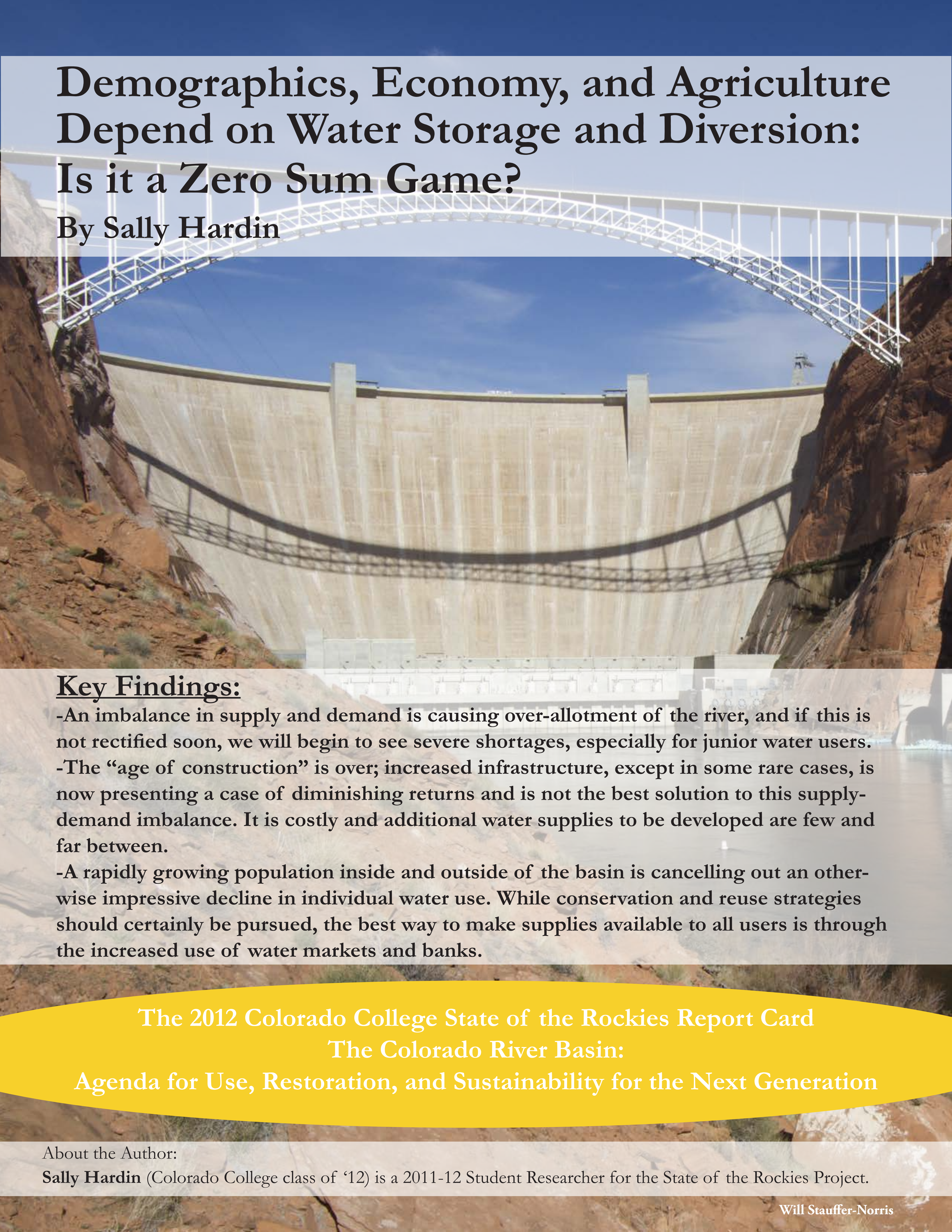
Demographics, Economy, and Agriculture Depend on Water Storage and Diversion: Is it a Zero Sum Game?

By Sally Hardin



Key Findings:

-An imbalance in supply and demand is causing over-allotment of the river, and if this is not rectified soon, we will begin to see severe shortages, especially for junior water users.

-The "age of construction" is over; increased infrastructure, except in some rare cases, is now presenting a case of diminishing returns and is not the best solution to this supply-demand imbalance. It is costly and additional water supplies to be developed are few and far between.

-A rapidly growing population inside and outside of the basin is cancelling out an otherwise impressive decline in individual water use. While conservation and reuse strategies should certainly be pursued, the best way to make supplies available to all users is through the increased use of water markets and banks.

The 2012 Colorado College State of the Rockies Report Card
The Colorado River Basin:
Agenda for Use, Restoration, and Sustainability for the Next Generation

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Will Stauffer-Norris

"There is a growing recognition that we live in an age of limits, that water from the Colorado River is not endless, and we cannot keep just using more."

-Jennifer Pitt, head of the Environmental Defense Fund's efforts on the Colorado River, speaking at the Colorado College, November 7th, 2011 as part of the State of the Rockies Project Speakers Series

Introduction

The Colorado River is one of the most highly dammed, diverted, and otherwise regulated rivers in the world. Located in the southwest United States, it has long been a critical force sustaining life in the most arid region of the country. The Homestead Acts of the late 1800s set a precedent for water use in the West, bringing multitudes of settlers into what was previously considered a remote, inhospitable region. Population has boomed and development has raced ahead at lightning speed since these first pioneers settled in the West, so much so that the Colorado River is today over-allocated.

The "face" of the river has been drastically altered, for better and for worse, from its historical variability and wildness for use by our societies. Compounded with recent drought, this means that demand is dangerously close to overtaking supply on the river. Early 2011 brought a brief respite, with the most snow and subsequent highest flows of the river since the drought began in 2001, buying a little more time before shortages become severe.

Yet, as population and municipal demands for water continue to increase rapidly, future supplies of the river are under serious threat, even without the projected impacts of climate change. Competing users and interests are stretching supplies thin from many directions, while simultaneously looking for new and innovative ways to get more water. Now we face the question whether consumptive use of the Colorado River is a zero sum game, where one user impedes and cancels out another? Or can efforts from all sides be made to reduce total consumption, improve efficiency of use, and secure a sustainable future for both humans and the environment in the Colorado River Basin?

Hydrology for Human Use: Past, Present, and Future

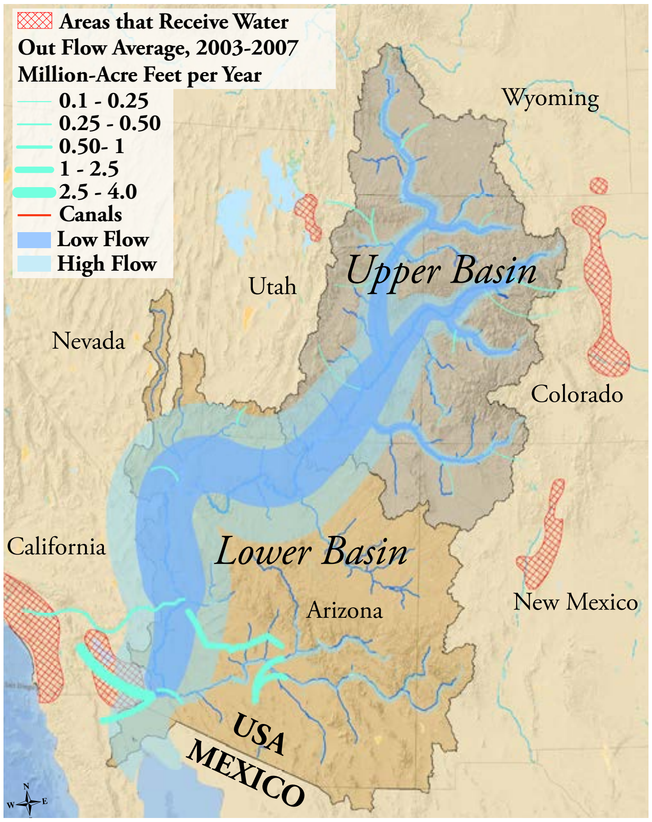
When John Wesley Powell first explored the Colorado River in 1869, the water ran fast, high, and muddy through pristine canyons such as the Grand. Today, many of these same stretches of river are clear and cold due to the construction of dams, and host lower flows because of upstream diversions. The river has changed immensely since Powell first charted its waters, in physical characteristics, environmental impacts, and its role in human society.

Once the Homestead Act was signed by Abraham Lincoln in 1862 and the West was opened up legally for further settlement by westward-migrating populations, land and water became more readily available. Following this was the General Mining Act of 1872, which allowed miners to stake a claim and, if valuable minerals were found, to purchase land for either $2.50 or $5.00 an acre. Because these two pieces of legislation also required water for their success, the system of prior appropriation and Western water law were born. Once all the best alluvial lands were claimed, the government passed the Enlarged Homestead Act in 1909 that was more conducive to dryland farming and gave homesteaders double the acreage because of lower land quality.[1] All of these acts only encouraged plentiful water use, as irrigation and small diversions became increasingly commonplace to support agriculture, and a precedent for western water consumption was set.

With the influx of people to the western U.S., population centers in and adjacent to the Colorado River Basin began to grow and transportation became increasingly key to a successful western economic system. Towns that became stops along the railroad often prospered disproportionately, Las Vegas being a perfect example. Established around 1905, the springs in Las Vegas allowed it to be a sort of oasis in the desert, one that settlers in small but growing numbers believed would become an agricultural paradise. The prior abundance of water in this now bone-dry city, which today survives entirely on water imported from the Colorado River, is what originally allowed it to grow into a booming metropolis.[2]

Figure 1 displays a comprehensive outline of the Colorado River Basin. The river and its tributaries are present,

Figure 1: Hydrology Map of the Colorado River with Infrastructure



Source: Jonathan Waterman, Samuel Velasco, and Robert E. Pratt, *Colorado River Basin: Lifeline for an Arid Land*, National Geographic Society, September 2010.

and the darker center and lighter outside shading surrounding the river line indicate periods of low and high flow, respectively. The major pipelines and canals are indicated by red lines, and major diversions, as well as amount of water diverted, are indicated by turquoise lines of varying thickness. Locations receiving diversions of water out of the basin, called transbasin diversions, are evidenced by red cross-hatching. This map provides a beginning idea of the layout of the river, as well as how and where Colorado River water is transported for use.

The Bureau of Reclamation was established in 1902, in part to begin what is today a legacy of damming, diverting, and otherwise managing the Colorado River. It dove right in to project creation in the basin, allowing for increased homesteading and western economic development.[3] Once it became clear that settlements in the West were not only permanent but also growing and demanding increasing water, the need for legal water allocations was recognized. In 1922, the Colorado River Compact was created, dividing the basin into Upper and Lower regions and creating water delivery requirements for each.

