# Drought and the Reengineering of the American West

BY ALAN S. BROWN

**Drought is reshaping the American West. Engineers have responded with massive projects to conserve and create water resources.**

San Diego's wake-up call came in 1991, when the Los Angeles-controlled Metropolitan Water District of Southern California cut its water allocation by 30 percent during a drought. That was when the fast-growing city realized it needed to secure new water supplies.

Las Vegas faced a similar moment during a drought in 2002. With only four inches of rain annually, Vegas is the driest city in America's driest state. It could not support future growth with the water it had.

San Diego and Las Vegas were not alone. Since the 1990's, countless Western cities, counties, and states have reassessed their water supplies. Many began looking for conservation and engineering solutions years ago.

It is a good thing they did. Today, signs of drought are visible everywhere and especially along the Colorado River. If the American West has a beating heart, it is the 1,450-mile Colorado, which serves nearly 40 million people and 5 million acres of farmland in seven states, 23 Native American reservations, and two states in Mexico. It supplies the nation's two largest reservoirs; Lake Mead, just southeast of Las Vegas, and Lake Powell, northeast of the Grand Canyon. And it is ailing.

Twenty years of low snowfall has slowed the once-mighty Colorado and dropped Lake Mead's and Lake Powell's storage levels precipitously. The lakes are so low, power companies worry about producing hydroelectric power from their dams. Others fret the reservoirs will drop to "dead pool," a point below their water distribution outlets.

The situation is so bad, the federal government intervened this spring when the basin's stakeholders could not agree on how to divvy up the Colorado's dwindling waters. Within the states, infighting continues among cities, suburbs, and farmers struggling for their shares.

Record snowfall in 2023 put off a day of reckoning, but not for long. "If you look at the record, there has been a significant decline in flow, not just in the 2000s, but going back to the 1980s," says Jim Schlaman, director of planning and water resources for Black & Veatch, a global water design/build engineering firm.

"People have their own views on climate change, but we don't need to debate the merits of what is causing it. You cannot stand on the edge of Lake Mead, Lake Powell, or Lake Mojave and say we don't need to be worried about this. We absolutely need to be thinking about those issues."

The problem is not just limited to the Colorado River Basin. It is everywhere in the West. A recent report warned that continued drought would dry up Utah's Great Salt Lake, allowing winds to blow toxic salts and minerals through the cities and towns on its eastern shore.

Fortunately, preparations go far beyond the usual campaigns to slash lawn watering and take shorter showers. Governments have invested heavily in recycling water, recharging aquifers and reservoirs, capturing rain runoff, reducing agricultural losses, and investing in toilet-to-tap and seawater desalination facilities.

In short, the fast-growing American West has been reengineering its infrastructure to thrive in a world where drought is the new norm. And that vast effort has only just begun.

## REFILLING THE RESERVOIR

Technology and civil engineering projects vary greatly from one community to the next. Some stretch water supplies through reuse. Others seek new sources of water.

Take Las Vegas, for example. About 10 percent of the city's water comes from a local aquifer, the rest from Lake Mead. Yet, despite the reservoir's decline, Vegas feels upbeat about its future.

This is because Vegas has attacked its water dependency along a broad front. It recycles nearly all water used indoors and sends much of it back to Lake Mead. It is allowed to withdraw every gallon of water it adds to the reservoir in addition to its regular allotment.

This is called indirect potable reuse. After wastewater exits the city's buildings, it goes to a large wastewater treatment plant. After mechanical rakes remove any solids, the water goes to settling tanks. There, flocculants sink solids to the bottom, where they are eventually dried by centrifuge and placed in landfills to speed trash decomposition.

Bacteria added to the remaining water break down organic contaminants and remove phosphorus while bubbling oxygen converts the ammonia in urine into nitrogen gas. Water then undergoes filtration through sand and anthracite coal to remove particulates and any remaining phosphorous. The final step involves treating the water with ultraviolet lamps to kill pathogens.

The entire process takes about six hours. The resulting water is not clean enough to drink. Instead, Las Vegas uses some of it to irrigate golf courses, parks, and schools; cool power stations; and suppress dust during construction.

It sends the rest, about 90 million gallons per day, to the 14-mile-long Las Vegas Wash. There, it mixes with rain runoff and shallow groundwater and winds through 200 acres of wetlands that filter out any remaining contaminants before it enters Lake Mead. The city then purifies the water it withdraws to drinking standards.

