SUSTAINABILITY

THE RADICAL GROUNDWATER STORAGE TEST

New tactics for capturing floods and surviving droughts could help communities across California and the world

By Erica Gies

Illustration by Bomboland

Erica Gies, a fifth-generation Californian, writes about science and the environment from Victoria, British Columbia, and San Francisco. Her work appears in the *New York Times,* the *Guardian,* the *Economist,* and elsewhere.

"Seventeen is closed, Skyline is closed, nine is closed, 152 is closed,"

my mom tells me at a restaurant in San Jose, Calif., rattling off highways between the San Francisco Bay Area and the Pacific coast, where I'm scheduled to drive the next morning. Last winter's torrential storms turned California's hillsides so sodden that they slid down over roads, cutting off communities. Between October 2016 and February 2017, the state saw about double the seasonal average annual precipitation. North of Sacramento, more than 188,000 people were forced to evacuate their homes as the Oroville Dam overflowed, eroding a giant crater into its spillway and threatening to release one of the state's biggest reservoirs. "I can't remember ever seeing it like this," my mom says, echoing the amazement of millions of longtime Californians.

It was a head-spinning reversal from the previous five years, when, at times, 100 percent of the state was in a drought. Empty reservoirs and brown lawns created a subconscious drumbeat: scarcity, scarcity, scarcity. The fear was palpable: Can we continue to live here? Can we support new residents? Should we continue to grow food for the world? The deluges first brought relief, then growing unease. But California water managers, still traumatized by the years of want, saw opportunity. They wondered: Can we capture all this extra water and save it for the next drought?

That question reflects a new reality. Although California has historically cycled between droughts and floods, scientists say climate change is making both phases more intense. Also, warmer temperatures are already reducing the Sierra Nevada's snowpack, predicted to shrink by up to 90 percent, which spells trouble. Most of the state's precipitation falls in the winter; summers are usually dry. On average, snow supplies 30 percent of California's human water consumption, melting slowly through the spring and summer, just when it is needed the most. And in the future, snow is expected to fall as rain, creating even more flooding in the winter and even less water supply in summer. Rapid population growth complicates these wilder swings: more people are living in the paths of floods and are demanding water during droughts. Water managers know they must alter their strategies.

Worldwide, changing precipitation patterns and rising population are impelling adaptation. Millions of people who have relied on snowpack and trickling glaciers—Asians living around the Himalayas, Europeans alongside the Alps, South Americans by the Andes—will also need new ways to capture floods to protect infrastructure and to store water for later.

In California, like other places, new reservoirs cannot solve the problem. "We've already dammed most rivers," says State Water Resources Control Board chair Felicia Marcus. But there is plenty of room underground. Aquifers—large water deposits—that have been depleted by farmers' pumping from progressively deeper wells, have 10 times the capacity of California's 1,400 reservoirs. And storing water underground is a comparative bargain, about one-fifth the cost of building reservoirs. A constellation of forward-thinking people in science, agriculture, conservation and public policy are designing ways to actively store water underground on an unprecedented scale, to reduce flood damage while increasing reserves.

Winter floods and spring melts once spread out across the Central Valley, gently percolating down into aquifers and feeding riparian forests and vernal pools that supported dense salm-

IN BRIEF

California could better survive flood years and drought years by capturing floodwaters and using them to recharge underground aquifers that farmers and municipalities now pump from when rains are scarce.

To do so, water users and managers have to regard surface water and groundwater as one connected resource.

A variety of test projects are proving that this approach can work. For example, farm fields can be flooded even when crops are growing so the water can percolate down into aquifers. Revising water rights and paying landowners to allow flooding can help the techniques work across California and the world.