With delivery requirements now in place, it became necessary to create means by which to store and control water past minimal irrigation diversions. The Hoover Dam was constructed between 1931 and 1936 during the Great Depression, and was at the time the largest man-made structure after the Great Wall of China.[4] Its construction controlled floods, provided irrigation water, allowed for hydroelectric power production, and created Lake Mead, which increased water security by providing a more reliable source of multi-year water. Following the construction of Hoover Dam came many more large-scale projects to store and move water, especially the construction of Glen Canyon Dam and its corresponding reservoir, Lake Powell, in 1966. Glen Canyon Dam allowed for increased development of the Upper Basin, as Hoover had allowed for the Lower Basin. These projects were accompanied by the growing concept of "water buffaloes," those water managers who were adamant about obtaining increasing amounts of water in order to maintain a high rate of economic and human development in the West.

The 1922 Compact divided water use by Upper and Lower Basins, apportioning a flow of 15.0 million acre-feet (maf) that was assumed to be the Colorado River's average flow. Unfortunately, 1922 fell in the wettest ten-year period in the century of recorded Colorado River flow history (1914-1923), and as such may have greatly overestimated the actual average flows of the river over decades.[5] This over-estimation, coupled with the attitude of assumed abundance of western water based on historical rates of consumption, presents a difficulty today as regional populations grow and expected flows decrease. The Boulder Canyon Act of 1928 divided up the Lower Basin's apportionment by state, while the Upper Colorado River Basin Compact of 1948 designated apportionments for Upper Basin states. **Figure 2** shows a comparison of consumptive water use by states from 1970-1975 and from 1996-2000, indicating the consumption has increased nearly across the board.

In 2000, the Colorado River basin entered a period of severe drought in which the region experienced reduced precipitation and reduced river flows. Droughts are generally multi-year cycles, and this drought has continued through the present day.[6] This cycle mandated the creation of the Interim Shortage Guidelines in 2007 in order to guide re-apportionment in a time of severe decreased flows. All Lower Basin states, apart from California, will accept reduced deliveries pending severity of flow reduction if the guidelines are enforced, and California is being strictly held to its 4.4 maf apportionment (which has not always been the case in the past).[7] This roughly translates into cutbacks mostly in municipal water use, with a less severe decline (if any) in water available for irrigated agriculture based on seniority of water rights.

As this drought continues, water storage levels have been hard hit as users continue to withdraw water for various uses at rates faster than replenishment. In October 2010, Lake Mead reached an historic low of 1,083 feet above sea level; operations of the first intake station fail at a water elevation of 1,050 and below.[8] So far, 2011 has been the wettest year since the drought began in 2000, and Lake Mead has risen to 1,107 feet. One wet year does not end a drought, however, and the bottom line is that historic flows are changing. In retrospect, it is proving harmful to existing and promised future human uses, as well as environments dependent upon instream flows, that annual water in the basin was overesti-

Figure 2: Table of Consumptive Water Use by State, 1971-2010

Basin State	**1971-1975 average per year**	**1996-2000 average per year**	**2006-2010 average per year**
Arizona	5.18 maf	4.83 maf	No Data
California	5.19 maf	5.14 maf	No Data
Colorado	1.73 maf	2.06 maf	2.14 maf
Nevada	0.15 maf	0.39 maf	No Data
New Mexico	0.27 maf	0.41 maf	0.42 maf
Utah	0.80 maf	0.94 maf	0.84 maf
Wyoming	0.32 maf	0.43 maf	0.42 maf
Water to Mexico	1.63 maf	2.91 maf	No Data
Total	17.3 maf	19.1 maf	No Data

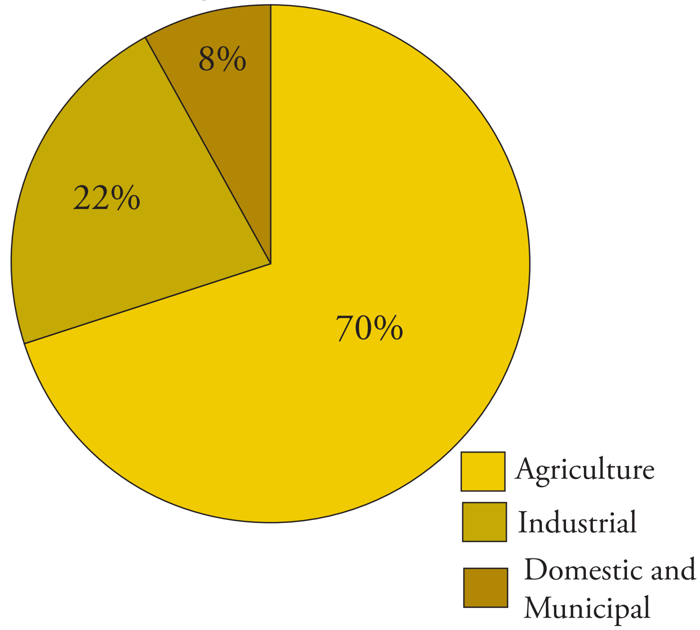
Source: U.S. Bureau of Reclamation, Colorado River System Consumptive Uses and Losses Reports, accessed December 12, 2011, http://www.usbr.gov/uc/library/envdocs/reports/crs/crsul.html mated when the Compact was created in 1922. The only consistent characteristic in flows of the Colorado River is variability, a phenomenon that Colorado River water users have historically tried to accommodate with multi-year storage, but to which humans and nature may soon be forced to adapt.

Water Supply and Demand: Trying to Make the Ends Meet

In order to understand the water supply of the basin, it is necessary to compare Colorado River supplies to those of other life-sustaining waters around the world. The Mississippi River is the fifth-largest river in the world by volume, with an average annual flow rate between 200,000 and 700,000 cubic feet per second (cfs). This is still only a fraction (usually around 9%) of the Amazon River, which experiences average annual flows around seven *million* cfs.[9] By contrast, the Colorado River had an average annual peak flow of 85,000 cfs before the construction of Hoover and Glen Canyon Dams, with tree ring analysis indicating a high of 250,000 cfs reached on a few occasions in the last 4,000 years. With the dams on the Colorado River in place today, average annual flows above Glen Canyon Dam are closer to 50,000 cfs, and sometimes as low as 30,000 cfs.[10]

The ways in which we use these limited flows in the southwest U.S. have varied throughout time, but always involve a strong agricultural emphasis. This is due in part to historical trends, as well as a climate in the Lower Basin that is highly conducive to winter crop growth. Agricultural use of Colorado River water today hovers around 80% of the river's total supply, whereas municipal and industrial use by cities is closer to 15% of the total. While today's trends are such that irrigated acreage in the basin is declining while municipal demands are increasing, water allotment has not yet shifted to reflect this. Note in **Figure 3**[11], which displays a breakdown of different water uses globally, that the percentage of water dedicated to agriculture in the arid southwest is higher than the global average.

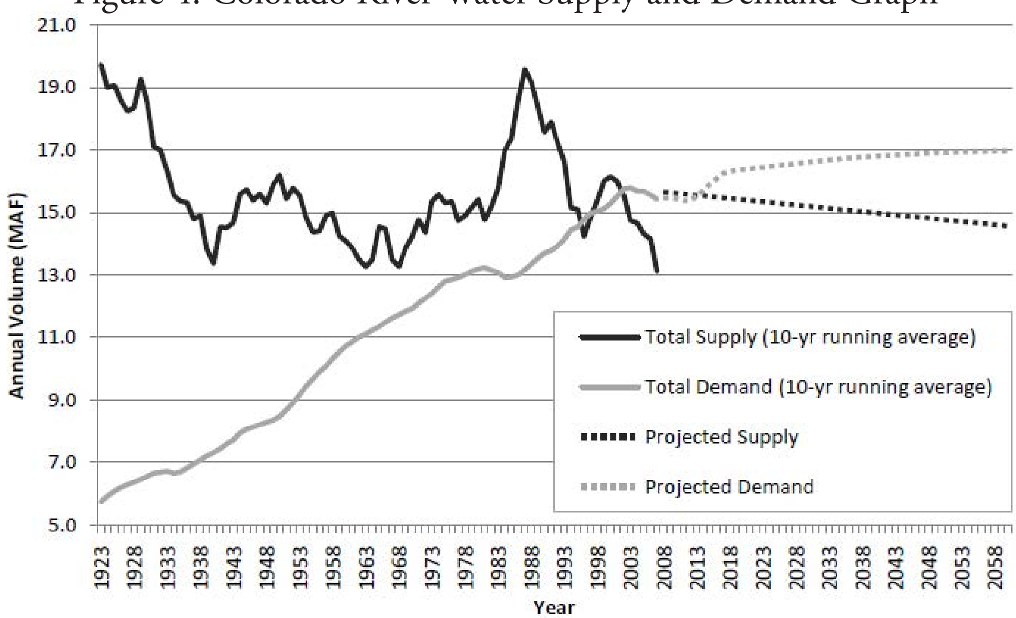
Figure 3: Global Water Use



The major stress in the system today is coming from these expanding municipal demands, created by rapid population growth. The numbers are startlingly simple; the basin and its outside service population are massive compared to the past, and flows are either plateauing or decreasing. With efforts made to conserve water or reduce demand still not enough to have a significant impact, this situation will lead to serious overapportionment and shortages. **Figure 4**, from a recent report by the Colorado River Governance Initiative (CRGI) takes the standard U.S. Bureau of Reclamation supply and demand graph and extends the imbalance projection to the year 2058 with a no-significant-behavior-change scenario.[12] This projection is impossible in actuality for a finite resource such as the Colorado River, and will require adaptation.

Timing is also an issue in the overapportionment of the Colorado River, as increasing numbers of previously marginalized water rights are being recognized. While legally sound, this presents an issue for the already fully-apportioned Colorado River. The delinquency of some Native American reservations in claiming their federally reserved water rights, as well as the delay in recognizing instream flows for national parks and other public lands as a priority, have caused tension as previously senior water rights holders are trumped by these groups. Junior water rights holders experience a further squeeze when these water rights are litigated and claimed, as even with increasing numbers of competing demands there is still only a

Figure 4: Colorado River Water Supply and Demand Graph

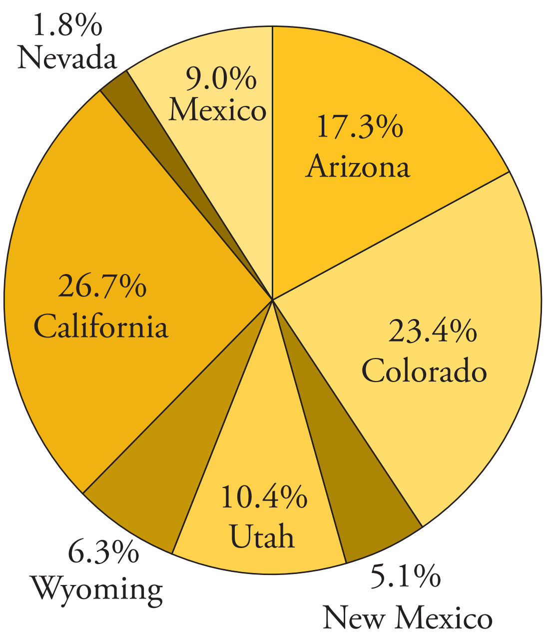


Source: Colorado River Governance Initiative, "Rethinking the Future of the Colorado River," *Draft Interim Report of the Colorado River Governance Initiative,* December, 2010.

finite supply of Colorado River water annually and over multi-year periods.

