Model Guide

Immersive Model for Lake Mead Based on the Principle of Divide Reservoir Inflow

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Introduction

The purpose of this tool is to give users the opportunity to immerse in and personify water user roles for a Lake Mead model based on the principle of divide reservoir inflow. The process is: **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:

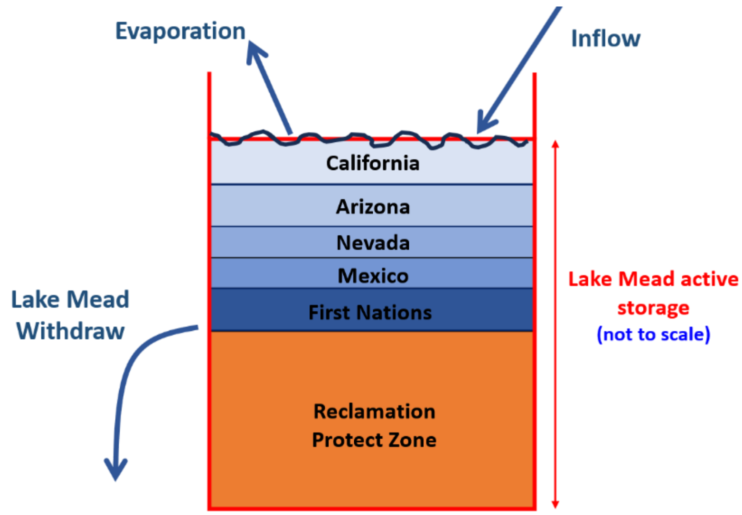
- As researchers we want to learn *Why* basin partners choose assumptions and *how* extreme; *Why* and *how* basin partners articulate their risk of uncertain future water supply and manage their vulnerability; and *Which* new insights they take from a model session.

- Provoke thought and discussion to:

    - Stabilize and recover reservoir storage under conditions of low storage *and* low inflow.
    - Give users more autonomy to manage their conflicting vulnerabilities to water shortages.

Key Model Ideas

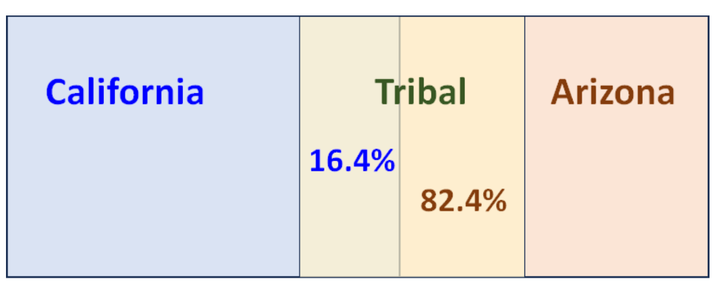
1. **Lake Mead water level is the sum of the protection elevation plus each user's available water.**



2. **Each user manages all their available water not just prior conserved water.**

$$\text{Available Water} = \text{Prior Available Water} + \text{Share of Lake Mead inflow} - \text{Share of Evaporation} + \underbrace{\text{Purchases} - \text{Sales}}_{\text{Optional}}$$

3. **Tribal Nations of the Lower Basin manage their own settled water rights**



(Ignore Nevada)

This User Guide 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 suggests 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.

Box 1. Steps to Guide a Model Session

Setup

1. Identify a Session Guide (may also participate).
2. Download the file **LakeMeadWaterBankDivideInflow.xlsx** to your computer.
3. Move the Excel file to your Google Drive. Open as a Google Sheet.
4. Open the **Versions** Worksheet to see updates.
5. Duplicate the **Master** Worksheet to save a blank version for later use.
6. Invite 1 or more participant(s) to join the Google Sheet.

   i. In the upper right of the Google Sheet, click the **Share** button.
   ii. Add emails, and set permissions so participants can access the Google Sheet. Or copy and share the sheet's URL.

