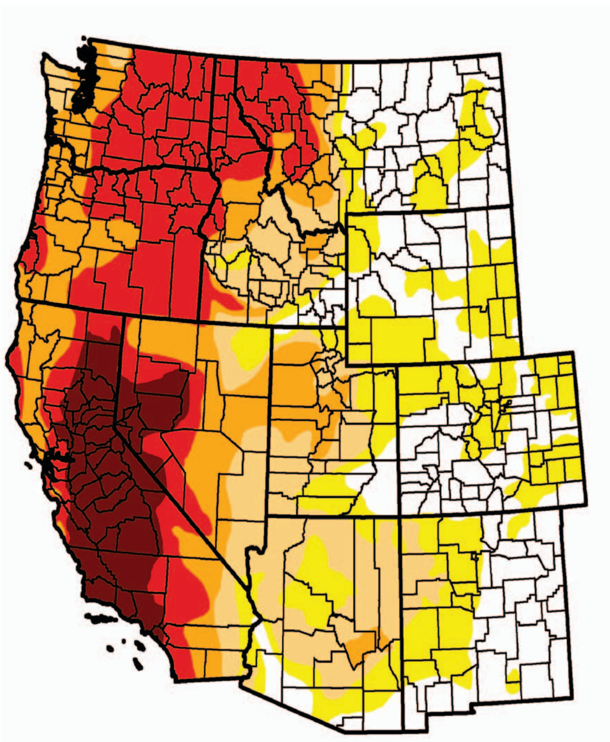
Peak Water? Choices Are Tough in California's Epic Drought

Five times the actual surface supplies are granted in water rights, and groundwater pumping is virtually unregulated. This state feeds the nation. So can we engineer a solution?

By **Trudy E. Bell** (Copyright 2015 Trudy E. Bell)

STARK FACTS: RIGHT NOW, CALIFORNIA is well into the fourth year of the worst drought in anywhere from 500[1] to 1,200 years.[2] Worse, it is on a juggernaut course toward what Gray Brechin, visiting scholar to the Department of Geography at the University of California, Berkeley, characterizes as potentially "apocalyptic" disaster: sucking dry not only its rivers but also its deep aquifers. In Brechin's view, Americans are "not worried enough"[3] about the long-term consequences for the entire country: California grows over half of U.S. nuts, fruits, and vegetables and a quarter of its meat and dairy products, plus 15% of U.S. agricultural exports.

On the supply side, many technological solutions have been proposed to tap sources of water undrinkable in their normal state, including desalination (drinking from the Pacific Ocean) and direct and indirect potable reuse (drinking from the toilet). But nagging technical and health concerns underlie those technologies. Moreover, ensuring water supply is only half the problem.



Map: Severe multiyear drought (red) or, the worst, exceptional drought (maroon) is afflicting half a dozen western states, with California suffering the worst. Credit: U.S. Drought Monitor. Insets: Billboards from agricultural interests are everywhere around the Central Valley. Photos: Trudy E. Bell

Yet, on the demand side, addressing the laws and public policies of water rights and water use has been called a political "third rail"—instant political electrocution for any legislator suggesting limitations to agriculture. Nonetheless, effective and lasting solutions for the state, and even the country, must squarely address the demand side—because many experts agree that even heavy rainfall during a strong El Niño year (as observations suggest 2015–2016 may be) is unlikely to reverse conditions: over the long term, climate models indicate that dryer weather is very likely California's new normal.

Here are some eye-popping stats for non-Californians. The 900-mile-long state now has a population topping 38.8 million and counting—that's 12% of the nation's and bigger than all of Canada's. Its annual gross domestic product is \$2.3 trillion; if it were a country unto itself, its economy would rank eighth in the world, virtually tied with Brazil's. Its land area of nearly 164,000 square miles is bigger than Japan's.

Two Main Watersheds

Topographically, the state consists of the Cascade Range to the north, the roughly north-south Coast Range of lower mountains along the west coast, and the high Sierras down the eastern border. Between the parallel mountain ranges lies the broad, flat Central Valley, varying from 40 to 60 miles wide and extending for 450 miles. This enormous valley—not much smaller than West Virginia—accounts for only 1% of U.S. farmland, but it is so fertile it raises more than a quarter of the nation's food.

