A 1,000-year drought is hitting the West: Could desalination be a solution?

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A hydropower plant on Lake Oroville was shut down when lake levels hit historic lows. Credit: Photo: Frank Schulenberg

The United States and many other parts of the world are reeling under the impacts of severe drought. One possible solution is the desalination of seawater, but is it a silver bullet?

The Western United States is currently experiencing what one paleoclimatologist called "potentially the worst drought in 1,200 years." The region has had many droughts in the past, including "megadroughts" that last decades, but climate change is making dry years drier and wet years wetter. Higher temperatures heat the ground and air faster, and the increased evaporation dries the soil and decreases the amount of precipitation that reaches reservoirs. Warming also leads to less of the snow-pack needed to replenish rivers, streams, reservoirs and moisten soil in spring and summer.

About 44 percent of the U.S. is experiencing some level of drought with almost 10 percent in "exceptional drought." Wildfires currently rage in 13 states, exacerbated by the hot and dry conditions. There have been unprecedented water cuts to the Colorado River—which provides water to seven states—and shutdowns of hydroelectric power plants. The aquifers of towns that depend on well water are depleted, forcing residents to truck in water. Normally, agriculture consumes over 90 percent of the water in many western states, but the drought has caused yields to plummet; some farmers have reduced their acreage or changed crops to less water-intensive ones, while others will likely go bankrupt. Ranchers are having to sell off parts of their herds. But even as the locals contend with these difficulties, more people are moving to the area.

Between 1950 and 2010, the Southwest's growth rate was twice that of the rest of the country. The U.S. population is expected to continue growing through 2040, with more than half of that growth in areas that have experienced severe drought in the last ten years. Many people continue to move to an area expected to get even drier in years to come, just as the latest IPCC report predicts that climate change will intensify droughts in these regions.

Every other continent in the world is also experiencing serious drought, except for Antarctica. And the U.N. has warned that 130 more countries could face droughts by 2100 if we do nothing to curb climate change. But as soon as 2025, two-thirds of the global population could face water shortages, according to the World Wildlife Fund. This could result in conflicts, political instability, and the displacement of millions of people.

The scarcity of fresh water may also make it harder to decarbonize society—something we must do to prevent catastrophic climate change—because some strategies to do this could further stress water resources. Green hydrogen, seen as key to eliminating emissions from aviation, shipping, trucking, and heavy industry, is produced by electrolysis, which splits water into hydrogen and oxygen. However, the process requires large amounts of purified water. One estimate is that nine tons of it are needed to produce one ton of hydrogen, but actually the treatment process used to purify the water requires twice as much impure water. In other words, 18 tons of water are really needed to produce one ton of green hydrogen. Nuclear energy, seen by the IPCC as an important tool for achieving our climate goals, also depends on fresh water for cooling, but as water shortages increase, nuclear plants may be forced to reduce their capacity or shut down.

Where there's water

While most of our planet is covered by water, only three percent of it is fresh water and only a third of that is available to humans since the rest is frozen in glaciers or is inaccessible deep underground. Meanwhile, global warming continues to melt more glaciers each year and increase evaporation, diminishing our fresh water resources.

As a result of water scarcity, some parts of the world have turned to desalination for drinking water. Desalination (desal) involves removing salt and minerals from salty water, usually seawater. This process occurs naturally as the sun heats the ocean—fresh water evaporates off the surface and then falls as rain. Arid regions like the Middle East and North Africa have long depended on desal technology for their fresh water. Today over 120 countries have desal plants with Saudi Arabia producing more fresh water through desal than any other nation. The United States also has a number of desal plants with the largest in the western hemisphere located in Carlsbad, CA. A new $1.4 billion desal plant in Huntington Beach, CA is likely to be approved soon.

Desalination approaches

Desal is usually done one of two ways. Thermal distillation involves boiling seawater, which produces steam that leaves the salt and minerals behind. The steam is then collected and condensed through cooling to produce pure water. The second method is membrane filtration which pushes seawater through membranes that trap the salt and minerals on one side and let pure water through.

