

## **Model Guide**

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

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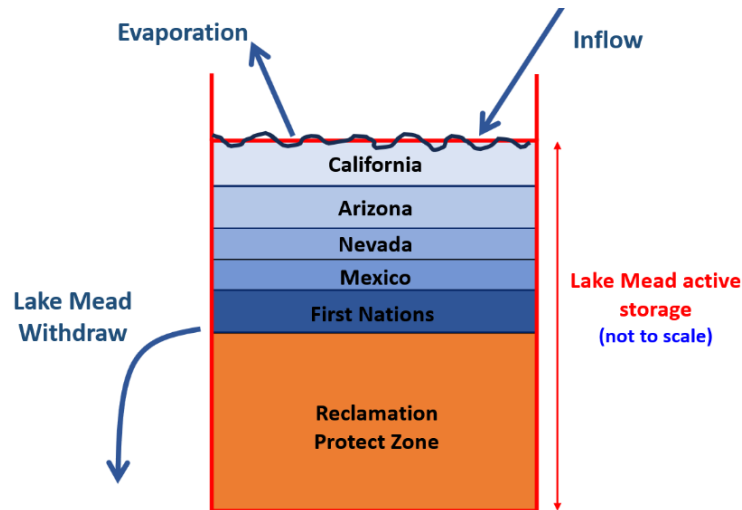
## Introduction

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

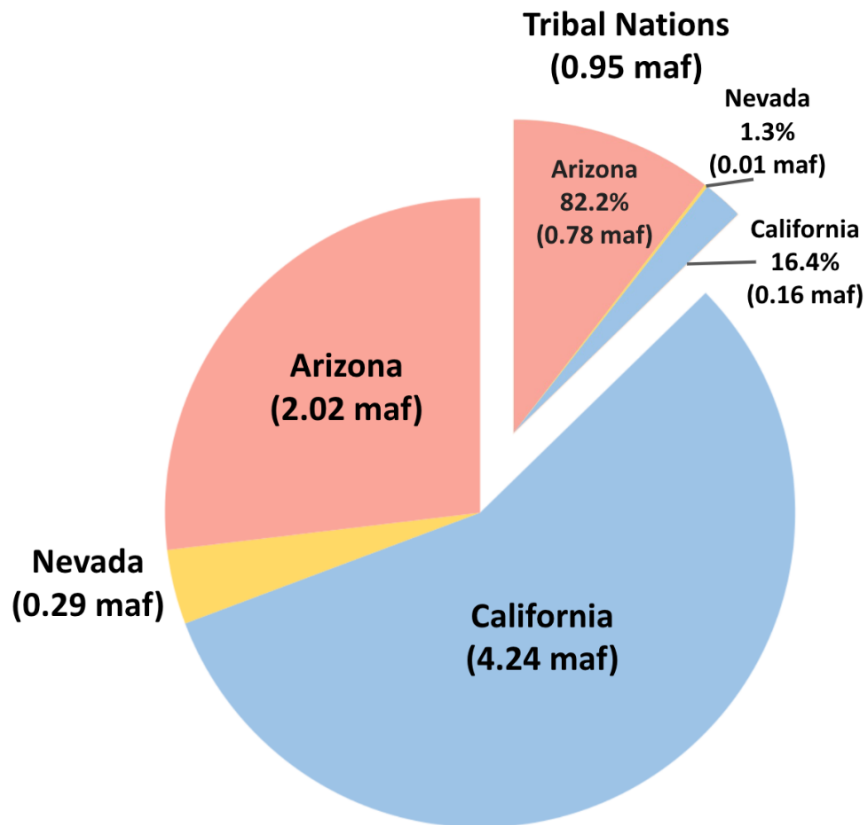
1. Lake Mead water level is the sum of the protection elevation plus each user's available water.