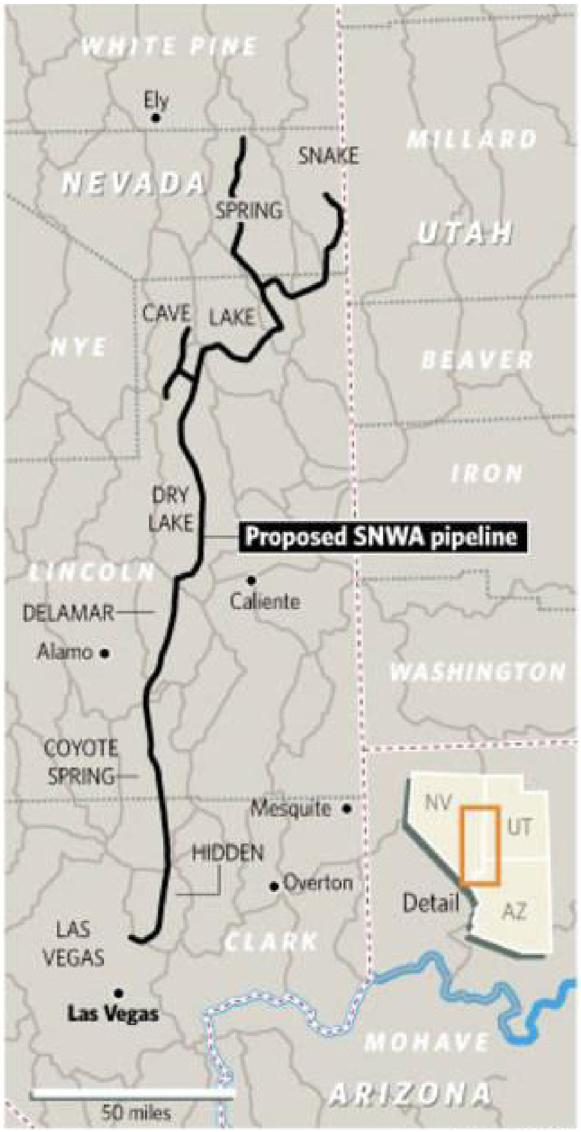
With the passage of the Interim Shortage Guidelines in 2007, the belt around water use is tightening. States, especially the historically larger water users in the Lower Basin, are being more closely held to their allotted water amount, which can be seen in **Figure 5**. One example of this is California, which prior to the shortage requirements was receiving closer to 5.6 maf annually as opposed to their allotted 4.4 maf. This was due in part to their location as one of the last downstream users, allowing them temporarily to take up the extras not consumed by the Upper Basin. It is also feasible because reclamation projects to help the Upper Basin states store and use their shares have been eclipsed by society's changing attitudes towards major dams, as well as severe budget limitations. In spite of this, it has come to the point where Lower Basin demands can only be met if the Upper Basin begins to release amounts beyond the obligations of the Compact.[13] Furthermore, the CRGI reports that demands on the Colorado River system as a whole now likely exceed long-term supplies, even without drought conditions.[14]

Figure 5: Water Apportionment by State



Users of Colorado River water (be they water utilities, project managers, farmers, etc.) had a tendency previously to always seek out new supplies through infrastructure creation, as opposed to accepting finite limits and engaging in conservation. This was due in part to the West's continued stereotype as a remote final frontier, a vision which does not consider the reality of booming metropolises and rapid population growth. One example of a project meant to satisfy growing municipal demand is in Las Vegas, where a $1.5 billion pipeline has been proposed. **Figure 6** provides a visual of the proposed project. The pipeline, which is very controversial among residents of the affected areas, would tap into the groundwater of various basins north of the city.

Figure 6: Las Vegas Pipeline Map



Source: The Las Vegas Sun

Some projects are more ecologically and monetarily feasible than others. One "wild" water supplement suggestion has been to create a pipeline drawing water to the arid West all the way from the Mississippi River Basin, something that most consider damaging and extremely expensive. Limits to growth in the American West are unappealing in a region of the country that is considered a newer economy, still rising to its full potential. Growing cities desire a reliable water supply for secure support, the antithesis of setting limits. As a result, those depending upon water in the Colorado River Basin display path-dependency, desiring to continue unconstrained growth with little or no limits on water. Reality confronts illusion in the current complex situation of existing demand outstripping supply; actions taken now to balance supply and demand will dictate the future withdrawal and instream water uses of the Colorado River.

The Growing Population of the Next Generation

At the advent of the Homestead Acts, population of the remote West began to grow, albeit slowly at first. Being the final frontier made the West a major attraction for farmers, miners, and later, developers. While this region has certainly experienced some serious boom and bust cycles with major transitions (from mining, to railroad, to services), the general trend of positive economic growth has resulted in consistently rapid expansions in population. In fact, perhaps in part due to its previously remote nature, the West has experienced the most intense population growth in recent years of any region in the country.

Between 1950 and 2000, the percentage of the nation's population living in the West[15] increased from just 13.3% to 22.5%, nearly a quarter of the total. The 13 western states (Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming) accounted for 50% of all U.S. population growth from 1990 to 2000, with 91.5 million (one-third) of the 281 million-person total living in this region.[16] Five of the six fastest-growing states in the U.S. between 2004 and 2005 were located in the West, including three Basin states: Arizona (3.5%), Nevada (3.5%), and Utah (2.0%).[17] **Figure 7** displays the change in population, from 1990 to 2008, of today's 12 largest cities in the basin.

Counter-intuitively for a region whose image is "rough and rural," the southwest U.S. is the most urbanized area of the country.[18] Recent influxes of population into southwestern cities, especially as the baby boomer generation begins to retire and settle in this warm area, have left rural areas in the Rockies region with lower-density populations than previous decades.[19]

Tens of millions of people from outside of the physical basin also acquire some or all of their water from the Colorado River; for example, more than half of the 30 million people receiving water from the basin live in southern California. A recent report by the Pacific Institute found that 70% of the population receiving water from the basin does not actually reside within physical basin boundaries.[20] Trans-basin diversions such as the Colorado River Aqueduct from Lake Havasu to Los Angeles (which pumps 1.2 maf per year) move millions of acre-feet of water out of the basin to municipal users annually, and municipal demands are only increasing as populations grow.

Just as the population served by the Colorado River Basin added 10 million people in only 18 years (1990-2008), so its growth is projected to continue into the future.[21] Nevada alone is expected to grow by one million people in the next 20 years, whereas the numbers for Colorado (an additional two million) and Arizona (an additional three million) are even greater.[22] That's six million additional people in twenty years between only three of the seven basin states, without even considering Mexico, which grew by 156% between 1990 and 2008. These significant additions to Colorado River water users only serve to stress further the already-dwindling river system.

Storage and Diversion: A History of Defying Nature to Optimize the River's Supply over Space and Time

For better or worse, water flowing through the Colorado River no longer reaches the sea at the Gulf of California. This is due to the massive amounts of infrastructure installed on the river, to control its flows for human "beneficial use" as dictated by the 1922 Compact. Beneficial use is defined by the U.S. Bureau of Reclamation (BOR) as "the consumption of water brought about by human endeavors," which includes water for "municipal, industrial, agricultural, power generation, export, recreation, fish and wildlife, etc., along with the associated losses incidental to these uses."[23] Beneficial uses were previously recognized only as those which were directly beneficial to humans, such as agriculture, municipal and industrial use, hydroelectric generation, and export. This also means that even evaporation from reservoirs is considered an

Figure 7: Change in Population of Water Agency and Provider Districts

Water Agency/Provider	1990	2000	2008	Growth, 1990-2008
The Metropolitan Water District (Los Angeles, CA)	14,393,420	16,145,476	17,987,917	25%
Southern Nevada Water Authority	750,621	1,364,248	1,922,069	156%
Tijuana & Rosarito, Mexico	829,233	1,323,214	1,632,508	97%
Phoenix, AZ	997,096	1,339,501	1,566,190	57%
Denver Water	891,000	1,000,000	1,154,000	30%
Tucson, AZ	662,251	835,504	952,670	44%
Mexicali, Mexico	363,149	568,983	890,032	145%
Albuquerque, NM	423,371	497,916	538,586	27%
Mesa, AZ	288,104	410,202	469,989	63%
Coachella Valley	235,722	332,485	462,386	96%
Colorado Springs, CO	303,522	382,693	424,416	40%
Salt Lake City, UT	333,000	372,192	391,515	18%

Source: Michael J. Cohen, "Municipal Deliveries of Colorado River Basin Water," Pacific Institute, June 2011, p. 6.

acceptable use because it is associated with a beneficial human use of the same water, saving it as a reliable water source.

Little consideration historically has been given to the idea of leaving water in the river for environmental or recreational purposes. This is more a result of rapid development and previously plentiful supplies than it is an example of hostile neglect. Obvious shortages, changing climatic conditions, and increasing instances of threatened and endangered species have forced a review of what uses constitute "beneficial," if not purely human. While most users understand what qualitatively constitutes beneficial use, the BOR recognizes that "an inability to exactly quantify these uses has led to various differences of opinion."[24]

Furthermore, a beneficial use may be classified as consumptive or non-consumptive based on the nature of water use. If the water is "consumed" in the sense that it cannot be returned to the system in any worthwhile manner, the use is considered consumptive. Examples of this include much of irrigated agriculture (although there are some return flows if the water can be treated) or certain municipal uses such as lawn-watering and air conditioning. Other uses, such as many uses in buildings (sinks, showers, etc.), are considered non-consumptive because they allow water to be returned to a wastewater treatment plant. From there, it can be treated and returned to the river, where it can generally be re-used by downstream water rights holders.[25]