THIS PAGE AND OPPOSITE PAGE: COURTESY OF JUDAH GROSSMAN *The Nature Conservancy*

PROLONGED DROUGHT had left California's Cosumnes River Preserve floodplain exceedingly dry. But when winter rains this year raised the river (*on horizon*), a gap cut in the levee there augmented flooding so more water could percolate through the ground to recharge the aquifer below.

on runs, elk, grizzlies and clouds of birds. That all changed in the 20th century, when California became arguably the apex of water engineering hubris. Massive dams, reservoirs, aqueducts, canals, levees and pumps changed the plumbing of the entire state and caused countless unintended consequences. This intensive infrastructure made possible modern California, but the recent drought and floods exposed how ill prepared this system is to handle current realities. One key weakness is that by cutting off rivers from their floodplains to protect cities and farms, engineers have greatly cut the recharging of aquifers.

Now managers and engineers are seeking to return, somewhat, to nature's way, by letting land flood in a controlled manner. Implementing this vision would require a shift in the dysfunctional "mine! mine!" culture that has long characterized water use in California. There are signs of motion. A groundbreaking state law passed in 2014 puts more responsibility for careful management on local water users, establishing a statewide vision while allowing local flexibility. Similarly, in an about-face from large waterworks, the new approach would be a patchwork of thousands of grassroots recharge projects across individual water basins.

To that end, scientists and local managers are running pilot projects to study how to exploit each site's unique hydrology, land use and financial accounting. They are searching for solutions that can serve multiple masters—for example, flooding farm fields to recharge aquifers at times that do not harm crops and that benefit wildlife.

Dry places around the world watch one another's water innovations closely: drip irrigation developed in Israel, Australia's overhaul of water rights and trading. This is California's move.

THE PUMPING MIRAGE

SUCCESSFUL PROJECTS START WITH correcting long-term misunderstandings about basic hydrology. This past April, after four months of big storms, California's drought had retreated to just 9 percent of the state, and Governor Jerry Brown declared it over. But "that's a surface-water-centric way of looking at it," says Sandi Matsumoto, associate director of the California water program at The Nature Conservancy (TNC). An aquifer and the lakes, rivers and streams on the surface above it are actually the same water, intricately linked by gravity and hydraulic pressure. The truth, Matsumoto says, is that even though California surface waters may look replenished this year, aquifers are still extremely depleted from decades of farmers and municipalities aggressively pumping up water. "It will take us decades, if not half a century, to recover from what we've done," she says.

Underground water, called groundwater, supplies about 60 percent of the state's demand during dry years and 30 percent in average years. Neither of those rates is sustainable because surface water percolating down to restore groundwater cannot keep up. More than half of the earth's largest aquifers have exceeded tipping points, according to a 2015 study of NASA satellite data.

That is worrisome because most of the pumped water helps farmers fill the world's food baskets. If these lands fall fallow because of groundwater depletion, it would be catastrophic, given that the United Nations Food and Agriculture Organization estimates we need to *increase* global food production by 70 percent to feed a projected 9.1 billion people in 2050.