Hydrologically, the Central Valley consists of two main watersheds: the Sacramento Valley (making up the relatively water-rich northern third by area) and the San Joaquin Basin (the dryer southern two-thirds), both named after the rivers that drain them. The Sacramento River flows south from Shasta Lake near the Oregon border, while the smaller San Joaquin River flows north from out of the eastern-central Sierras. The two rivers mingle in the thousand-square-mile marshy Sacramento–San Joaquin Delta tidal estuary between Stockton and Sacramento and then flow out to the Pacific Ocean through the San Francisco Bay. The southernmost part of the large San Joaquin Valley includes the Central Valley's driest hydrologic region, the Tulare Basin.

Climatologically, most of California's precipitation falls November and March: if no rain or snow falls then, the rest of the year is parched. Three-quarters of its rain and snow fall in the Cascade and Sierra mountains, Before and after images three years apart of Lake Oroville, California's second-largest reservoir for the State Water Project, illustrate the depth of the multiyear drought. *Photos: California Department of Water Resources.*

averaging from 50 inches of precipitation in the northern Sierras down to less than 30 inches in the southern Sierras. Three-quarters of California's population, however, lives in the coastal and southern regions. Rainfall in the flat Central Valley itself ranges widely from an annual average of about three feet (about the same as northern Ohio) in Redding at its northern edge down to under 6.5 inches near Bakersfield. Thus, much of the southern San Joaquin and Tulare basins are climatologically a desert: arid land that averages below 10 inches of rain per year.

An Engineered Landscape

Because of the Central Valley's deep, fertile, well-mixed topsoils and mild winters as well as California's booming population, the federal and state governments built two enormous water storage and transportation networks to convey meltwater and rainfall runoff from the water-rich north to the arid south. In the 1930s, the U.S. Bureau of Reclamation undertook its biggest-ever earth-moving project: the Central Valley Project (CVP), now consisting of 20 dams and reservoirs—the first and largest being Shasta Dam and Lake—plus more than 600 miles of canals, primarily to convey surface water to agricultural lands in the Central Valley. In the 1960s, California began constructing its own comparable State Water Project (SWP), consisting of another 21 dams and reservoirs—including the mighty Oroville Dam, tallest in the nation at 770 feet high—plus more than 700 miles of aqueducts, primarily to distribute drinking water to coastal urban areas including San Francisco and Los Angeles; about 30 percent of the water is also used for Central Valley agriculture. The two systems share water at several points. In addition, five other major aqueduct systems running from east to west, built between 1913 and 1949, add more dams and another 1,000 miles of canals to convey water from the Sierras or the Colorado River to the coast.

One last point: in discussing large volumes of water resources, hydrological engineers use some specialized units. The acre-foot (variously abbreviated "af," "ac-ft," "acre-ft") is the volume of water needed to cover 1 acre 1 foot deep in water; in round numbers, 1 af is a bit less than 44,000 cubic feet, or just shy of 326,000 gallons. In metric, the unit of choice is a cubic decameter ("dam^3"), a volume 10 meters on a side or 1,000 cubic meters. In round numbers, 1 dam^3 is about 0.8 af. In human terms, at the average California residential water consumption of just under 200 gallons per day per person (half of which goes for residential and commercial landscaping), 1 af represents roughly a day's supply for a small town of about 1,600 people, or a bit more than enough water for a family of four for a year. And 1 million af (1.25 million dam^3)—about the capacity of the CVP reservoir Folsom Lake—would supply the entire state population of nearly 39 million people for about six weeks, assuming no losses to evaporation or leaks and no industrial or agricultural use. Thus, in a year, the population alone consumes some 8.7 million af. The federal CVP system delivers about 7

Winter snowpack in the Sierras is nature's annual deposit into California's hydrological checking account; snowmelt then waters the state through the hot, dry summer. Natural color image at left, made March 27, 2010 with NASA's Aqua satellite, showes the last year of average snowpack at the end of winter. Image at right shows minimal snowpack this March 29, 2015 (most of the white is clouds). Note also the Central Valley's change in color from green to increasing brown.

million acre-feet per year (afy) from north to south and the state SWP another 2.3 afy; the five east-to-west projects collectively convey 5.1 afy; all seven systems total about 14.4 million afy.