Before the 1980s, 84 percent of desal used the thermal distillation method. Today, about 70 percent of the world's desal is done with a membrane filtration method called reverse osmosis because it is the cheapest and most efficient method. In natural osmosis, molecules spontaneously move through a membrane from a solution with less dissolved substances to a more concentrated solution, equalizing the two sides. But in reverse osmosis, saltier water is moving through a membrane to a less salty solution. Because this is working against natural osmosis, reverse osmosis requires high pressure to push water through the semi-permeable membranes. The resulting fresh water is then sterilized, usually with ultraviolet light.

Concerns about desalination

Though desal may be the only solution for some regions, it is expensive, consumes a great deal of energy and has detrimental environmental impacts.

"Desalination of seawater is one of the most expensive ways to get water," said Ngai Yin Yip, assistant professor of earth and environmental engineering at Columbia University. "This has just got to do with the fact that getting salt out of water is not an easy thing to do. But we have to have water—there's just no substitute for water. So it can be costly. But the fact that we cannot survive without water means that it is a necessary cost."

Large-scale desal facilities are very expensive to build and the plants consume a great deal of energy. Thermal distillation plants require energy to boil water into steam and electricity to drive pumps. Reverse osmosis does not require energy to generate heat but relies on energy for the electricity to drive its high-pressure pumps. In addition, the fouling of membranes by less soluble salts, chemicals, and microorganisms can impact their permeability and reduce productivity, adding to maintenance and operational costs.

According to Yip, the most economical way to go about doing desalination is to target sources of water that contain less salt, such as groundwater. "The less salt there is, the less work you need to do to take it out," he said. "So from a purely economic perspective, groundwater would be more economical than seawater." Desalinating groundwater can be done sustainably in places where it is abundant. But where it is decreasing, drawing up groundwater can lead to land subsidence, or in coastal areas, to saltwater intrusion of the aquifer. If there is no groundwater available, Yip feels reverse osmosis of seawater is the best technology to use.

Many Middle Eastern plants, however, use older thermal plants that run on fossil fuels. As a result, desal plants are currently responsible for emitting 76 million tons of CO_2 each year. As demand for desal is expected to increase, global emissions related to desal could reach 400 million tons of CO_2 per year by 2050.

Desal also has impacts on the marine environment because of the amount of brine it produces. For every one unit of pure water that's produced, about 1.5 units of concentrated brine—twice as salty as seawater and polluted with copper and chlorine used to pretreat the water to prevent it from fouling the membranes—results. Globally, each day over 155 million tons of brine are discharged back into the ocean. If brine is released in a calm area of the ocean, it sinks to the bottom where it can threaten marine life. A 2019 study of the Carlsbad desal plant near San Diego that dilutes its brine before releasing it, found that there were no direct impacts on marine life, however, salt levels exceeded permissible limits and the brine plume extended further offshore than permitted.

Improving desalination

Researchers around the world are attempting to solve desal's challenges. Here are a few examples of some of their solutions.

Renewable energy

NEOM is a $500 billion futuristic smart city-state being built in northwest Saudi Arabia along the shores of the Red Sea. To provide water for the estimated one million future residents, it will construct an innovative solar desal system comprising a dome of glass and steel 25 meters high over a cauldron of water. Seawater is piped through a glass enclosed aqueduct and heated by the sun as it travels into the dome. There, parabolic mirrors concentrate solar radiation onto the dome, superheating the seawater. As it evaporates, highly pressurized steam is released and condenses as fresh water, which is piped to reservoirs and irrigation systems. The system is completely carbon neutral and theoretically reduces the amount of brine waste produced. NEOM, expected to be completed in 2025, claims it will produce 30,000 cubic meters of fresh water per hour at 34 cents per cubic meter.

