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# Water Allocation Concerns in the Colorado River Basin: an Analysis of the Colorado River Compact

## Colorado River Basin background

The Colorado River drainage basin spans much of the southwestern United States, draining water from an area covering over 240,000 square miles (National Research Council 2007). It extends across seven US states (Wyoming, Colorado, Utah, Nevada, Arizona, New Mexico, and California), various Native American reservations, and Mexico. The Colorado River, which is the main stem fed by numerous tributaries, travels southwest from Colorado to the Gulf of California in Mexico (Fig. 1, National Research Council 2007)). About 90% of the total water draining into the basin originates above Lees Ferry in the Upper Basin, with most of the runoff coming from snowpack in the Rocky Mountains (Christensen et al. 2004). Hence, the flow is driven by winter precipitation and subsequent spring snowmelt (National Research Council 2007).

Fig. 1: Colorado River Basin (National Research Council 2007)

Throughout the twentieth century, the average flow of the Colorado River was about 15 million acre feet/year (maf; one acre foot is the amount of water needed to cover one acre one foot high), but the flow varies greatly from year to year (Fig. 2, National Research Council 2007). To place this amount of water into context, the average flow of the Mississippi River is 500 maf/year, and an average home in Denver, Colorado uses about 0.5 maf/year (Kuhn and Fleck 2019). Even though the Colorado River has the lowest discharge per area of any river basin in the US (Carlson and Muth 1989), it is heavily relied upon in the arid Southwest for a variety of purposes including irrigation, hydropower, and domestic use (Adler 2008). It serves as the primary water supply for major cities throughout the southwestern United States, serving more than 40 million people both inside and outside of the basin proper (Udall and Overpeck 2017). With that in mind, the purpose of this paper is to address how water is divided in the Colorado River Basin, and to assess potential areas of concern surrounding its allocation. For the scope of this paper, focus will be placed mainly on water allocation as determined by the foundational Colorado River Compact, but further considerations are needed when accounting for the needs of Native American reservations and Mexico.

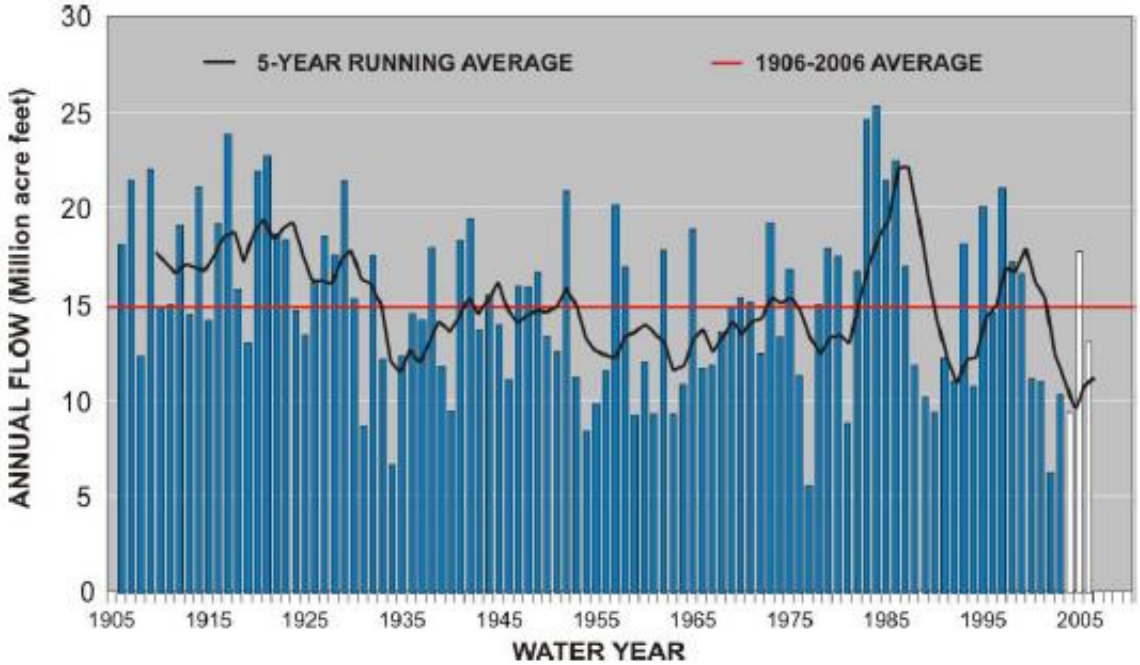


Fig. 2: Colorado River flow measured at Lees Ferry (National Research Council 2007)

