# 18

# Water Resources Management in the Colorado River Basin

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## 18.1 Introduction and Background

The Colorado River is a vital resource for the people, environment, and economy of the south-western United States and north-western Mexico. The geography of the Colorado River Basin is diverse, from snow-capped mountains over 4000 m (c. 13 000 ft) tall to deserts with awe inspiring canyons cut by the river over millennia. The legal framework that guides the management is complex, developed over a century through a series of federal and state laws, court cases, agreements, and an international treaty. In recent years, as drought continues to stress the region, the challenges associated with responsibly using and managing this resource continue to mount, as illustrated by some of the river's nicknames; 'lifeline of the West', 'hardest working river in the west', 'basin of contention', and 'one of America's most endangered rivers'.

Throughout the basin, there are numerous catchment management issues, including environmental, water quality, and water quantity concerns, each of which include their own challenges and success stories. Federal statutes (federal laws, passed by the US Congress and signed into law by the US President) provide the basis for the solutions to many of these management issues. For example, there are several ongoing programmes (such as the San Juan Basin Recovery Program, Upper Colorado River Endangered Fish Recovery Program, Glen Canyon Dam Adaptive Management Program, and Lower Colorado River Multi-Species Conservation Program [LCR MSCP])[1] that focus on the protection and restoration of threatened and endangered species throughout the US portion of the basin to ensure compliance with the 1973 Endangered Species Act.[2] These programmes work collectively with federal science, management, and recreation agencies, state water agencies, municipal and agricultural water providers, and non-governmental organisations (NGOs) to identify opportunities to provide environmental benefits

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while maintaining water delivery and hydropower benefits. There are many local water quality issues with ongoing work to ensure compliance with the 1972 Clean Water Act amendments to the 1948 Water Pollution Control Act.[3] Continual efforts seek to maintain or reduce the salinity concentration in the river to protect agricultural, municipal, and industrial water users in accordance with the 1974 Colorado River Basin Salinity Control Act.[4]

The major challenge facing the basin today is one of water quantity (i.e. an overall imbalance in water supply and water demand), particularly given a changing climate. This chapter offers a discussion of that challenge and the issues associated with it as a case study in water resources management. The discussion begins with background on the geography and hydrology of the basin and an overview of the legal and policy framework that guides the management and use of the river. The challenge of the imbalance in water supply and demand is then outlined along with the current approaches to addressing the issues related to that challenge. The conclusion offers some thoughts and considerations regarding Colorado River water policy decision-making in the future.

### 18.1.1 Geography and Hydrology

The Colorado River and its tributaries flow through seven US states and two Mexican states. The basin drains an area of 637 000 $km^2$ (c. 246 000$mi^2$), an area about equal to the area of France, Belgium, and the Netherlands combined. The basin is an arid, snowmelt dominated basin with over 90% of the run-off generated by snowmelt from precipitation in the states of Colorado, Utah and Wyoming, primarily from the areas above 2400 m (c. 8000 ft). Run-off in the basin is highly variable year to year, with an average natural flow of nearly 19.7 billion cubic metres ($Bm^3$; 16 million acre-feet [maf]) per year. Throughout this chapter, water supply is reported as natural flow; i.e. the flow that would have occurred at a given location absent consumptive use and reservoir regulation upstream of that location. The term consumptive use refers to water that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise not available for immediate use, including water transferred out of the basin (Bruce et al. 2018).

Today, over 40 million people rely on the Colorado River and its tributaries for some, if not all, of their municipal water needs, and water from the river is used to irrigate over 2 million ha (5 million acres) of land. The river and its tributaries also provide essential physical, economic, and cultural resources to 29 federally recognised Indian tribes[5] (throughout this chapter, 'Indian tribe' or 'tribe' refers to a native tribe, band, nation, pueblo, village, or community that is federally recognised in the US pursuant to the Federally Recognised Indian Tribe List Act of 1994) throughout the basin. Many of the water users with the biggest diversions are located outside of the hydrologic basin (Figure 18.1) and receive Colorado River water through basin diversion tunnels and canals. As development has continued and population has increased over the past century, the total annual consumptive use throughout the basin has also increased, resulting in the 10-year average basin use exceeding the 10-year average basin supply in recent years (Figure 18.2). Water consumed for irrigated agriculture continues to be the largest use, representing over half of the total consumptive use basin-wide.


**Figure 18.1** Map of the Colorado River Basin.

In addition to providing water to municipal, industrial, agricultural, and tribal water users, the Colorado River also provides numerous recreational benefits (Box 18.1) and environmental benefits (discussed in more detail later) as it flows through nine National Park Units and seven national wildlife refuges (Reclamation 2015).

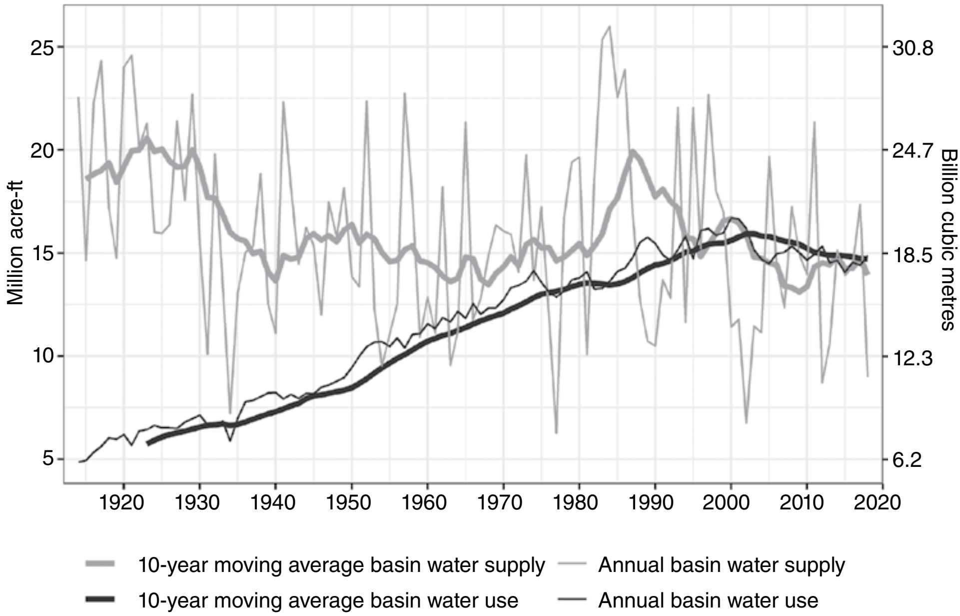


**Figure 18.2** Colorado River Basin supply and use.

The Bureau of Reclamation, a water management agency established in 1902 within the US Department of the Interior, has constructed several large dams throughout the basin over the past 80+ years, primarily to provide water storage capacity to mitigate the high annual variability in run-off and to minimise reductions in water delivery in dry years. Overall, there is capacity in the basin to store approximately four times the average annual natural flow, with the two largest human-made reservoirs in the US Lakes Powell and Mead (Figure 18.1), providing over 80% of the 74 $Bm^3$ (60 maf) of total storage capacity in the basin. In addition, most of the dams include hydropower plants that provide more than 4200 MW of electrical generating capacity, helping to meet the power needs of the western United States and offset the use of fossil fuels (Reclamation 2012).