The U.S. Army and the University of Rochester researchers have developed a simple and efficient method of desalinating water also dependent on the sun's energy. Using a laser treatment, they created a "super-wicking" aluminum panel with a grooved black surface that makes it super absorbent, enabling it to pull water up the panel from a water source. The black material, heated by the sun, evaporates the water, a process made more efficient because of its super-wicking nature. The water is then collected, leaving contaminants behind on the panel, which is easy to clean. It can be reconfigured and also be angled to face the sun, absorbing maximum sunlight, and because it is moveable, could easily be used by military troops in the field. Larger panels would potentially enable the process to be scaled up.

European companies are developing the Floating WINDdesal in the Middle East, a seawater desal plant powered almost entirely by wind energy. The floating semi-submersible plant is being built in three sizes, with the largest expected to be able to produce enough water for 500,000 people. The plants can be moved by sea, making them easy to mobilize for emergencies and can be deployed in deeper water where brine disposal would have less impact on marine life. Because they float, they will not be affected by rising sea levels.

Membranes

Membrane research is focused on increasing membrane permeability which would reduce the amount of pressure needed, reducing the fouling that occurs, and making membranes more resilient to high pressure.

A discovery by scientists at the University of Texas, Penn State and DuPont could improve the flow of water through membranes and increase their efficiency, which would mean that reverse osmosis would not require as much pressure. Using an electron microscope technique, the researchers discovered that the densely packed polymers that make up even the thinnest membranes could slow the water flow. The most permeable membranes are those that are more uniformly dense at the nanoscale, and not necessarily the thinnest. The discovery could help makers of membranes improve their performance.

Reverse osmosis desal is hindered when microorganisms grow on the membrane surface, slowing the flow of water. Some coatings that have been used to prevent this "biofouling" of membranes are hard to remove, so they result in more energy use as well as more chemicals released into the sea. King Abdullah University of Science and Technology (KAUST) researchers created a nontoxic coating that adheres to the membrane and can be removed with a flush of high-saline solution.

Desal without membranes

Columbia University engineers led by Yip, developed a method called temperature swing solvent extraction (TSSE) that doesn't use membranes at all to desalinate. The efficient, scalable, and low-cost technique uses a solvent whose water solubility—the amount of a chemical substance that can dissolve in water—changes according to temperature.

At low temperatures, the solvent mixed with salt water draws in water molecules but not salt. After all the water is sucked into the solvent, the salts form crystals that can easily be removed. The solvent and its absorbed water are then heated to a moderate temperature, enabling the solvent to release the water, which forms a separate layer below. The water can then be collected. Yip explained that the process is designed to deal with very salty water, which reverse osmosis cannot handle. For example, the water that comes up during oil and gas extraction can be five to seven times saltier than regular seawater. The textile industry also produces very salty water because of the solutions it uses to dye cloth. According to Yip, TSSE is not the best way to obtain drinking water, but it could help replenish our water resources for other needs.

Brine

Brine impacts can be lessened by how much brine is discharged and how the desal process is carried out.

Stanford University researchers have developed a device that can turn brine into useful chemicals.Through an electrochemical process, it splits the brine into positively charged sodium and negatively charged chlorine ions. These can then be combined with other elements to form sodium hydroxide, hydrogen, and hydrochloric acid. Sodium hydroxide can be used to pretreat seawater going into the desal plant to minimize fouling of the membranes. It is also involved in the manufacture of soap, paper, detergents, explosives and aluminum. Hydrochloric acid is useful for cleaning desal plants, producing batteries, and processing leather; it is also used as a food additive and is a source of hydrogen. Turning brine components into chemicals that have other purposes would decrease brine waste and its environmental damage, as well as improve the economic viability of desalination.

Diluting brine can also lessen its impacts. "You take more seawater, and you premix it [with the brine] in an engineered reactor," said Yip. "Now the salinity of that mix is not two times saltier than seawater. It's still saltier than seawater, but it's lower. And instead of discharging it at one point, you discharge it at several points with diffusers. These are engineering approaches to try to minimize the impacts of brine," he explained.

Other solutions for the drought

Despite improvements in desal's environmental and economic profile, however, it is still an expensive solution to water scarcity. This is especially so given that most water in the U.S. is used for agriculture, taking showers, and flushing toilets. Newsha Ajami, the director of urban water policy at Stanford, said "I disagree with using tons of resources to clean the water up just to flush it down the toilet."