**Development of the Colorado River Compact**

Most states in the Colorado River Basin follow prior appropriation water rights, which is essentially the practice of "first come, first served" (Dineen 2016). This water rights system allows the diversion of water by users for a demonstrated beneficial use such as agriculture or domestic use. The first users to do so establish senior water rights, which then supersede all other users that come after them (junior water rights holders), even during times of scarcity (Dineen 2016). This practice, which was upheld in the 1922 Supreme Court case of *Wyoming vs. Colorado*, concerned slower-developing states in the early twentieth century (Adler 2008). Because California was undergoing rapid growth at the time, there were fears that this development would require large-scale water diversions from the Colorado River resulting in California establishing senior water rights that could exclude slower-growing states in the basin (Adler 2008). Therefore, there was a push for a policy that would ensure each state had access to water in the Colorado River Basin. In 1922, representatives from each of the seven states of the basin met along with the Secretary of Commerce, Herbert Hoover, to come to an agreement surrounding water rights. The resulting agreement was the Colorado River Compact which still acts as the foundation of water allocation policy in the basin (Adler 2008).

The Colorado River Compact divides the Colorado River Basin into two regions: the Upper Basin and the Lower Basin, with the dividing line located at Lees Ferry near the Arizona-Utah border (USBR 1922). Instead of creating specific water allotments for each state, the Compact apportions water for each basin. States that make up the Upper Basin are Wyoming, Colorado, Utah, and New Mexico, while Lower Basin states include Nevada, California, and Arizona (USBR 1922). According to the terms of the Compact, 1) each basin receives 7.5 maf/year, and the Lower Basin has the right to use an additional 1 maf/year if it can be put to beneficial use. 2) If the US were to ever enter into a treaty that requires water be provided to Mexico (which did occur with the 1944 US-Mexico Water Treaty), this allotment would first come from any water surplus; if there were no surplus, the burden would be split between both basins. 3) The Upper Basin is prohibited from allowing the average ten-year flow at Lees Ferry to drop below 75 maf. Moreover, 4) the Upper and Lower Basins are forbidden from withholding or demanding, respectively, water that cannot be put to beneficial agricultural or domestic us. Additional definitions and requirements are included in the Contract (USBR 1922).

Since the creation of the Colorado River Compact, numerous laws, contracts, and court rulings have further regulated flow in the Colorado River Basin. Collectively, these policies have been referred to as the Law of the River (Adler 2008). Although the Colorado River Compact only allocates water for the Upper and Lower Basins, policies (e.g. the Boulder Canyon Project Act, Upper Colorado River Basin Compact, and *Arizona vs. California* Supreme Court Case) have since been created which further divide both basins' 7.5 maf/year allotments among states and Native American tribes (National Research Council 2007). The delivery of 1.5 maf/year to Mexico was also pledged under the US-Mexico Water Treaty of 1944, and subsequent agreements referred to as Minutes have added conditions (such as water quality stipulations and delivery adjustments depending on reservoir storage levels) to the original treaty (Stern and Sheikh 2019). Altogether, the Law of the River has served as the framework for handling water allocation decisions both domestically, and internationally, and at the cornerstone of this framework, is the Colorado River Compact. Despite the fact that the Compact has never been amended (Dineen 2016), there are various concerns surrounding it which may create problems in the future.

**Concerns of Colorado River Compact interpretation**

Due to the specific wording used, several points in the Colorado River Compact may be interpreted differently between states of the Upper and Lower Basins. The document itself is quite general, which makes it flexible, but it also leaves room for interpretation. Various hypothetical cases have been explored which may cause contention in the future (Meyers 1966, Robison and MacDonnell 2014). For example, the Compact stipulates that each basin's water allotment is put toward "beneficial consumptive use", yet the term is not defined in the document (USBR 1922). The Upper Basin does not include water being put to beneficial consumptive use as part of the their allotment if that water were going to be lost naturally in the system; for instance, if water were already lost in a meadow due to flooding, but that meadow were turned into pasture for grazing, states of the Upper Basin would not include this as a part of their allotted 7.5 maf/year (Meyers 1966), essentially giving them access to water above their apportionment. Under some interpretations, evaporation is not counted as consumptive loss either (Robison and MacDonnell 2014). In that sense, the Upper Basin may need to supply more than 7.5 maf/year at Lees Ferry for the Lower Basin in order to account for the water lost to evaporation (Robison and MacDonnell 2014).