### 18.1.2 Legal and Policy Framework

Underlying the legal and policy development for the management of most water systems in the western United States (including the Colorado River) is the doctrine of prior appropriation, often stated as 'first in time, first in line' (Box 18.2). With that underpinning, management of most western US water systems evolved to meet specific objectives and constraints and the Colorado River is no exception. The river is managed pursuant to numerous compacts, federal and state statutes, court decisions and decrees, regulations, contracts, and other legal documents and agreements, collectively referred to as the 'Law of the River',[6] of which the 1922 Colorado River Compact (1922 Compact) is the cornerstone.

Among the many management issues at the time of the 1922 Compact negotiation, a primary concern was that ongoing water projects in the lower portion of the basin (primarily

**Box 18.1 Recreational Opportunities Along the Colorado River**

The Colorado River Basin offers world-renowned rafting, boating, fishing, camping, hiking, and other recreational activities to millions of visitors each year in both reservoir and free-flowing river settings. Most of the recreational corridor is managed as national parks, national recreation areas, national forests, other federally managed lands, and state and local parks (Reclamation 2015).

Cataract Canyon, Westwater Canyon, and the Grand Canyon are some of the most popular and famous white water stretches along the river, which are paddled by tens of thousands of private and commercial boaters each year. The Grand Canyon alone sees more than 22 000 visitors annually (Reclamation 2015). Additionally, the 30-mi stretch of the Colorado River below Hoover Dam, designated as a National Water Trail in 2014 and the first such trail in the south-western United States, offers unique flat water paddling through extraordinary desert canyons and wildlife refuges.

In 2018, over 26 million people visited the nine National Park Service units considered directly linked to the Colorado River and its tributaries (Arches National Park, Black Canyon of the Gunnison National Park, Canyonlands National Park, Curecanti National Recreation Area, Dinosaur National Monument, Glen Canyon National Recreation Area, Grand Canyon National Park, Lake Mead National Recreation Area, and Rocky Mountain National Park), spending over US$ 2.3 billion in total. The two largest reservoirs, Lake Powell and Lake Mead, accounted for 4.2 and 7.6 million visitors, and US$ 411 and US$ 336 million in spending, respectively (Thomas et al. 2019). While the quantified economic benefit is substantial, the visitors' experiences are considered priceless.

**Box 18.2 The Doctrine of Prior Appropriation**

Underlying the legal and policy development for the management of most water systems in the western United States (including the Colorado River) is the doctrine of prior appropriation (Gopalakrishnan 1973). This doctrine originated in the mid-1800s, as the relatively scarce water resources in the western United States were beginning to be used primarily for mining and agricultural purposes. This doctrine, often stated as 'first in time is first in line', refers to the principle that the first entity to put water to beneficial use has the right to continue to use water for that purpose in perpetuity, and each subsequent use is considered 'junior' in priority to those uses that came before it. Absent additional laws, policies, and/or agreements, water rights are fulfilled in priority order during times of water shortages.

The prior appropriation doctrine differs from the system of water law known as the riparian doctrine, primarily utilised in the eastern United States. Under the riparian system, absent additional laws, policies, and/or agreements, the owner of land with water on, adjacent to, or under their property has the legal right to use that water and in the case of a river or stream, all riparian landowners have an equal right to use the water.

by California) would deprive the other states in the basin (Arizona, Nevada, Colorado, New Mexico, Utah, and Wyoming) of their ability to use Colorado River water in the future under the prior appropriation doctrine. Additionally, the states in the lower portion of the basin were concerned that future water development in the upper portion would adversely affect their ability to use Colorado River water, particularly in times of drought.

Although the negotiators were unable to agree on the allocation of Colorado River water to each Basin State, a compromise was reached by dividing the basin into the Upper Basin (those parts of the states of Arizona, Colorado, New Mexico, Utah, and Wyoming within and from which waters naturally drain into the Colorado River System above Lee Ferry as well as the parts of those states outside of the drainage area served by water diverted from the system) and the Lower Basin (those parts of the states of Arizona, California, Nevada, New Mexico, and Utah within and from which water naturally drain into the Colorado River System below Lee Ferry as well as the parts of those states outside of the drainage area served by water diverted from the system) with the dividing point at Lee Ferry (Figure 18.1) and apportioning 9.25 $Bm^3$ (7.5 maf) per annum of consumptive use in perpetuity to each. Another compromise was reached whereby the Upper Division States (defined in the 1922 Compact as Colorado, New Mexico, Utah, and Wyoming) were directed to 'not cause the flow of the river at Lee Ferry to be depleted below an aggregate of 92.5 $Bm^3$ (75 maf) for any period of 10 consecutive years'. The interpretation of this provision is subject to extensive debate (Colorado River Governance Initiative 2012) and to date has not been tested in practice or in court.

In recognition that Mexico could be the recipient of a right to consumptive use of Colorado River water sometime in the future, the Compact stated that if surplus water (i.e. water over and above the US apportionments) is insufficient to meet Mexico's right, any deficiency would be shared equally by the Upper Basin and the Lower Basin (The Utilisation of Waters of the Colorado and Tijuana Rivers and of the Rio Grande Treaty Between the United States and Mexico [1944 US–Mexico Water Treaty] subsequently allocated 1.85 $Bm^3$ [1.5 maf] per year to Mexico). Although most tribal water rights had not been adjudicated at the time, the Compact also stated that 'Nothing in this compact shall be construed as affecting the obligations of the United States of America to Indian tribes'.

Although the 1922 Compact left many important policy issues unresolved (e.g. the specific allocation of water to each Basin State and to Mexico, the resolution of specific tribal water rights claims, etc.), some key issues were resolved that allowed the planning and development of water projects in the Lower Basin to proceed. The construction of the Hoover Dam, which created Lake Mead, as well as some irrigation facilities downstream, was subsequently authorised by the 1928 Boulder Canyon Project Act (BCPA).[7] The 1928 BCPA also divided the Lower Basin's 9.25 $Bm^3$ (7.5 maf) apportionment as follows: Arizona, 3.45 $Bm^3$ (2.8 maf); California, 5.43 $Bm^3$ (4.4 maf); and Nevada 0.37 $Bm^3$ (0.3 maf) (Table 18.1), and it approved the 1922 Compact.

