NCEP Network of Conservation Educators & Practitioners

Developing capacity to sustain the Earth's diversity

NPS/Mike Quinn

## Introduction

The Colorado River is considered one of the great rivers of North America. Although other rivers are longer or carry more water, few rivers can compare with the wonder of the Colorado River as it winds through the landscape, cascading down mountains, carving colossal canyons, and nourishing habitats in arid and thus biologically strained environments. The natural landscape of the regions influenced by the River, such as the Colorado Mountains, the Grand Canyon, and Delta region, are legendary, however the fame of the Colorado River lies in the often complex and critical role it plays in today's society. In the climate of the Southwestern United States and Northwestern Mexico, the waters of the Colorado River are as valuable as gold. Cities have grown to depend on it for human consumption; some of the most productive agricultural lands in the United States require it for irrigation; houses depend on the hydroelectric power generated by it. Meanwhile native species depend on the ecosystems nourished by it.

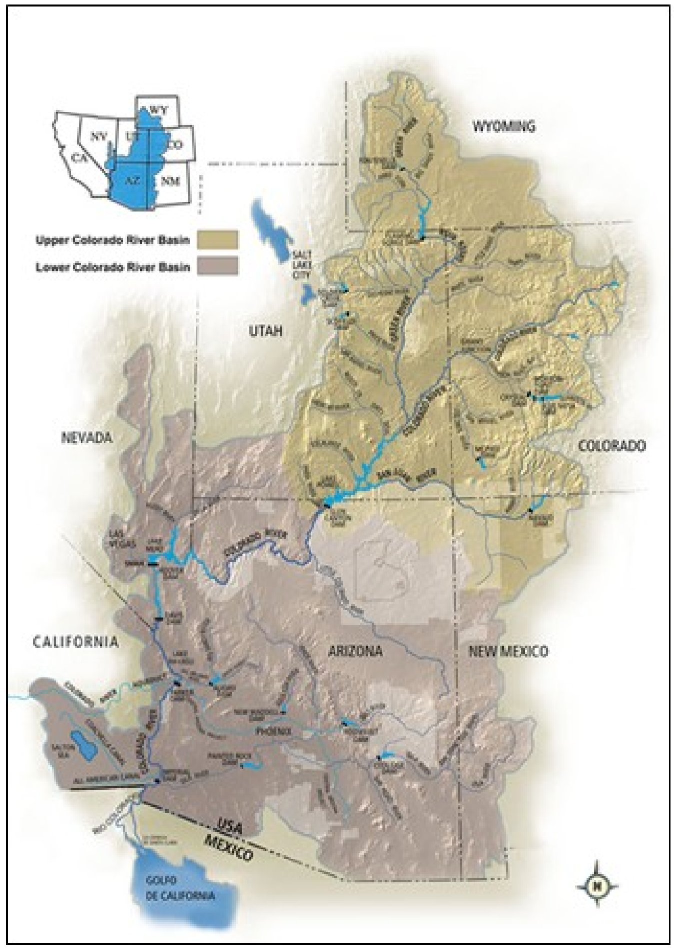
All of these demands combine to make one of the most interesting studies in multi-objective planning and management. With such a critically scarce supply and high demand, essentially every drop of the Colorado River is accounted for and diverted from the River, often leaving the channel dry as it enters the ocean.

In this unit we will discuss:

1. The Geographic Layout of the Basin
2. The History of People in the Basin
    - Native Americans
    - Spanish Explorers
    - American Explorers
3. The Law of the River
4. Modeling the Colorado River