Another question that arises is how to divide the 1.5 maf/year allotment owed to Mexico under the US-Mexico Water Treaty in years of low flow. According to the Colorado Compact which preceded this treaty, the water is to be first taken from any surplus that may exist, but if there is none, then the burden is to be split between the two basins (USBR 1922). Thus, if both basins provide water to Mexico, the Lower Basin states may have an argument to request replacement water from the Upper Basin if they can put the requested water to agricultural or domestic use (Meyers 1966). According to the Compact, the Upper Basin states are not allowed to withhold water that they cannot put to such uses, but if they do provide that water, then they could cut into their own allotment which is not guaranteed in the same way that the Lower Basin states are guaranteed 75maf/decade (Meyers 1966). Until this point in time, scenarios such as these have primarily served as thought experiments, but these hypothetical cases aren't entirely unrealistic, especially when historic flow trends are considered along with projected flows under a changing climate.

**Concerns of over-allocation**

One of the primary issues surrounding Colorado River water allocation is the concern that the water was over-allocated from the onset. The allotments created in the 1922 Compact were based on flow records from 1899-1920, which indicated an average flow of about 16.5 maf/year (Adler 2008). Flow can vary greatly in the Colorado River Basin, however; a more comprehensive analysis of the nineteenth century flow shows that the average flow was around 15 maf/year between 1906-2003, with yearly flows ranging from 5.27 maf to 24 maf (Christensen and Lettenmaier 2007). Since the start of the twenty-first century, the flow has been even lower, averaging only 12.4 maf/year (Stern and Sheikh 2019). Hence, supply may be more limited than originally thought, which could create disputes if demand is too high.

To better understand typical historic stream flows in the Colorado River system, tree ring analyses have been utilized. Because tree growth is dependent upon factors such as precipitation and evapotranspiration, studies of tree ring sizes can serve as a method for determining past climatic conditions, and subsequently, historic stream flows (Woodhouse et al. 2006). Reconstructions of the period 1490-1998 reveal that the median century-long flow in the upper basin was about 14 maf/year with the wettest century averaging about 15 maf/year and the driest averaging 13.3 maf/year (McCabe and Wolock 2007). Moreover, paleoclimate analyses reveal that historic droughts from 900-1300 were longer and more severe than any drought since then, with the most severe drought lasting two decades (Woodhouse et al. 2010). Based on such studies, evidence suggests that the flow data used to create the Colorado River Compact was collected during a particularly wet period compared to the previous five centuries, and was therefore likely over-allocated (Woodhouse et al. 2006). Understanding these historic flow regimes may be useful in predicting worst-case climate scenarios in the future and how stream flow will respond (Woodhouse et al. 2010).

**Concerns of supply and demand in the future**

Not only does the Colorado River Compact suffer from its use of unrealistic short-term flow data, but it also fails to consider stressors to water supply that are likely to arise in the region. Under a business as usual emissions scenario (RCP 8.5), projected temperatures are expected to increase 2.8˚C in the Colorado River Basin by the middle of the century (Udall and Overpeck 2017). When a more moderate mitigation scenario is used (RCP 4.5), temperatures are still projected to rise 2.6 ˚C by 2050 (Udall and Overpeck 2017). Such increases in temperature will have numerous effects including a higher rain/snow ratio, earlier snowmelt, increased evapotranspiration, and decreased flow (Christensen et al. 2004). Annual flow loss modeled under RCP 8.5 and RCP 4.5 and various evaporative-loss sensitivity levels (the average water loss per degree Celsius increase) serve to bookend the potential losses under possible future conditions (Fig. 3, Udall and Overpeck 2017). Under the most extreme water-loss models using an RCP 8.5 scenario and the most severe sensitivity (10% water loss per ˚C), the average annual flow loss is predicted to be greater than 25% of the 1906-1999 average by the middle of the century (Udall and Overpeck 2017). Even under the moderate emission scenario of RCP 4.5 and a low sensitivity (3% water loss per ˚C), average annual flow loss is predicted to be greater than 5% by the middle of the century. These projections are even greater when extended to the end of the century, with average flow loss ranging from nearly 10% to over 50% (Fig. 3, Udall and Overpeck 2017). Such losses in flow would be problematic if there is not enough water stored to fulfill state water allotments.