Play

1. On the **Master** Worksheet, scroll down Column A. Participants enter values in row blocks with **Blue Text**.

   i. For example, in Rows 4-10, participants select a **User,** articulate the User's **vulnerability to water shortages**, and define a **strategy to manage vulnerability. If fewer than 6 participants, participants select multiple users**.
   ii. Enter the Lake Mead starting storage in **Cell B19**.
   iii. On **Row 20, Column B**, the Reclamation user sets the elevation for the protection zone - Lake Mead will never fall below this level.
   iv. In **Cell B21**, enter the total Water Conservation Account (Intentionally Created Surplus) Balance. This value includes California, Arizona, Nevada, and Mexico.
   v. Enter the Lake Mead Inflow for Year 1 in **Cell C28**. Cells below will populate.
   vi. Participants continue to enter values in Year 1 (Column C) down to **Row 109** in row blocks with **Blue Text**.
2. Move to Year 2 (Column D). Enter a new Lake Mead Inflow in **Cell D28**.
3. Find linked help for each row in **Column N**.

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 1a)(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 (USGS, 2016)
- First Nations (Ten Tribes Partnership, 2018)

Table 1a. 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*

Account	Reason(s) to Include	Potential Strategy(s)
		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)	• Currently 0.47 of 0.95 million acre-feet of settled water rights are used and consumed (Ten Tribes Partnership, 2018). • 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 assign 0.95 maf of settled water rights to Arizona and California.

1A. Explain cell types

Four model cell types are defined by fill color (Table 1b).

Table 1b. Model Cell Types

Cell Type	Explanation
Physical watershed data	Flow and evaporation assumptions required by the model. Participants agree on this data and information.
Individual decision	A participant's individual choices such as strategy, conservation, consumption, and purchaces from the account.
Joint decision	Decisions participants make together such as the reservoir protection elevations, how to split existing storage and inflow among accounts, or how to split combined storage between Lake Powell and Lake Mead.
Calculated cell	Formula used to calculate cell such as reservoir evaporation or an account's available water.

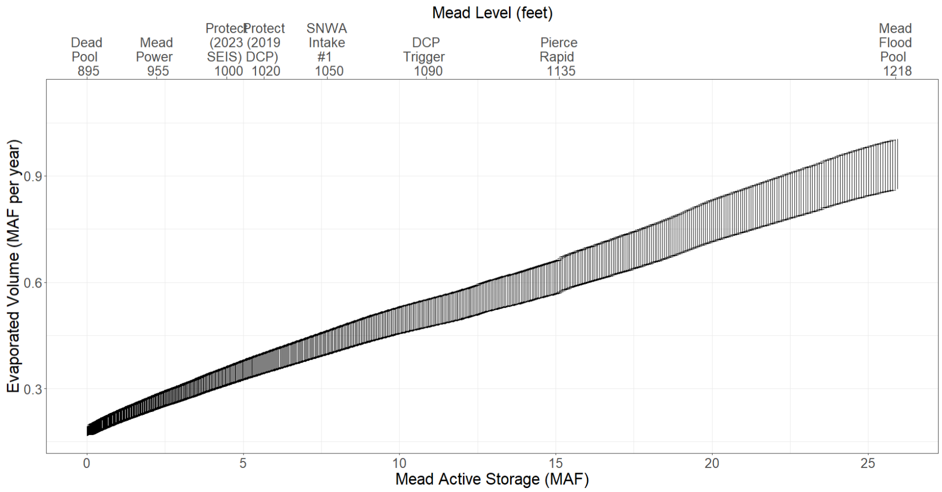
1B. Make Assumptions

(i) Evaporation rates

Evaporation rates for Lake Mead are presently entered as the midpoint within reported ranges of measurements (Table 1c)(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 1c. Reservoir evaporation rates (feet per year)

Reservoir	Midpoint	Range
Mead	6.0	5.5 – 6.4



Range of Lake Mead Evaporation vs Active Storage

(ii) Start storage

Reservoir start storage is taken from the data portal (USBR, 2021b). Text in Column D lists the date. Figure 1 shows Lake Mead storage over time (Solid black line).