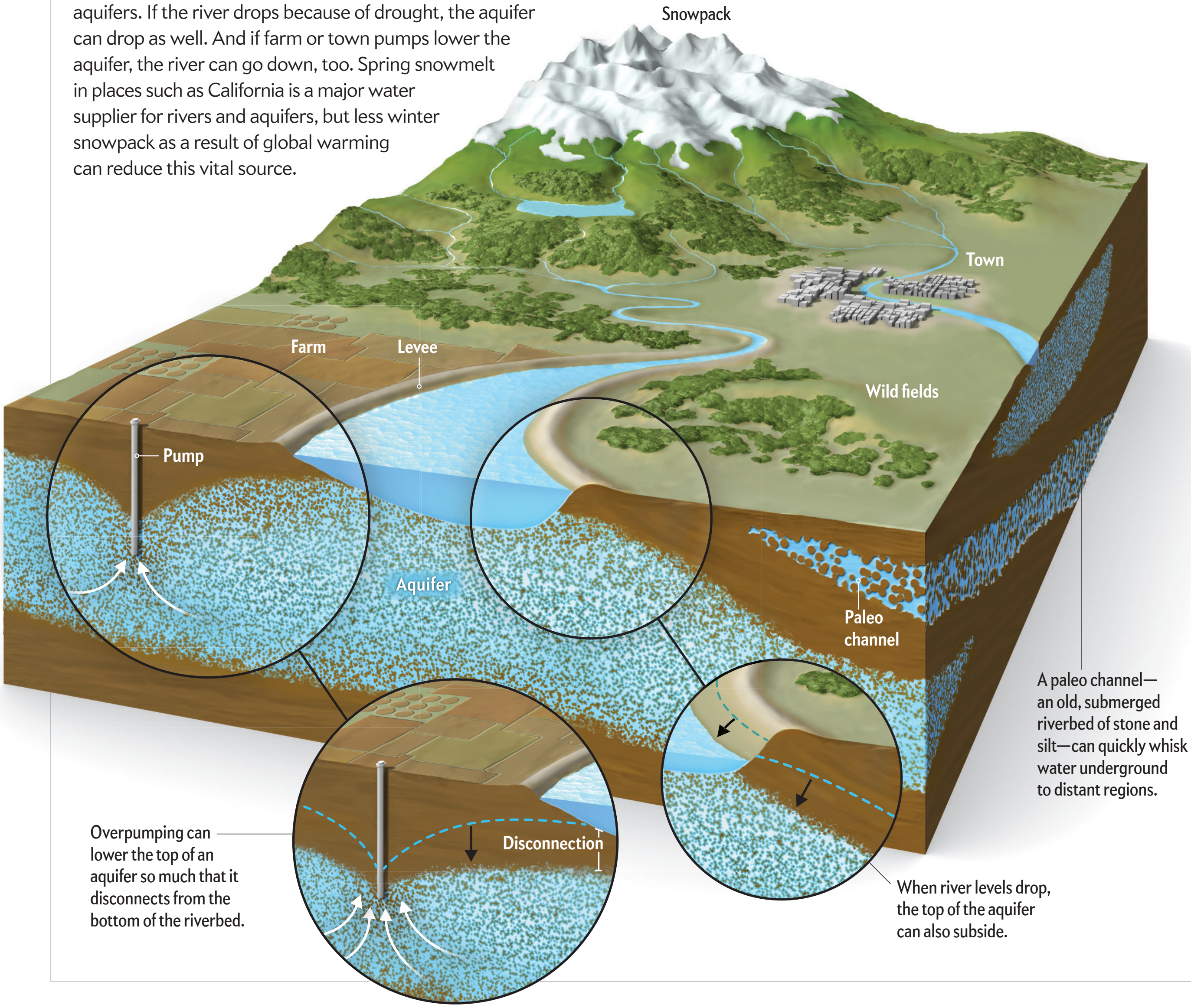
For more than a century California managed only its surface water. Groundwater, in contrast, was a property right: you could dig a well on your land and pump all the water you needed, regardless of how that affected your neighbor's supply. This management schism treated surface water and groundwater as two separate resources, even though a full aquifer can help feed a river's flow during the dry season, and when groundwater sinks, river water can filter down to replenish it.

Pumping a sunken aquifer can therefore deplete surface water, the very problem that spurs farmers and cities to pump in the first place. In the San Joaquin Valley, water tables have fallen so far belowground in some places that they have become functionally disconnected from the streams they once exchanged water with, says Helen E. Dahlke, professor of integrated hydrologic sciences at the University of California, Davis. The disconnect also harms aquatic species by drying up wetlands, seeps and springs. Groundwater recharge could reconnect some aquifers with their rivers, making the whole hydrologic system more resilient. These multiple benefits are "the way we make it in the future," Marcus says, "as opposed to us each fighting for our molecule of water."

This ethos sets California's new test projects apart from earlier storage approaches that treated aquifers as a water bank: if you made a deposit, you would get an equal withdrawal. The problem is that water does not necessarily stay in a tidy underground basin waiting to be pumped out when needed. For the state's new vision to become reality, people will have to shift their notion of water ownership to something more communal. Spain, for example, has demonstrated that kind of thinking, says Alvar

One Big Water Supply

Surface water and groundwater are intimately connected. Water in rivers and creeks often percolates down into groundwater aquifers. If the river drops because of drought, the aquifer can drop as well. And if farm or town pumps lower the aquifer, the river can go down, too. Spring snowmelt in places such as California is a major water supplier for rivers and aquifers, but less winter snowpack as a result of global warming can reduce this vital source.