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

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

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



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. In **Cell B20**, the Reclamation user sets the elevation for the protection zone - Lake Mead will never fall below this level.
  - iv. In **Cell C22**, 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 116** 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 participants 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).	<ul style="list-style-type: none"> <li>• 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.</li> <li>• Lower the protection elevation to allocate more active storage to other users</li> </ul>
California	Article II(c to g) of the Colorado River Compact (1922).	<ul style="list-style-type: none"> <li>• 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 <i>MandatoryConservation</i> sheet. These values exclude 0.95 maf per year of use by First Nations in the Lower Basin.</li> <li>• Cut back an addition amount per year to represent the 500-Plus Plan (Allhands, 2021).</li> <li>• Buy water to reduce mandatory conservation.</li> <li>• Save some water for future years.</li> </ul>
Arizona	Article II(c to g) of the Colorado River Compact (1922).	<ul style="list-style-type: none"> <li>• 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 <i>MandatoryConservation</i> sheet. These values exclude 0.95 maf per year of use by First Nations in the Lower Basin.</li> <li>• Cut back an addition amount per year to represent the 500-Plus Plan (Allhands, 2021).</li> <li>• Buy water to reduce mandatory conservation.</li> <li>• Save some water for future years.</li> </ul>
Nevada	Article II(c to g) of the Colorado River Compact (1922).	<ul style="list-style-type: none"> <li>• 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 <i>MandatoryConservation</i></li> </ul>

Account	Reason(s) to Include	Potential Strategy(s)
		<p>sheet. These values exclude 0.95 maf per year of use by First Nations in the Lower Basin.</p> <ul style="list-style-type: none"> <li>• Cut back an addition amount per year to represent the 500-Plus Plan (Allhands, 2021).</li> <li>• Buy water to reduce mandatory conservation.</li> <li>• Save some water for future years.</li> </ul>
Mexico	1944 U.S.-Mexico Treaty and subsequent Minutes	<ul style="list-style-type: none"> <li>• Continue mandatory conservation and cutback from 1.5 maf per year as Lake Mead levels decline (IBWC, 2021). See <i>MandatoryConservation</i> sheet.</li> <li>• Conserve more water beyond mandatory targets.</li> <li>• Lease water to get money for non-water projects.</li> </ul>
Tribal Nations of the Lower Basin	<ul style="list-style-type: none"> <li>• Include more accounts (USBR, 2020)</li> <li>• Tribal water study (Ten Tribes Partnership, 2018)</li> </ul>	<ul style="list-style-type: none"> <li>• Currently 0.47 of 0.95 million acre-feet of settled water rights are used and consumed (Ten Tribes Partnership, 2018).</li> <li>• Lease settled, undeveloped water to other users to acquire capital to build new projects.</li> <li>• Save water for future use.</li> </ul>

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 purchases 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.