Show Base Map
Historic Flows
Current Flows

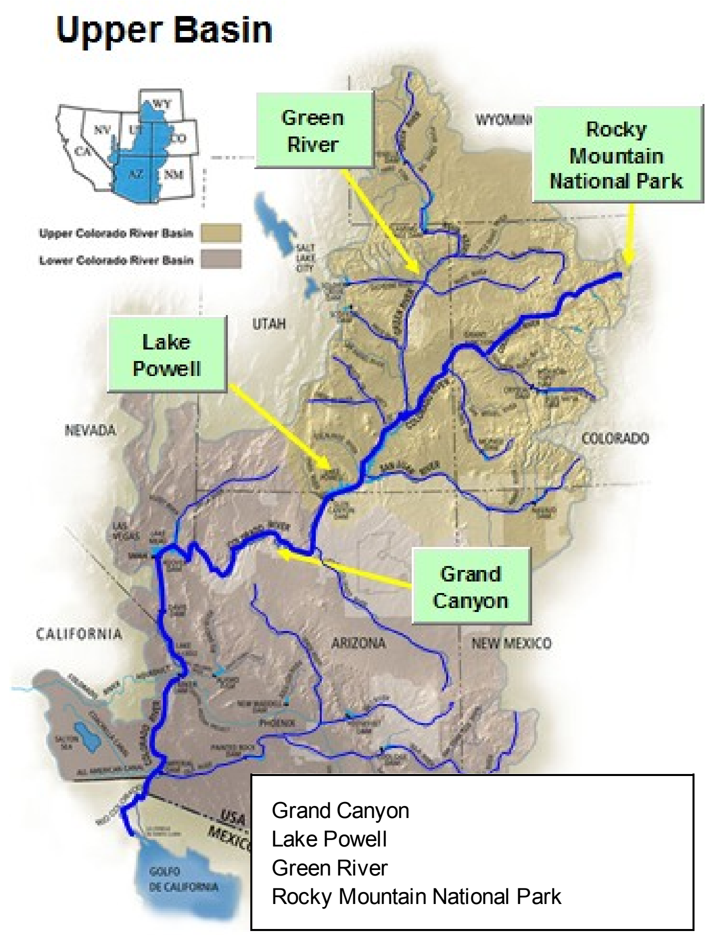
Show Dams



## Geographic Information

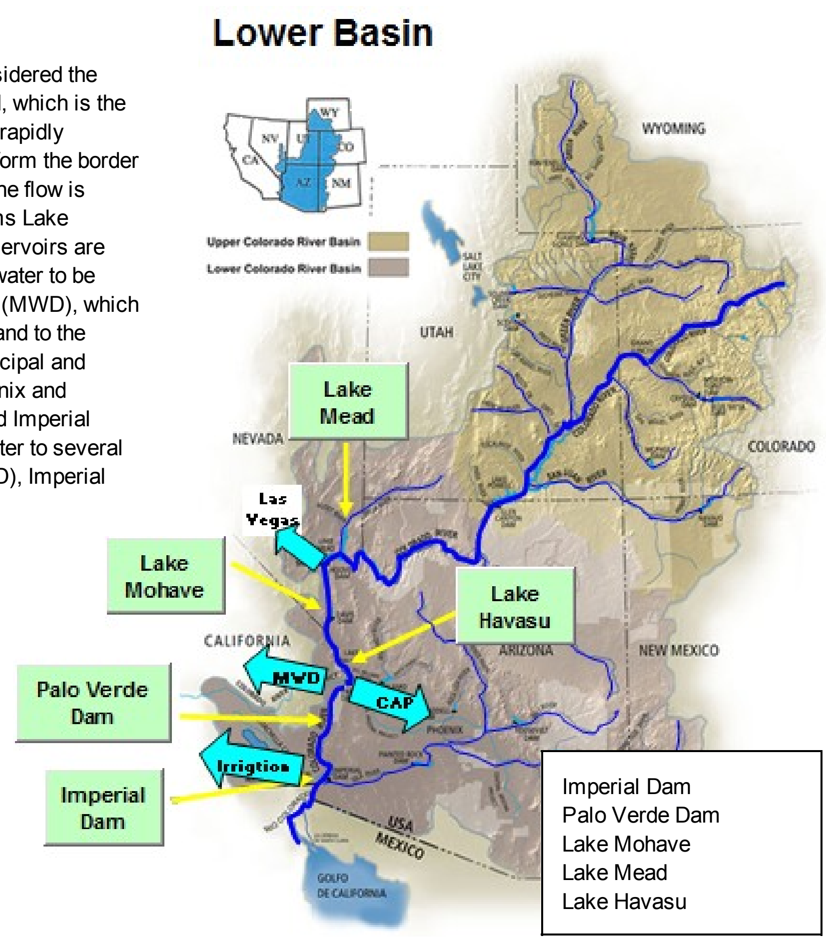
The Colorado River collects water that falls over a 245,000 square mile (635,000 km$^2$) area, covering a region known as the Colorado River Basin. The source of the Colorado River is typically considered to be in the high mountains of Colorado in Rocky Mountain National Park at elevations near 14,000 ft (4200 m) above mean sea level. Although the vast majority of the water does come from the high mountains of Colorado and Wyoming, the channel of the Colorado River is fed by rain and snow that falls throughout the basin.

The River descends from the western side of the Rocky Mountains and winds its way through the red sandstone canyons of Utah. After joining with waters from the Green River flowing from Wyoming, the Colorado River flows into Lake Powell. This major reservoir provides numerous recreational opportunities in addition to water storage for downstream uses. After passing the Glen Canyon Dam which forms Lake Powell, the River winds through the world famous Grand Canyon in Arizona, which provides a stunning view and understanding of the ancient role the River has played in sculpting the land surface.



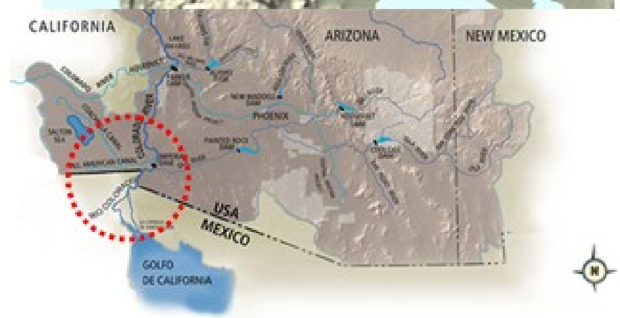

## Geographic Information (continued)

Below the Grand Canyon, the Colorado River flows past Lee Ferry, considered the legal division between the Upper and Lower Basins, and into Lake Mead, which is the major storage reservoir created by the Hoover Dam and adjacent to the rapidly expanding city of Las Vegas. Below Lake Mead, the River continues to form the border between Nevada and Arizona and California and Arizona. In this reach the flow is blocked by four additional major dams, including Davis Dam which forms Lake Mohave and Parker Dam which forms Lake Havasu. Although these reservoirs are much smaller in size compared to Lakes Powell and Mead, they allow water to be diverted from the River to be supplied to the Metropolitan Water District (MWD), which delivers water to the cities of Los Angeles and San Diego in California, and to the Central Arizona Project (CAP), which supplies water to numerous municipal and agricultural water users throughout Arizona, including the cities of Phoenix and Tucson. The additional dams include the Palo Verde Diversion Dam and Imperial Diversion Dam, which do not form significant reservoirs, but provide water to several large irrigation districts including the Palo Verde Irrigation District (PVID), Imperial Irrigation District (IID), and Coachella Irrigation District.