Escriva-Bou, a Spanish-born research fellow at the Public Policy Institute of California (PPIC) Water Policy Center.

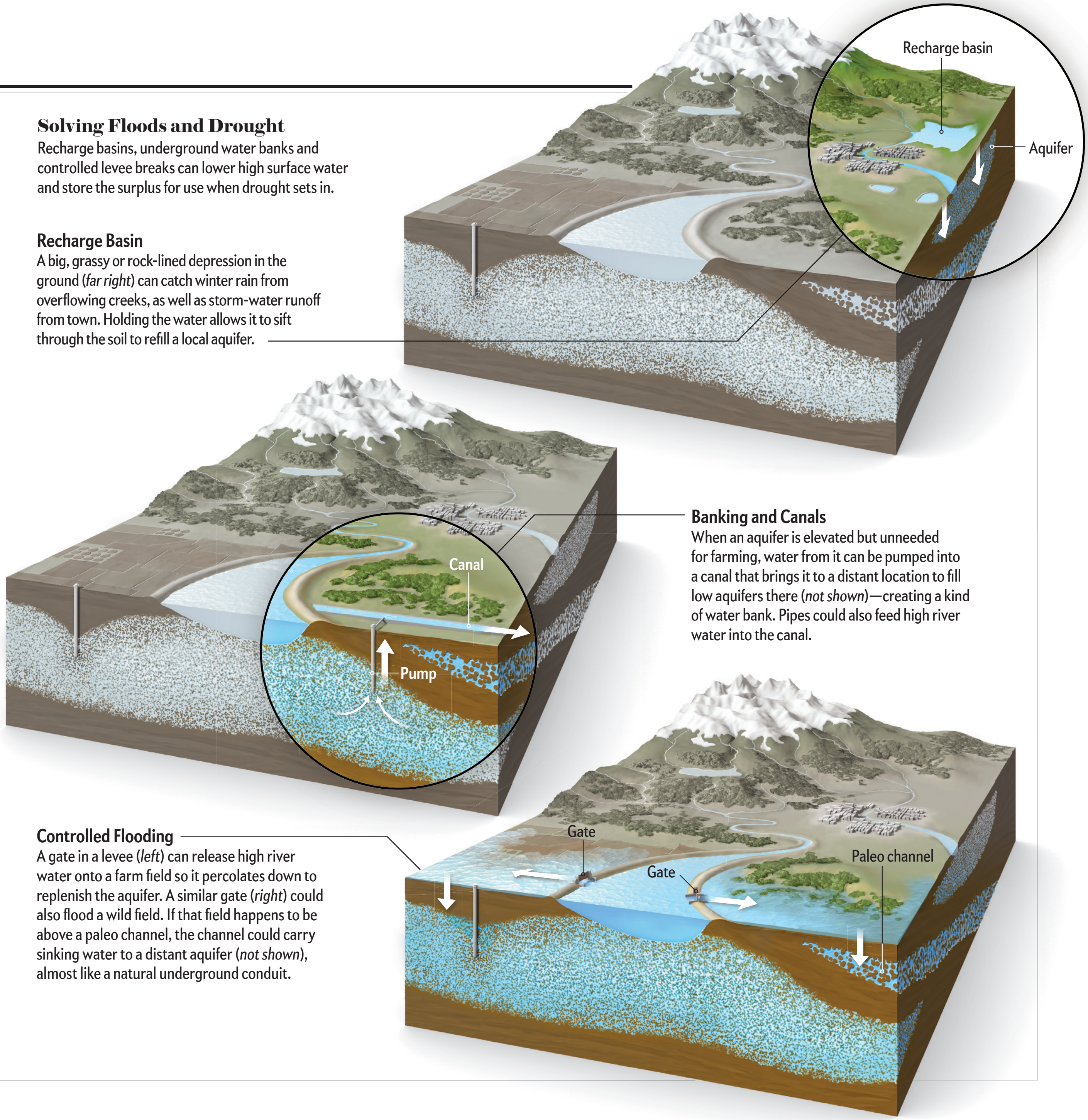
THE REVOLUTIONARY COMPROMISE

CALIFORNIA'S WATER RIGHTS were considered politically inviolable until the recent drought, when the panicked pumping it induced cracked open a door. After decades of trying, the state legislature passed the most significant water reform in a century: the 2014 Sustainable Groundwater Management Act (SGMA), pronounced "SIG-ma." The act prescribes management at the level of groundwater basins—three-dimensional areas that include surface water and the permeable aquifer below. California has 515 basins, but just 127 of those account for 96 percent of groundwater pumping, so the state has prioritized them for better management. Each basin must form a groundwater sustainability agency, craft a groundwater sustainability plan by 2022 and manage groundwater sustainably by 2040. That target is challenging because most basins lack robust data collection, says Tara Moran, who oversees sustainable groundwater work at Stanford University's Water in the West program.

The SGMA rules encourage recharge by requiring cities and irrigation districts to stop depleting groundwater. "Most groundwater sustainability agencies would prefer to do groundwater recharge rather than restrict pumping," says Esther Conrad, a postdoctoral researcher at Water in the West who has been attending local water meetings across the state.