## INCENTIVES

Recycled, or non-consumptive, water accounts for about 40 percent of Las Vegas' water use. The remaining 60 percent is consumptive water the city cannot reclaim. The two largest consumptive uses are irrigation for landscaping and evaporative cooling systems for hotels, warehouses, and office buildings.

Large irrigation systems, such as golf courses and parks, often use non-drinkable recycled water. Residences, however, use drinking water to irrigate their homes. To reduce use, Vegas limits watering to three nights per week (to prevent evaporative losses during hot days). It prohibits new grass lawns and offers incentives of up to $3 per square foot to replace grass with sand, stone, and native plants that do not need watering. It also limits pool sizes to 600 square feet to prevent evaporative losses that can reach 100,000 to 150,000 gallons annually from 2,000-to-3,000-square-foot "megapools."

The city also targets evaporative, or swamp coolers used to air condition hotels and warehouses. They work by drawing hot air through water-saturated media. As the air heats and evaporates the water, its temperature drops. Swamp coolers transfer heat very efficiently in hot, dry environments but vaporize a lot of water along the way. A large hotel might operate 40 to 50 such units.

Las Vegas put a moratorium on evaporative coolers, says Dave Johnson, deputy general manager of operations for the Las Vegas Water District. It also launched a program that pays companies half the cost, up to $500,000, to convert to more water-efficient mechanical (compression-based) coolers.

The Las Vegas Wash just before its waters enter Lake Mead. Photo credit: Stan Shebs

Mechanical systems, however, use up to 20 percent more energy. This translates into a lot of money, especially for hotels that run them 24/7. As a result, some participants choose to convert to hybrid systems that combine mechanical and evaporative elements to reduce water while managing electricity costs.

"This program has been successful so far, and is really, really good at capturing small to medium-large projects," Johnson says. "We've also worked with people who want to participate on a larger scale, even if it doesn't fit the confines of our policy."

In addition to maximizing consumptive and non-consumptive water, Las Vegas also built a $1.4 billion intake pipe and a low-lake pumping station to draw water from Lake Mead. They will continue to supply water even if the reservoir drops below its former "dead pool" point.

## TOILET-TO-TAP

Other municipalities have also embraced indirect water reuse. Just south of Los Angeles, the Orange County Water District met its needs from local aquifers throughout the 1990s. Today, the county recycles 130 million gallons of partially purified water daily, injecting it into those same groundwaters. This stops seawater from seeping into the aquifer while breaking down contaminants over time.

Los Angeles County itself operates 10 reclamation facilities as part of one of the world's largest indirect water reuse programs. Rather than discharging wastewater to the Pacific Ocean, LA injects some recycled water into local aquifers and sends the rest through purple pipes (so no one confuses it with drinking water) for industrial, commercial, and recreational use.

LA is also building an ambitious series of cisterns in greenspaces around the city to capture stormwater runoff, so the county can treat and reuse it.

According to the LA County Sanitation District, the water it recycles "essentially meets drinking water standards." So, why not purify it the rest of the way? All it would take is an additional ozonation step. After all, injecting mostly pure reused water into an aquifer only re-contaminates it with naturally occurring microbes and chemicals that have leached underground. Moving from indirect potable reuse (IDR) to direct potable reuse (DPR) would simplify processing and save the county money.

Even if the technical argument is straightforward, a process unfortunately tabbed "toilet-to-tap" 30 years ago is clearly not for everyone.

LA, however, might be a special situation, says Lindsay LaBrecque, a water engineer at Jacobs Engineering, a major water project developer. LaBrecque, who grew up in LA and works there now, remembers listening to conservation campaigns as a child. "We've been conditioned to understand water shortages and how serious they are," she says. "I think that has made everyone more open-minded."

DPR hinges on government regulations, which California promises to deliver by the end of 2023. After suffering from severe droughts from 2007-09 and from 2011-17, California is looking for new sources of water. It is not alone. Texas has approved DPR and so has Arizona (on a case-by-case basis). Colorado is considering legalization and so is Florida.

Still, progress is slow. In Texas, Wichita Falls operated a DPR plant for a year in 2014, during a punishing five-year drought. Its 5-million-gallon daily output replaced one-third of the city's drinking water. El Paso, which operated a DPR demonstration plant for eight months in 2016, plans to open a 10-million-gallon facility in 2026.