Over the following four decades, development in the Lower Basin progressed, beginning with the construction of the Colorado River Aqueduct in the 1930s to divert water for municipal use in southern California[8] (California established the Metropolitan Water District in 1928 with the primary purpose to construct and operate the 390-km [242-mi] aqueduct, which began delivery of water in 1939) and including two additional mainstream dams below Hoover Dam (Parker Dam in 1938 and Davis Dam in 1951) to facilitate the

**Table 18.1** Annual US State apportionments[a] and allocation to Mexico.

| | Apportionment/allocation | | |
|---|---|---|---|
| | %[b] | Million cubic metre | Acre-ft |
| *Upper Basin* | | | |
| Arizona | — | 61 674 | 50 000 |
| Colorado | 51.75 | 4 755 535 | 3 855 375 |
| New Mexico | 11.25 | 1 033 812 | 838 125 |
| Utah | 23.00 | 2 113 571 | 1 713 500 |
| Wyoming | 14.00 | 1 286 522 | 1 043 000 |
| *Lower Basin* | | | |
| Arizona | — | 3 453 749 | 2 800 000 |
| California | — | 5 427 320 | 4 400000 |
| Nevada | — | 370 045 | 300 000 |
| Mexico | — | 1 850 223 | 1 500 000 |

a) All US entitlements, including tribal rights, are included in these apportionments.
b) Percentages are listed for the Upper Basin as the 1948 Upper Basin Compact apportioned the available water on a percentage basis to Colorado, New Mexico, Utah, and Wyoming, after apportioning a fixed volume to Arizona.

delivery of water to California, Arizona, and Mexico. Arizona further desired the ability to divert water off-stream for use in central Arizona in order to use its full apportionment; however, California disagreed, and the long-standing dispute was ultimately settled by the US Supreme Court in its 1964 Decree.[9]

The Court effectively established the Secretary of the US Department of the Interior (Secretary) as the 'water master' of mainstream Colorado River water in the Lower Basin. Specific responsibilities include determining the amount of mainstream water available annually for consumptive use, releasing water apportioned but unused by one state for use in another state in any a given year (but with no rights to the recurrent use of such water in subsequent years), and accounting for all water use from the mainstream in the Lower Basin on an annual basis. Most of the Secretary's Lower Basin water master responsibilities are carried out by Reclamation, as well as the annual, monthly, daily, and hourly scheduling, operation, and maintenance of the mainstream dams. The Court also affirmed the individual State apportionments as specified by the 1928 BCPA despite Arizona's inability to consumptively use its amount. This led to the 1968 Colorado River Basin Project Act (CRBPA) authorising the Central Arizona Project (CAP). The CAP was completed in 1994, effectively allowing Arizona to use its state's full apportionment.

In addition, the Court allocated specific amounts of water to several 'federal establishments' that included the five Indian tribes with reservations on the lower Colorado River, a recreational area, two wildlife refuges, and the local municipality near Hoover Dam. The Court further specified that any mainstream water used within a state (including the water for the federal establishments) would be satisfied from the State's apportionment where the uses occur.

During this time, a different framework was established for the allocation of Colorado River water in the Upper Basin. The 1948 Upper Colorado River Basin Compact[10] (1948 Upper Basin Compact) apportioned the available Colorado River water supply to the Upper Division states (Colorado, New Mexico, Utah, and Wyoming) on a percentage basis (Table 18.1). The 1948 Upper Basin Compact also established an interstate administrative agency (known as the Upper Colorado River Commission) to implement the provisions of the Compact including: adopting rules and regulations; collecting, analysing, and publishing water data and information; forecasting water run-off on the Colorado River and its tributaries; and making findings as to the quantity of Colorado River water used each year in the Upper Basin and in each State. Specific water entitlements and contracts are established and managed by each state, subject to the prior appropriation doctrine and other policies and agreements. Additional dams were authorised and constructed in the Upper Basin in the late 1950s and early 1960s including Glen Canyon Dam upstream of the Grand Canyon[11] (The 1956 Colorado River Storage Project Act authorised construction of the Colorado River Storage Project, which allowed for comprehensive development of the water resources of the Upper Division States) which created Lake Powell. While Reclamation owns, operates, and manages many projects and dams in the Upper Basin, Reclamation does not have direct authority over Colorado River water use in each state.

The volumes of Colorado River water apportioned to the individual states in both the Upper and Lower Basins include water consumptively used for environmental purposes (Box 18.3) and water allocated and used by tribes (Box 18.4). Some tribal water rights claims remain, and settlement discussions/negotiations are ongoing.

**Box 18.3 Water for Environmental Resources**

During the initial allocations of water in the Colorado River Basin (e.g. the 1922 Colorado River Compact, the 1928 Boulder Canyon Project Act, the 1944 US–Mexico Water Treaty, and the 1948 Upper Colorado River Basin Compact), environmental uses for water were not clearly defined nor even directly acknowledged. As management of the river progressed and environmental consciousness evolved (i.e. with the passage of national laws such as the 1973 Endangered Species Act), providing water for environmental purposes has become more important and is now addressed through multiple federal, state, and local programmes throughout the basin.

The use of water for environmental purposes in the basin broadly falls into two categories: consumptive uses and nonconsumptive uses (e.g. water for instream flows). For environmental uses that consumptively use Colorado River water, the consumptive volume counts towards the state's apportionment. For example, several wildlife refuges have entitlements within the state of Arizona, including the Havasu National Wildlife Refuge that has an entitlement to consumptively use 46.13 $Mm^3$ (37 399 acre-ft) each year out of Arizona's apportioned 3.45 $Bm^3$ (2.8 maf).

In the Lower Basin, the LCR MSCP provides Endangered Species Act compliance for specific federal ongoing and future flow and non-flow-related actions in the Lower Basin through 2055 and works to balance the delivery and use of the Colorado River

**Box 18.3 (Continued)**

water resources and hydropower production with the conservation of native species and their habitats. Because the current vegetation along the Lower Colorado River mainstream differs significantly from historical conditions, one specific component of the LCR MSCP allows for the removal of non-native vegetation and replaces it with native vegetation in order to build habitat for covered species. In doing this, no water rights are obtained because the consumptive use by vegetation is considered a 'system loss' which is not part of any Lower Basin states' apportionment. Switching from non-native to native vegetation is viewed as a 're-purposing' of water that is already used by the system.

In many other cases, instream environmental flow targets or requirements have been established to help protect fish and other aquatic life. For example, the Upper Colorado River Endangered Fish Recovery Program and the San Juan River Basin Recovery Implementation Program established flow targets below several Reclamation reservoirs, and the reservoirs are operated to help meet those flow targets. In some states, e.g. Colorado, nonconsumptive instream flow water rights have been established to maintain minimum flows between specific points on a stream. In both of these examples, the environmental flows do not count towards a state's apportionment, as these flows are nonconsumptive.