Water recycling

Paulina Concha Laurrari, a senior staff associate at the Columbia Water Center, said "Water reuse definitely has to be an important part of the solution. Our wastewater can get treated, either to potable standards, like it's been done in other parts of the world and even in California, or to a different standard that can be used for agriculture or other things."

Recycling the approximately 50 million tons of municipal wastewater that is discharged daily around the U.S. into the ocean or an estuary could supply 6 percent of the nation's total water use. Recycled water can be used for irrigation, watering lawns, parks and golf courses, for industrial use and for replenishing aquifers. The House of Representatives is considering a bill that would direct the Secretary of the Interior to establish a program to fund water recycling projects and build water recycling facilities in 17 western states through 2027.

The technology to recycle water has been around for 50 years. Wastewater treatment facilities add microbes to wastewater to consume the organic matter. Membranes then are used to filter out bacteria and viruses, and the filtered water is treated with ultraviolet light to kill any remaining microbes. The water can be used for agriculture or industry, or it can be pumped into an aquifer for storage. When it is needed for drinking water, it can be pumped out and repurified. If the water is for human consumption, some minerals are added back in to make it more drinkable.

Waste not

Every year in the U.S., approximately 9 billion tons of drinking water are lost due to leaking faucets, pipes and water mains, and defective meters. President Biden's $1.2 billion infrastructure plan includes substantial sums for upgrading clean drinking water and wastewater infrastructure.

In the U.S., 42 billion tons of untreated stormwater enter the sewage system and waterways and ultimately the ocean each year. This means that the rainwater that could soak into the ground to replenish groundwater supplies is lost. Green infrastructure, such as green roofs, rain gardens, trees, and rain barrels, would reduce some of this water waste.

Sensible water use

It's also important to figure out how to put the water that's available to the best use in a particular area. "For example, having a better planning strategy of what is the best use for water, like what to plant where," said Laurrari. "Instead of using it, say, for alfalfa, how do we use it for higher value crops? Or even tell farmers, "I will pay you not to use this water' and the state can have it to replenish our aquifers or to source cities or something else."

Determining the most reasonable and economical uses for water would help everyone understand and appreciate its true value. "In some of these places where they're having droughts, there are still people who are watering their lawns, and happily paying the fine," said Yip. "So really, there's a mismatch between what is happening and what the reality is. We need to adjust our activities such that we are not putting that kind of a human-imposed strain on the water supply. We need to be thinking about how we make drastic wholesale changes to the way we organize our activities that actually make sense."

Israel's example

Israel is located in one of the driest regions of the world and has few natural water resources, however, it is considered "the best in the world in water efficiency" according to Global Water Intelligence, an international water industry publisher.

Israeli children are taught about water conservation beginning in preschool, and adults are reminded not to waste water in television ads. Low-flow showerheads and faucets are mandatory, and Israeli toilets usually have two different flushing options for urine and bowel movements. The country adopted drip irrigation, which uses half the water than does traditional irrigation while producing more yield. Israel also resolutely attends to small leaks in pipes before they become large. In addition, 75 percent of its wastewater is recycled, more than that of any other country. And because Israelis pay for their water themselves, they are careful about how much they use and readily adopt water-saving technology. As a result, it's estimated that the average Israeli consumes half as much water each day as the average American.

Israel began desalination in the 1960s. Today it has five desal plants with two more on the way and will soon get 90 percent of its water from desal.

While Israel has invested a lot of money in desal, it has also made huge investments in water awareness and water efficiency. These other measures enabled the country to delay building desal plants and build them more economically and smaller than they would otherwise have needed to be because the citizens were already conserving water.

101 things you can do

Here are 100 ways to conserve water.

And one more. "Become more actively involved with the decisions that government makes in terms of investments of infrastructure," said Laurrari, "Because yes, you can conserve water at home, but what is really going to matter is what's done at the larger scale by politicians. So having a more active role, knowing where your water comes from, and what your local issues are is important."

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