Los Angeles' demonstration plant opens in late 2024. The facility will purify water from the nearby Glendale water recycling plant but will recycle it through its aquifers to ensure the facility hits safety specifications consistently.

## DESALINATION

Fast-growing San Diego faced many of the same challenges as Los Angeles, but with two critical differences. Much of its water came from the LA-controlled Metropolitan Water District of Southern California. When LA needed water during a 1991 drought, it cut San Diego's allocation by 30 percent. Also, San Diego lacked the type of aquifers needed to recycle water.

San Diego realized that 95 percent of its water came from outside its jurisdiction and attacked the problem along a broad front. In 2003, it signed a deal with farmers in Imperial Valley, who use nearly three-quarters of the water California receives from the Colorado River. The valley's irrigation district distributed much of that through canals lined with packed soil that let water soak into the ground. In exchange for building 58 miles of impervious concrete canals, San Diego received a portion of the 25 billion gallons of water saved annually.

Pressure recovery modules at Poseidon Water's Carlsbad desalination plant in San Diego County.
Photo credit: Poseidon Water


Las Vegas built its own intake tunnel to draw water from the lowest depths of Lake Mead even during drought. Brierley Associates used a custom-built drilling machine to dig out the tunnel. Photo credit: Brierley Associates


Orange County Water District manages the large groundwater basin that provides reliable, high quality groundwater to 19 municipal and special water districts that serve 2.4 million customers in north and central Orange County. Shown here, an array of reverse osmosis cartridges. Credit: Orange County Water District

In 2015, the city raised the San Vicente Reservoir by 117 feet, more than doubling its storage capacity. The reservoir captures runoff from the foothills 25 miles northeast of the city and gives the county, which has scant underground aquifers, a way to recycle water. San Diego is also planning to build a DPR plant to purify more of its water for drinking.

The city's most ambitious project, however, was its water desalination plant, the largest in the Western Hemisphere. Opened in 2015 by Poseidon Water, a Canadian company, it produces up to 54 million gallons per day (20 billion gallons per year) of dependable, drought-proof, drinkable water.

Modern desalination plants are built around reverse osmosis (RO) membranes and pressure exchangers. RO membranes are paper-thin films of inexpensive polyamide (nylon) stretched over a costly polysulfone support layer. The Poseidon plant pressurizes seawater to 1,000 pounds per square inch, forcing it through the spaces between the membrane's long polyamide molecules while leaving the charged salt ions on the other side.

When the plant first opened, it could turn 30 to 40 percent of seawater into fresh water. That has risen to 50 percent today, says Michelle Peters, Poseidon's technical and compliance manager.

It takes a lot of energy to pump 50 million gallons of water through membranes every day. Pressure exchangers reduce those costs. Pioneered by Energy Recovery of San Leandro, CA, these ceramic systems have a single moving part, a rotor. As it rotates, high pressure water exiting the RO membranes contacts low-pressure seawater coming into the exchanger. This accelerates the seawater out of the exchanger, boosting its pressure to 600 psi to 700 psi. Mixing this stream with seawater entering the pump slashes the energy needed to raise its pressure to 1,000 psi by 40 percent, Peters says.

Even so, desalinated water is expensive. It costs about $2,200 to $2,500 per acre-foot (equivalent to 325,000 gallons), about twice as much as piping in Colorado River water.

In times of drought, however, that price could be a bargain, says **Meagan Mauter,** *TX G '06*, research director of the National Alliance for Water Innovation, a desalination technology research hub funded by a five-year, $110 million Department of Energy grant. Desalinated water is always available, even during the worst drought, and San Diego's contract with Poseidon caps the cost. "During a drought, it's better than being extorted for $4,000 by farmers who hold senior water rights," she says.

Sometimes, desalination can even compete with indirect potable reuse. "The only suitable place for San Jose to inject IPR water is the Los Gatos foothills west of the city," Mauter says. "Building a pipeline in a city is expensive and the total infrastructure would cost about $1 billion, if you could get it done with all the right-of-way and environmental issues. It's going to take 15 years to get anything built, and so it's practically impossible."

Desalination plants, however, raise environmental red flags. Their briny discharge may deplete ocean oxygen and harm seagrass, small fish, and other aquatic life. Plant operators insist that locating outlet pipes properly and equipping them with diffusers solves most of these problems. Even so, environmental risk was a key reason Los Angeles voted down a desalination plant in early 2023.