**Box 18.4 Indian Reserved Water Rights in the Colorado River Basin**

The 1922 Colorado River Compact did not explicitly address water rights for Indian tribes when apportioning water to the Upper and Lower Basins nor did the 1928 Boulder Canyon Project Act and 1948 Upper Colorado River Basin Compact when apportioning water to each state. However, Indian water rights count towards the state apportionments (Table 18.1) for the state in which they are established.

The doctrine of Federal Indian Reserved Water Rights, also known as the *Winters* doctrine, holds that when the US Congress reserves land for an Indian reservation, Congress also implicitly reserves water to fulfil the purpose of the reservation. Furthermore, the Court ruled that Federal Indian Reserved Water Rights have a priority date of either the date the reservation was created or time immemorial, which makes them senior to almost every other water right in the basin.

Federal Indian Reserved Water Rights differ from state water rights in at least two ways. Typically, state water rights in the Colorado River Basin are fixed by the date and quantity of the initial beneficial use of water and may be forfeited if not put to beneficial use for some period of time. Federal Indian Reserved Water Rights, however, are quantified based on the water needed to accomplish the reservation's purposes (including past, present, and future uses) and cannot be lost due to nonuse (Reclamation 2018).

*(Continued)*

**Box 18.4 (Continued)**

The 10 tribes that have reserved water rights from the Colorado River mainstream currently divert about 1.7 $Bm^3$ (1.4 maf) of water per year, almost all of which is used for agriculture. Including unresolved claims, the tribes' reserved water rights total nearly 3.4 $Bm^3$ (2.8 maf) of water per year from the Colorado River and its tributaries.

Although *Winters* recognised Federal Indian Reserved Water Rights and set the stage for resolving Indian water rights claims, these claims are being resolved at a slow pace whether through a Court adjudication or a negotiated settlement process, with fewer than half of the tribes in the basin with fully settled or adjudicated reserved water rights. These unresolved water rights claims create complications for both tribal and other water users in the basin, the most significant of which is the uncertainty it creates regarding water availability. The tribes are critical partners as the Colorado River Basin faces future water supply challenges, and Reclamation is committed to exploring opportunities that enhance tribes' ability to put their water to full beneficial and economic use (Reclamation 2018).

## 18.2 Current Challenge – Imbalance of Water Supply and Demand

The most important issue currently facing the basin stems from the likelihood of decreasing water supplies and increasing water demands over the long term, both likely to be exacerbated in the future by changes in climate. In 2010–2012, Reclamation, in partnership with the Basin States, conducted a detailed, long-range (through 2060), basin-wide study[12] (Basin Study) to define current and future imbalances in water supply and demand in the basin (including the adjacent areas that receive Colorado River water) and developed and analysed adaptation and mitigation strategies that could be used to resolve those imbalances. In addition, the potential impacts of a changing climate on water resources is a research and study topic of interest worldwide, and in this section, some key findings of these studies are summarised.

Since 2000, the basin has been in a state of prolonged drought with the period 2000–2018 having the driest 19-year average in the historical record and, using paleo-reconstructions of streamflow (Meko et al. 2007), one of the lowest 19-year periods dating back to 762 CE. Based on a comparison of different drought lengths, the current twenty-first century drought is one of the most severe that has been experienced since 1906 (Udall 2018). Figure 18.3 shows the effects of the drought on Lake Mead, which fell from 87% capacity in 2001 to 37% capacity in 2015.

Temperatures in the basin, particularly in the run-off generating Upper Basin, are rising through time and are contributing to the decreasing supply, even with near or above average precipitation (McCabe et al. 2017; Udall and Overpeck 2017; Xiao et al. 2018). Since about 1988 (McCabe et al. 2017), temperatures in the Upper Basin have been consistently above the long-term average basin temperature. In this period (1988–2018), Upper Basin run-off is 89% of the long-term average.

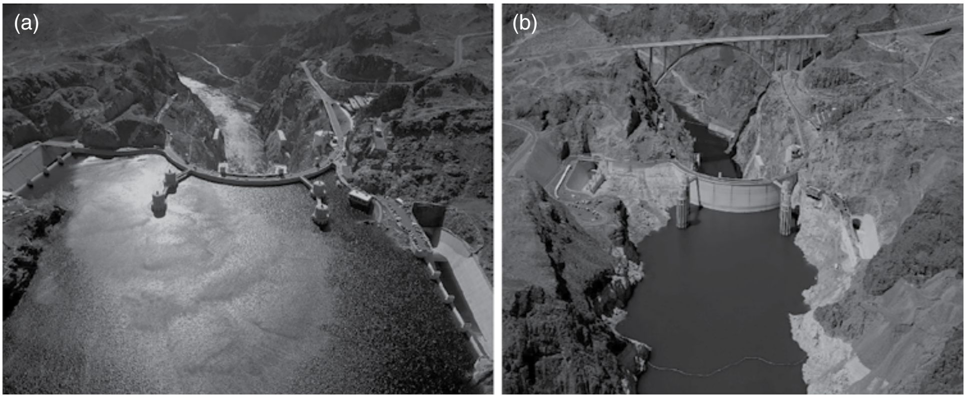


**Figure 18.3** Comparison of water elevation at Lake Mead showing the effects of the ongoing drought on reservoir levels. (a) Elevation 364.5 m (1196 ft) or 87% of capacity in 2001. (b) Elevation 327.7 m (1075 ft) or 37% of capacity in 2015.

Climate projections from the International Panel on Climate Change (IPCC) Fifth Assessment (IPCC 2013) generally agree that temperatures across the basin will continue to rise in the future, with an estimated average increase of 2.8–3.3 °C (5–6 °F) by the end of the twenty-first century (Reclamation 2016). The projections of changes in precipitation are variable, ranging from decreases of 12% to increases exceeding 25%. Hydrology models, which rely on these temperature and precipitation projections, indicate in some cases that the increased precipitation is enough to overcome the increasing temperatures and result in either no change or a net increase in run-off. Overall, annual flow projections range from decreases nearing 35% to increases of more than 30%, while there is a projected shift towards an earlier peak flow and increases in the historically low flow months of December through March. Regardless, it is clear the hydrology in the basin is not stationary and that there is increasing uncertainty in future supply in the basin.

