5-21.pdf>.

USBR. (2021b). "Boulder Canyon Operations Office - Program and Activities: Water Accounting Reports." U.S. Bureau of Reclamation. <https://www.usbr.gov/lc/region/g4000/wtracct.html>.

USBR. (2021c). "Lake Mead at Hoover Dam, End of Month Elevation." Lower Colorado River Operations, U.S. Buruea of Reclamation, <https://www.usbr.gov/lc/region/g4000/hourly/mead-elv.html> [Accessed on: October 5, 2021].

USBR. (2021d). "Lake Powell Unregulated Inflow." <https://www.usbr.gov/uc/water/crsp/studies/images/PowellForecast.png> [Accessed on: September 28, 2021].

USGS. (2016). "Colorado River Basin map." U.S. Geological Survey. <https://www.usgs.gov/media/images/colorado-river-basin-map>.

Wheeler, K., Kuhn, E., Bruckerhoff, L., Udall, B., Wang, J., Gilbert, L., Goeking, S., Kasprak, A., Mihalevich, B., Neilson, B., Salehabadi, H., and Schmidt, J. C. (2021). "Alternative Management Paradigms for the Future of the Colorado and Green Rivers." Center for Colorado River Studies, Utah State University, Logan, Utah. <https://qcnr.usu.edu/coloradoriver/files/WhitePaper_6.pdf>.

Wheeler, K. G., Schmidt, J. C., and Rosenberg, D. E. (2019). "Water Resource Modelling of the Colorado River – Present and Future Strategies." Center for Colorado River Studies, Utah State University, Logan, Utah. <https://qcnr.usu.edu/coloradoriver/files/news/White-Paper-2.pdf>.

Zagona, E. A., Fulp, T. J., Shane, R., Magee, T., and Goranflo, H. M. (2001). "Riverware: A Generalized Tool for Complex Reservoir System Modeling." *JAWRA Journal of the American Water Resources Association*, 37(4), 913-929. <https://doi.org/10.1111/j.1752-1688.2001.tb05522.x>.