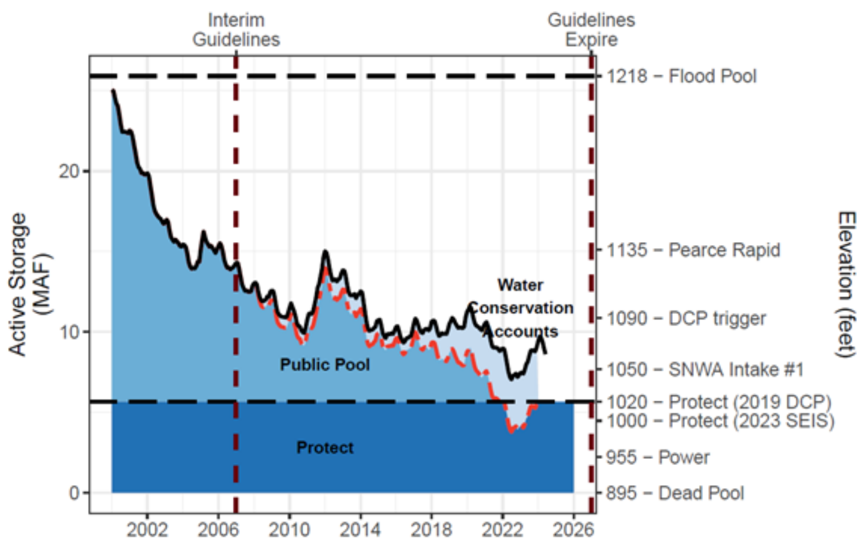


Figure 1. Lake Mead Storage (solid black line), Water Conservation (ICS) Account Balances (light blue fill), and anticipated lake volume absent the water conservation program (dashed red line). The conservation program kept Lake Mead level above elevation 1,020 feet (5.9 million acre-feet) during low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

(iii) Protection elevation

The Reclamation user decides the Lake Mead elevation/volume to protect against further drawdown. A default value of 1,020 feet (5.7 million acre-feet) is used because this level was specified 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). When lowering the Lake Mead protection elevation, the storage above the Protect Zone increases so that more of the starting reservoir storage is assigned to the other users as their initial available water. The model maintains the Protection elevation/volume because the Reclamation user is always assigned a share of inflow that exactly equals its 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 other users as their initial available (see Row 35).

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

This entry is the sum of all existing water conservation program account balances from 2007 to present (Figure 1, light blue fill). These balances are also referred to as the Intentionally Created Surplus (ICS) account balances and are reported at (USBR, 2021a). 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.

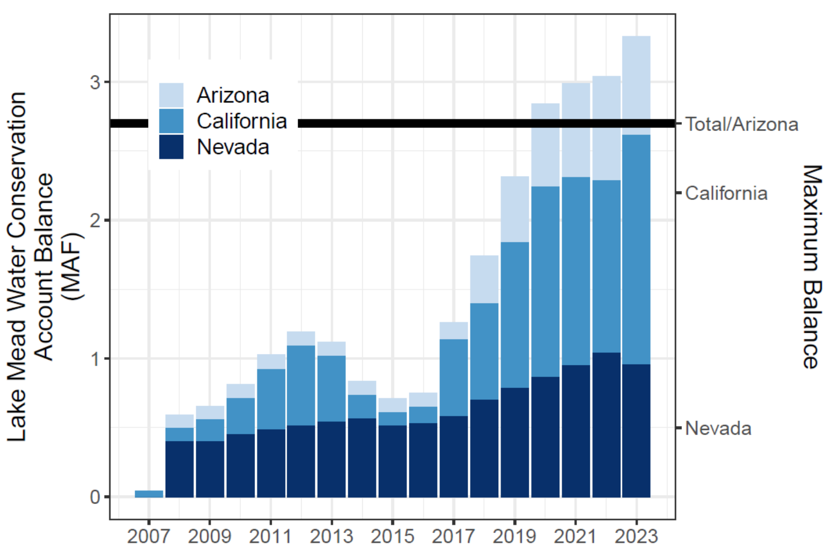


Figure 2. Lake Mead Water Conservation (ICS) Account balances over time

(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 1). This storage represents additional storage that may be allocated to the Lower Basin states or other users such as Tribal Nations of the Lower Basin as their initial available water (see Step 3 Split storage in Row 35).