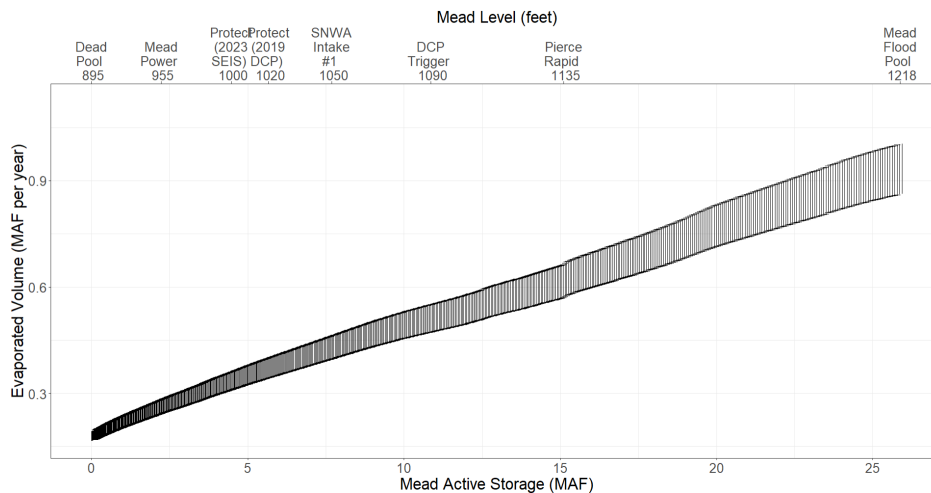
## 1B. Make Assumptions

### (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)**

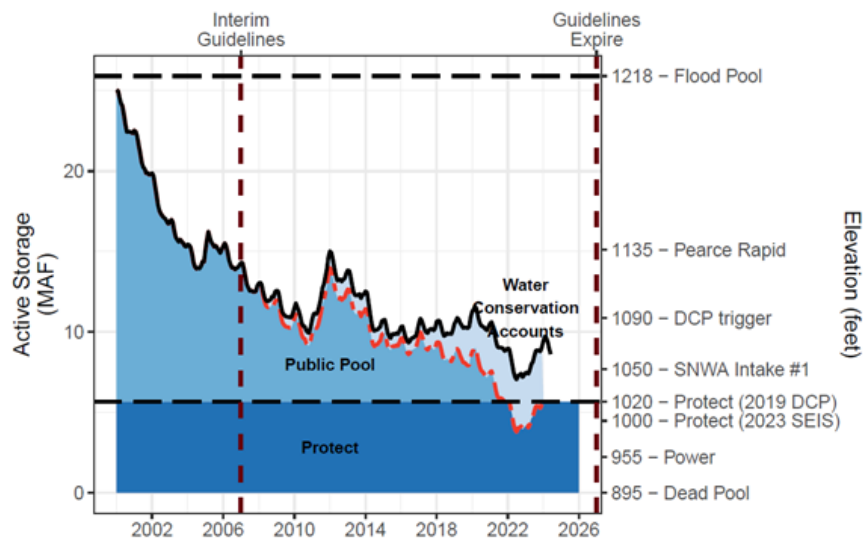
Reservoir	Midpoint	Range
Mead	6.0	5.5 – 6.4



**Figure 1a. 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 1b shows Lake Mead storage over time (Solid black line).



**Figure 1b. 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 1a, dark blue fill labeled

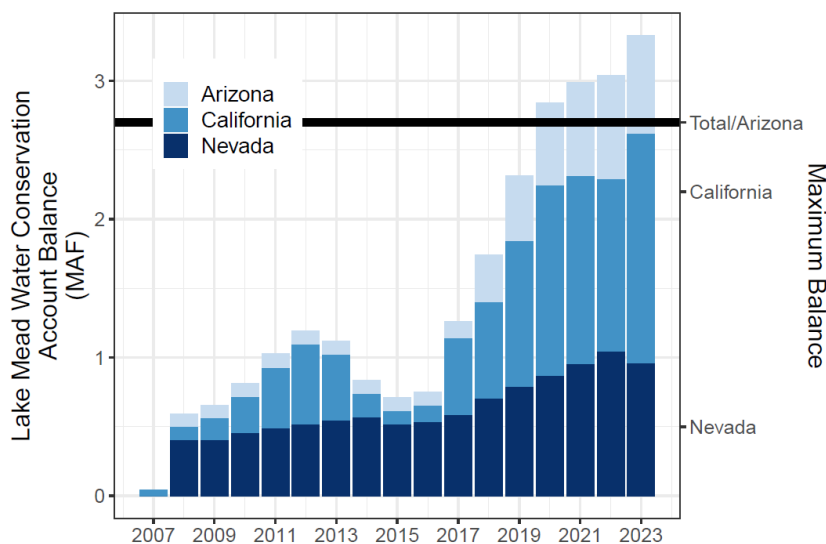
Protect)(USBR, 2019). More recently there has been discussion to lower the protect elevation to 1,000 feet (Buschatzke et al., 2024). When lowering the Lake Mead protection elevation, the storage above the Protect Zone increases so that more of the starting reservoir storage is assigned to the other 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 1a, 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 1a, light blue fill). These balances are also referred to as the Intentionally Created Surplus (ICS) account balances and are reported at (USBR, 2021a). Figure 1b 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 1c.



**Figure 1c. Lake Mead Water Conservation (ICS) Account balances over time**

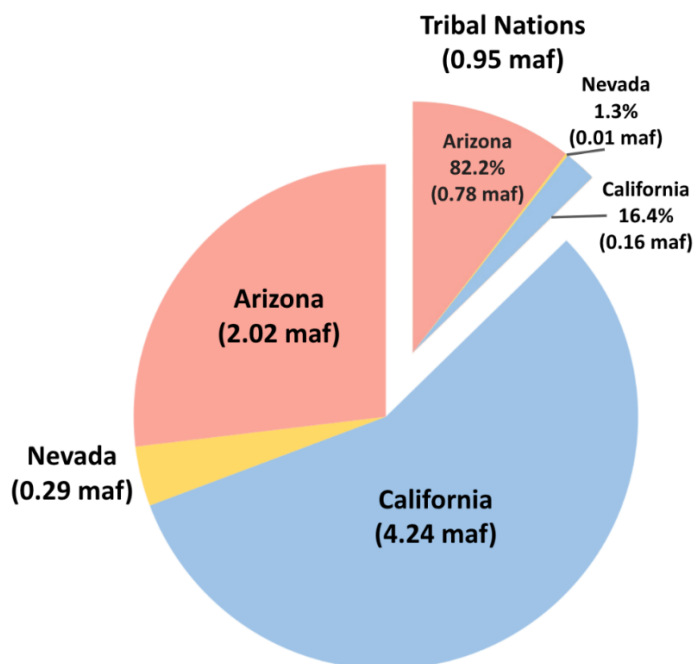
#### (vi) Remaining Storage above the Protect and ICS Balances