Precipitation should also be addressed when considering future climate scenarios in the Southwest. Precipitation from the Upper Basin is the main contributor to runoff in the Colorado River Basin (Udall and Overpeck 2017), and about 70% of that precipitation is in the form of snowfall (Christensen and Lettenmaier 2007). Unsurprisingly, years of greater runoff in the Upper Basin are associated with greater flow, but in order to offset the temperature-induced flow losses projected for 2100, precipitation would have to increase by nearly 22% in the most extreme water-loss scenario and by greater than 4% in the more moderate scenario (Fig. 3, Udall and Overpeck 2017). Unfortunately, such increases are unlikely as the wettest decade in the twentieth century was only an 8% increase in precipitation compared to the 1906-1999 average (Udall and Overpeck 2017). Despite the fact that projections tend to indicate future temperature increases, precipitation projections are not as clear. Part of the difficulty in forecasting precipitation is due to uncertainties in parameters such as the position of storm tracks or the length of multi-decade droughts in the future (Udall and Overpeck 2017). Different global climate models produce disparate results: some show declines in precipitation of up to 12.3% while others show increases of up to 10.1% (Dawadi and Ahmad 2012). Therefore, increased precipitation cannot be relied upon to augment stream flows.

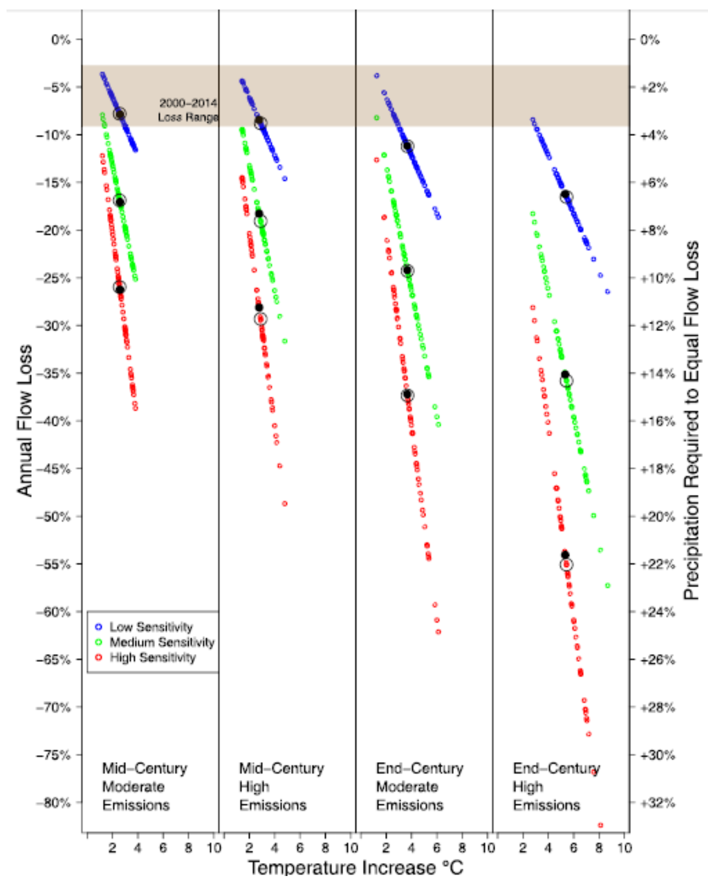


Fig. 3: Annual flow-loss estimates under future climate projections, and the precipitation needed to offset such changes (Udall and Overpeck 2017).

While flow in the Colorado River Basin is expected to decrease due to greater evapotranspiration, demand for water is expected to increase. It is projected that by 2060, demands will rise from 3.8 to 5-6 maf/year in the Upper Basin and from 8 to 8.5-10 maf/year in the Lower Basin (USBR 2012). From 2000-2010, the average release from Lees Ferry was 8.4maf/year, and while this may be sustainable currently, it will not continue to be with predicted growth in the lower basin (Robison and MacDonnell 2014). Much of the projected increase in demand is due to increased municipal and industrial use to support growing populations (USBR 2012). Although agricultural use is currently the largest source of water demand (and it is predicted to continue being the largest by 2060), its relative proportion of overall demand is expected to decrease as land currently used for agriculture is dedicated to other areas such as municipal and industrial use and tribal use (USBR 2012).