## Geographic Information (continued)

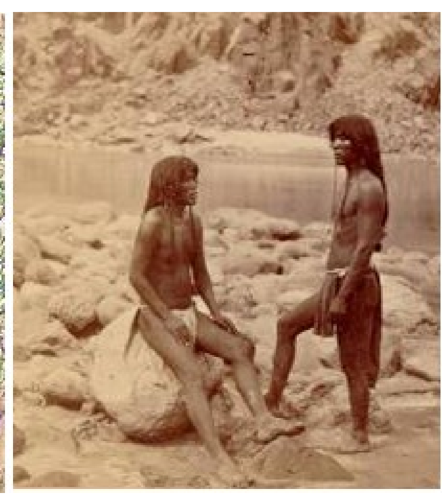
Below California at the Northern International Boundary (NIB), the River forms the international border between the United States and Mexico for approximately 24 miles (39 km) where the final structure, the Morelos Diversion Dam, diverts any remaining water for use in the Mexicali Valley and local municipalities. Finally, below the Southern International Boundary (SIB), the river channel is entirely in Mexico. After the 1450 mile (2330 km) journey from the Mountains of Colorado, the river empties into the Gulf of California, also known as the Sea of Cortez. The Historical Colorado River Delta extends from the Northern International Boundary to the Gulf.


## History - Native Americans

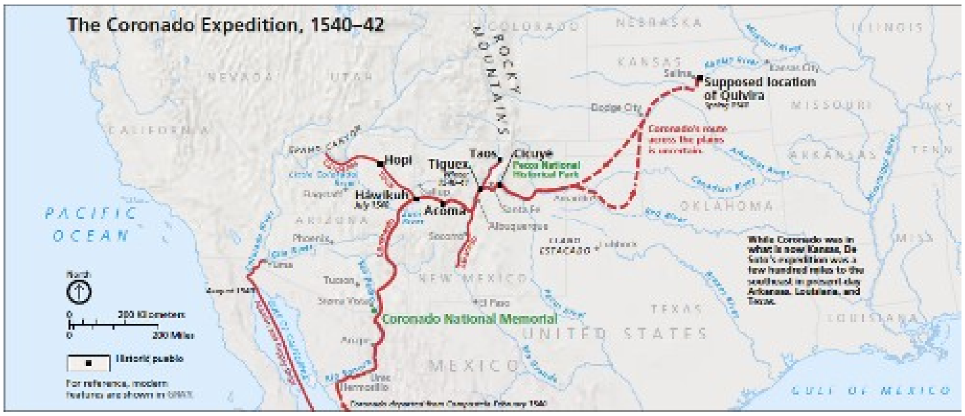
Native Americans have lived around the Colorado River and used its waters for thousands of years. These tribes built their cultures within the Basin long before Europeans arrived in the area. Elaborate canal systems and reservoirs indicate that many of these tribes had sophisticated water management practices to irrigate fields of crops, while other tribes relied extensively on the ecosystems the River provided for hunting grounds. Many of these tribes, such as the Mohave, Chemehuevi, Hopi, and Navajo, continue to use water from the river to farm and irrigate lands as well to pursue other economic opportunities.

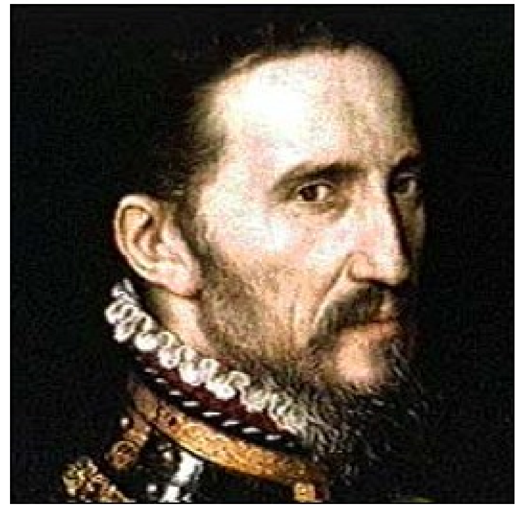




## History – Spanish Explorers

Spanish explorers were the first Europeans to see portions of the Colorado River. In 1539, a Spanish explorer named Francisco de Ulloa traveled around the mouth of the Colorado River. From 1540 to 1541, Francisco Vásquez de Coronado led an expedition through much of Arizona and New Mexico searching for the city of Cíbola, which was believed to be one of the seven cities of gold. As part of this effort, he sent Hernando de Alarcón to explore the Delta region. Alarcón explored from the Gulf of California as far upstream through the river as he could row. During this effort, he made the first recorded contact with a tribe called the Cacupá, or the People of the River, who farmed extensively in the Delta region. At the same time, Melchior Díaz traveled across an overland route through Sonora to reach the mouth of the Colorado. His party explored the confluence with the Gila River near Yuma while unsuccessfully trying to make contact with Alarcón's party. Another explorer named Don García López de Cardenas was also sent by Coronado to seek a route to meet Alarcón's fleet and reported seeing the Colorado River from what is believed to be the South Rim of the Grand Canyon.