(vii) Percent of Tribal Nation water in California

This cell (B24) indicates the percentage of the 0.95 million acre-feet of total settled water rights of Tribal Nations in the Lower Basin that are located in California (Table 1d)(Ten Tribes Partnership, 2018). The location and amounts for each Tribal Nation are shown in Table 1e.

Table 1d. Location of settled water rights of Tribal Nations within Lower Basin States.

State	Volume (acre-	Percent
Nevada	12,534	1.3%
Arizona	783,134	82.2%
California	156,522	16.4%
Total	**952,190**	**100.0%**

Table 1e. Location of each Tribal Nation and amount of settled water rights

Tribal Nation	State	Decreed Diversion (acre-feet)	Unresolved Diversion Claim (acre-feet)
Fort Mojave Indian Tribe	Nevada	12,534	
Fort Mojave Indian Tribe	Arizona	103,535	
Fort Mojave Indian Tribe	California	16,720	
Chemehuevi Indian Tribe	California	11,340	
Colorado River Indian Trib	Arizona	662,402	
Colorado River Indian Trib	California	56,846	
Quechan Indian Tribe	Arizona	6,350	
Quechan Indian Tribe	California	71,616	
Cocopah Indian Tribe	Arizona	10,847	22,928
Total		**952,190**	**22,928**

Tables 1d and 1e and the associated calculations are also shown in the **TribalWater** worksheet within the Excel model file.

(vii) Percent of Tribal Nation water in Arizona

This cell specifies the percent of settled water rights for Tribal Nations of the Lower Basin that are located in Arizona (see also Table 1d and 1e). This cell is calculated as 100% minus the percentage entered for California in Cell B24.

Step 2. Specify Lake Mead Inflow

Each Lake Mead inflow for the year will be specified by the person guiding the model session at the beginning of each timestep (Table 2a). These choices will ensure an accurate representation of uncertainty, unreliability, and variability in flow for Colorado River Basin management. Because Lake Mead inflow is uncertain—and likely differing from historical inflows because of aridity—we can only specify inflow as a scenario (Rosenberg, 2022). We are particularly interested in scenarios of extreme low inflow to Lake Mead because if we can manage for extreme conditions, then we can also manage for less extreme conditions.

Table 2a. Scenarios of Lake Mead Inflow

Scenario (MAF each year)	Powell release (MAF each year)	Grand Canyon tributary flow (MAF each year)	Years of Powell release	Notes
2.8	2.3	0.5	Not observed; not in guidelines	Minimum annual natural flow to Lake Powell from Trace 17 in RCP_85_100 ensemble (Salehabadi, 2023)
3	2.5	0.5	Not observed; not in guidelines	Very small inflow to both Lake Powell and Lake Mead. Lake Powell has to release enough to make up for low tributary flow.
3.8	3.3	0.5	Not observed; not in guidelines	Minimum annual natural flow to Lake Powell from Trace 65 in CMIP5_BCSD ensemble (Salehabadi, 2023)
4.6	4	0.6	Not observed; not in guidelines	Lake Powell is in a dire situation. The Lake Powell release is to stabalize Lake Powell level.
5	4.5	0.5	Not observed; not in guidelines	Low tributary flow rate. Lake Powell release to match the low inflow rate.
5.9	5.3	0.6	Not observed; not in guidelines	Minimum annual natural flow to Lake Powell from Trace 55 in CMIP3 ensemble (Salehabadi, 2023)
5.9	5.2	0.7	Not observed; not in guidelines	Minimum annual natural flow to Lake Powell from Trace 56 in Drought_Millennium ensemble (Salehabadi, 2023)
6	5.3	0.6	Not observed; not in guidelines	Low tributary flow rate. Lake Powell release to match the low inflow rate.
7	6.4	0.6	Not observed; not in guidelines	Three-year sequences (Rosenberg 2021a)
8	7.3	0.7	2017	Sequences of up to five years (Rosenberg 2021a)
8.4	7.5	0.9	2014	Within interquartile range (Rosenberg 2021a)
8.6	8.0	0.6	1989, 1992	Three-year sequences (Rosenberg 2021a)