Taken together, "the 2012–2014 drought is the worst in our combined NOAA-NADA estimate and 2014 is the single most arid case in at least the last 1200 years," report scientists writing in *Geophysical Research Letters* in December 2014.[2] Meteorologically, a drought is an extended period of below-average rainfall; hydrologically, it is an extended period of below-average runoff. California is no stranger to droughts. Indeed, the absolute lowest annual precipitation in the Sierras since official record-keeping began around 1895 was in 1923–1924 as part of the prolonged dry period that brought the Dust Bowl. Although annual precipitation since 2011 has remained above those levels, "high temperatures have combined with the low but not yet exceptional precipitation deficits to create the worst short-term drought of the last millennium for the state of California."[2]

First, in the seven months from July 1, 2013 through January 31, 2014, winter rainfall in the San Francisco Bay Area was less than that recorded for the same period in Death Valley.[4] In February 2014, hydrologists monitoring Folsom Lake—recall, this federal CVP reservoir is in the water-rich north—projected that for the first time in 60 years, water levels risked falling below the water pump intakes that summer, a "dead pool" situation that would have turned off all water supply to the state capital of Sacramento and much of the irrigation water in the northern Central Valley. In 2015, Folsom Lake continued to be critically low: the U.S. Bureau of Reclamation ordered water flows out of the reservoir to be halved.

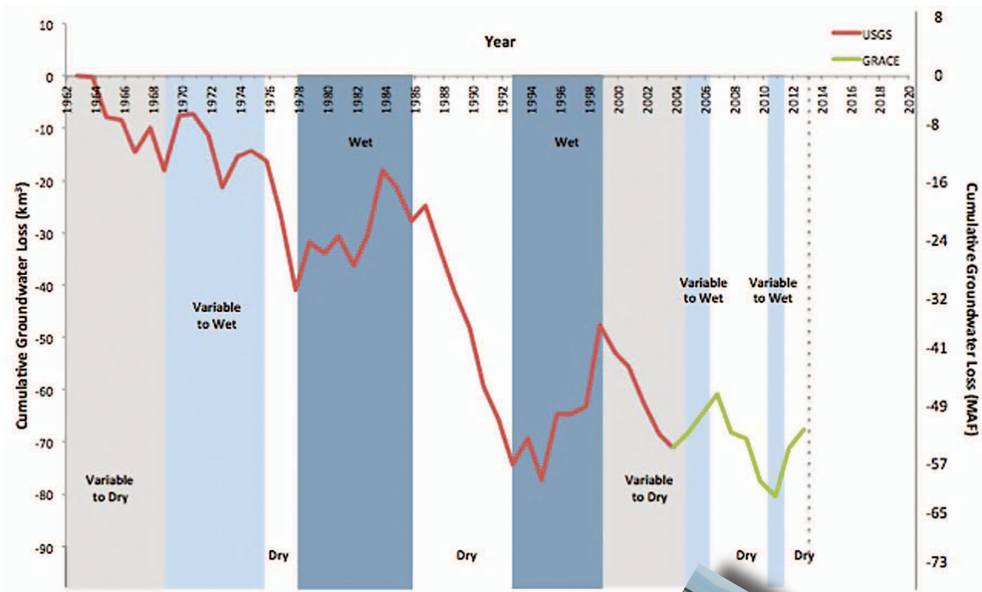
Second, the drought has been hot: both summer and winter temperatures in California have been above historic seasonal norms, part of a half-century trend toward higher average annual temperatures. Heat exacerbates drought: it accelerates evaporation from soils, vegetation, and water bodies; it warms lakes and rivers, stressing fish and other species; it increases demand for irrigation (more on that in a bit); and it reduces mountain snowpack. This last is especially grave, as bountiful snowpack in the Cascades and the Sierras feeds rivers that distribute water throughout the state for the rest of the year, usually supplying 30 percent of the state's water needs. Indeed, all western states rely on winter snowpack to supply up to three-quarters of their water and Los Angeles relies on meltwater from as far away as Colorado and Wyoming. But heat delivers a double whammy: mountain runoff river flow is sensitive not only to snowpack but also to how much water is taken up by trees and vegetation. In frigid winters, higher-elevation species go dormant; in warmer winters, mountain vegetation remains active longer, thickening and expanding above the tree line, also reducing river runoff.[5]

Third, human water demands are stressing diminished supplies to an unprecedented extent. During those record low-rainfall years in the 1920s, California's population was about a tenth what it is today. By 1950, it was still only 10 million. But today, its population is increasing faster than any other state and is on track to reach 50 million before 2050. That is the equivalent of adding both New York City and Los Angeles—the country's two biggest cities—to the state's existing population.