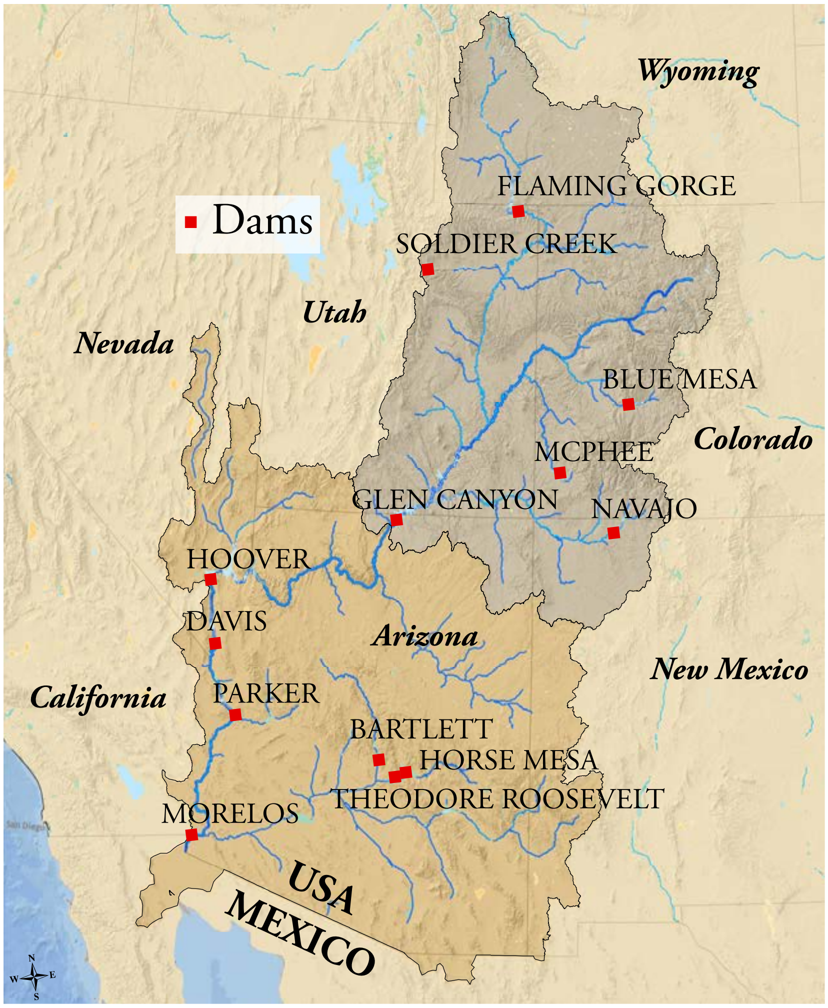
The Colorado River has long been diverted for use by individual farmers, miners, and other small scale uses. In 1902, President Theodore Roosevelt created the BOR by signing the Reclamation Act, authorizing the study of irrigation, needs as well as the construction of dams throughout the U.S. A canal system was already in place in parts of the Colorado River Basin at this time, but it was old and dilapidated. In 1905, high floods broke through one head gate near the Imperial Valley, which flooded the region and recreated the Salton Sea. The 1928 Boulder Canyon Project Act ushered in the age of large-scale infrastructure construction on the Colorado River by authorizing the construction of the Hoover Dam and the All-American Canal. The construction of Parker Dam in 1938 created Lake Havasu and allowed water storage for southern California, and Glen Canyon Dam's completion in 1963 created increased storage for the Upper Basin.[26]

Each dam, reservoir, pipeline and canal on the Colorado River has a different story behind the reasons for its construction, but the underlying theme is increased control of an otherwise hugely variable natural-flow resource. There are over 20 major dams on the Colorado. Considerably more are in the Upper Basin, but the ones located in the Lower Basin are much larger.[27] Many have associated reservoirs as well, which at a most basic level not only protect against damaging floods but also allow for water security by having a reliable water source even in times of drought.[28]

Dams and Reservoirs

The following is a list of the major dams and their associated reservoirs along the Colorado River, which gives background information on their time of completion and main purposes. **Figure 8** is a basin map showing the location of each dam and reservoir on the Colorado River system.

Figure 8: Map of the Colorado River Basin with Major Dams



Source: U.S. Geographic Names Information System

Figure 9 is a table providing the storage and active capacities of each reservoir, allowing for their comparison by size and current capacity. **Figure 10** provides the hydropower output of each major dam, again allowing for a comparison of productivity. This list will be useful when reading further about the issues with massive infrastructure along the river and the possibilities of water sharing between agricultural and urban water users in the following sections.

Hoover Dam:
•Finished 1936
•Located in the Black Canyon between Arizona and Nevada
•First major dam on the Colorado River, as well as the largest

Lake Mead:
•Created by Hoover Dam
•Roughly 28.5 maf capacity: 1.5 maf is reserved for flood control, roughly 2.4 maf for sedimentation control, roughly

Figure 9: Storage and Active Capacity for Major Reservoirs of the Colorado River Basin

Reservoir	Total Storage Capacity (acre-feet)	Active Capacity (acre-feet)	Percent Full on 12/12/2011
Lake Mead	29,755,000	15,853,000	53%
Lake Powell	27,000,000	16,392,535	61%
Flaming Gorge Reservoir	3,788,900	3,428,026	90%
Lake Mohave	1,820,000	No Data	NoData
Navajo Reservoir	1,708,600	1,320,840	77%
Blue Mesa Reservoir	940,800	611,147	65%
Lake Havasu	720,000	No Data	No Data
Fontenelle Reservoir	345,360	231,908	67%

Source: U.S. Bureau of Reclamation

15.8 maf for multiple uses (flood control, power, irrigation, municipal and industrial waters), and just over 10 maf for inactive storage.[29]
•Currently at 46% capacity with 11.95 maf of active storage[30]
•800,000 acre-feet (af) of evaporation annually because 247-square-mile surface area

Sally Hardin, Glen Canyon Dam

Glen Canyon Dam:
•Finished in 1966, part of the 1956 Colorado River Storage Project (CRSP) to develop the Upper Basin
•Located 15 miles upstream of Lee's Ferry in the Upper Basin
•Provides Upper Basin with storage
•Controversial; flooded the colorful Glen Canyon and has since caused numerous ecological issues
•Nearly failed in 1983 due to massive flooding

Lake Powell:
•Created by Glen Canyon Dam
•27 maf capacity
•As of July 2011 was at 18.34 maf (75% capacity)[31]
•Lowest historic level was 33% in 2005
•Threatened by sediment build-up, with an estimated 100 million tons annually (approximately 30,000 dump-truck loads daily)[32]
•Loses 860,000 af annually to evaporation (enough to supply Los Angeles for a year, 6% of the Colorado River's annual flow, and three times Nevada's annual allotment)[33]

Flaming Gorge Dam and Reservoir:
•Located on the Green River, 32 miles downstream of the Utah-Wyoming border in Utah
•Part of the 1956 CRSP
•Reservoir holds 3.8 maf at full capacity
•Reservoir currently at 3.59 maf because of 159% of normal precipitation in 2011[34]

Wayne Aspinall Unit:[35]
•Comprised of three dams and corresponding reservoirs in Colorado
•Part of the 1956 CRSP
•290,000 kilowatt capacity, which is 17% of CRSP system
•Allowed for agriculture in an otherwise fallow system
Blue Mesa Dam and Reservoir
•Furthest upstream of the Aspinall Unit
•Completed in 1966
•Reservoir is the biggest body of water in Colorado with 0.94 maf storage capacity
•Currently at 0.8 maf active capacity
Morrow Point Dam and Reservoir
•Largest and most productive of the three parts with 60% of the unit's total hydropower
•Reservoir is smaller, with a 117,190 af storage capacity and a 113,200 af active capacity at present
Crystal Dam
•Smallest of the three

Figure 10: Table of Dams and Hydropower Capacity

Dam	Location	Installed Hydroelectric Capacity
Hoover	Lower Basin	2,078,800 kW
Glen Canyon	Upper Basin	1,320,000 kW
Davis	Lower Basin	255,000 kW
Flaming Gorge	Upper Basin	151,950 kW
Parker	Lower Basin	120,000 kW
Blue Mesa	Upper Basin	86,400 kW

Source: US Bureau of Reclamation, USBR Projects, accessed December 12, 2011, http://www.usbr.gov/projects/Facility.jsp.

Figure 11: All-American Canal system in the Imperial Valley

Source: The National Atlas of the United States

Parker Dam:
•Located 155 miles downstream of Hoover Dam
•Constructed from 1934-1938
•Often referred to as the world's "deepest dam" because 85% of its structure is located below the riverbed
•Primary purpose was to create increased water storage

Lake Havasu:
•Created by Parker Dam
•Storage capacity is 646,200 af; presently at 584,300 af
•Supplies water for the Colorado River Aqueduct (transports water to Los Angeles, San Bernardino, and San Diego counties) and the Central Arizona Project; incredibly important desert water source[36]

Morelos Dam:[37]
•Located on the border of Arizona and Mexico
•Run by the International Boundary and Waters Commission (IBWC), all operations and maintenance done by Mexico
•Completed in 1950 pursuant to the 1944 treaty requiring 1.5 maf annual flow of the Colorado River into Mexico
•L-shaped, meaning it diverts almost all of the Colorado River and generally stops the natural flow
•No storage component

Infrastructure for Agriculture

The following is a list of Colorado River infrastructure that was constructed mainly to provide for agricultural water needs. All of the major infrastructure for agriculture is located in the Lower Basin.

All-American Canal System:[38]
•Located in the southeastern corner of California, near the border with Mexico
•Authorized by the Boulder Canyon Act of 1928
•Consists of the Imperial Dam and Desilting Works, the All-American Canal (AAC; 80 miles), and the Coachella Canal (CC; 123 miles)
•Water flows through Imperial Dam and Desilting Works, gets desilted, and goes to either the AAC or the CC; **see Figure 11** for a system map
•System irrigates around 600,000 acres of land in Imperial and Coachella Valleys
•Because the reservoir above Imperial Dam quickly filled with sediment (originally 85,000 af storage capacity, now 1,000 af), Senator Wash was built two miles upstream to hold water from sporadic precipitation events

The All-American Canal (AAC):[39]
•Largest irrigation canal in the world
•The canal was leaking lots of water, and after much debate it was relined in 2010; this saves 67,700 af of water annually

Thomas McMurray, Aerial Photograph of Morelos Dam

•The relining required rebuilding 23 miles of the canal
•Water saved will be used to fulfill Native American water rights and to decrease California's current dependence on surplus water
•Disadvantage is that Mexico used to receive water seepage lost from the canal, so their share has been decreased, straining relations further

Drop 2 (Brock) Reservoir:[40]
•Approved in 2007, constructed in Oct. 2010
•8,000 af storage capacity; can save up to 70,000 af annually
•Previously, agricultural water orders were made three days in advance at Parker Dam, then cancelled if there was an unexpected precipitation event, meaning the water was lost to Mexico; now those flows can be stored
•Caused further conflict with Mexico, who benefitted from the excess flows

Infrastructure for Municipalities

The following is a list of infrastructure that was constructed mainly to supply water to various western municipalities that are rapidly growing. Again, the major existing infrastructure for municipalities is located in the Lower Basin; however, there are multiple proposed projects for pipeline construction in the Upper Basin due to population growth and steadily increasing urban demand for water.