For inspiration, the agencies can look to communities that had to reckon with troubled basins decades ago. One of those is

Illustration by Emily Cooper



Solving Floods and Drought
Recharge basins, underground water banks and controlled levee breaks can lower high surface water and store the surplus for use when drought sets in.

Recharge Basin
A big, grassy or rock-lined depression in the ground (*far right*) can catch winter rain from overflowing creeks, as well as storm-water runoff from town. Holding the water allows it to sift through the soil to refill a local aquifer.

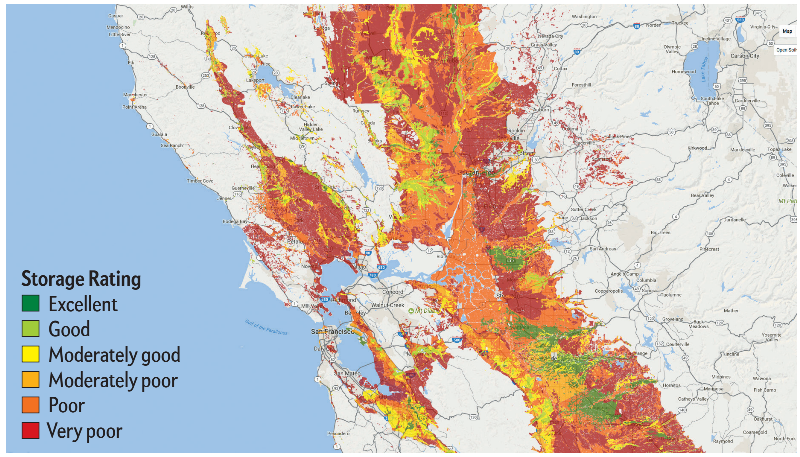
Banking and Canals
When an aquifer is elevated but unneeded for farming, water from it can be pumped into a canal that brings it to a distant location to fill low aquifers there (*not shown*)—creating a kind of water bank. Pipes could also feed high river water into the canal.

Controlled Flooding
A gate in a levee (*left*) can release high river water onto a farm field so it percolates down to replenish the aquifer. A similar gate (*right*) could also flood a wild field. If that field happens to be above a paleo channel, the channel could carry sinking water to a distant aquifer (*not shown*), almost like a natural underground conduit.