Another area of concern not addressed anywhere in the Colorado River Compact is groundwater use in the basin. If surface water flows decrease in the future as projected, groundwater may be used to supplement the demand for water (Meyers 1966). Unfortunately, groundwater depletion actually seems to be occurring at a faster rate than reservoir depletion; research focusing on relative groundwater and surface reservoir losses in the Colorado River Basin found that between 2004 and 2013, groundwater accounted for about 77% of the total freshwater lost during the study period (Fig. 4, Castle et al. 2014). Groundwater recharge, however, is not enough to offset the increased use (Castle et al. 2014), which may pose problems in the future if communities attempt to utilize groundwater to supplement decreasing surface water reserves. This is particularly concerning considering the fact that 2000-2014 marked the region's worst recorded drought (Udall and Overpeck 2017) and that greater groundwater loss has been shown to follow times of drought and very low snowpack (Castle et al. 2014).

Altogether, it is quite plausible that the Colorado River Basin will experience future issues with supply and demand. While there have already been discrepancies over water rights, settlements have generally been reached, as demonstrated by the ever-growing Law of the River. The success so far in settling disputes, however, is likely due in part to the fact that some states, particularly those in the Upper Basin, have not relied on their entire water allotments (USBR 2012). If populations continue to grow in these areas, however, more states may begin to fulfill (and perhaps exceed) their allotments, which could lead to more contentious disputes.

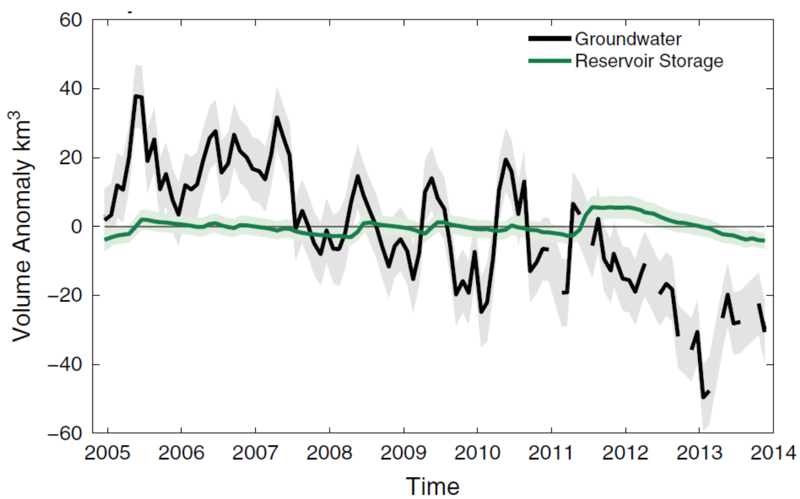

Fig. 4: Monthly water storage anomalies (from the study period mean) in the Colorado River Basin (Castle et al. 2014).

**Coping with limited water**

As a means of planning for future supply and demand issues, states have employed several strategies to store and conserve water. Colorado, despite sharing its unused water with California in the past, has started storing excess water (up to its allotment) to prepare for future conditions (Dineen 2016). Arizona, partially financed by Nevada in exchange for access to some of the water, also banks excess water (Adler 2008). Other strategies have also been enacted to limit Colorado River reliance: a desalination plant has been established in San Diego, and in Arizona, agricultural fields have been leveled using lasers to increase water efficiency (Dineen 2016). It has even been suggested that removing water-hungry tamarisk could conserve water, although this may not be the most effective option since these plants only consume about 1% of mean annual flow (Nagler et al. 2008).