A 10-year moving average of annual Colorado River consumptive use clearly shows that use has steadily increased throughout the twentieth century (Figure 18.2). Currently, the Upper Basin is using about half of its 9.25 $Bm^3$ (7.5 maf) apportionment, while the demand in the Lower Basin grew to its full apportionment by the late 1990s. Given the ongoing drought and additional conservation and efficiency measures undertaken since the early 2000s, noting that voluntary conservation efforts in the Lower Basin in response to the ongoing drought have reduced annual Lower Basin consumptive use by about 5% on average over the past few years, overall consumptive use has declined over the past several years. However, the cities served by the Colorado River continue to be some of the fastest growing communities in the United States.

Demand for Colorado River water is expected to increase by 1.9–4.9 $Bm^3$ (1.5–4.0 maf) by 2060, mostly due to increasing demands in the municipal and industrial sector (Reclamation 2012), and demands may also increase due to additional tribal water settlements (see Box 18.4). As with water supply, water demand is also affected by climate change. The projected increases in temperature would result in increased evaporation from reservoirs and increased demand from crops due to increases in evapotranspiration (Reclamation 2012).

This implies that agricultural water users already using their full allocation will grow less product with the same amount of water, and those not yet using their full allocation would need to use more water to grow an amount equivalent to what is currently being grown.

Not only did the Basin Study examine the water supply–demand challenges likely to confront the basin over the next 50 years, options and strategies were also considered to mitigate these challenges. It found that across a wide range of future supply scenarios, including hydrology derived from paleo-reconstructions and Global Circulation Models, and a range of future demand scenarios that accounted for varying increases in population and land use change, the Colorado River may face a supply–demand imbalance ranging from 0 to 8.6 $Bm^3$ (7 maf) in 2060 (the median imbalance was 3.95 $Bm^3$ [3.2 maf]). The Basin Study investigated a wide range of options to help resolve these imbalances, including demand management (conservation) and augmentation (desalination or inter-basin transfers), and found that a wide range of solutions will be needed to mitigate and adapt to future shortfalls.

Based on the solid foundation established by the Basin Study, two follow-up studies have been conducted. The first study involved a very broad range of partners and stakeholders basin-wide and was focused on water conservation, reuse, and environmental and recreational flows (Reclamation 2015). The second study documented how the 10 tribes with adjudicated water rights on the mainstream of the Colorado River currently use their water, projected how future water development could occur, and described the potential effects of future tribal water development on the Colorado River system (Reclamation 2018).

## 18.3 Recent Approaches to Meeting Challenges

### 18.3.1 The Collaborative, Incremental Approach

The past two decades on the Colorado River have been marked by a collaborative, incremental approach to dealing with basin-wide challenges. This approach focuses on building consensus among partners and stakeholders and utilising flexibilities in the Law of the River to develop new policy solutions to address the challenges. Building consensus throughout the process involves a 'give and take' approach by all parties and results in solutions that minimise the chance of litigation. Taking an incremental approach also allows those involved to focus on the most urgent challenges at the time. Additionally, these incremental solutions are typically only in effect for a finite time period, often referred to as an 'interim period', allowing partners and stakeholders to try new approaches without having to make long-term commitments (short-term solutions are often termed 'a pilot project' or 'pilot program' and are used to evaluate the feasibility, cost, and impacts of the actions being taken). This allows Reclamation, Mexico, the Basin States, and other partners the opportunity to gain valuable operational experience when implementing the interim policies. It also results in the need to renegotiate the decision in the future, which can have both positive and negative consequences. On the positive side, it allows all those involved to continue the policies that work best and modify those that need improvement, further decreasing the chance of litigation. On the negative side, it requires the commitment in advance to reengage in difficult analyses and negotiations and can also result in longer-term uncertainty regarding what policies will be in effect.

This approach, while time- and labour-intensive, has been successfully used over the last 20 years and has resulted in several important operation and management agreements and decisions primarily in response to the effects of changing hydrology on available water in storage in Lakes Powell and Mead (Figure 18.4). Four examples of decision-making using the collaborative, incremental approach are discussed below.

### 18.3.2 Interim Surplus Guidelines and California '4.4 Plan'

With Arizona and Nevada approaching their full apportionments in the mid-1990s, attention was focused on California, who had been using more than their allocated 5.4 $Bm^3$ (4.4 maf) for many years. California had been relying on unused apportionment as well as surplus water made available year to year by Secretarial determination. Although consistent with the 1964 Decree, the Secretary did not have specific criteria for determining the availability of surplus water (i.e. delivering more than the apportioned 9.25 $Bm^3$ [7.5 maf] to the Lower Division States). In recognition that hydrology would likely change, and noting that in 1999, water storage in Lakes Powell and Mead was at 95% of capacity and Upper Basin run-off had been near or above average for several years, Arizona and Nevada would soon be using their full apportionments, and that more formal criteria for surplus determinations would provide greater certainty to water users, a public process pursuant to the National Environmental Policy Act (NEPA)[13] was undertaken to develop surplus criteria (The 1969 NEPA, as amended, is a US environmental law that promotes the enhancement of the environment. It established the President's Council on Environmental Quality and requires federal agencies to evaluate the environmental effects of their proposed actions). Using the collaborative, incremental approach, Interim Surplus Guidelines were implemented in 2001, envisioned to be in place through 2016. These guidelines specified the amounts of water necessary in Lake Mead (by identifying specific elevation 'triggers') to identify when surplus conditions occur and the volume of surplus deliveries that would be made available to Arizona, California, and Nevada.

In parallel, California agreed to implement a '4.4 Plan'[14] to reduce their Colorado River water use to their apportionment and stay within that amount long term. The 4.4 Plan consists primarily of compensated, water conservation and subsequent water transfers from higher priority agricultural uses to lower priority municipal uses. In 2003, the appropriate water districts and sate agencies in California executed the Quantification Settlement Agreement and the Secretary signed the Colorado River Water Delivery Agreement,[15] effectively implementing the 4.4 Plan for 35 years with provisions to extend for up to 75 years.

The 15-year interim period for the Interim Surplus Guidelines was intended to give California a 'soft landing' (i.e. sufficient time to fully implement their water conservation/transfer programmes); however, just as the Interim Surplus Guidelines were being completed, a period of extended drought began. In fact, Upper Basin run-off from 2000 to 2004 was the lowest five-year period in the historical record and resulted in Lakes Powell and Mead declining from a combined 95% of capacity to 54% of capacity (Figure 18.4). Despite the declining Lake Mead levels resulting in the lack of surplus water, California successfully implemented their 4.4 Plan in just a few years.