There are two ways to interpret the extreme scenarios of inflow to Lake Mead:

1. **Low natural inflow to Lake Powell** minus **Lake Powell evaporation** plus **gains along Grand Canyon**. Under extreme conditions, the Lake Powell evaporation equals gains along Grand Canyon so the natural inflow to Lees Ferry translates to the inflow to Lake Mead. This method also assumes there is *no* Upper Basin consumptive use.
2. **An extreme low Lake Powell release** needed to stabilize Lake Powell plus **gains along Grand Canyon**.

The magnitude of extreme low natural inflow to Lake Powell has been determined by using 21 ensembles on the worksheet *HydrologicScenarios* (Salehabadi et al., 2024). Each ensemble typically had 100 traces. Using code written in Python, the three consecutive smallest values in each ensemble and each trace were found. This was done by iterating through all traces in all ensembles and calculating the average of three consecutive values for each cell. Using the smallest average, the position of the beginning value of the consecutive three was found.

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). Additionally note that gains along Grand Canyon over the same period were 600,000 to 1 million acre-feet per year (Rosenberg, 2022; Wang and Schmidt, 2020; Figure 5).

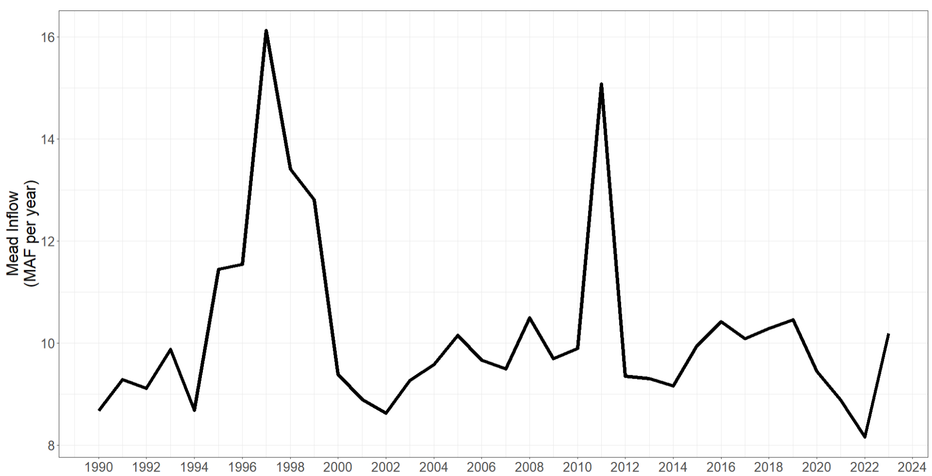


Figure 3. Lake Mead inflow as measured by nearest USGS gages.

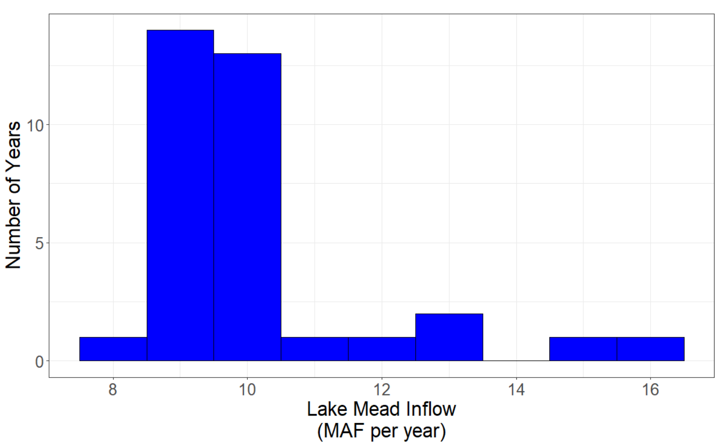


Figure 4. Histogram of Lake Mead inflows as measured by the nearest gages.