First-ever Statewide Mandatory Restriction

In winter 2015, NASA remote sensing satellites and its Airborne Snow Observatory plus manual ground measurements documented that statewide snowpack in the Sierras—which typically peaks in early April—was only 5% of normal, based on records going back to 1950: its water content was only 1.4 inches, compared to a historical average of 28.3 inches.[6] Thus, on April 1, speaking from a snow-free Sierra peak at an altitude of 6,800 feet, Governor Edmund G. Brown, Jr., announced an executive order for the first-ever statewide mandatory water restriction across the state: 25% below 2013 usage for potable urban water through February 2016.

But that 25% mandatory water reduction does not apply to agriculture, which accounts for 80% of water used



Groundwater pumping has caused land in the Central Valley to sink so much that this bridge over the Delta-Mendota Canal nearly touches the water. *Photos: Trudy E. Bell.* Graph shows cumulative groundwater loss in cubic kilometers since 1962. *Graph: USGS and NASA GRACE.*

in the state.[7] Even if urban water use went to zero, it wouldn't nick that lion's share. And therein lies the potential for true disaster.

Today, in the severe drought's fourth year, Californians now obtain over 60 percent of their water from aquifers deep underground—the state's hydrological long-term savings account. Groundwater is being pumped to the surface faster than double its recharge rate,[8] gambling that at some future time enough snow and rain will fall so the aquifers can recharge. In 2010, before this drought, the U.S. Geological Survey documented that California's massive groundwater pumping amounted to 12.3 billion gallons per day, or about 4.5 trillion gallons per year.[9] That's a geologically significant volume: equivalent to 13.8 million af, or 17.3 million dam^3, or 17.3 km^3, or 4.1 cubic miles per year. For perspective, that magnitude of groundwater pumped—independently confirmed by measurements from NASA's twin Gravity Recovery and Climate Experiment (GRACE) satellites[10]—is just shy of the total annual volume of surface water conveyed by all seven of California's aqueduct systems, and nearly 20% of all groundwater pumped in the United States.[11]

Sinking a Foot Per Year

That wholesale removal of groundwater is also having geologically significant consequences. A battery of instrumentation technologies—including continuous GPS monitoring, vertical extensometers, interferometric synthetic aperture radar (InSAR), laser light detection and ranging (LIDAR), the Canadian Space Agency's Radarsat, GRACE, and standard surveying—all document that the annual removal of cubic miles of groundwater is causing the overlying land to subside (sink), by an *average* of a foot per year, and as much as 2 inches per *month* in some regions of the San Joaquin Valley.[12] The greatest rate of subsidence extends from north of Mendota to south of Bakersfield, an area of about 5,200 square miles—almost the size of the state of Connecticut. The subsidence is visibly affecting built infrastructure, including cracking and buckling some areas of the concrete water-transport canals themselves or locally deviating their slope—an engineering concern because in the miles between pumping stations they are gravity-fed at very slight slope.

As if that were not ominous enough, GRACE has also documented that the removal of such mass of groundwater is allowing hydrostatic uplift of the Coast Range: the mountains are literally rising 1 to 3 millimeters per year—enough to reduce stress locking the San Andreas fault, thereby increasing risk of seismic failure.[13] This wholesale repositioning of California's geology is, to quote the U.S. Geological Survey, "the largest human alteration of the earth's surface"[14]

This fast groundwater pumping has lowered the water table so far that in the San Joaquin and Tulare basins, some private and municipal drinking water wells are running dry. In some locations, wells for agricultural irrigation now are being drilled to unheard-of depths of 1,000 to 2,500 feet[15] before reaching water—some only to tap fossil groundwater laced with arsenic and other toxins. Gravest of all, as the groundwater is removed at record rates, the weight of soil layers overhead is collapsing and inelastically compacting the aquifers, permanently diminishing their water-holding capacity *for all time*. Thus, even if/when enough rain will fall again to soak down deep through the soil layers—and for long enough (at least two years for every year the pumping rate has been double the recharge rate)—to completely recharge the aquifers, their now-diminished full capacity will hold less water than originally. This means less of a buffer against future droughts. And the

Pressure vessels containing reverse osmosis membranes are the heart of the Carlsbad Desalination Plant, to start supplying 8 percent of San Diego County with desalinated ocean water by mid-2016. *Photo: Poseidon Water*

rate of drilling and pumping has accelerated since 2011. According to Jay Famiglietti, NASA JPL senior water scientist, "We may only be a few decades away from hitting bottom."[16]

Every day, seemingly limitless volumes of Pacific Ocean water roll up along California's coastline. Why not remove the salt from the seawater to produce drinking water, as is already done in Australia, Chile, Israel, and Saudi Arabia? Some 17 California communities are either building desalination plants or looking into their possible viability as drought-proof water supplies.