Central Arizona Project (CAP):
•Largest and most expensive aqueduct system ever constructed in the U.S., at $4 billion
•Authorized by the 1968 Colorado River Basin Act, intended to irrigate one million acres in Pima, Pinal, and Maricopa counties, but because it took 20 years to complete (1993) water now goes to rapidly developing urban areas (Tucson, Phoenix) as well
•Draws water from Lake Havasu through a 336-mile diversion canal
•All CAP rights are junior to older (senior) rights in California; presently challenging because Interim Shortage Guidelines of 2007 cutback on water use by junior users[41]
•Arizona also invested $28.6 million in California's Drop 2 Reservoir, meaning they will get 100,000 af of California water annually starting in 2016[42]

WikiCommons, Aerial Photograph of the Central Arizona Project

Colorado River Aqueduct (CRA):[43]
•Completed in 1941
•242-mile system that takes water from Lake Havasu to Los Angeles and San Diego
•Consists of two reservoirs, five pumping stations (which move water a total of 1,617 vertical feet), 63 miles of canals, 92 miles of tunnels, and 84 miles of buried conduit and siphons
•Pumps 1.2 maf from the Colorado River annually
•Run and regulated by the Metropolitan Water District of Southern California (MWD); these water rights are junior to the agricultural rights of California, but as a trade-off the MWD gets up to 5 maf of storage in Lake Mead in the future; they have also historically consumed any surplus from Arizona and Nevada, putting California over its 4.4 maf official allotment
•Adds to the complex relationship of water rights between Arizona and California

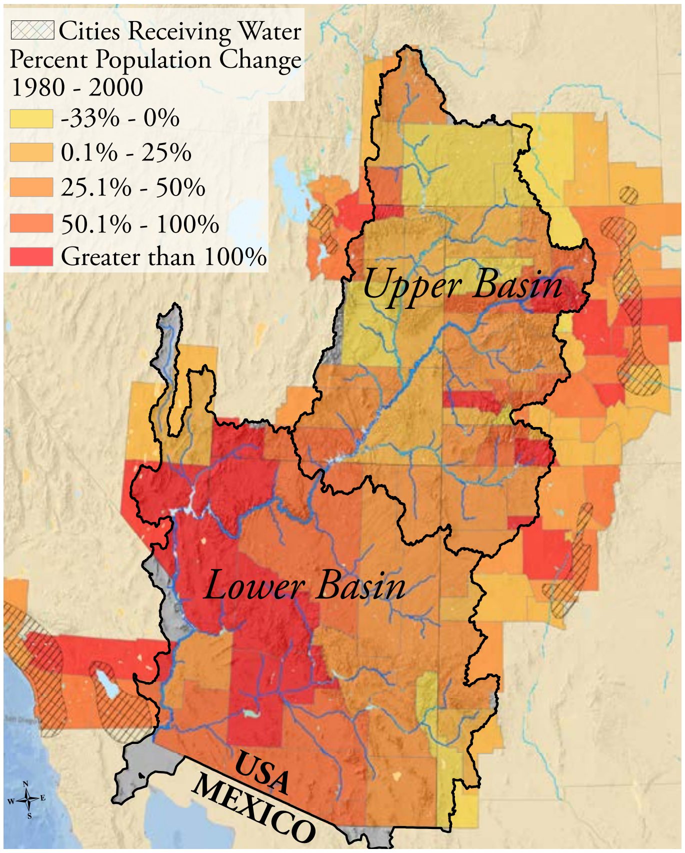
While agriculture is dwindling as a livelihood, as shown in **Figure 12**, and subsequently as a water-using sector in many parts of the U.S., there are many regions supplied by the Colorado River that are still going strong. Examples include both the Imperial and Wellton-Mohawk Irrigation districts at the southern tip of the Lower Basin bordering Mexico, where around 600,000 acres of land are irrigated with Colorado River water. This continuously presents contention over which new infrastructure developments should be prioritized: those for cities or those for continuing agricultural production. This region of the Lower Basin is an example where agriculture takes priority, but many developing areas in the Upper Basin present the opposite outcome.

Figure 12: Farming's Changing Role in the Nation's Economy

Year	Percent of Total Labor Force Employed in Agriculture	Agricultural GDP as a share of total GDP
1900	41.0%	No Data
1930	21.5%	7.7%
1945	16.0%	6.8%
1970	4.0%	2.3%
2002	1.9%	0.7%

Source: Compiled by Economic Research Service, USDA. Share of workforce employed in agriculture, for 1900-1970, Historical Statistics of the United States; for 2000, calculated using data from Census of Population; agricultural GDP as part of total GDP, calculated using data from the Bureau of Economic Analysis.

Figure 13: Population Change by County, 1980-2000



Source: The U.S. Census Bureau

As the West shifts rapidly from a rural to an urbanized region of the country, water infrastructure for municipal purposes is increasingly prioritized on the agendas of water managers. This shift can be seen in the maps in **Figure 13**, charting population density over time in the basin. The question is becoming not only how to sustain these growing populations, but also simultaneously how to allow the dry West's agricultural sector to continue to prosper. Increasing instances of environmental stresses and shortages are causing more and more managers to look towards various water conservation methods as the best alternative for future supplies. However, many proponents of economic growth and development still see continued infrastructure construction as the best option for a secure and reliable water supply. Most of the largest diversions are out-of-basin, moving Colorado River water from within the basin to large municipalities outside. This requires increasing amounts of energy, but generally growing cities are willing to pay.

Traditional Beneficial Uses: The Smaller Pieces to the Greater Whole

Many of the stresses on the Colorado River today arise from competing users. All stakeholders believe their consumption purpose to be the most important, but prior appropriation dictates which rights are senior and junior. Agricultural users in the basin hold rights of the highest priority, and nearly 80% of the flows from the Colorado currently

Case Study: The Flaming Gorge Pipeline

Source: Western Resource Advocates, http://www.westernresourceadvocates.org/pipeline/

The Lower Basin has historically demanded more water from the Colorado River than the Upper Basin, in large part due to the incredibly dry climate characterizing the region, but new developments in the Upper Basin prove that water security is desired everywhere. One example is the Flaming Gorge Pipeline, proposed by private developer Aaron Million, as well as a coalition of small water utilities in Colorado and Wyoming. The proposed project would require construction of a 560-mile pipeline east from the Flaming Gorge Reservoir to southeastern Wyoming and south to various locations on the Front Range of Colorado. For comparison, the Central Arizona Project (CAP) is only 336 miles, and CAP is the largest and most expensive aqueduct ever created in the U.S. The Flaming Gorge Pipeline is predicted to cost $9.5 billion to construct, and accrue $217 million each year in operating costs.[44]

If built, the pipeline to the Front Range would supply the municipalities there with 225,000 additional af of water annually, which is the equivalent of a football field covered with a column of water 43 miles high. There is some debate about whether water to supply this amount actually exists on the Green River, as a 2007 study by the Bureau of Reclamation suggested that actual surplus supplies are closer to 165,000 af. Furthermore, in July 2011, the Army Corps of Engineers terminated an environmental impact review of the proposed pipeline, ruling that the purpose of the project fell more closely under the Federal Energy Regulatory Commission's (FERC) line of review due to possible energy generation as part of the project. After this ruling, FERC also ruled the proposal to be "deficient" and have requested greater specificity. Million and the coalition of small utilities continue to push the proposal, however, as they emphasize that the pipeline could potentially supply water to an additional 1.1-1.4 million new residents along the Colorado Front Range,[45] which nears growth estimates for the next 50 years.

All of these existing and proposed transbasin diversions of Colorado River water are two-faced, as they fulfill the necessity of fueling a growing populace while further depleting the limited supplies of the Colorado River.

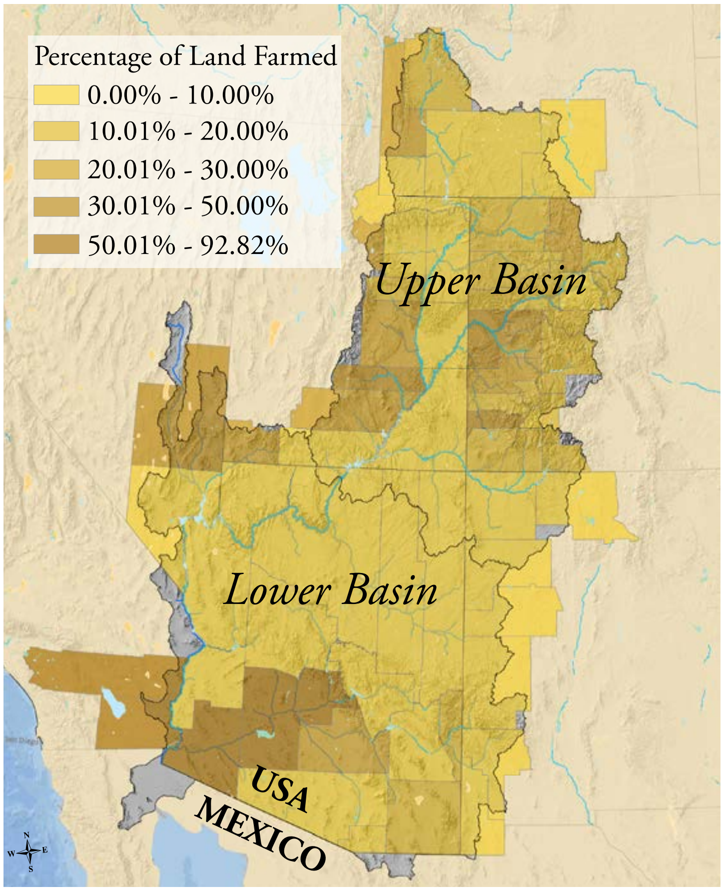
are used for agricultural purposes. However, farming is beginning to dwindle in the basin as increased urbanization overtakes this historically rural area. Municipal and industrial use of Colorado River water is 15% and growing quickly as populations explode. Most cities have junior water rights, however, due to their later establishment, and therefore agricultural users and municipal users occasionally clash over distributions. Other important beneficial uses of water are for recreation and hydropower production, two activities that are easily forgotten in the resource race between agriculture and municipalities.

Water Use for Agriculture

Despite its reputation as perhaps the driest region in the country, large portions of the southwest have a climate generally conducive to year-round farming, as long as water can be provided. According to the Colorado River Water Users Association (CRWUA), the agriculture fed by water from the Colorado River basin supplies 15% of the nation's crops, as well as 13% of the livestock.[46] It is agricultural giants such as Imperial and Coachella Valleys in California and the Wellton-Mohawk District in Arizona that are primarily responsible for this output, but there are also fairly fertile areas in the Upper Basin that host a fair share of irrigated land. **Figure 14** shows the acres of cropland per county as a percentage of that county's total land area.

While the Upper Basin states experience harsh winter climates, Wyoming and Colorado are both boosted by a $1 billion input to their economies from their respective seasonal agriculture. Utah has 340,000 acres that are irrigated by the Colorado River, and New Mexico has 100,000 acres. New Mexico boasts an alfalfa crop that contributes between $35 and $60 million annually to their economy. Nevada is actually the only basin state that uses none of its Colorado River apportionment for agriculture.[47]

Figure 14: Percentage of Land Farmed per County, 2007



Source: USDA National Agricultural Statistics Service

Figure 15: Top Twenty Basin Counties by Total USDA Subsidies, 1995-2010

County	State	Total USDA Subsidies 1995-2010
Maricopa	Arizona	$485,334,259
Pinal	Arizona	$462,288,174
Yuma	Arizona	$123,530,633
Cochise	Arizona	$99,105,005
La Paz	Arizona	$81,678,473
San Juan	Utah	$43,774,886
Moffat	Colorado	$43,108,035
Montezuma	Colorado	$34,824,040
San Juan	New Mexico	$34,493,923
Dolores	Colorado	$28,781,069
Montrose	Colorado	$22,157,852
Delta	Colorado	$21,775,592
Hidalgo	New Mexico	$21,455,046
Duchesne	Utah	$20,068,643
Uintah	Utah	$17,048,539
Emery	Utah	$13,376,653
Lincoln	Wyoming	$13,222,518
Imperial	California	$10,542,939
Rio Arriba	New Mexico	$9,400,186
Carbon	Wyoming	$9,213,433

Source: Environmental Working Group, 2011 Farm Subsidy Database, accessed December 12, 2011, http://farm.ewg.org/.