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 1b). 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 (Figure 1c).



**Figure 1c. How 0.95 maf of settled water rights of Tribal Nations of the Lower Basin are drawn from each Lower Basin state.**

The volumes and percentages of the Tribal callout pie section in Figure 1c were calculated from the volumes of settled water rights and their location as enumerated in Reclamation’s Tribal Water Study (Tables 1d and 1e)(Ten Tribes Partnership, 2018).

**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%
<b>Total</b>	<b>952,190</b>	<b>100.0%</b>

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

<b>Tribal Nation</b>	<b>State</b>	<b>Decreed Diversion (acre-feet)</b>	<b>Unresolved Diversion Claim (acre-feet)</b>
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
<b>Total</b>		<b>952,190</b>	<b>22,928</b>

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 Figure 1c, Table 1d, and Table 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 stabilize 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)

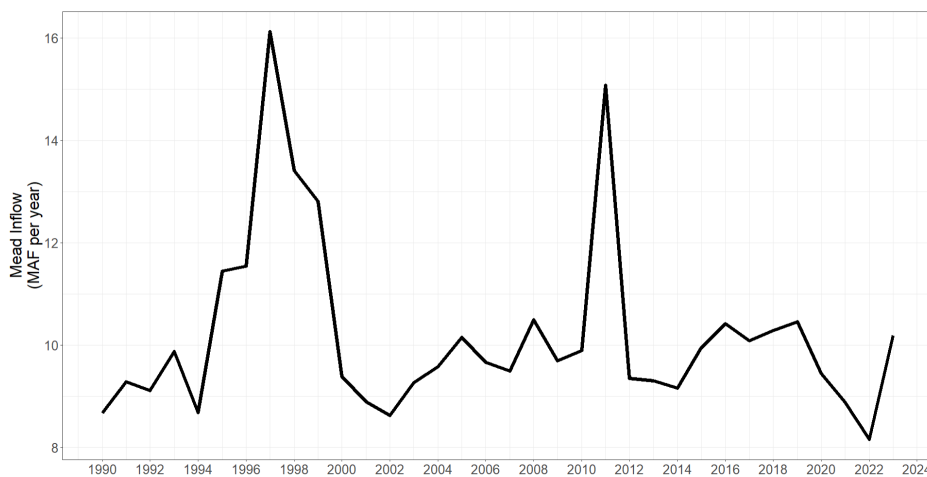
There are two ways to interpret the extreme scenarios of inflow to Lake Mead:

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.

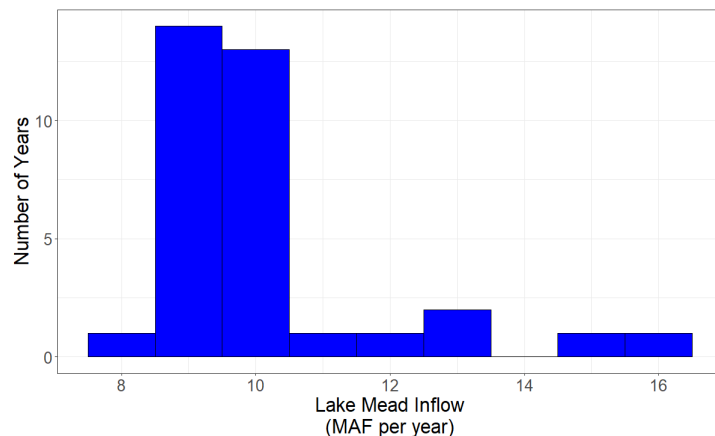
2. **An extreme low Lake Powell release needed to stabilize Lake Powell plus gains along Grand Canyon.**

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.