Operating costs also keep costs high. The Poseidon plant, for example, operates 16,000 RO membranes, and they are vulnerable to biofouling, Peters said. To prevent organic matter from gunking them up, they are backflushed frequently.

Even then, the site's RO trains move water from the first to the last membrane in a train. To perform optimally over their five-to-seven-year lifespan, plant technicians must constantly monitor and swap membranes to equalize their exposure to seawater.

Despite their issues, RO membranes are a critical water purification technology. They are essential for purifying seawater and also the brackish water found in estuaries and other places where fresh water meets seawater. Many direct and indirect water reuse plants also use RO membranes to remove salt often found in wastewater.

RO membranes could solve many of the West's water issues. Fortunately, there is still room for improvement.

## ATTACKING COSTS

The National Alliance for Water Innovation is one of several large research organizations looking for ways to improve water resiliency by rethinking water systems as well as RO membranes. Mauter sees several ways to reduce cost.

One possibility involves distributed processing. Rather than release wastewater into a municipal sewer system, she believes large facilities will increasingly recycle water to not-quite-drinkable standards and reuse it for toilets, air conditioning, industrial processes, landscape maintenance, and the like. Many industrial facilities already reclaim water for processing water, heat exchange, cooling, and other applications.

San Francisco makes closed-loop recycling mandatory for new office buildings larger than 100,000 square feet. Salesforce Tower, the city's tallest office building, is an example. Its wastewater processing system takes up 10 parking spaces. In that space, it squeezes filters, a fast, high-pressure biodigester to breakdown wastes, an ultrafiltration membrane to remove particulates and bacteria, and an RO membrane. The system then treats water with ozone to destroy bacteria and chlorinates it to keep it from contaminating the building's water distribution system. Hundreds of sensors monitor the system, inspecting water quality and processing equipment.

Membranes could also use an upgrade. Mauter wants them to run at higher recovery rates without scaling, handle hot industrial water, and stand up to chlorine and acid. She wants materials that are easier to clean.

She also expects breakthroughs in system engineering. "RO-based plants are complex, interconnected systems to operate," she says. "We have been trying to evaluate where a small change in technology could have a large impact on the overall system."

One possibility is membranes that can remove more freshwater and withstand higher brine concentrations. This requires membranes that withstand higher pressures and whose selectivity is tailored to specific applications. Research also shows that better mass and thermal transfer at the membrane's surface has a significant impact on unit operations.

She also wants to see better ways to respond to water emergencies, which are often local. "That would involve inexpensive modular plants that we could run for a year or two and then send it somewhere else it is needed," Mauter says. "That's a very different design space than we are building now."

## SECURING WESTERN WATER

Those design spaces will certainly continue to evolve. Reengineering the West's future water security will bring together the latest technologies, like desalination plants and water recycling systems, and some of its most ancient, like water storage cisterns and dams.

Today, most of that work is confined to cities and suburbs. Yet, agriculture uses much of the West's water. It absorbs 80 percent of the Colorado River's flow, using it to irrigate 15 percent of the nation's farmland and produce 90 percent of its winter vegetables.

Farmers have begun to reduce consumption as water supplies have declined. Some have lined canals while others have switched to spray or drip irrigation. Yet, many farms still flood their fields to prevent the buildup of herbicides, pesticides, and other agricultural chemicals on their land.

Farmers often have senior water rights, but governments may be rethinking that. In Arizona, the state's ire focused on Saudi Arabian companies that grow alfalfa and ship it overseas as fodder for dairy cows. The state recently rescinded two of their water drilling permits.

San Diego County's Pure Water Oceanside plant will purify recycled water to drinking water standards. Along with two sister facilities, the plant will provide more than 30 percent of the city's water supply. Photo credit: City of Oceanside /Jeremy Kemp

Yet, Saudi farmers represent only a small fraction of the problem. Arizona has other farmers who are depleting state aquifers during a drought. In California, it takes about one gallon of water to grow each almond nut, and about 70 percent of them are exported overseas. Eventually, Arizona, California, and every other Western state must either increase water resources dramatically or rethink the type of agriculture it allows and how it allocates water between cities and farms.

No matter what they decide, cost will play a role. "Water is going to be more expensive," Black & Veatch's Schlaman says. "In the past, we had ample supply and low demand. Now, that is tipping and we're going to have to invest in infrastructure to make sure our supplies are sustainable."

"Look what we pay for cable or phones or electricity. Water should not cost one-tenth the amount of those other commodities. If our population is going to grow, we will have to invest."

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