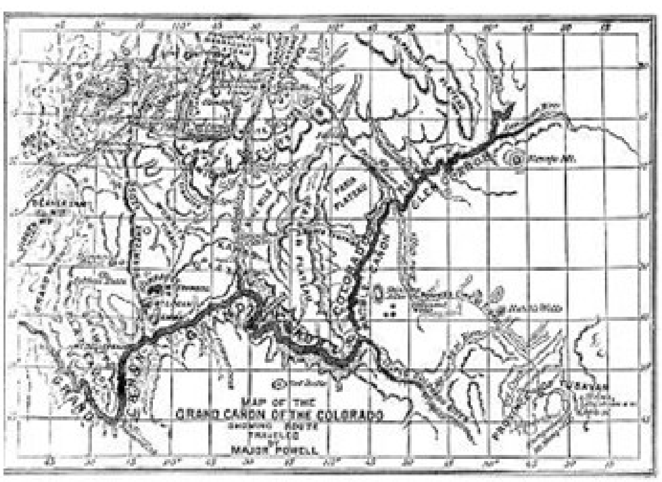


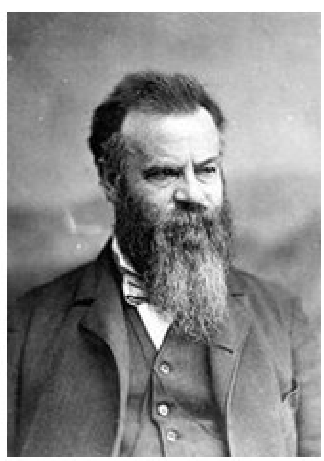



## History – American Explorers

American trappers and fur traders were the next group of Europeans to take interest in the Colorado. William H. Ashley organized the American fur trade in the Rocky Mountains and hired Jedidiah Smith, who discovered the beaver-rich Green River. Ashley himself descended the Green River—conducting the first navigation of the river—in 1825 in bullboats and provided the first authentic information regarding the upper Colorado, painting "Ashley, 1825" on a huge rock at Ashley Falls.

In 1869, an American named John Wesley Powell made the first thorough exploration of the Colorado River and the Green River. Powell's crew navigated downstream from the Green River through the confluence with the Colorado River (at that time called the Grand River) and down the Grand Canyon. In 1871-1872, Powell retraced his route with another expedition producing photographs and an accurate map of his journeys.



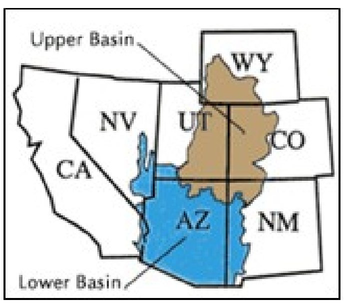
## Law of the River

Deciding how to share Colorado River water between the various demands across the United States and Mexico is a formidable task. The Colorado River is managed and operated under numerous compacts, federal laws, court decisions and decrees, contracts, and regulatory guidelines, collectively known as the "Law of the River." This collection of documents apportions the water and regulates the use and management of the Colorado River among the seven basin states and Mexico.

Because the "Law of the River" is comprised of many components that have evolved and adapted through time and many of these components are specific to certain portions of the River, it is only reasonable to highlight some of the major pieces that significantly influence the system as a whole.

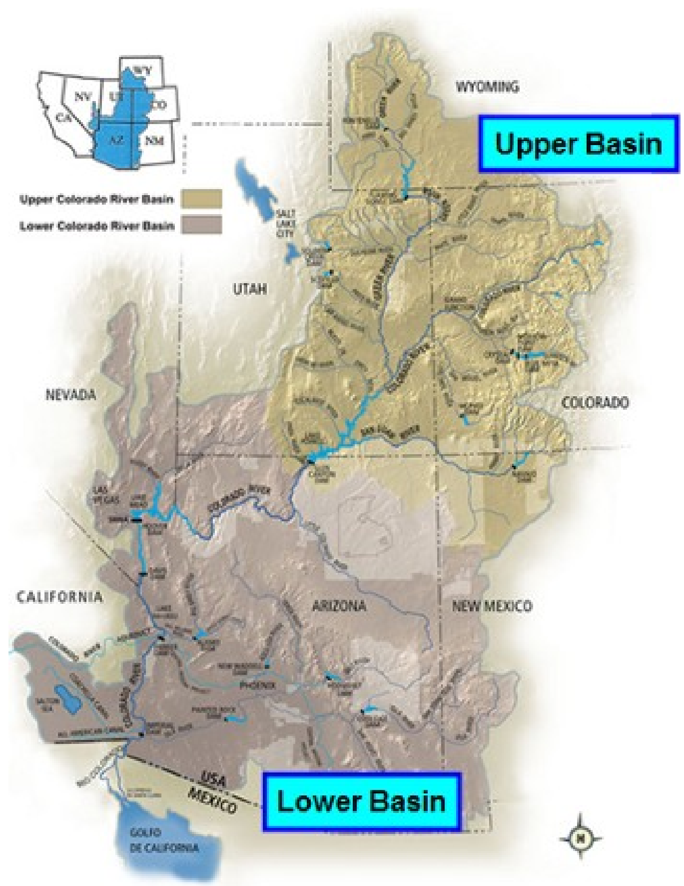
## Law of the River (continued)

**Colorado River Compact of 1922**




The cornerstone of the "Law of the River", this Compact was negotiated by the seven Colorado River Basin states and the federal government in 1922. It defined the relationship between the Upper Basin states, where most of the river's water supply originates, and the Lower Basin states, where most of the water demands were developing. At the time, the Upper Basin states were concerned that plans for Hoover Dam and other water development projects in the Lower Basin would, under the Western water law doctrine of prior appropriation, deprive them of their ability to use the river's flows in the future.

Using an estimate of 15 million acre-feet (maf) of water being available every year on average, the basin was divided into an upper and lower half, with each basin having the right to develop and use 7.5 maf of river water. This approach reserved water for future Upper Basin development and allowed planning and development in the Lower Basin to proceed. It is important to note that this estimate of 15 maf was based on the limited amount of data that was available at the time. In other words, this estimate was made with data collected over only a few years. Flows occurring prior to the existence of stream gages were simply unknown at the time. Recent research based on tree ring data has suggested that the long term annual average may be as little as 14.3 maf.