Late in 2015, a new $1 billion Carlsbad Desalination Plant, the nation's largest, was completed 35 miles north of San Diego and began half a year of testing. Some 100 million gallons (about 300 af) per day of seawater passes through 18 gravity-driven anthracite-sand filter beds and then through micronic filters to remove suspended particulates. Next, high-pressure pumps force the clean, salty water through reverse osmosis (RO) membranes—the heart of the desal plant—at about 1,000 psi. The membranes pass pure water but reject most salts and dissolved minerals, separating the seawater into two roughly equal streams. The desalinated pure water is further treated—pH-balanced, disinfected (chlorinated), fluoridated, etc.—and mixed with the other drinking water piped to homes and businesses. Meanwhile, the separate stream of brine—very clean but now about twice as salty as natural seawater—is diluted with other seawater in a huge mixing pond before being discharged into the surf zone, where it rapidly mixes back into the coastal Pacific. In mid-2016, the Carlsbad plant will begin producing up to 50 million gallons of drinking water per day (about 56,000 afy), supplying the needs of up to 400,000 people, about 8 percent of San Diego County.

But desalination poses nontrivial engineering challenges (and environmental concerns about sucking in ocean organisms and discharging brine) that have put some projects on hold. Its biggest practical problem: the process is an energy hog. It requires massive power to mechanically shove seawater through the RO membranes at 1,000 psi, as well as operate intake and discharge pumps. The good news: energy-recovery technologies reclaim a good share of pressure energy from the high-pressure brine stream to partially pressurize the next block of incoming filtered seawater. For the Carlsbad plant, this energy recovery system saves a net of 15 MW, augmented by another 1 or 2 MW of power generated onsite by photoelectric solar panels. However, even after those savings, the Carlsbad plant still draws 36 MW of power, accounting for about a third of the cost desalinating the water. Out the door, the water is estimated to run $2,000 per acre-foot; that's less than a penny per gallon, but more than the current cost of importing water from the northern Sierras or Colorado River.

Voracious Power Demand

Desalination's voracious power demand—and associated carbon dioxide emissions if fossil fuels generate the electricity—especially for the number of people ultimately served, concerns many coastal communities. The economics of desalination are steep enough at the Pacific Coast, where seawater supplies and water-drinking communities are collocated. But they become prohibitive if the desalinated water is destined for the Central Valley, meaning it must be lifted over the Coast Range (water is heavy: a pint's a pound the world around). Already, nearly 20% of California's electricity—48 terawatt-hours per year—is consumed in manhandling water around the state. The huge draw has been dubbed the water-energy nexus. The drought itself is driving higher energy costs as groundwater is pumped up from ever-deeper wells.

Another proposed solution is recycling treated sanitary sewer wastewater in several different ways.

According to the *2013 California Plumbing Code,* recycled or reclaimed water is "nonpotable water that meets California Department of Public Health statewide uniform criteria for disinfected tertiary recycled water." Quick definitions: Primary water treatment is mechanical sieving or removal of gross suspended solids and sediments; secondary treatment is removal of dissolved organic or biological materials, commonly through use of beneficial microbes; tertiary is a somewhat woolly term meaning any further treatment such as disinfection (e.g., chlorination), but can range up to "full advanced treatment" (FAT)—a term from the California Department of Public Health that includes microfiltration, reverse

A dying orchard stands across the road from a living orchard near Wasco just north of Bakersfield. The difference between them? One is being irrigated. *Photo: Trudy E. Bell*

osmosis, and an advanced oxidation process.[17] Tertiary treated wastewater is usually discharged downstream into waterways and out to sea.

One big idea is not to discharge the treated wastewater downstream as effluent, but to use it immediately for tasks not requiring potable water: watering parks and freeway medians, cooling towers, flushing of public toilets and urinals, etc. In 2013, the California State Water Control Board issued a Recycled Water Policy that set goals for rapidly increasing the state's use of recycled water over 2002 levels by at least 1 million afy by 2020 and 2 million afy by 2030. A rapidly increasing use for nonpotable recycled water is agriculture: irrigating crops, including root crops where the water touches the edible food, and forage for dairy or beef cattle.[18] Of growing concern to some is the fact that some nonpotable recycled water for agriculture includes treated oilfield (fracking) wastewater,[19] legally applied to 10 percent of food crops grown in Kern County in 2015, and not required to be tested for such problematic compounds as acetone, heavy metals, and radioactivity.[20]