Much of U.S. agriculture is feasible because of significant subsidies from the government, which are detailed by the table on agricultural subsidies by county in **Figure 15.** These subsidies are due in part to a continuing belief in the importance of producing our own food as a nation and not relying on imports from other countries. "It's a national resource that we should protect," says Vince Brooke, Assistant Water Manager of the Imperial Irrigation District.[48] For many agriculturalists of the Colorado River Basin, these subsidies come in the form of reduced water and energy prices.

In the Imperial Irrigation District, for example, growers pay nothing for water, but merely pay for the price of its delivery; even then, it is only $20/af.[49] This does not reflect the true cost of water from the Colorado River in the dry Lower Basin, but makes it possible for farmers to grow productive crops without being overly concerned about spending huge amounts on irrigation. A similar situation is true in the

Wellton-Mohawk Irrigation District, where each property has a water right of 4 af per year per acre at a low rate. Beyond this, there is a tiered rate system, and water rates have increased for the last four years, but only minimally. Farmers and the overall economy desire an abundant crop, and the irrigation districts are in place to supply water at a low rate to insure this.[50]


Brendan Boepple, A groundwater pump in the Wellton-Mohawk District

The region of Mexico supplied by Colorado River water is also a significant agricultural area. Unlike the U.S., however, the relationship between farmers and the government is less supportive, and Mexican farmers in the Sonoran Valley receive little or no subsidies for their food production. Due to their close proximity to the U.S. border where crops are highly subsidized, Mexican farmers are frequently fighting a difficult battle and losing significant amounts of money through their crops, which cannot compete on a price basis with subsidized U.S. production.[51]

All of this is possible in part because of the seniority of most agricultural rights. Miners, turned farmers after the boom and bust cycle of mining ended in the late nineteenth century, were often the first landowners to establish any water rights in the Colorado River Basin. Wellton-Mohawk Irrigation District, for example, holds the most senior water rights for the Colorado River, meaning when shortages are imposed they are the last water users to feel any change.

Brendan Boepple, The All American Canal in the Imperial Irrigation District

Imperial Valley and Wellton-Mohawk combined produce nearly 80% of the nation's winter vegetables, indicating their importance as a production center along the Colorado River. Imperial Valley has 475,000 acres of cropland, most irrigated by flood irrigation, and has an average use of 5 af per acre of crop, annually. The top crops in Imperial in 2009 were alfalfa (28.2%), wheat (21.9%), Bermuda grass (11.1%), Sudangrass (6.6%), and lettuce (6%). For this, Imperial Valley diverts a total of 3.1 maf annually, a significant portion of California's Colorado River allotment (the rest goes to southern California municipalities through the CRA). Evaporation from canals causes a loss of approximately 10% of this water.[52]

Wellton-Mohawk District (the largest irrigation district in Arizona) is significantly smaller but relatively successful, with only 65,000 irrigated acres of farmland. For this, they divert 450,000 af of Colorado River water annually, but return 120,000 to 140,000 af downstream, flows which actually create the Cienega de Santa Clara wetlands in Mexico (**see case study on page 50**). This means that the annual consumptive use limit of water by the Wellton-Mohawk District is around 278,000 af. The most prevalent crops in Wellton-Mohawk are iceberg lettuce, cotton, wheat, Sudangrass, and some little seed crops. Corn, alfalfa, and wheat all require flood irrigation, which is generally less efficient than drip irrigation. Twelve-thousand af are reserved for municipal and industrial uses in the district annually, but because of having a rural population, rarely is the 12,000 af ever fully used.[53]

Because of extreme uncertainty over prices in agriculture, most farmers in these regions of the Colorado River Basin attempt to diversify their crop yield. One example of this is the fact that cotton is selling for some of the highest prices it has in decades. It also helps that farmers are able to grow two crops each year in some fields, due to the warm climate.[54]

The largest economic revenue, however, comes from the livestock in Imperial and Wellton-Mohawk Valleys. The latter has the largest cattle feeding yard west of the Mississippi River at 150,000 head, but the lot actually consumes more power than it does water.[55] Livestock is the biggest agricultural commodity revenue-wise in Imperial as well, where it generated an income of $343,201,000 in 2009.

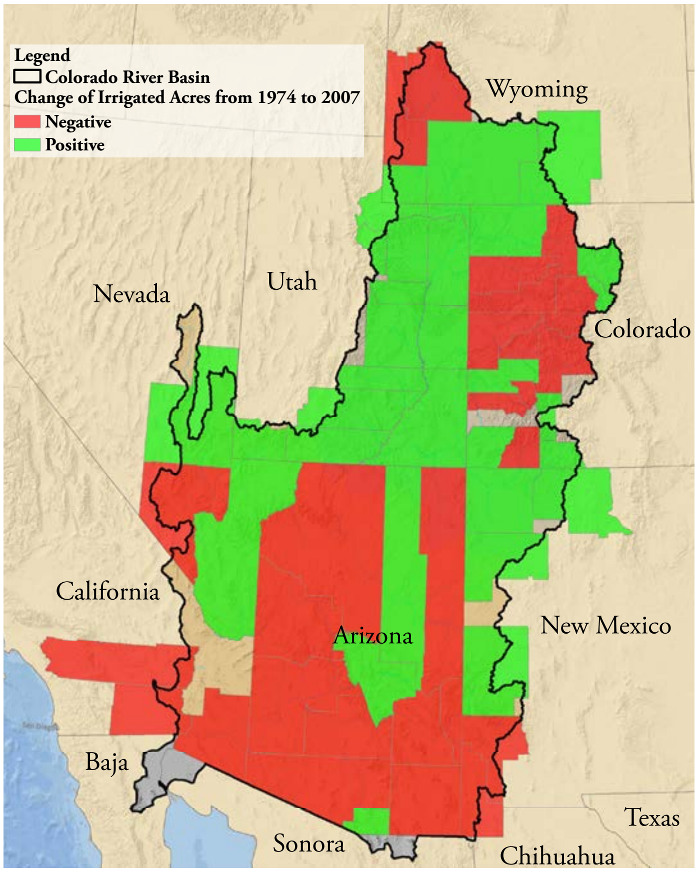
Despite large subsidies, the revenue generated by agriculture in various regions of the basin is still fairly significant. As the largest agricultural region in the basin, Imperial's commodity total in 2009 was $1.45 billion, down from $1.68 billion in 2008. For comparison, the entire state of Arizona generated $1.8 billion in agricultural revenue in 2007, including the contributions of the Wellton-Mohawk District. Because farms in the Upper Basin are generally smaller or more specialized (an example being the Western Slope of Colorado), revenue is not quite on the same scale, although Colorado and Wyoming regularly bring in close to $1 billion annually.[56]

Changes are occurring throughout the basin, however, as the population becomes increasingly urbanized. Demands for water transfers from agriculture to urban areas are growing steadily as pressures are put on water managers to supply increasing water to municipalities. This has caused some tension between agricultural communities and cities in the basin. "If they're short water, the first thing they do is run to the ag communities to get it," said Vince Brooke.[57] Imperial Valley has actually started a fallowing program, however, in which farmers are compensated for leaving their fields bare and transferring water over to municipal users.[58] This is true of many agricultural regions throughout the basin, where programs from basic fallowing all the way to the "buy and dry" technique are being implemented to better balance out water supply and demand. **Figure 16** shows the change in irrigated acreage throughout the basin since 1974. While some areas have experienced an increase in irrigated acreage, overall irrigated acreage in the basin decreased by 13.7%.

In Imperial Valley, over $40.1 million has been put towards advancing a successful fallowing program since December 2003. Over 1,100 fields have been contracted out for fallowing purposes, and in total over 111,000 acres have been left fallow. This amounts to approximately 700,000 af of water 'conserved,' or delegated for other uses throughout the basin.[59]

These programs are especially pressing in regions of the Upper Basin where agricultural areas are not quite as large or well-established as those in the Lower Basin. This is also arguably where the pressing demands of urbanization are being felt most as the population is jumping from rural to urban at an unprecedented rate. Because of the historic nature

Figure 16: Percentage Change of Irrigated Acres from 1974 to 2007



Source: USDA National Agricultural Statistics Service

of agriculture in the West, however, there is much opposition to these changes. Agriculture is an ingrained part of much of the cultural identity throughout the Colorado River Basin. Along with mining, it was one of the key livelihoods of nineteenth-century settlers, and even as times change people are reluctant to relinquish this past livelihood, which is still moderately successful.

Water use and distribution have always been politically charged topics, and in times of shortage, the tension only heightens. It is hard during shortages to recognize and weigh the importance of various water uses on the Colorado River. Population centers claim to be of primary importance, serving the needs of the people. Yet, as Kenny Baughman of the Wellton-Mohawk Irrigation District said, "The people… thought that milk and bread came from the grocery store. They have no idea it comes from farms."[60] While agriculture can often appear as hoarder of Colorado River waters, it is equally necessary to recognize its importance.

Municipal and Industrial Water Use

The numbers are crystal clear when it comes to Colorado River supply and demand. The population is increasing, which leads naturally to increasing demand. The Pacific Institute recently published a report detailing municipal water use inside and outside the Colorado River Basin, which found that although per capita use of water is actually declining in the basin, total overall demand continues to increase.[61] This is

Figure 17: Change in Water Use as Compared to Change in Population, 1990-2008			
State	**Gallons Per Capita per Day (GPCD) Change**	**GPCD Percent Change**	**Population Increase**
Arizona	-53	-23%	2,659,637
California	-51	-21%	6,548,506
Colorado	-47	-22%	1,548,817
Nevada	-107	-31%	1,343,930
New Mexico	-60	-27%	449,791
Utah	-84	-28%	928,966
Wyoming	20	10%	70,361

Source: United States Census Bureau; Michael J. Cohen, "Municipal Deliveries of Colorado River Basin Water," Pacific Institute, June 2011, p. 7.

due to a population growth rate that outstrips the rate of decrease in water use. **Figure 17** details the decline in gallons per capita per day (GPCD) for each state in the basin. These numbers can then be compared to **Figure 4** earlier in this section. It is evident that the GPCD percentage declines do not cover the massive population growth rates.