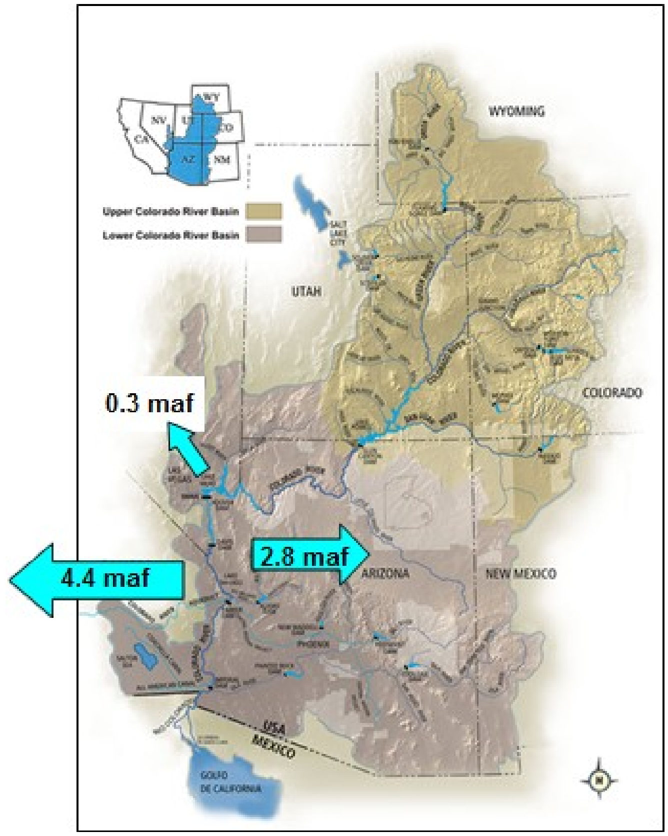


## Law of the River (continued)

**The Boulder Canyon Project Act of 1928**

This act had four major components that paved the path for major water development on the Colorado River. These items included:

- Ratification of the 1922 Compact
- Authorization for the construction of Hoover Dam and related irrigation facilities in the Lower Basin
- Apportionment of the Lower Basin's 7.5 maf among the states of Arizona (2.8 maf), California (4.4 maf), and Nevada (0.3 maf)
- Authorization and directive to the Secretary of the Interior to function as the sole contracting authority for Colorado River water use in the Lower Basin.




## Law of the River (continued)

**The Mexican Water Treaty of 1944**

This agreement between the United States and Mexico committed 1.5 maf of the river's annual flow to Mexico.

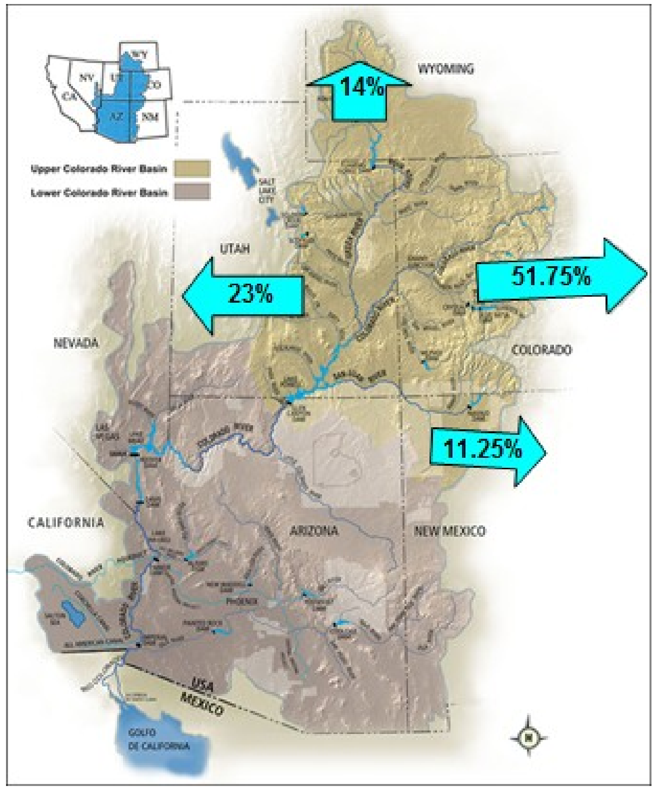
**Minute 242 of the U.S. – Mexico International Boundary and Water Commission of 1973**

Required the U.S. to take actions to reduce the salinity of water being delivered to Mexico at Morelos Dam.

## Law of the River (continued)

**Upper Colorado River Basin Compact of 1948**

Created the Upper Colorado River Commission and apportioned the Upper Basin's 7.5 maf among Colorado (51.75%), New Mexico (11.25%), Utah (23%), and Wyoming (14%); the portion of Arizona that lies within the Upper Colorado Basin was also apportioned 50,000 acre-feet annually.




## Law of the River (continued)

**Colorado River Interim Surplus Criteria - 2000**

Established guidelines for defining surplus conditions based on reservoir levels and established allocations of surplus water to the Lower Basin States and Mexico depending on reservoir conditions.

**Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lakes Powell and Mead - 2007**

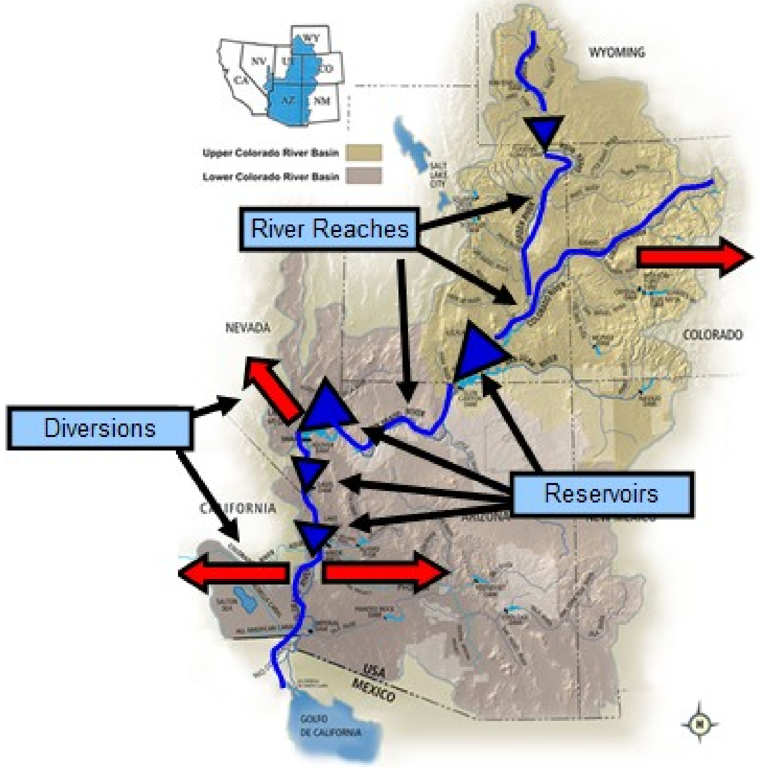
Established guidelines for defining shortage conditions based on reservoir levels of Lakes Powell and Mead and governed the operation of the reservoirs in such conditions; also specified mandatory reductions in consumption for the Lower Basin states and Mexico.

The table to the right shows how Lakes Powell and Mead are operated under various storage conditions of the reservoirs. Notice that on Lake Mead there can be "Surplus" conditions when the reservoir is high and "Shortage" conditions when the reservoirs are low. Complex operational rules are also established to determine the releases from Lake Powell based on the elevations of the two reservoirs. Often the contents of the two reservoirs are "balanced".

| Lake Powell Elevation (feet) | Lake Powell Operational Tiers | Lake Powell Storage (maf) | Lake Mead Elevation (feet) | Lake Mead | Lake Mead Storage (maf) |
|---|---|---|---|---|---|
| 3,700 | **Equalization Tier** Equalize, Avoid Spills or Release 8.23 maf | 24.3 | 1,220 | **Flood Control or 70R Surplus** | 25.9 |
| 3,636 - 3,666 (2008-2026) | | 15.5 - 19.3 (2008-2026) | 1,200 | | 22.9 |
| | **Upper Elevation Balancing Tier**[1] Release 8.23 maf; if Lake Mead < 1,075 feet, balance contents with a min/max release of 7.0 and 9.0 maf | | | **Domestic Surplus** | ICS Surplus |
| | | | 1,145 | **Normal Operations** | 15.9 |
| 3,595 | | 11.3 | 1,125 | | 13.9 |
| 3,575 | | 9.5 | 1,100 | | 11.5 |
| 3,560 | **Mid-Elevation Release Tier** Release 7.48 maf; if Lake Mead < 1,025 feet, release 8.23 maf | 8.3 | 1,075 | **Shortage 333 kaf**[2] | 9.4 |
| | | | 1,050 | **Shortage 417kaf**[2] | 7.5 |
| 3,525 | **Lower Elevation Balancing Tier** Balance contents with a min/max release of 7.0 and 9.5 maf | 5.9 | 1,025 | **Shortage 500 kaf**[2] **and Consultation**[3] | 5.8 |
| 3,490 | | 4.0 | 1,000 | | 4.3 |
| 3,370 | | 0 | 895 | | 0 |

## Modeling the Colorado River

The Colorado River has many tributaries that supply water and many demands that extract water. The River is managed by the numerous laws, decrees and court rulings that are collectively referred to as the “Law of the River.” Understanding how all of these factors interact is a complex task, especially when supplies of water from rainfall and demands for water are constantly changing through time. To help us understand this complex system, water managers rely on computer models. These models are simplified representations of the real physical river and are built inside computer programs or spreadsheets. They often include the major components of a river basin such as river reaches, reservoirs, and lakes, and major water diversions such as cities or irrigation districts.



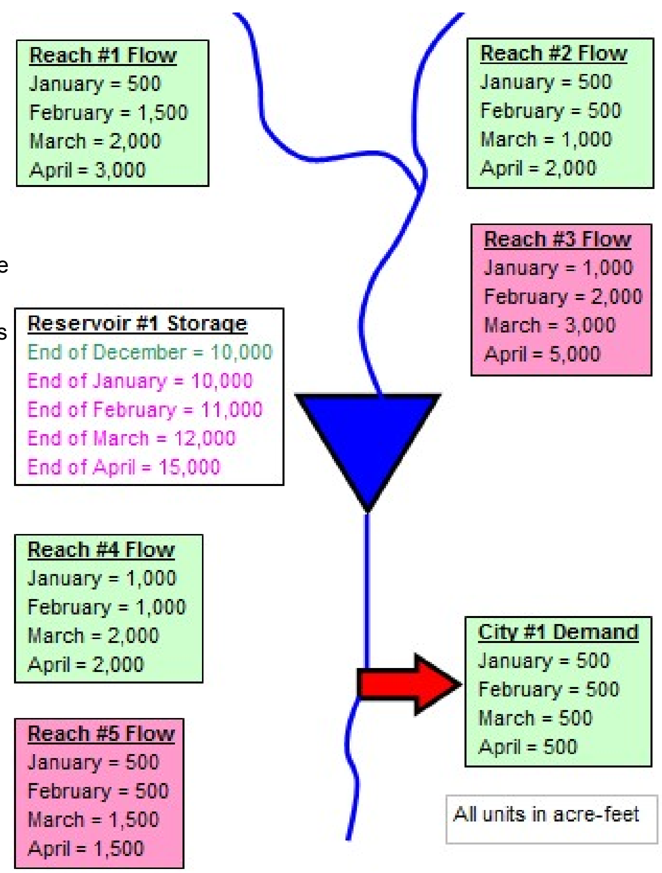

## Modeling the Colorado River – Generic Example

Data are collected such as how much water is available at different locations and how much water is demanded at different locations over a fixed period of time. Information is also entered that represents how much water is stored in reservoirs.