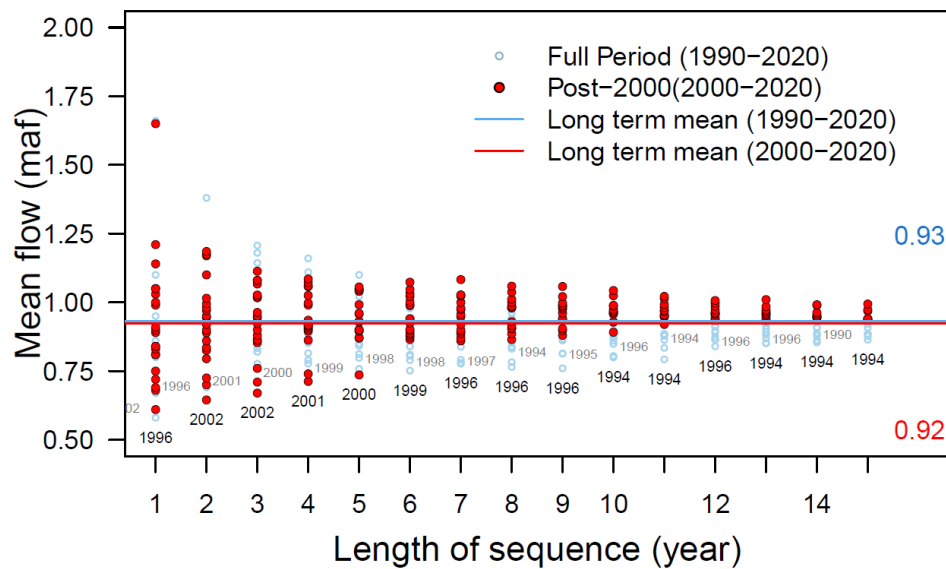
For reference, historical Lake Mead inflows since 1990 varied from 8 to 16 million acre-feet per year (Figure 2a) with the preponderance of inflows between 9 and 10 maf per year (corresponding to a Lake Powell release between 8.23 and 9 maf per year; Figure 2b). Additionally note that gains along Grand Canyon over the same period were 600,000 to 1 million acre-feet per year (Rosenberg, 2022; Wang and Schmidt, 2020; Figure 2c).



**Figure 2a. Lake Mead inflow as measured by nearest USGS gages.**



**Figure 2b. Histogram of Lake Mead inflows as measured by the nearest gages.**



**Figure 2c. 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](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 3a). 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 3a. 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 1a.
California	Water Conservation (ICS) account balance shown in Figure 1b (rollover).
Arizona	Water Conservation (ICS) account balance shown in Figure 1b (rollover).
Nevada	Water Conservation (ICS) account balance shown in Figure 1b (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 1a.

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

- Fall below the Reclamation protect elevation (such as in 2022 in Figure 1a), 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 1a) 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).

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

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.

#### Step 4. Split Lake Mead inflow among accounts

Participants split the Lake Mead inflow among accounts [Rows 52 to 61, where the flow in Row 52 equals the reservoir inflow entered in Row 28].

To **maintain the Reclamation protection elevation**, this user is assigned *the first block of inflow on Row 53* that exactly offsets to its share of the annual reservoir evaporation (Row 46). This volume will vary from year to year as Lake Mead storage and evaporation vary.

**There are lots of ways to split the remaining reservoir inflow among the users.** These splits can be (i) By pro-rata shares of historical allocations, (ii) Giving California some priority over Arizona, (iii) Including Tribal Nations of the Lower Basin, (iv) Combinations of i to iii, or (v) other methods.

As a default, we use percentages shown in grey highlighted Row 5 of Table 4a.