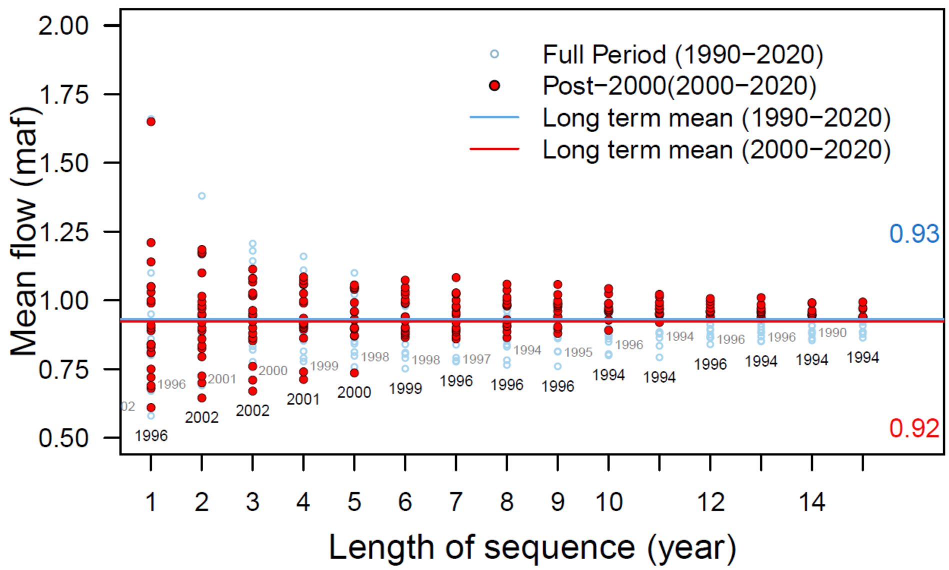


Figure 5. Mean Grand Canyon tributary flow (Glen Canyon Dam to Lake Mead) for different sequence lengths.

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.

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 2c). 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 2c. 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).

$$User\ share\ of\ evaporation = \left(\begin{matrix} Lake\ Mead \\ Evaporation \end{matrix}\right) \frac{(User\ account\ balance)}{(Total\ Active\ Storage)} \qquad \text{Eq. 1}$$

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 4a). 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 4a. Prior agreed Lower Basin shortages and shares of shortages (Buschatzke et al., 2024).

Total Shortage (maf per year)	Arizona	Nevada	California	Mexico	Total
As Percent of Total Shortage					
0	0.0%	0.0%	0.0%	0.0%	0.0%
0.0 to 0.3	80.0%	3.3%	0.0%	16.7%	100.0%
0.3 to 1.5	43.3%	3.3%	36.7%	16.7%	100.0%
1.5 to 2.7	To be determined				
As Volume (maf per year)					
0	0	0	0	0	0
0.3	0.24	0.01	0.00	0.05	0.30
0.4	0.28	0.01	0.04	0.07	0.40
1	0.54	0.03	0.26	0.17	1.00
1.5	0.76	0.05	0.44	0.25	1.50
1.5 to 2.7	To be determined				