Look at the figure on the right. Each reach has some information representing the amount of water it has during each month. The reservoir has information that shows how much water it has at the end of each month.

- Notice how the water in Reach #1 and the water in Reach #2 combine to determine the amount of water in Reach #3.
- Notice how the amount of water changes between Reaches #3 and #4 and how this affects the amount of water stored in Reservoir #1
  - During January, 1,000 acre-feet of water was in Reach #3 and 1,000 acre-feet was in Reach #4, and we also notice that the Storage in Reservoir doesn’t change from the end of December to the end of January.
  - Now notice that in February there is 2,000 acre-feet in Reach #3 but only 1,000 acre-feet in Reach #4. Also notice how the storage in the reservoir increased from 10,000 to 11,000 acre-feet. In this model, the reservoir stored 1,000 acre-feet of the water during February and bypassed 1,000 acre-feet.
- Notice how the demands from City #1 changes the amount of water between Reach #4 and Reach #5 by always diverting 500 acre-feet

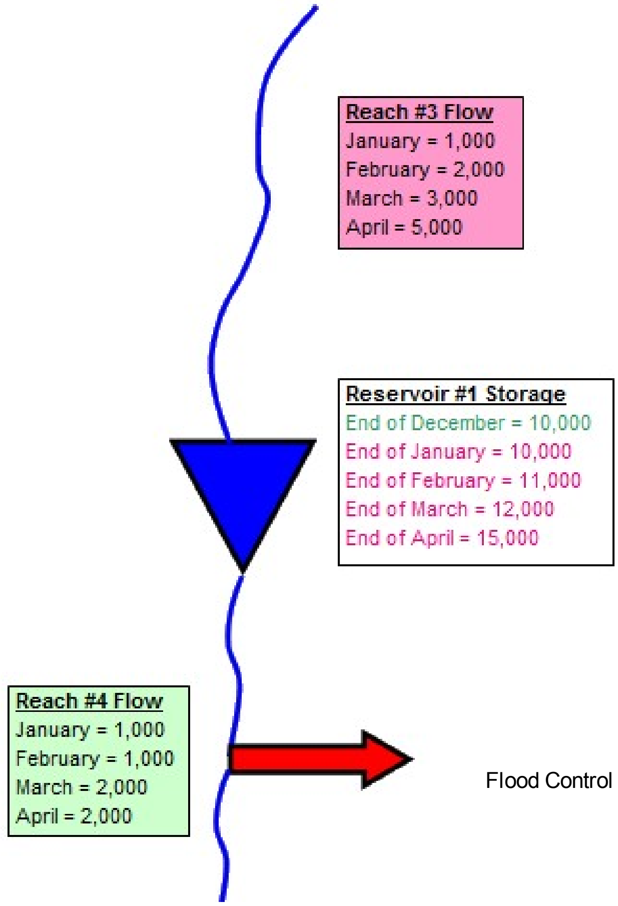
Now convince yourself that if you have all the inputs (the information in green), then you can determine all the outputs (information in pink). That is what modeling is all about!



## Modeling the Colorado River – Generic Example

Modeling can get a lot more complicated. While we won't discuss the numerous ways that models increase in complexity, here are a few points think about.

- Models can represent policies. Notice in our example, we said that the water in Reach #4 was an input. Since this is the same thing as the outflow from Reservoir #1, it is something we can change by operating the reservoir differently. If we wanted to make sure the storage in the reservoir does not get too high during the spring runoff, we may want to manage the reservoir differently so the reservoir doesn't overflow.
  - Look at the example on the right. This is the same situation as we saw before. Notice how the storage in the reservoir increases from 10,000 acre-feet to 15,000 acre-feet.
  - Now let's say that we didn't want the reservoir to ever have more water than 10,000 acre-feet. Press the Flood Control scenario button to see how we could manage the reservoir better to make this happen.
  - Notice that now we have the same inflows and the reservoir starts out with 10,000 acre-feet just as before, but now we are going to make larger releases starting in January to make room in the reservoir to capture the spring runoff.
- The concept of time steps is very important to understand modeling. These time steps can vary anywhere from annual increments (e.g., 2010, 2011, 2012) to monthly increments (e.g., January 2010, February 2010, March 2010) to even hours, minutes, or seconds!
  - If you are doing a long-term planning study to asses the impacts of Climate Change, you may only need to use an annual time step.
  - If you are studying how flows from a large storm event will affect the amount of water that passes through a river to understand its effects on fish and other species, you may need to use a daily or even hourly time step.
  - There is always a trade-off between accuracy and complexity. The more accurate you try to make a model by using a smaller time step, the more data you need to run the model and therefore the more complex it becomes.