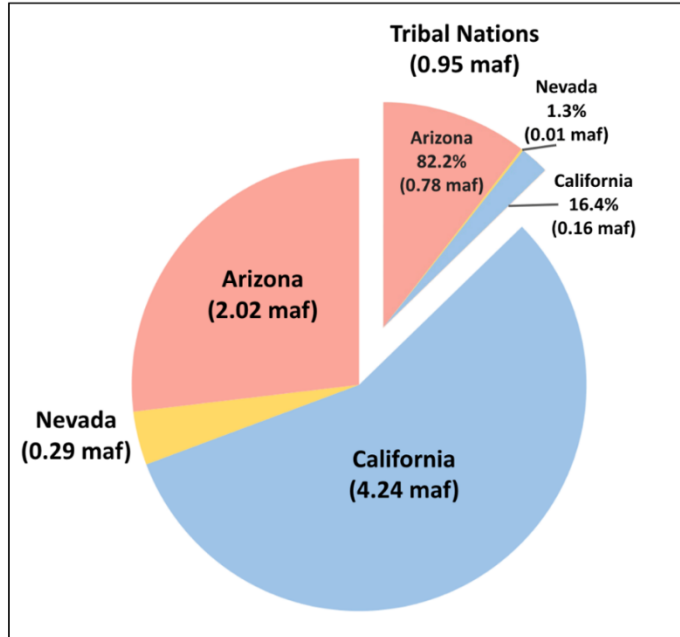
**Table 4a. Splits of reservoir inflow based on 2024 Lower Basin Shortage Agreement with Tribal Nations included.**

Based Off of 2024 Lower Basin Shortage Agreement: Tribal Nations Included in Lake Mead Inflow Allocation														
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]	Tribal Nations [G]	Total	Arizona [H]	Nevada [I]	California [J]	Mexico [K]	Tribal Nations [L]	Total [M]
[1]	0.0	9.0	2.02	0.29	4.24	1.50	0.95	9.0	22.4%	3.2%	47.1%	16.7%	10.6%	100%
[2]	0.3	8.7	1.91	0.28	4.14	1.45	0.92	8.7	22.0%	3.2%	47.6%	16.7%	10.6%	100%
[3]	0.4	8.6	1.88	0.27	4.10	1.43	0.91	8.6	21.8%	3.2%	47.7%	16.7%	10.6%	100%
[4]	1.0	8.0	1.67	0.26	3.89	1.33	0.85	8.0	20.9%	3.2%	48.7%	16.7%	10.6%	100%
[5]	1.5	7.5	1.50	0.24	3.72	1.25	0.79	7.5	20.0%	3.2%	49.6%	16.7%	10.6%	100%
[6]	2.7	6.3	1.08	0.20	3.30	1.05	0.67	6.3	17.2%	3.2%	52.4%	16.7%	10.6%	100%
[7]	4.0	5.0	0.63	0.16	2.85	0.83	0.53	5.0	12.6%	3.2%	56.9%	16.7%	10.6%	100%
[8]	4.4	4.6	0.49	0.15	2.71	0.77	0.49	4.6	10.7%	3.2%	58.8%	16.7%	10.6%	100%
[9]	5.2	3.8	0.22	0.12	2.43	0.63	0.40	3.8	5.7%	3.2%	63.9%	16.7%	10.6%	100%
[10]	8.0	1.0	0.17	0.03	0.52	0.17	0.11	1.0	17.2%	3.2%	52.4%	16.7%	10.6%	100%

We derived these values as follows.

1. At full allocation (zero shortage; Row 1 of Table 4a), we first give 0.95 million acre-feet per year to Tribal Nations of the Lower Basin (Table 4a, Row [1] Column [G]; callout pie section in Figure 4a). This volume corresponds to their settled water rights enumerated in Reclamation's Tribal Water Study (Ten Tribes Partnership, 2018).
2. We deduct volumes from the three other Lower Basin states based on the locations of the Tribal water users (Remainder of Figure 4a; Table 4a, Row 1, Columns [C] to [G]).
3. Next, we draw on percentage shares of total shortage specified in the recent Lower Basin Alternative (Buschatzke et al., 2024)(Table 4b). This proposal allocated user reductions as a percentage of the total mandatory reduction (Table 4b). Note, percent shares of shortages to Nevada and Mexico remain constant across Total Shortage Volumes.
4. To simplify, we select volume/percent shortages associated with 1.5 maf of total shortage (Table 4b, Rows [3] and [8]) .
5. We calculate Lake Mead Inflow (Table 4a, Column [B]) by subtracting the Total Shortage Volume (Table 4a Column [A]) shortage volume from the full allocation of 9.0 maf.