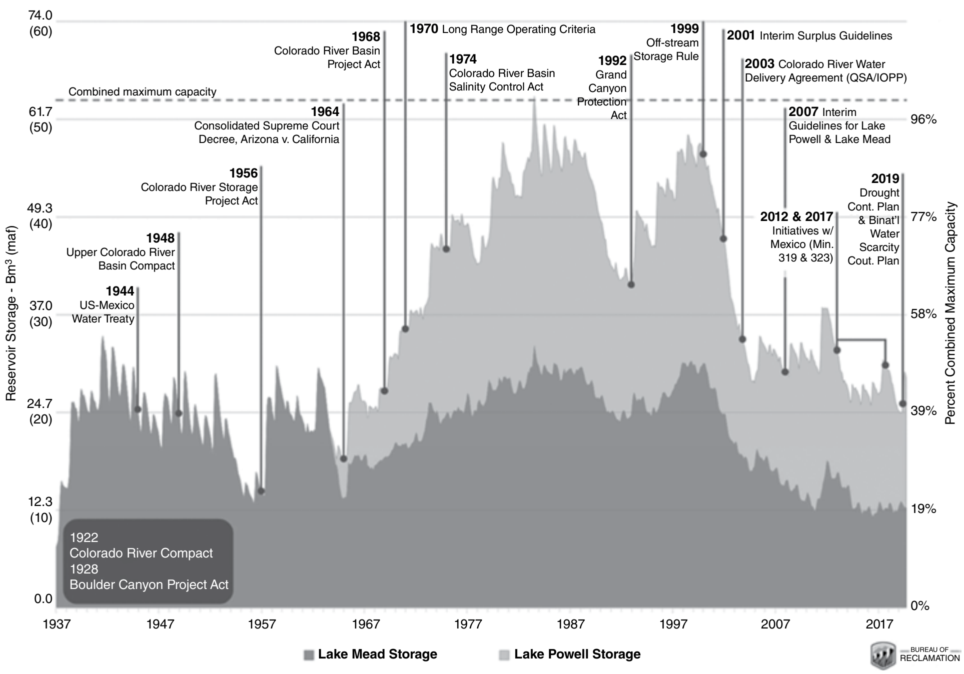


**Figure 18.4** Combined Lake Powell and Lake Mead storage from 1937 (the year after the completion of Hoover Dam) through 2019, with key laws and policies identified.

### 18.3.3 2007 Interim Guidelines

Concern for continued drought and declining reservoir levels grew basin-wide. Similar to the ability of the Secretary to deliver surplus water, the 1964 Decree also contains provisions for the Secretary to reduce deliveries if there is not sufficient water to meet the 9.25 $Bm^3$ (7.5 maf) apportionment to the Lower Division States; however, criteria for determining when shortages would occur and how shortages would be administered is not specified. In response to the rapid decline of the reservoirs by 2005, Reclamation initiated a NEPA process to determine the criteria for shortages. Working closely with the Basin States and other partners and stakeholders, this process resulted in the 2007 Interim Guidelines (Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead),[16] in place from 2008 to 2026, which specify guidance for determining shortages in the Lower Basin along with three other elements (described below). The 2007 Interim Guidelines defined reservoir levels in Lake Mead when specified volumes of shortage would be imposed and allocated those reductions to Arizona and Nevada in accordance with 1968 CRBPA providing certainty regarding how the Secretary would administer shortages pursuant to the 1964 Decree.

In addition to specifying shortage criteria for the Lower Basin, the 2007 Interim Guidelines contain three other main elements. First, they modify the 2001 Interim Surplus Guidelines, by extending certain provisions through 2026 and reducing the number of surplus levels. Second, they include coordinated operations of Lakes Powell and Mead, intended to keep the storage conditions more equitable between the Upper and Lower Basins (Lake Powell is at the headwaters of the Grand Canyon and is located in the Upper Basin, while Lake Mead is at the bottom end of the Grand Canyon and is located in the Lower Basin). The coordinated operations provide specific reservoir elevations (dependent on elevations at both Lakes Powell and Mead), where releases from Lake Powell could increase or decrease from the previous 'standard' release of 10.15 $Bm^3$ (8.23 maf). Third, the 2007 Interim Guidelines include a mechanism known as Intentionally Created Surplus (ICS), which allows water users to store conserved water in Lake Mead and then use the stored water at a later date. This helps to increase the storage in Lake Mead and keep it from declining to lower levels, while still allowing users to know they can rely on this water in future times of need. All together these four elements of the 2007 Interim Guidelines help protect reservoir conditions, while providing certainty to water users particularly in the Lower Basin regarding water deliveries.

Although not explicitly a part of the 2007 Interim Guidelines effort, the Upper Basin also undertook a study to determine the water availability in the Upper Basin in recognition that further Upper Basin water development is not without risks of additional shortages (see Box 18.5).

### 18.3.4 Minutes 319 and 323

While the 2007 Interim Guidelines specified guidance for determining shortages in the United States, additional work was necessary to develop an agreement with Mexico regarding operating criteria for circumstances of low elevation reservoir conditions necessitating the delivery of less than 1.85 $Bm^3$ (1.5 maf) to Mexico. The 1944 US–Mexico Water

**Box 18.5 2007 Hydrologic Determination of Water Availability from Navajo Reservoir and the Upper Colorado River Basin for Use in New Mexico**

In 2007, a determination of the availability of water to meet a proposed long-term service contract for use of water from Navajo Reservoir was investigated as required by Public Law 87-483, Section 11(a). This determination relied on projections of future estimated water uses and water supplies through 2060. Based on this hydrologic investigation, water depletions by the Upper Basin states from the Upper Colorado River Basin were found to reasonably be allowed to rise to an annual average of 7.1 $Bm^3$ (5.76 maf) per year, exclusive of reservoir evaporation from Lake Powell, Flaming Gorge Reservoir, and the Aspinall Unit. To achieve this depletion level through 2060, the study[17] assumed an overall 6% shortage or less over any consecutive 25 years.

This study found that given projections of water supply and water uses through 2060 at the time, the Upper Basin should not expect to reasonably be able to use their full compact apportionment without experiencing significant shortage, greater than 6% in some years. Since this study, the Upper Basin states have strived to provide projected schedules for Reclamation-led modelling studies that do not exceed the 7.1 $Bm^3$ (5.76 maf) per year determination through 2060.

Treaty states that in times of 'extraordinary drought' Mexico and the United States will share in reductions, but it does not specify criteria for defining that circumstance. In another collaborative, incremental step, federal agencies in the United States[18] and Mexico (federal agencies in Mexico included the Mexican Section of IBWC [CILA], the National Water Commission [CONAGUA], and the Ministry of the Environment and Natural Resources), Basin States in both countries, as well as other stakeholders in both countries worked together to define when Mexico would share in shortage and surplus with the United States.