## Modeling the Colorado River

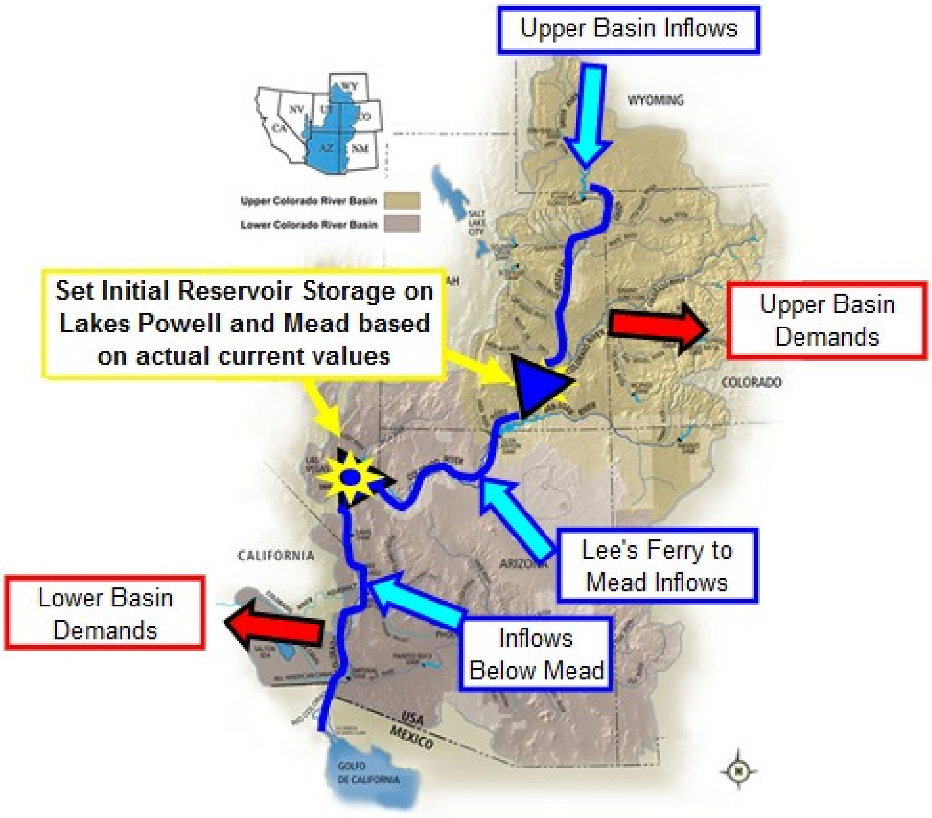
Throughout this set of interactive exercises, we will use a simplified model of the Colorado River to demonstrate how water distribution is simulated. This model consists of:

- Three inflow points:
  - Inflows above Lake Powell
  - Inflows between Lee's Ferry and Hoover Dam
  - Inflows below Lake Mead
- The two major reservoirs:
  - Lake Powell
  - Lake Mead
- Three aggregate demands:
  - Upper Basin demands above Lake Powell
  - Demands from Lake Mead (SNWA)
  - Lower Basin demands below Lake Mead

To understand the logic behind the simulation model, walk through the 12 steps below. Notice what pieces of data are input and what data are calculated.

## Modeling the Colorado River (continued)

Step 1: Input initial sotrage
Step 2: Input Upper Basin inflows
Step 3: Input Upper Basin demands
Step 4: Calculate Powell inflows
Step 5: Calculate Powell evaporation
Step 6: Calculate Powell releases
Step 7: Calculate new Powell sotrage
Step 8: Input Lee's Ferry to Mead inflows
Step 9: Deduct SNWA depletions
Step 10: Calculate Mead evaporation
Step 11: Calculate Mead releases
Step 12: Calculate new Mead sotrage




## Modeling the Colorado River (continued)

Once we understand how the logic of a model works, we can use its outputs to estimate things like:

- How much water will be available for different water users?
- How full will the reservoirs be for recreational users?
- How much water will be available for habitats along the river corridor?

Furthermore, the real power of a model is its ability to explore future scenarios. In other words, we can change the inputs to observe what the effects on the outputs are.

In the **Hydrology Unit**, we will explore how we develop the inflows to the model using historical flows and the assumptions we make about the future.

In the **Climate Change Unit**, we will explore how changes in temperature and precipitation will change the amount of water that is available for water users and the environment.

In the **Economics Unit**, we will explore what the economic benefits are to the various water users and how those benefits might change under different water distribution scenarios.

In the **Native Ecosystems Unit**, we will explore how water management has changed the amount of water available for various native species and what is needed to keep these species alive.

In the **Water Conservation Unit**, we will explore how much water can be conserved by changing water use practices and who benefits from these savings.

## Image Credits

**Slide 1**

- Glen Canyon Dam Adaptive Management Program. **http://www.gcdamp.gov/images/ColBasinfinal.jpg**

**Slide 2**

- Glen Canyon Dam Adaptive Management Program. **http://www.gcdamp.gov/images/ColBasinfinal.jpg**

**Grand Canyon**

- Wikimedia Commons/ Luca Galuzzi. **http://upload.wikimedia.org/wikipedia/commons/f/f9/USA_09847_Grand_Canyon_Luca_Galuzzi_2007.jpg**
- Sullivan, J. Grand Canyon Hikers/ Jon Sullivan. **http://www.public-domain-image.com/nature-landscape/canyon/slides/grand-canyon-hikers.jpg**

**Lake Powell**

- Pernick, A. Aerial view of Glen Canyon Dam/ Glen Canyon Adaptive Management Program/ Andrew Pernick. **http://www.gcdamp.gov/gallery/gen/pages/pg1.html**
- Lake Powell from above Wahweap Marina/Davejen1ns. **http://en.wikipedia.org/wiki/File:Lake_Powell_Above_Wahweap_Marina.jpg**

**Green River**

- Thomas, G. Upper Green River, Wyoming, looking east towards Squaretop Mountain/ G. Thomas. **http://en.wikipedia.org/wiki/File:GreenRiverWY.jpg**

**Rocky Mountain National Park**

- Wikimedia Commons/Nmadhubala. Rocky Mountain National Park/ Nmadhubala. **http://commons.wikimedia.org/wiki/File:Rocky_Mountain_National_Park.jpg**

**Slide 3**

- Glen Canyon Dam Adaptive Management Program. **http://www.gcdamp.gov/images/ColBasinfinal.jpg**