Municipal uses vary extensively from city to city, depending on people's needs, the climate, or water availability. The average human requires two quarts of water each day for basic survival. However, the U.S. average for a single family home is 80 gallons per person per day in winter, and 120 gallons in summer.[62] This is quite high compared to drought-stricken areas such as the Murray-Darling Basin in Australia, where an extreme lack of water has forced water use in cities such as Brisbane all the way down to 38 GPCD.[63] Water use in the Colorado River Basin, however, is even higher than the national average, due in part to a drier climate, as well as a higher consumptive pattern.[64]

Apart from industry, households are the main consumers of water in municipalities, especially in suburban regions with large lawns and properties. In cities such as Las Vegas and Denver, where the climate is not naturally conducive to luscious lawns, upwards of 50% of municipal water is often used on maintaining non-native grasses.[65] This is a consumptive use, as the water cannot be easily reclaimed for reuse downstream. Many efforts are being made, especially in Las Vegas, to replace turf with more water-efficient materials such as rocks and desert plants (Xeriscaping), but many people are hesitant to yield the aesthetic comfort of green lawns.

Using Las Vegas as an example of municipal water use, we see that about 40% of water goes to buildings (mostly non-consumptive) while 60% is used outside (consumptive). For Las Vegas, there is the added factor of both resorts and tourists. Contrary to popular belief, however, resorts are not huge water users; they only consume about 3% of Nevada's Colorado River apportionment, but provide 70% of Las Vegas's economic benefits. Furthermore, upwards of 80% of Las Vegas's permanent residents live in planned communities, which are culprits of large lawns and general water inefficiency (appliances). One of the largest consumptive uses of water in Las Vegas today (as many lawns are phased out in favor of Xeriscaping) is actually air conditioning, due largely to the warm, dry climate.[66]

The Pacific Institute study reports that even with a general decline in per capita municipal demand (people are using less water now than they did in 1990), agencies delivering water from the Colorado River now deliver approximately 6.7 maf annually, as opposed to the 6.1 maf that was the norm in 1990 due to an overall growth of urban population.[67] The following section discusses conservation and efficiency measures that are being pushed in order to decrease municipal water demand further. It is important to remember that at present, the driving issue is not vast overconsumption of water by municipalities, but rather the ballooning population of cities dependent on water from the Colorado River.

Other Uses

There are many other uses, apart from just agriculture and municipal/industrial water use, which are deemed beneficial in the Colorado River Basin. However, these uses make up only a small fraction of total demand in comparison to the two giants. There is increasing attention being paid to the careful balance that must exist between users in order for there to be enough water to go around, as well as rising emphasis being put on instream flows and the idea of leaving water in the river for environmental purposes. It is a challenge, however, to shift apportionments and prioritization of uses in modern times when allocations and water use structures were molded by the Compact in 1922 when society did not recognize the eventual value of dedicated instream flows.

Hydroelectric power generation is another fairly significant user of Colorado River water, and is an added benefit that comes from infrastructure creation. While dams do have harmful environmental impacts, hydropower is relatively environmentally-friendly in that it does not require consumptive use of water and does not discharge carbon dioxide into the atmosphere.

Recreation is another beneficial use, as it generates fairly significant revenue for the western states in which it occurs (see page 76 for the Recreation section in this report). These activities need not only be river-based, but can also include anything that relies on water from the Colorado River (i.e., skiing). However, because recreation generally relies on water that stays in the river, there is no prioritization or given allotment; it is merely an enjoyable side effect of a healthy river system. Many are concerned about what the future will bring for river recreation, with near over-apportionment at present and the looming risk of climate change which threatens to further dry up river supplies.

The Next Generation of Colorado River Water Users: Is it a Zero Sum Game?

At some point, the questions of competing uses, supply and demand imbalances, and growing transbasin diversions boil down to a single question: Is there enough water to go around? Can we find a way to equitably meet the demands (on a reasonable scale) of all users, while maintaining a healthy river system? Or will differing uses, overapportionment, and continued shortages out-compete one another, making it so that use by one stakeholder cancels out that of another in what is termed a zero sum situation?

Understanding the Basin's Natural and Geographic Limits and Possibilities

With 45% of the Colorado River's waters leaving the basin to supply 70% of the population partially or fully reliant on the Colorado River,[68] transbasin diversions are a point of contention in water use. On the one hand, the cities are outside the basin; Los Angeles, San Diego, Denver, Albuquerque, Salt Lake City, and Colorado Springs, among others, as can be seen in **Figure 18**. On the other hand, increasing amounts of water leaving the basin to support these growing external population centers presently only mean less water for those users on its interior.

Out-of-basin municipalities are also pushing for increased reliability of water sources, meaning the creation of more storage reservoirs. This is due in part to experience with shortages from the recent prolonged drought, as well as the desire to successfully support continued population growth in urban areas. Presently, 25% of Colorado River storage capacity directly supports municipalities, and this is only growing, especially as cities are able to acquire agricultural water rights that accompany their storage. However, reservoirs are both costly and inefficient, as they have a high loss of water due to evaporation and their costs must be paid for up front. In their recent report entitled "Filling the Gap," Western Resource Advocates expands on the disadvantages of reservoirs, and pushes instead for decreasing the demand side of the equation through improved conservation measures.[69]

Figure 18: Map of Transbasin Diversions

Source: Michael J. Cohen, "Municipal Deliveries of Colorado River Basin Water," Pacific Institute, June 2011, p. v., and Ray Ahlbrandt, U.S. Bureau of Reclamation.

Also associated with the downsides of reservoirs are the pipelines that are needed to pump water out of the basin. These are costly to construct and are hugely energy-inefficient.[70] According to the Filling the Gap report, it is estimated that six pipelines that are currently being considered would each cost somewhere between $8 billion and $10 billion in just capital costs, not to mention operation and maintenance costs.[71]

One alternative to massive reservoir and pipeline construction is the creation of small, efficient reservoirs that are designed to take advantage of existing supplies and peak-season runoff, called "smart-storage."[72] These projects would work with the river and its natural flow variability, storing naturally-occurring downstream flows for later use. Their smaller size makes them less intrusive of the existing ecosystem, as well as less susceptible to major evaporation loss.[73]

Some cities are desperate for water, however, and will do anything to increase supplies through infrastructure. Las Vegas is a perfect example, in part because it is one of the leading cities in terms of conservation and low demand. Despite these conservation achievements, their reality as a metropolis in a desert requires water managers such as Southern Nevada Water Authority (SNWA) head Patricia Mulroy to look into tapping the groundwater systems of other basins, including the Great Basin. Opposition to the proposed Las Vegas pipeline is fierce in the Great Basin, however, in part due to the pervasive notion that it would drastically alter the ranching lifestyle in the region by creating a zero sum environment; water taken by Las Vegas would no longer be available for Great Basin ranchers.[74]

The *Filling the Gap* report addresses just that question, of zero sum tradeoffs. By reviewing the water situation on Colorado's Front Range, they reveal four strategies—acceptable planned projects, conservation, reuse, and ag/urban cooperation—that will work together to decrease demand while simultaneously creating additional water supply.[75] While such strategies would require both sacrifices and cooperation, shortages are becoming enough of a reality that the benefits of comprise may soon outweigh any perceived disadvantages.

Weighing the Agricultural Tradition Against the Growing Demographic Pressure: Potential Solutions for Future Water Sharing

Water distribution is the newest battleground for users of the Colorado River. At present, a standoff is developing between agricultural water users, who have regional history backing them, and municipal users, who are quickly growing in numbers. Agriculture holds the senior water rights, is often actually located within the basin, and has the title of largest user of Colorado River waters by a long shot—nearly 80%.

There is also a deep history of agriculture present in the region, still very much felt by the agricultural community, and so while they may be small in numbers, they are strong in organizing against any movements to take away their water. Municipalities generally hold junior water rights, and have the disadvantage of often being located outside the basin—but this is where the people are, with an increasingly loud voice demanding water.

The topic is wildly charged, with each side on the defensive about who gets what water at what priority. If this present path is followed, then the Colorado River is headed for self-destruction; it is not feasibly sustainable. However, many experts believe that this relationship need not be zero sum. In fact, this interface of users provides the perfect opportunity for a give-and-take relationship that has the potential to restore a semblance of balance to the Colorado River system.

Figure 19: Change in Gallons Per Capita Per Day (GPCD), 1990 to 2008

State	GPCD in 1990	GPCD in 2008	GPCD Change	Percent Change
Arizona	234	181	-53	-23%
California	246	195	-51	-21%
Colorado	214	167	-47	-22%
Nevada	348	242	-107	-31%
New Mexico	223	163	-60	-27%
Utah	298	214	-84	-28%
Wyoming	197	217	20	10%

Source: Michael J. Cohen, "Municipal Deliveries of Colorado River Basin Water," Pacific Institute, June 2011, p. 7.

One proposed solution is decreasing the demand side of the equation, which would mostly require efforts on the part of municipal water users. This would include heightened water conservation and reuse measures. Experts believe that reuse strategies are more promising, as conservation in the last decade has been startling effective and yet the continually growing population essentially negates this progress. There have been substantial per capita declines in water use, meaning that municipal deliveries would be nearly 2 maf lower than in 1990 if demand had remained constant[76] (**see Figure 19**). However, because of population increases, these demands were instead increased, hence the turn towards reuse as a more reliable strategy for water consumption reduction.

Reuse generally encompasses two different strategies. First, water can be physically reused by municipalities after treatment at a wastewater treatment plant, or after storage (direct reuse). Second, water can be returned to the river in the form of return flows for use by downstream users (indirect reuse). In this second situation, the upstream user is compensated for their water return.[77]

Part of what direct reuse would entail is municipal infrastructure that is friendlier towards grey-water usage, for example in Colorado Springs where green lawns are sometimes watered with non-potable waters in order to cut down on overall consumption. There need not be a massive overhaul of all plumbing systems in municipalities, merely incentives in place to entice water customers to reuse, as well as methods that make reuse an easier practice. Giving big water consumers, especially industrial users, incentive to reuse waters in their various processes would likely have the most noticeable impact. Western Resource Advocate's "Filling the Gap" report indicated that an additional 199,000 af of water would be made available annually if Colorado Front Range water users were to engage in reuse practices.[78]

The main disadvantages to both conservation and reuse are their voluntary nature. There are some regulations in place in many cities fed by Colorado River water, such as sanctions on lawn-watering during drier, hotter months, but nothing that is stringent enough. It would be possible for water providers to introduce a tiered water rate structure, meaning that water would become significantly more expensive the more a user consumed; however, at present, this is less economically desirable for all involved parties. As Doug Bennett, Conservation Manager for the Southern Nevada Water Authority, said in reference to water conservation, "Conservation loves a crisis."