6. Similarly, we calculate each user's volume share of the inflow (Columns [C] to [G]) as their allocation at 9.0 maf of inflow (Row [1]) minus the Total Shortage (Column [A]) multiplied by the user's agreed-upon share of the shortage (from Step 4).
7. Finally, we calculate each users percentage share of the inflow as their volume (Table 4a, Columns [H] to [L]) by the total available water (Column [B]).



**Figure 4a. Chart Detailing the Tribal Nations Share of Lake Mead Inflow.** The main portion of the pie chart represents the volume of water Arizona, Nevada, and California will receive during a full inflow year to Lake Mead.

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

Total Shortage (maf per year)	Arizona	Nevada	California	Mexico	Total
<b>As Percent of Total Shortage</b>					
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%
<b>As Volume (maf per year)</b>					
0	0	0	0	0	0
0.3	0.13	0.01	0.11	0.05	0.30
0.4	0.17	0.01	0.15	0.07	0.40
1	0.43	0.03	0.37	0.17	1.00
1.5	0.65	0.05	0.55	0.25	1.50
1.5 to 2.7	To be determined				

**Here are some example calculations that include the Tribal Nations in the share of Lake Mead inflow allocation (Table 4a):**

1. Total Lake Mead inflow [B] = 9.0 — Total Shortage [A].
  - a. For example, a total shortage of 1.5 maf yields a Lake Mead inflow of 9.0 — 1.5 = 7.5 maf per year.
2. At 9.0 maf of total inflow [Row 1], each user's share of the reservoir inflow:
  - Arizona's volume share [C] = Arizona's Historical Allocation — Arizona's percent of the Tribal Nations (from Figure 4a) \* Tribal Nations volume [G].
    - i. For example, Arizona's share [C] = 2.8 — 0.822 \* 0.95 = 2.02 maf.
  - Nevada's share [D] = 0.3 — 0.013 \* 0.94 = 0.29 maf.
    - i. California's share [E] = 4.4 — 0.164 \* 0.95 = 4.24 maf.
  - Mexico [F] and Tribal Nations [G] are unchanged from their historical allocations (1.5 and 0.95 maf).
  - Total Reservoir Inflow = [C] + [D] + [E] + [F] + [G] =
    - i. 2.02 + 0.29 + 4.24 + 1.5 + 0.95 = 9.0 maf
  - b. A user's Percent of Reservoir Inflow is their share by volume divided by the total volume.
    - Arizona [H] = [C] / [G]
    - Nevada [I] = [D] / [G]
    - And so forth.
    - Tribal Nations [L] = [G] / Lake Mead full inflow [B]. Total Percentage of Reservoir Inflow [L] = [H] + [I] + [J] + [K] + [T] = 100%.

3. At 6.3 maf of total inflow [Row 6], each user's share of the reservoir inflow is their historical allocation minus their share of the associated shortage minus their share of the Tribal Water. For example:

Tribal Nation's share [G] =  $0.106 * 6.3 = 0.95 - 0.106 * 2.7 = 0.67$  maf.

Arizona's share [C] =  $2.8 - 0.43 * 2.7 - 0.822 * 0.67 = 1.08$  maf

California's share [E] =  $4.4 - 0.367 * 2.7 - 0.164 * 0.67 = 3.30$  maf.

Mexico's share [F] =  $1.5 - 0.167 * 2.7 = 1.05$  maf.

## Observations

- A. Mexico is not influenced by the inclusion of the Tribal Nations in the Share of Lake Mead Inflow Allocation. This is because none of the Tribal Nations water is stored in Mexico.
- B. The Tribal Nations have a steady Lake Mead Inflow percentage of 10.6%.
- C. The percentages highlighted in lilac were chosen to calculate the share of Lake Mead allocation for any inflow in the Master Sheet.
  - Inflow to User = percentage of inflow \* allocation of reservoir inflow for remaining users.
    - i. For example, at 5.3 reservoir inflow, California's inflow is  $0.496 * 5.30 = 2.63$  maf.