Another big idea is indirect potable reuse (IPR): injecting the treated sanitary wastewater into upstream drinking water aquifers or reservoirs for later withdrawal and purification for drinking water. Orange County has been doing exactly that with its Groundwater Replenishment System since 2008, producing 100 million gallons per day. Las Vegas drinks another form of IPR water: the city's treated wastewater flows into Nevada's drinking water reservoir Lake Mead for later withdrawal. In 2013, San Diego completed an IPR demonstration project in which treated wastewater was directed into its Advanced Water Purification Facility, which discharged 1 million gallons per day of treated water into San Vicente Reservoir before being withdrawn with other reservoir water for customary treatment to produce drinking water. It plans to break ground in 2019 for a commercial-scale IPR plant to produce 30 million gallons per day by 2021, and ultimately 83 million gallons per day—a third of San Diego's needs—by 2035.

But what has really grabbed headlines in the drought is "toilet to tap:" direct potable reuse (DPR), where treated sewage wastewater does not go through an aquifer, reservoir, or other environmental buffer, but is piped right back into the regular drinking water treatment plant and out to customers' kitchen sinks. Pilot plants experimenting with treating wastewater to drinking water standards include the Silicon Valley Advanced Water Purification Center. Some studies suggest that DPR would be cheaper than either importing water from northern California or the Colorado River (the two sources that currently supply 85% of San Diego's water) or desalination; others indicate it would still be around $2,000 per af.

Depending on the level to which sanitary wastewater is treated and the technologies used, however, some experts have raised concerns about both IPR (questioning whether it could degrade the quality of water naturally occurring in aquifers) and DPR. The main concern for human exposure is not the impurities or pollutants for which water is already routinely tested, but those for which it is not—and which routinely get washed down bathroom and kitchen sinks and garbage disposals or flushed down the toilet, not to mention down the drains of industrial plants and hospitals. Endocrinologists are concerned about endocrine-disrupting chemicals that can interfere with any of the body's hormone systems. These include oral contraceptives, steroids, and other prescription drugs (which get excreted); engineered nanoparticles in cosmetics and other personal care products (especially antimicrobials such as nanosilver); and plasticizers such as PVC and BPA—all contaminants of emerging concern (CECs). Endocrine disruptors can act even in trace concentrations—parts per trillion or even less—comparable to what is found in advanced treated sewer water; moreover, some compounds can become more concentrated if the same water is repeatedly recycled, of particular concern for DPR.[21] The California State Water Resource Control Board Division of Drinking Water acknowledges concerns about CECs and is currently exploring the feasibility of developing criteria for DPR.[22]

Water Rights And Wrongs

California and other western states allocate surface water rights according to a doctrine called "prior appropriation," whose foundational principle is "first in time, first in right." That was codified into a hierarchical legal system in 1914, in which farmers or other users with "senior" rights (rights to river waters granted before 1914) get priority; any later users have "junior" rights, meaning they must wait until senior users get their allocations first, which can be problematic in dry years. (In contrast, many eastern states follow a system of "riparian rights," where anyone with land abutting a waterbody, no matter when acquired, may use the water at any time.)

Historically, however, California has routinely overestimated how much water its rivers actually carry—by a lot. In 2014, a University of California study calculated that rights have been granted to *five times* more water than the state's actual mean annual runoff and *up to 100 times* the actual surface water supply in some basins.[23] This colossal and chronic overestimation of actual water supply has precipitated a feeding frenzy of bitter competition pitting agriculture against cities and both against the environment, with the result that all parties are losers as rivers and wells are being sucked dry. Like the proverbial canary in the coal mine—a small creature heralding a big warning—83% of California's native species of freshwater fish including Chinook salmon and steelhead trout are threatened with extinction in the very near future unless at least enough water is released from dams to keep streams flowing above critical minima.[24]

The groundwater situation is even worse. Until 2014—the third year of this epic drought—California was the only state in the union with absolutely no policy or regulations governing groundwater pumping: it was simply first come, first served, as much property owners could pump—and until summer 2015, records of pumping were not public.[25]

In 2014, California adopted the Sustainable Groundwater Management Act (SGMA). The new law requires municipalities to create local groundwater sustainability agencies by 2017, come up with management plans for critically overdrafted groundwater basins by 2020 (and all other basins by 2022), and to implement practices to achieve complete sustainability in all basins by 2040. The good news: the law empowers the agencies to register groundwater wells, measure and regulate pumping, require reports, assess fees, and other mechanisms to ensure compliance. The bad news: none of that touches groundwater pumping for several years—deliberately, so that growers and other users can "get through the current drought,"[26]—and full sustainability for the state's groundwater is not required for a *quarter century*.