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

Row	Total Shortage (maf per year) [A]	Lake Mead Inflow (maf per year) [B]	Share of Lake Mead Inflow (maf per year)					Percentage of Lake Mead Inflow				
			Arizona [C]	Nevada [D]	California [E]	Mexico [F]	Total [G]	Arizona [H]	Nevada [I]	California [J]	Mexico [K]	Total [L]
[1]*	0	9.0	2.80	0.30	4.40	1.50	9.00	31.1%	3.3%	48.9%	16.7%	100%
[2]	0.3	8.7	2.56	0.29	4.40	1.45	8.70	29.4%	3.3%	50.6%	16.7%	100%
[3]	0.4	8.6	2.52	0.29	4.36	1.43	8.60	29.3%	3.3%	50.7%	16.7%	100%
[4]	1	8.0	2.26	0.27	4.14	1.33	8.00	28.2%	3.3%	51.8%	16.7%	100%
[5]	1.5	7.5	2.04	0.25	3.96	1.25	7.50	27.2%	3.3%	52.8%	16.7%	100%
[6]	1.5 to 2.7	7.5 to 6.3	To be determined					To be determined				
[7]**	2.7	6.3	1.52	0.21	3.52	1.05	6.30	24.1%	3.3%	55.9%	16.7%	100.0%

* Historical allocations

** If percentage shares of total shortages for 0.3 to 1.5 maf per year are continue to total shortages for 1.5 to 2.7 maf per year.

Example calculations of share of Lake Mead inflow by volume and percentage (Table 8) are:

1. Total Lake Mead inflow [B] = 9.0 ─ Total Shortage [A].
    a. 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.
        i. 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.
        i. 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.
        i. 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.
        i. 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.

    a. Arizona [H] = [C] / [G]
    b. Nevada [I] = [D] / [G]
    c. And so forth.

5. Total Percentage of Reservoir Inflow [L] = [H] + [I] + [J] + [K] = 100%.

Observations

A. 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.
B. 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 7).

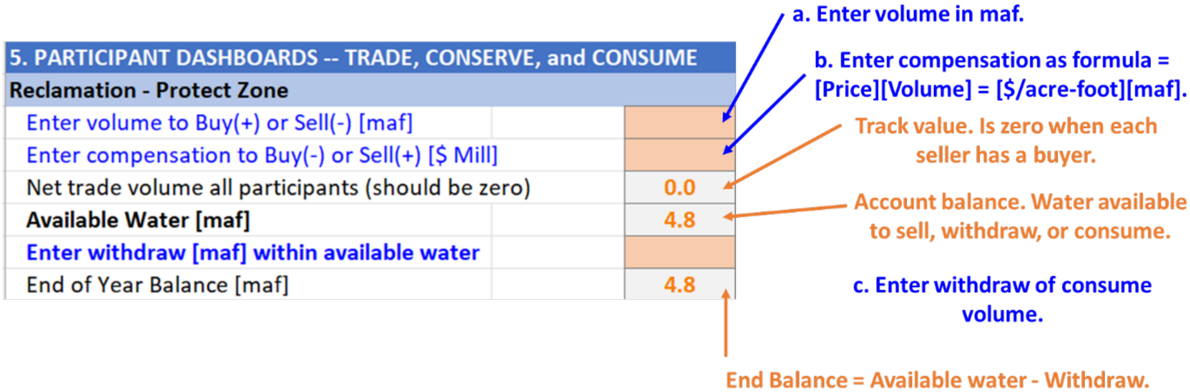


Figure 7. Reclamation Protect Dashboard annotated. Starting storage is 1,061 feet (8.5 maf), the reservoir protect elevation is 1,005 feet (4.8 maf), and there is 9.5 maf inflow this year. Thus, there is 4.8 maf of water available. No trades or withdraws have been entered. So the ending balance is also 4.8 maf.

(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, 2021).

(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 compensation and water prices for recentvoluntary, compensated, and mandatory Colorado River Basin water conservation programs (Allhands, 2021; UCRC, 2018; UCRC, 2024; USBR, 2021a; USBR, 2021c).

- 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:

$$\text{Compensation} = (0.5)(500) + (0.2)(1{,}200) = \$850 \text{ million.}$$

The program has conserved more water than other voluntary, compensated, or mandatory Colorado River Basin water conservation program and is less expense than other options such as desalination (Table 7; Allhands, 2021; James, 2021; UCRC, 2018; UCRC, 2024; USBR, 2021a; USBR, 2021c).