**When excluding Tribal Users, the percentage shares of reservoir inflow simplify (Table 4c).**

**Table 4c. Share of Lake Mead inflow by volume and percentage excluding Tribal Nations.**

Standardized												
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	9.0	31.1%	3.3%	48.9%	16.7%	100%
[2]	0.3	8.7	2.67	0.29	4.29	1.45	8.7	30.7%	3.3%	49.3%	16.7%	100%
[3]	0.4	8.6	2.63	0.29	4.25	1.43	8.6	30.5%	3.3%	49.5%	16.7%	100%
[4]	1	8.0	2.37	0.27	4.03	1.33	8.0	29.6%	3.3%	50.4%	16.7%	100%
[5]	1.5	7.5	2.15	0.25	3.85	1.25	7.5	28.7%	3.3%	51.3%	16.7%	100%
[6]	2.7	6.3	1.63	0.21	3.41	1.05	6.3	25.9%	3.3%	54.1%	16.7%	100%
[7]	4	5.0	1.07	0.17	2.93	0.83	5.0	21.3%	3.3%	58.7%	16.7%	100%
[8]	4.4	4.6	0.89	0.15	2.79	0.77	4.6	19.4%	3.3%	60.6%	16.7%	100%
[9]	5.2	3.8	0.55	0.13	2.49	0.63	3.8	14.4%	3.3%	65.6%	16.7%	100%
[10]	8	1.0	0.26	0.03	0.54	0.17	1.0	25.9%	3.3%	54.1%	16.7%	100%



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

Each participant has a dashboard where they can trade, conserve, and consume their available water (Figure 5a).

5. PARTICIPANT DASHBOARDS -- TRADE, CONSERVE, and CONSUME			
Reclamation - Protect Zone ( )			
Starting Available Water [maf]		4.5	Starting Available Water = Share of inflow + Storage account balance - Share of evaporation.
Enter volume to Buy(+) or Sell(-) [maf]		0.3	a. Enter volume in maf.
Enter price per acre-foot to Buy(-) or Sell(+)		-\$100	b. Enter price per acre-foot.
Compensation [Mill]		-\$30	Compensation. Will automatically be calculated and appear here. Compensation = [Price][Volume] = [\$/acre-foot][maf].
Net trade volume all participants (should be zero)		0.0	
Available Water [maf]		4.8	Track value. Is zero when each seller has a buyer.
Enter withdraw [maf] within available water		0.0	c. Enter withdraw of consume volume.
End of Year Balance [maf]		4.8	Account balance. Water available to sell, withdraw, or consume. End Balance = Available water - Withdraw.

**Figure 5a. Reclamation Protect Dashboard annotated.** Starting storage is 1,055 feet (8.0 maf), the reservoir protect elevation is 1,005 feet (4.8 maf), and there is 8.0 maf inflow this year. There is 0.44 maf total evaporation for the year, of which Reclamation's share is 0.26 maf. Thus, Reclamation has 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) Pricing

Enter the price in \$ per acre-foot – if buying, enter as a negative (-) and if selling, enter as a positive (+).

Table 5a shows water prices and compensation for recent voluntary, compensated, and mandatory Colorado River Basin water conservation programs (Allhands, 2021; UCRC, 2018; UCRC, 2024; USBR, 2021a; USBR, 2021c). 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 5a; Allhands, 2021; James, 2021; UCRC, 2018; UCRC, 2024; USBR, 2021a; USBR, 2021c)

**Table 5a. Colorado River Basin water conservation programs and accomplishments.**

Program	Years	Volume (million acre-feet)	Cost (\$ per acre-foot)	Compensation (\$ million)
<b>Existing Programs</b>				
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
Existing Programs				
Lake Mead Water Conservation Accounts	2007 to 2023	4.10	None	None
Mandatory Conservation - Not ICS	2019 to 2023	0.63	None	None
<b>Comparison Options</b>				
Lower Basin agricultural value	2021	None yet	\$700 to \$1,000	None yet
Desalination at the Sea of Cortez	2021	None yet	\$2,000	None yet
500+ Plan - Lower Basin	2021 to 2022	1.00	\$200	\$200

### (iii) Compensation

The total compensation will be automatically calculated. 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:

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

### (iv) 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.

### (v) 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).

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

### (vi) Enter Withdraw within Available Water

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

Enter withdrawals 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 5b (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 5c)(Ten Tribes Partnership, 2018).

**Table 5b. 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 5c. Diversion and consumptive use by Tribal Nations of the Lower Basin (acre-feet).**

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

#### (vii) End of Year Balance

The account balance at the end of the year after deducting withdrawals 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](mailto: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](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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