The big under-recognized problem is that, hydrologically speaking, surface waters and groundwater are connected.[27] Massive pumping of groundwater dries up groundwater-fed streams and rivers. Deeper wells draw groundwater from under neighboring properties, causing other people's and towns' water wells to run dry. Rapid depletion of the state's groundwater in this totally legal free-for-all has been called "a tragedy of the commons."[27]

Moreover, major agricultural interests have made two strategic planting decisions that further lock in intensified groundwater demand.

First, responding to lucrative global marketing demand more than drought, they continue to raise water-intensive crops: not only almonds (which recently got bad PR for annually needing a gallon of water per nut), but also rice (California growers are pushing to export rice to Asia) and—thirstiest of all—alfalfa and pasture for beef cattle. Altogether, the state's five most water-intensive crops—alfalfa, almonds, pistachios, pasture, and rice—demand 14.8 million afy, *more than half* (52%) of agriculture's total annual water use (28.6 afy), with alfalfa and pasture alone accounting for 8.3 afy.[29]

Second, nearly two-thirds (64 percent) of California's 2015 crop value comes from fruits and nuts. Thus, farmers are planting more orchards of lucrative fruit and nut trees instead of row crops such as vegetables. For almonds alone just since 2000, Central Valley land area has nearly doubled from 510,000 to 890,000 acres, with the average number of trees per acre increasing from 99 to 114.[30] This widespread move from annuals to perennials is significant for California's water budget and hydrologic vulnerability: with annual row crops, in a drought year farmers can let fields lie fallow (unplanted) and consume no water—but trees must be irrigated every year, *especially* during drought.

But wait, there's more. California produces 100 percent of U.S. almonds, walnuts, pistachios, dates, figs, kiwi fruit, and olives.[30] California also grows 82% of the almonds in the entire world. But under a third are consumed within the United States; indeed, for the 2015 harvest, *70%* of California's almonds are to be exported to other countries.[31] Now, that inevitably means that *70% of California's water* devoted to raising almonds this year is also being exported. That comes to about 2.1 million afy—almost the total annual volume of surface water transported by California's SWP aqueducts, enough to supply the city of Los Angeles plus the entire San Francisco Bay Area for a year.

Now, almonds are not a staple food without which people anywhere in the world are starving—indeed, the Almond Board of California markets them as a midmorning snack food. So from a public policy viewpoint, one has to ask: in this epic drought, is exporting such monumental volumes of California water—whether in the form of almonds or alfalfa or any other water-intensive crop—a prudent long-term choice for the survival of the state?

An insightful *New Yorker* cartoon by Robert Mankoff comes to mind. It depicts a speaker at a business luncheon standing at a lectern and concluding: "And so, while the end-of-the-world scenario will be rife with unimaginable horrors, we believe that the pre-end period will be filled with unprecedented opportunities for profit."[32]

Not Just California's Disaster

Droughts don't stop at state lines. Indeed, according to the USDA's U.S. Drought Monitor, this drought overspreads many western states, with "exceptional" (the worst measure) or "extreme" (second worst) drought also afflicting parts of Nevada, Oregon, Washington, Idaho, and Montana. As part of this larger drought, Nevada's Lake Mead, the nation's largest reservoir—impounded behind Hoover Dam, and supplying water to Nevada, Arizona, and California—is lower than ever recorded in its eight-decade history.[33] Moreover, in July 2015, research from NASA's GRACE satellites revealed that a third of global groundwater basins are rapidly being depleted by human consumption despite the fact that people have no idea how much—or little—water they hold and how much is left; in the U.S., the Central Valley aquifer system is stressed worst by far, but next worse is the larger Atlantic and Gulf Coastal Plains aquifer on the east coast (who knew?).[34]

Is the apparent solution to the drought of pumping groundwater a mirage, like this apparent lake over a dusty field?
Photo: Trudy E. Bell

What's the answer? Pray for rain? At this stage, even a good soaking winter will not be enough to end California's drought. Moreover, rain will help only if it falls far enough north to be captured by the CVP and SWP reservoirs; rainfall in central or southern California would grant only a brief respite for local areas, or even create mudslides if rain falls intensely on slopes denuded of vegetation from drought or wildfires, as happened north of Los Angeles in mid-October. This drought might end only after a run of at least four years of above-average rainfall[35] plus cold winters bringing deep, water-packed snow to the Cascades and Sierras—and also to mountains in other western states, if Los Angeles's snowpack meltwater supply is to be ensured.