Table 7. Colorado River Basin water conservation programs and accomplishments.

Program	Years	Volume (million acre-feet)	Cost ($ per acre-foot)	Compensation ($ million)
Existing Programs				
Lake Mead Water Conservation	2007 to 2023	4.10	None	None
500+ Plan - Lower Basin	2021 to 2022	1.00	$200	$200
Mandatory Conservation - Not ICS	2019 to 2023	0.63	None	None
System Conservation Pilot Programs				
Lower Basin	2015 to 2019	0.18	$77 to $240	$30
Upper Basin	2023	0.04	$150 to $611	$16
Upper Basin	2015 to 2017	0.02	$161 to $670	$5
Comparison Options				
Lower Basin agricultural value	2021	None yet	$700 to $1,000	Non yet
Desalination at the Sea of Cortez	2021	None yet	$2,000	None yet

(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 user. Sales decrease and purchases increase available water (Eq. 2).

$$\text{Available Water} = \text{Prior Available Water} + \text{Share of Lake Mead inflow} - \text{Share of Evaporation} + \underbrace{\text{Purchases} - \text{Sales}}_{\text{Optional}} \qquad \text{(Eq. 2)}$$

(v) Enter Withdraw within Available Water

Account withdraws are consumptive use. This consumptive use occurs by a user physically withdrawing from Lake Mead.

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

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

For reference, recent withdrawals are shown in Table 8 (USBR, 2021a). These withdrawals include to Tribal Nations within each state . Tribal Nations of the Lower Basin have recently consumed about 460,000 of their 0.95 million acre-feet of settled water rights (Table 9)(Ten Tribes Partnership, 2018).

Table 8. Recent Lower Basin and Mexico user withdrawals (million acre-feet).

Year	Arizona	California	Nevada	Mexico	Total
2023	1.89	3.70	0.19	1.43	7.2
2022	2.01	4.42	0.22	1.45	8.1
2021	2.43	4.41	0.24	1.46	8.5
2020	2.47	4.06	0.26	1.43	8.2
2019	2.49	3.84	0.23	1.46	8.0
2018	2.63	4.20	0.24	1.49	8.6
2017	2.51	4.03	0.24	1.52	8.3
2016	2.61	4.38	0.24	1.50	8.7
2015	2.60	4.62	0.22	1.50	8.9

Table 9. Diversion and consumptive use by Tribal Nations of the Lower Basin (acre-feet).

Water Use Category	Diversion	Consumptive Use
Irrigatedd Agriculture & Livestock	769,208	441,381
Domestic, Commercial, Industrial	15,340	9,017
Environmental, Cultural, Recreatio	2,844	1,698
Transfers, Leases, Exchanges	13,000	13,000
Total	**800,392**	**465,096**

(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.

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.

Lake Mead – End of Year

The Lake Mead storage 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 user accounts (including the Reclamation protect volume).

Step 7. Move to next year

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

The purpose of this modeling activity is to provoke thought and discussion about new Lake Mead operations. So continue to play years so long as the discussion provokes new insights.

Step 8. Finish

Congratulations. You finished! If you wish to provide feedback – new insights, 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 https://github.com/dzeke/ColoradoRiverCollaborate/tree/main/LakeMeadWaterBankDivideInflow.

Requested Citation

Rosenberg (2024). "Lake Mead Water Bank based on the Principle of Divide Reservoir Inflow." Utah State University, Logan, UT. https://github.com/dzeke/ColoradoRiverCollaborate/tree/main/LakeMeadWaterBankDivideInflow.

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** 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. **2023 to Present.** Process to plan for operations post 2026 when interim guidelines and drought contingency plans expire (USBR, 2023a; USBR, 2023b)**.**

10. **2026. Interim Guidelines and Drought Contingency Plans expire.**

11. **Castle and Fleck (2019)**:
    a. Summarize current Colorado River operations in more detail than Items #1-9.

b. 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.

12. **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.

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