# Model Guide

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

David E. Rosenberg | Utah State University | [david.rosenberg@usu.edu](mailto:david.rosenberg@usu.edu)

| <http://rosenberg.usu.edu>

January 24, 2025

# I**ntroduction**

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.**

A diagram of water evaporation

Description automatically generated

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

A white background with black text

Description automatically generated

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

A graph with different colored text

Description automatically generated with medium confidence

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.



## 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](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 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* 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**



## 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 |

A graph of a line graph

Description automatically generated with medium confidence

**Range of Lake Mead Evaporation vs Active Storage**

### (ii) Start storage

Reservoir start storage is taken from the [data portal](https://www.usbr.gov/lc/region/g4000/hourly/mead-elv.html) (USBR, 2021b). 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

Description automatically generated with medium confidence

**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.

A graph of different colored bars

Description automatically generated with medium confidence

**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**.

A table with numbers and text

Description automatically generated

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

A table with numbers and text

Description automatically generated

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**

A table of information

AI-generated content may be incorrect.

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**. is hneeded Lake Powell releases Although the natural flow values from represent the inflow to Lee’s Ferry, they can also be used to represent inflow value to Lake Mead during arid years.

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). 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).

A graph showing a line

Description automatically generated

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

A graph of a number of blue bars

Description automatically generated with medium confidence

**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.

## 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).



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).**

A table with numbers and a number of percentages

Description automatically generated

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

A screenshot of a report

Description automatically generated

**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].
   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 7).

A screenshot of a computer

Description automatically generated

**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:

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

A screenshot of a table

Description automatically generated

### (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).

|  |  |
| --- | --- |
|  | (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).**

A table with numbers and a number of states

Description automatically generated

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

A table with numbers and text

Description automatically generated

### (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**](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. **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)**:
    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.
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.

# 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].

James, I. (2021). "Southwest braces for water cutbacks as drought deepens along the Colorado River." *Arizona Republic*. <https://www.azcentral.com/story/news/local/arizona-environment/2021/04/06/colorado-river-drought-deepens-arizona-prepares-water-cutbacks/4808587001/>.

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

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>.

Rosenberg, D. E. (2021). "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/>.

Salehabadi, H., Tarboton, D. G., Wheeler, K. G., Smith, R., and Baker, S. (2024). "Quantifying and Classifying Streamflow Ensembles Using a Broad Range of Metrics for an Evidence-Based Analysis: Colorado River Case Study." *Water Resources Research*, 60(7), e2024WR037225. <https://doi.org/10.1029/2024WR037225>.

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>.

UCRC. (2018). "Colorado River System Conservation Pilot Program in the Upper Colorado River Basin." *Upper Colorado River Commission*. <http://www.ucrcommission.com/RepDoc/SCPPDocuments/2018__SCPP_FUBRD.pdf>.

UCRC. (2024). "Colorado River System Conservation Pilot Program in the Upper Colorado River Basin." *Upper Colorado River Commission*. <http://www.ucrcommission.com/wp-content/uploads/2024/06/2023_SCPP_Report_June2024.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). "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. (2021b). "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. (2021c). "Pilot System Conservation Program." U.S. Bureau of Reclamation, <https://www.usbr.gov/lc/region/programs/PilotSysConsProg/pilotsystem.html> [Accessed on: October 14, 2021].

USBR. (2023a). "Integrated Technical Education Workgroup." U.S. Bureau of Reclamation, <https://www.usbr.gov/ColoradoRiverBasin/post2026/itew.html> [Accessed on: September 18, 2023].

USBR. (2023b). "Post-2026 Colorado River Reservoir Operational Strategies for Lake Powell and Lake Mead: Summary of the Federal Register Notice Input Received." Reclamation, <https://www.usbr.gov/ColoradoRiverBasin/Post2026Ops.html> [Accessed on: September 20, 2022].

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

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>.