Droughts Likely to Increase

How likely is such a run of wet years? Not very. Computational climate simulations suggest that droughts are likely to increase in frequency and intensity. The Scripps Institution of Oceanography at UC San Diego estimates that by 2100, April 1 winter snowpack like 2015's essentially will be the new normal.[36] It's happened before. That same study of tree rings from California's centuries-old blue oaks that revealed this is a 1,200-year drought also reveals that between 800 and 1300 AD, before written meteorological records, California suffered two "megadroughts" of several decades each.[2]

So, one has to ask: what if California's drought continues? A study with exactly that title published by the Public Policy Institute of California in August did not offer comfort about the economic impacts. Can technology help? According to some experts, engineering offers no silver bullet, but possibly offers "silver buckshot."[37] While high-tech desalination and potable reuse have grabbed headlines for new water supplies, several humbler but important approaches not yet widely implemented could offer significant savings in supplies the state already has.

You can't manage what you don't measure. Studies have repeatedly shown water use drops 15% to 25% if apartments are individually submetered and billed for water use rather than having water included in rent. In Los Angeles where 62% of residents rent—but 90% of apartment complexes have just a master meter—submetering could save huge volumes of water. Detecting and plugging leaks—especially underground leaks in utility systems—could yield a similar big win. But major water utilities don't even have a handle on how much water is being lost from their urban distribution systems. Various analyses suggest urban utility losses could be 10% of deliveries, or some 1 million afy. Very likely it's much higher.[38] That magnitude of water leaked away statewide could supply all of Los Angeles with water for a year. Added to that should be untold leaks along California's thousands of miles of aqueducts and canals, whose concrete is cracking and buckling because of age, earthquake tremors, and land subsidence.

But supply and conservation technologies can't do it alone. Nor can urban areas. Truly needed are creative and *fast* industry-scale agricultural solutions that could slash the state's water consumption by half or more. Some solutions are technological. Indeed, some already exist and are even partially implemented, such as highly efficient irrigation techniques (microsprinklers and drip irrigation). More universal acceptance is needed.

Other solutions involve policy and behavior. State agencies need to reevaluate the water rights granted against measured actual—and far less—surface water supplies. And they need to start tracking groundwater *now*. At current rates of consumption, California's water supplies may not last for 25 years while waiting for the SGMA sustainability deadline. Right now, agricultural concerns must stop behaving as though groundwater supply were infinite—a situation described as "a slow-moving train wreck" by Richard Howitt, UC Davis professor emeritus of agricultural and resource economics and lead author of a 2014 study on the drought's economic impact. "A well-managed basin is used like a reserve bank account," he explains. Instead, "we're acting like the super rich who have so much money they don't need to balance their checkbook."[39]

Moreover, just because a business plan looks profitable doesn't mean it's sane—not for the state, nor even for the survival of the business itself beyond the current year or the next. Already the drought has forced farmers to stop watering entire orchards so they wither and die—a costly loss; but given the dry climate outlook, once those dead trees are ripped out, why repeat the mistake by planting yet more trees that lock in high water demand? Does raising cattle make sense in a region routinely so dry every summer that pasture land must be watered and cattle fed irrigated alfalfa? Already some California cattle concerns have realized that cows can graze more cost-effectively in parts of the nation where it rains year-round. And export California's water as luxury crops or hay? Plug that drain.

Last, in light of the long-term prospect for increased western drought, the nation at large needs to drought-proof its food supply by rethinking its heavy reliance on the Central Valley. The water-rich Midwest and eastern states can—and used to—raise many of the vegetables and fruits now predominantly raised in California (California's market edge is its ability to grow veggies in winter). Any durable, sustainable solution for both California and the U.S. must re-engineer national agricultural policies—notably removing subsidy disincentives to allow other states to turn away from corn and soybeans and return to diversified crops. It won't be easy or cheap: the technologies for planting and harvesting other crops are not the same. But there is precedent: once tobacco subsidies were removed decades ago, the tobacco-growing states diversified their crops quite profitably.

After all, points out UC Berkeley's visiting scholar Gray Brechin, "when there's no water—well, *there's no water.*"[3]

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