In addition to defining operating rules, two other components were critical to reaching an agreement: water conservation and infrastructure improvements; and environmental enhancements (i.e. environmental restoration). The outcome was Minute 319 (Minutes are implementing agreements executed jointly by the US and Mexican Sections of the International Boundary and Water Commission pursuant to the 1944 US–Mexico Water Treaty), a historic agreement between the two countries that included provisions where Mexico would share in shortages and surpluses with the United States and be able to store conserved water in Lake Mead, similar to the ICS capability in the United States (the terms shortage and surplus do not appear in Minutes with Mexico, as they are not defined under the 1944 US–Mexico Water Treaty. Instead, Minutes use the terms low- and high-elevation reservoir conditions). The agreement also included the ability for US federal and nonfederal entities to provide financial support for water conservation activities in Mexico that conserve water primarily through infrastructure improvements in exchange for a portion of the conserved water. A commitment was also made between the two countries to provide water for the environment, including a historic 'pulse flow' that resulted in water reaching the Colorado River Delta for the first time in decades (see Box 18.6).

**Box 18.6 Environmental Deliveries, Monitoring, and Restoration in the Colorado River Delta, Mexico**

Beginning in March 2014, the United States and Mexico jointly implemented a transboundary environmental flow under Minute 319, the first international agreement to allocate a specific amount of water across an international boundary for environmental benefit (King et al. 2014). From late March to mid-May 2014, approximately 130 $Mm^3$ (105 392 acre-ft) of water was released from Morelos Dam on the Arizona–Mexico border as a 'pulse flow' to mimic (on a smaller scale) natural, pre-dam spring-time flows and temporarily achieved connectivity of the Colorado River from Morelos Dam to the Sea of Cortez.

This accomplishment was the result of collaboration and coordination between federal, state, water district, and NGOs in both the United States and Mexico. The pulse flow, provided by the federal governments in both countries, was in addition to a base flow in the amount of approximately 71.1 $Mm^3$ (57 621 acre-ft) delivered by a binational coalition of NGOs from 2012 to 2017. Combined, these environmental water deliveries totalled 195 $Mm^3$ (158 088 acre-ft).

The hydrologic and ecological results of the pulse flow were monitored and measured by a binational team of science experts, with co-leads from each country.[19] The scientists also provided input to a binational Environmental Work Group that oversaw the development of the delivery plan for the environmental flows, monitoring programme, and restoration implementation. The binational Science Team and Environmental Work Group continue in their roles under Minute 323 as the US and Mexican federal governments and partners continue with water delivery, monitoring, and habitat restoration efforts.

Minute 319 was a five-year agreement, ending in 2017, and both countries agreed to extend the major provisions of Minute 319 through 2026 in a subsequent Minute (Minute 323), ensuring alignment of each country's operational commitments for that time period. In Minute 323, Mexico took the lead in recognising that in the face of continued drought, additional reductions in deliveries may be required to protect Lake Mead and included a 'Binational Water Scarcity Contingency Plan' in the Minute. In that plan, Mexico agreed to take less water under prescribed conditions if the United States also agreed to do the same through a proposed 'Lower Basin Drought Contingency Plan' (LB DCP). As stated in the Minute, 'The United States and Mexico share a common vision on a clear need for additional and continued actions due to the impacts on Lake Mead elevations from meeting system demands, hydrologic conditions, increased temperatures, and other factors'.[20]

### 18.3.5 Drought Contingency Plans in the United States and Mexico

In the United States, work on a Basin-wide DCP began in 2013, when the Secretary of the Interior convened a meeting of the Governors' representatives of the Basin States to discuss the increasing risk of reaching critically low-reservoir levels in Lake Mead and Lake Powell and what might be the best path forward to deal with that risk. When the 2007 Interim Guidelines were under development, detailed analysis showed the chance of reaching critically low-reservoir levels in Lake Mead through 2026 to be well below 10%. Some 10 years later, updated assessments indicated the risk may have increased nearly fourfold under some hydrologic scenarios. The Basin States agreed to work with the federal government to develop a DCP and after over five and a half years, the seven states representatives signed a letter to the US Congress in February 2019, transmitting agreements to implement the Basin-wide DCP in two parts (an Upper Basin DCP and a Lower Basin DCP) and asking Congress to direct the Secretary to implement the plan. The US Congress passed the legislation on 16 April 2019 (US Public Law 116-14) and, on 20 May 2019 the DCP was executed by the seven Basin States and the US federal government. On 11 July 2019, the final step necessary to trigger Mexico's Binational Water Scarcity Contingency Plan was also executed through a binational Joint Report.[21]

The LB DCP is essentially an 'overlay' to the 2007 Interim Guidelines; that is, the 2007 Interim Guidelines continue to operate with the additional agreed-to actions in the LB DCP that will reduce the risk of reaching low-reservoir levels, particularly in Lake Mead, to near the chances anticipated in 2007. These conservation activities will result in less water being taken from Lake Mead, either through ICS activities with the restriction that such ICS can be delivered only when Lake Mead recovers above a specified level, or through simply leaving the water in Lake Mead as system water. The Binational Water Scarcity Contingency Plan is similar in many respects.

In the first year of implementation (2020), the LB DCP will result in a total of 297.3 $Mm^3$ (241 000 acre-ft) of required conservation in Arizona, Nevada, and Mexico since Lake Mead was projected in August 2019 to be below elevation 332.2 m (1090 ft) on 31 December 2019, the elevation that LB DCP contributions are first required. If Lake Mead drops to an elevation below 318.5 m (1045 ft), California will also make required LB DCP contributions. Inclusion of required contributions for California is historic, while still recognising their high priority by not requiring their contributions until lower elevations at Lake Mead.

### 18.3.6 Reclamation's Role

Over the past 20–25 years,[22] as illustrated by the examples discussed in this chapter, Reclamation has fulfilled a variety of roles; facilitator, mediator, and in the Lower Basin, the water master as mentioned previously. Perhaps most importantly, Reclamation has acted as the 'honest technical broker', helping find solutions to a series of complex water management challenges by ensuring the best state-of-the-art data and information are available to all partners and stakeholders. As an example, in addition to working with federal agencies, universities, NGOs, and others to develop a wide range of future inflow scenarios, Reclamation relies on a long-term reservoir operations and policy model, available to outside entities, to develop and analyse alternative operating policies (see Box 18.7). Reclamation's ability to continue to fulfil these and perhaps other roles is critical to reach collaborative solutions in the future.

**Box 18.7 Using Reclamation's Reservoir Operations Planning Model to Help Address the Challenges**

Reclamation's Colorado River Simulation System (CRSS) is a Basin-wide reservoir operations model[23] designed to compare different operating policies. The legacy model, originally developed in the 1980s in Fortran, is now implemented in RiverWare[24] (Zagona et al. 2001), a generalised river basin modelling software. CRSS is accepted as the de facto modelling tool for policy decisions affecting Lakes Powell and Mead and other Basin-wide initiatives. RiverWare allows basin policy to be written in a transparent user readable format, ensuring operating rules are understood and accepted by all stakeholders. It can be run by partners and stakeholders along with Reclamation, and through a Stakeholder Modelling Workgroup these partners are continually apprised of all changes to the model, while Reclamation maintains and advances the model.