Aside from state-level actions, large-scale formal agreements have also been made to deal with potential shortages in the basin. In 2007, interim guidelines outlining the response during times of water shortage were established between states of the Lower Basin (Mulroy 2008). The agreement, which will be updated in 2020 and remain effective until 2026, formalizes how much flow will be reduced to each state when reservoir levels fall below an elevation of 1075 feet in Lake Mead (Mulroy 2008). As of August 2018, Lake Mead storage was at about 1077 feet, so no actions have yet been taken, but storage is still well-below the 1219.6-foot mark which is considered full (Sullivan et al. 2019). Since the establishment of the 2007 interim guidelines, Minutes 319 and 323 were also created in accordance with previous Minutes to formalize how much the flow delivery to Mexico would increase or decrease in times of surplus or deficit, respectively (USBR 2012, USBR 2017). Additionally, in order to readdress the interim guidelines and maintain water storage levels, Drought Contingency Plans were developed (Stern and Sheikh 2019). Upper Basin states developed water-storage plans to maintain Lake Powell water levels 35 feet above the minimum level needed to operate its hydropower plant (3525 feet), while Lower Basin states outlined curtailment plans aimed at increasing water levels in Lake Mead (Table 1, Stern and Sheikh 2019). The process was slow in the Lower Basin, however, due to barriers such as distrust among stakeholders and a declining sense of urgency as weather conditions improved; therefore, it has been recommended that a more adaptive form of governance be created in the Colorado River Basin, one where there is more collaboration between stakeholders (Sullivan et al. 2019).

Table 1: Lower Basin curtailments as stipulated by current agreements (units are thousand acre-feet) (Stern and Sheikh 2019)

| Lake Mead Elevation (ft) | 2007 Interim Shortage Guidelines | | Minute 323 Delivery Reductions | DCP Curtailment | | | Binational Water Scarcity Conting. Plan | Total Volume of Curtailment (% of Colorado River Apportionment) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AZ | NV | Mexico | AZ | NV | CA | Mexico | AZ | NV | CA | Lower Basin | Mexico |
| 1,090 - >1,075 | 0 | 0 | 0 | 192 | 8 | 0 | 41 | 192 (6.8%) | 8 (2.6%) | 0 (0%) | 200 | 41 |
| 1,075 - >1,050 | 320 | 13 | 50 | 192 | 8 | 0 | 30 | 512 (18.2%) | 21 (7%) | 0 (0%) | 533 | 80 |
| 1,050 - >1,045 | 400 | 17 | 70 | 192 | 8 | 0 | 34 | 592 (21.1%) | 25 (8.3%) | 0 (0%) | 617 | 104 |
| 1,045 - >1,040 | 400 | 17 | 70 | 240 | 10 | 200 | 76 | 640 (22.8%) | 27 (9.0%) | 200 (4.5%) | 867 | 146 |
| 1,040 - >1,035 | 400 | 17 | 70 | 240 | 10 | 250 | 84 | 640 (22.8%) | 27 (9.0%) | 250 (5.6%) | 917 | 154 |
| 1,035 - >1,030 | 400 | 17 | 70 | 240 | 10 | 300 | 92 | 640 (22.8%) | 27 (9.0%) | 300 (6.8%) | 967 | 162 |
| 1,030 - 1,025 | 400 | 17 | 70 | 240 | 10 | 350 | 101 | 640 (22.8%) | 27 (9.0%) | 350 (7.9%) | 1,017 | 171 |
| <1,025 | 480 | 20 | 125 | 240 | 10 | 350 | 150 | 720 (22.8%) | 30 (10.0%) | 350 (7.9%) | 1,100 | 275 |

## Conclusion

Water allocation among states of the Colorado River Basin is a complex issue that impacts millions of stakeholders and spans state and national boundaries (National Research Council 2007). Although the 1922 Colorado River Compact helped to prevent a free-for-all between states trying to establish water rights in this highly utilized river system, there are several issues surrounding this foundational document. Not only does it include verbiage that is open to interpretation (Meyers 1966), but it was also created using unrealistic flow data resulting in its over-allocation (McCabe and Wolock 2007, Woodhouse et al. 2006). The Compact did not take into account the high variability of river flow, nor did it account for uncertain future conditions. Therefore, as the climate continues to warm and demand continues to increase in order to support growing populations (Udall and Overpeck 2017, USBR 2012), water disputes will likely become more complicated. Still, despite its shortcomings, the Colorado River Compact has lasted in part due to its flexibility (Adler 2008). Additional laws and compacts have been subsequently created, and together, these policies making up the Law of the River have given some structure for determining the division of water. Agreements have already been created at the regional and international level to plan for potential shortages (Stern and Sheikh 2019). Hence, as conditions continue to change in the Colorado River Basin, policies surrounding water allocation will likely adjust accordingly as they have for years.

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