The second approach to balancing the supply and demand equation of the Colorado River involves increased cooperation between agricultural and municipal water users. The simplest way of viewing the issue and solution is that agricultural users have a significant portion of the water rights, and therefore a significant portion of the water; municipal users have far fewer water rights, and therefore far less water. However, because irrigated acreage in many parts of the basin is decreasing (excluding the southern-most agricultural producers like Imperial Valley and Wellton-Mohawk), the need by agricultural users for that water is arguably decreasing as well. For example, there has been a decrease in irrigated acreage in Colorado from a high of 1.02 million acres in 1976 to only 840,000 acres in 2005.[79]

One way to use this imbalance of water rights and needs to provide increased water to municipalities is through a more traditional system termed "buy and dry." This is when municipal water users, who generally have a fairly high willingness to pay for water, buy up certain acres of agricultural land that are not productive enough to make them worthwhile to the farmer (or because the offer is more agreeable than producing crops would be). This purchase transfers the senior agricultural water right to the municipal user along with the land. However, it also permanently puts the land out of commission for agricultural purposes, which is often very unappealing to farmers who depend on the land for their continued livelihood.[80]

Instead of this socioeconomically undesirable method, more and more water managers are looking towards a combination of rotational fallowing and water banking to ease the process of transferring water from agricultural to municipal water users. Markets are an ideal tool to allocate a scarce resource, and therefore the creation of organized, regulated water banks composed of various willing agricultural water rights holders has the promise to be both more efficient and more socially acceptable.[81]

Having a rotational fallowing arrangement means that farmers do not have to permanently sell their fields, but instead can leave certain acres fallow and temporarily transfer that water right to a bank. This does not physically mean the transfer of water, but rather that the water that would normally be used is instead left in the river, available for use by the purchaser of that particular water right. This is economically favorable to agriculturalists because it allows for compensation of revenue lost by not growing and selling crops for a season. The "water bank" itself is merely a regulator of transactions between agriculturalists and municipal users, making sure that the process runs smoothly and that there is appropriate compensation.[82]

This strategy has already been successfully implemented by the Super Ditch Company in the Arkansas River Valley. Here, several Arkansas River ditch companies pooled their water rights under a centralized banking system, from which municipalities can then lease them. The key factor here is that many ditch shareholders expressed interest and willingness to enter into this centralized collective, because without that, water banks cannot exist or succeed.[83]

There are a few issues with water banking that have already been identified. First, it requires extensive cooperation between agricultural communities and municipal water users, something that is not always appealing to the agricultural community due to past grievances (so frequently being accused of being water hogs, wanting to uphold a culture of agriculture, etc.).[84] There are also problems with instream flow rights being disrupted because of water being taken out of a different area of the river than before. Finally, transaction costs to quantify and legally transfer water rights are quite high, which makes the whole endeavor less profitable for the agriculturalist and simultaneously more expensive for the municipal buyer.[85] Despite these flaws, however, water banking using rotational fallowing is arguably the most economically, socially, and environmentally palatable strategy yet implemented for addressing the crisis of supply and demand along the Colorado River.

Conclusion: Is the Colorado River Basin Faced with a Zero Sum Struggle?

Decades of immense human ingenuity and vast sums of money have been invested in "taming" the Colorado River. This is often seen as one of the human wonders of the world: carving out immense reservoirs backed up behind gigantic dams, while diversion structures carry water hundreds of miles from the river itself to fertile agricultural regions and urban areas even beyond the hydrologic boundaries of the basin. A steady supply of water over the decades, varying by the year according to drought conditions, is now rapidly being disrupted by growing demand for water to be put to "beneficial" uses. Colliding with the traditional definitions of "beneficial uses," new demands arise for maintaining instream flows to protect the fragile riparian areas and vast public lands of the region.

Many believe that the height of human engineering in the basin is nearing an end, with a few remaining proposals for massive diversion increasingly being challenged by environmental concerns. The result: a situation that increasingly pits existing users against one another, as urban areas seek to obtain water dedicated to agriculture, and out-of-basin demands seek any remaining surplus or unused allotments to individual states.

We have traced the thread of human development of the Colorado River Basin in this section, with the purpose of seeking answers to what many argue is now a zero sum game. Additional water obtained by urban areas must now come from a decline in water use by agriculture (potentially signaling a decline in agricultural production itself). Any further water diversions, even pursuing remaining surplus allotments to individual states, must come at the expense of diminished instream flows, thus harming further rivers and their associated flora and fauna.

Should today's youth look at this collision of steady and perhaps dwindling water supplies, as climate changes occur, against rising human demands as the ultimate threat to the basin as we know it? Or are we witnessing in the vibrant experiments discussed above innovative opportunities for new techniques of water sharing and conservation? The tentative answer we reach as Colorado College State of the Rockies Project student researchers is that the future sustainability of the Colorado River Basin remains to be determined. Encouraging signs of conservation and water sharing techniques give hope that our children will inherit a vibrant Colorado River. Water use in the Colorado River Basin need not be a zero sum game. On its current trajectory, it could certainly be classified as such. However, we are encouraged by promising alternatives for water conservation, reuse, and sharing of this scarce resource that together have the power to alter this path of destruction.

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Case Study: The Wellton-Mohawk Irrigation District and the Cienega de Santa Clara

Many environmental problems of serious nature have arisen on the Colorado River as more and more infrastructure is added to dam and divert the river's contents. Rarely has anything ecologically beneficial come from such projects. Yet the Cienega de Santa Clara, a 40,000-acre-wetland near where the Colorado River used to meet the Gulf of Mexico, defies this generalization.

The Cienega is created by the brackish, overly saline drain waters coming from the Wellton-Mohawk Irrigation and Drainage District (WMIDD). The WMIDD, located in southwestern Arizona by the border with Mexico, is largely composed of 65,000 acres of irrigated cropland and is a highly productive agricultural region. The drain waters used to be a part of Mexico's annual Colorado River allotment (1.5 million acre-feet/year) designated by the 1944 Treaty with Mexico, until they were ruled to be too saline for beneficial use.[1]

The Colorado River has not reached the sea since 1998,[2] but the delta region was parched long before this. The wetlands that used to make up the delta region were compromised and eventually destroyed by a lack of water flowing to that region, due largely to urban development, construction of dams, and agricultural water use in the United States region of the Colorado River Basin. However, the flows of brackish water in what is termed the Mode Canal, which stretches from the WMIDD down into Mexico just east of the Colorado River's original path, have created a vibrant ecosystem in this previously desolate region.[3] The delta itself is still barren, but the Cienega de Santa Clara, just east of it, hosts a vibrant selection of healthy flora and fauna.

Ecology

The Cienega de Santa Clara is home to thousands of both migratory and resident birds. Located in a key region of migration corridors (including the Pacific Flyway), the wetlands at one point or another serves upwards of 75% of North American birds. It is the habitat of several endangered species, including 70% of the total Yuma Clapper Rail population in existence, and boasts a very healthy array of brackish riparian vegetation.[4]

The Biosphere Reserve of the Upper Gulf of California and the Colorado River Delta was extended to include the Cienega as a protected area, an important step in its conservation. Further, the Cienega was included in the Ramsar Convention on Wetlands of International Importance, meaning that the whole delta region's critical ecological role has been recognized and will subsequently be protected. Finally, Minute 306 was created for further protection; it jointly commits the United States and Mexico to continued study of the delta ecosystem in order to define water needs and identify ways to secure this water.[5] This includes finding alternate water supplies if the Yuma Desalting Plant ever comes into operation, desalinating the brackish flow from the Mode Canal and no longer sending this water down to the Cienega.

The Salinity Control Act of 1974

The highly saline drain water from WMIDD was historically included in Mexico's 1.5 maf total allotment from the United States. However, the Salinity Control Act of 1974 declared this water to be too brackish for human consumption and subsequent beneficial use. The Bureau of Reclamation was therefore responsible for finding other water to replace this, so that the full allotment was still met.[6] Arizona continues to get return credit for the Mode Canal flows, however, even with the Salinity Control Act in place.[7]

At first, the Bureau of Reclamation used surplus water from the lining of the Coachella and All-American Canals (previously lost to leakage) to fulfill Mexico's allotment. However, California's water rights were lowered and therefore the water was no longer surplus, and was instead needed to fulfill California's own allotments.[8]

Yuma Desalting Plant

The Yuma Desalting Plant (YDP) seemed to be the easiest solution to the problem. This large reverse-osmosis center in Yuma, Arizona, was intended to treat the saline return flows of the WMIDD, making them usable as part of Mexico's Colorado River allotment. Since its construction in 1992, however, it has only been used twice, both trial runs (one at one-third capacity and the other at two-thirds) to see what various effects the plant would have on water conditions.[9]

When it was built, the energy-intensive YDP cost $258 million. It has sat largely idle since that point, and it costs an average of $2.2 million each year to maintain. If in operation, this cost would be raised to between $33 and $42 million each year. This is in order to produce 68,000 acre-feet (af) annually, which is still 40,000 af short of the 108,000 af currently supplied to Mexico by the Yuma Area Bureau of Reclamation office. When one does the math, this comes out to anywhere between $305

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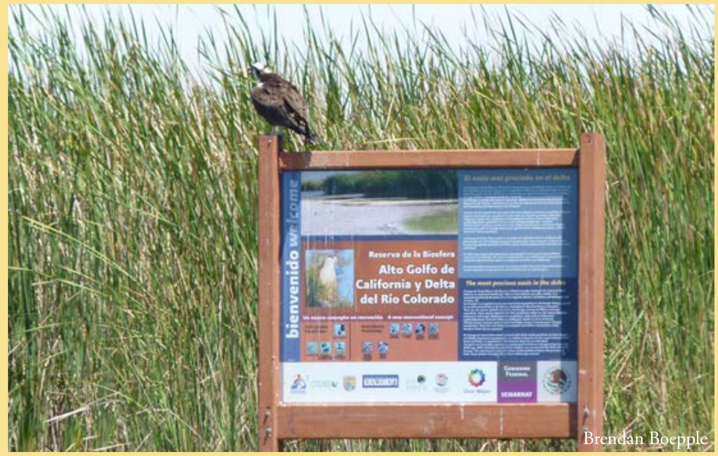

Brendan Boepple

and $480 per acre-foot for treated water,[10] compared to some agricultural water in the WMIDD, which (due to subsidies) can cost farmers as little as $4/af.[11] Therefore, the YDP is arguably not cost-effective at present.

Environmentally speaking, the YDP would also be damaging. The Cienega wetland has proven to be fairly resilient in the wake of the trial runs, as lost acreage returned quickly with renewed water supply.[12] In 1993, however, flooding and repairs in the WMIDD led to a temporary cut-off of flows, causing a 60% habitat loss. Running the YDP continuously without finding a replacement water source to the Cienega would result in the Cienega's eventual disappearance.[13] It would cause a 70% decrease in the amount of water delivered to the Cienega, and a three-fold increase in salinity levels, throwing the ecosystem entirely out of balance due to water-starved and salt-choked marshlands.[14]

The YDP is not without its advantages. The overarching reason for its construction was to help decrease the risk of long-term water shortages in the Colorado River's Lower Basin. The idea behind this is that agricultural return flows that are treated and sent to Mexico will leave more water in Lake Mead for use in the United States.[15]

Presently, the YDP is not in operation, and the Cienega is thriving. In order to fulfill its allotments to Mexico, the Bureau of Reclamation is engaging in a form of water transfer in which they lease water from willing sellers.[16] The ultimate goal is to create an actual market for water leasing, but if this does not happen the Cienega will once again be under threat.

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