Each of the key milestones discussed in Section 18.3 used CRSS to analyse policy alternatives and facilitate discussions among partners during each respective process. At the beginning of each process, Reclamation and the other involved partners came together to agree on the modelling assumptions that were used. Where consensus could not be reached, the default was to 'model it all ways' to understand the sensitivity of results to the assumptions and to provide a range of scenarios. The process to agree on model assumptions, coupled with the long-standing acceptance of CRSS, helped to focus energy on policy decisions, rather than debating which model is 'best' or whose assumptions are 'right'.

## 18.4 Future Thoughts and Considerations

As discussed in this chapter, the past two decades on the Colorado River have been marked by a collaborative, incremental approach in addressing Basin-wide challenges. By utilising flexibilities in the Law of the River, new operations and management solutions have been successfully designed and implemented. By building broad consensus Basin-wide, major litigation has been avoided, allowing efforts to focus primarily on the technical and policy issues, not differing legal interpretations. Given that these incremental solutions are typically only in effect for interim periods, significant operational experience has been gained that provides valuable information for upcoming policy negotiations and decision-making.

In the short term, water managers representing the Basin States, tribes, and Mexico, as well as NGOs and other interested parties, must focus on devising new guidelines for the operation of Lakes Powell and Mead, which expire in 2026, and new Minute(s) for specific aspects of implementation of the 1944 US–Mexico Water Treaty, since the current Minute expires in 2026. This work will begin with a formal review of the effectiveness of the existing 2007 Interim Guidelines, specified in the 2007 decision document to begin no later than 31 December 2020. Similar reviews, perhaps in a more informal manner, are anticipated with respect to the Minutes with Mexico and the DCPs. The experience gained and documented through these reviews will be invaluable as the discussion regarding post-2026 operations begins. The scope, time period, potential options and alternatives, and other key topics will be addressed through a NEPA process.

Some discussions have already begun as exemplified in recent publications (Castle and Fleck 2019) and meetings. At the bi-annual Colorado River Symposium[25] held in September 2019, a panel of experts discussed many aspects of how to best move forward in order to solve pressing Colorado River issues. Essentially, the debate centred on the idea of an incremental vs. a visionary approach; however, some, including the authors of this chapter, do not see these concepts as mutually exclusive.[26]

For the longer term, the 2012 Basin Study established a framework to identify and address the broad range of future water supply–demand imbalances. Clearly, no single approach or option will suffice; rather, a 'portfolio' approach is necessary, whereby different actions are devised and implemented depending upon current and future risk. The actions will likely include additional water conservation and reuse, water marketing, expanded water banking, and larger-scale augmentation projects, both in the United States and Mexico. Indeed, as part of Minute 323, a binational work group is exploring the feasibility of a variety of new water sources projects, including augmenting the system with large-scale desalinisation off the coast of Mexico. Significant uncertainties will also need to be better understood in order to secure the commitment of the necessary and substantial resources, for example, the feasibility of larger-scale solutions which depend on many variables, such as permitting, energy requirements, and overall cost.

Significant uncertainties also exist with respect to future water demand and supply. Resolution of outstanding tribal water rights is critical to better understand and reduce the large uncertainty regarding water needs throughout the Basin. Additionally, the ever-increasing demand for Colorado River water may be balanced with the need for demand management (for example, the Pilot System Conservation Program which is a 'pilot program' in the United States designed to pay users in both the Upper and Lower Basin to conserve water resulting in increased storage in Lake Powell or Lake Mead) to mitigate risks to the Basin (Castle and Fleck 2019). There is also increasing uncertainty in future supply in the Basin due to the changing climate. Opportunities that improve future climate projections will need to be pursued to help address these uncertainties. Enhancements to the operational and planning tools used in the Basin to better understand the vulnerabilities of different policy alternatives is another approach that will help deal with these future uncertainties.

Although the allocations in the 1922 Compact were based on a relatively wet period of time that led to an over-allocation of available water supply, the 1922 Compact was quite visionary and still remains the cornerstone of the Law of the River today (Hundley 2009). Certainly, the Law of the River continues to evolve over time and currently does not address all of the contemporary water management issues, particularly in times of severe and sustained drought (MacDonnell et al. 1995). It is our belief, however, that a collaborative and incremental approach continues to be the best course to ensure a reliable and sustainable Colorado River system, now and for the future.

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## Notes

**1** See https://www.usbr.gov/uc; https://www.usbr.gov/lc
**2** See https://www.fws.gov/international/laws-treaties-agreements/us-conservation-laws/endangered-species-act.html
**3** See https://www.epa.gov/laws-regulations/history-clean-water-act
**4** See https://www.coloradoriversalinity.org
**5** See https://www.govinfo.gov/content/pkg/FR-2013-05-06/pdf/2013-10649.pdf
**6** See https://www.usbr.gov/lc/region/pao/lawofrvr.html
**7** See https://www.usbr.gov/lc/region/pao/pdfiles/bcpact.pdf
**8** See http://www.mwdh2o.com/WhoWeAre/History/Pages/default.aspx
**9** See https://www.usbr.gov/lc/region/pao/pdfiles/scconsolidateddecree2006.pdf
**10** See https://www.usbr.gov/lc/region/pao/pdfiles/ucbsnact.pdf
**11** See https://www.usbr.gov/uc/rm/crsp/index.html
**12** See https://www.usbr.gov/lc/region/programs/crbstudy.html
**13** See https://ceq.doe.gov
**14** See https://www.watereducation.org/aquapedia/colorado-river-water-use-44-plan
**15** See https://www.usbr.gov/lc/region/g4000/crwda/index.htm
**16** See https://www.usbr.gov/lc/region/programs/strategies.html
**17** See https://www.usbr.gov/uc/envdocs/eis/navgallup/FEIS/vol1/attach-N.pdf
**18** See https://www.ibwc.gov/home.html
**19** See https://www.ibwc.gov/Files/Minute_319_Monitoring_Report_112818_FINAL.pdf
**20** See https://www.ibwc.gov/Files/Minutes/Min323.pdf
**21** See https://www.ibwc.gov/Files/joint_report_min323_bi_water_scarcity_contingency_plan_final.pdf
**22** See https://www.usbr.gov/lc/region/programs/CRdocuments2008.html
**23** See https://www.usbr.gov/lc/region/g4000/riverops/model-info.html
**24** See https://www.colorado.edu/cadswes
**25** See https://www.watereducation.org
**26** See https://www.watereducation.org/western-water/can-grand-vision-solve-colorado-rivers-challenges-or-will-incremental-change-offer

Source: N. Dyer, CSIRO, Canberra, Australia.