Santa Clara Valley, known today as Silicon Valley. In the 19th and 20th centuries it was called the Valley of Heart's Delight, a nod to its stone fruit orchards—Blenheim apricots, Bing cherries, Burbank plums. To keep the crops viable during dry summers, farmers pumped groundwater enthusiastically. The hurrah was short-lived. Between 1890 and 1920 water levels plummeted and the land surface sagged. Downtown San Jose dropped 13 feet.

Local leaders decided to try to refill aquifers by capturing heavy water flows that would otherwise rush through creeks and rivers to the ocean. Just as beavers dam a stream to create a pool, human engineers built partial walls across Page Creek in Los Gatos, using burlap sacks filled with dirt. The structures created ponds alongside the creek that gave the water time to percolate underground. Earthen dams followed, such as the 34-foot-tall Vasona Percolation Dam across Los Gatos Creek. Heavy rains might flood the town park surrounding the dam, allowing extra recharge without threatening homes or businesses. The water projects halted land subsidence and receding groundwater levels. But the valley's population boomed after World War II and beyond, and the district needed more water than the ecosystem naturally offered. It built pipes to the massive canals constructed by the state and federal government to route northern California water southward, securing an extra share.

Today the Santa Clara Valley Water District benefits from recharge basins—barriers people built alongside more than 90 miles of local creeks that will slow rushing water so it swells the banks and sinks into the ground. The district has an additional 300 acres of freestanding percolation ponds, which fill with water piped in from nearby creeks when they are high. Recharge really showed its value during the recent drought; groundwater provided 51 percent of the county's water in 2014, even though the state water shortage was acute.



BEST WATER STORAGE: Allowing floods in certain California areas would maximize the water that seeps down into underground aquifers for storage. The best sites (*green* and *yellow*) are flat and have permeable soil that drains quickly and will not become compact.

SOURCE: SOIL AGRICULTURAL GROUNDWATER BANKING INDEX, UNIVERSITY OF CALIFORNIA DIVISION OF AGRICULTURE AND NATURAL RESOURCES; COURTESY OF ANTHONY O'GEEN AND HTTPS://CASOILRESOURCE.LAWR.UCDAVIS.EDU/SAGBI/

GO WITH THE FLOW

AN OBVIOUS QUESTION ABOUT widespread groundwater recharge is, Where will the water come from? "Most people's [water-rights] permits are for planting and growing season," Marcus explains. "There's plenty of excess water in winter." A study published by Dahlke this past July confirms that there is enough to resupply Central Valley aquifers.

The challenge is to move the water, when it pours, to where it can be absorbed underground. In California, more water falls in the winter in the north, and more water is used in the summer in the south. Yet the big engineered canals and aqueducts that start up north and fill irrigation systems in the south are underused in winter when fewer growers need to irrigate. The infrastructure could send excess winter water to southern farm fields for recharge rather than allowing it to flow out to the ocean.

Another possibility is reverse banking. Comparatively water-rich areas such as farms around the Sacramento River would pump groundwater when it is plentiful during wet years to irrigate crops and send their surface water southward via the infrastructure to recharge the needy aquifers there, says Ellen Hanak, director of the PPIC Water Policy Center. The accounting would be tricky, though. Managers still need to work out compensation techniques before that practice would become widespread.

Capturing excess winter water is also difficult "because everything is saturated and every reservoir is full," Hanak says. But some stretches of land are already set up to function as flood-relief valves, and increasing their area could allow recharge right there or serve as short-term storage until pipes or other structures could move the water to refill storage sites farther away. To get a sense of what that might look like, I traveled in February to the Sacramento–San Joaquin Delta, where those two mighty northern and southern rivers meet, meander and ultimately empty into San Francisco Bay. For more than a century individual farmers remade this marsh-scape by pushing up earthen levees, creating farmland protected from river floods.

When I arrive, I meet Josh Viers, a watershed scientist at the University of California, Merced, at the Oneto-Denier restoration site in the Cosumnes River Preserve. Two experts join us from TNC, including Judah Grossman, director of this project. We walk atop an earthen levee, flanked on either side by floodwater three to six feet deep. Valley oaks, cottonwoods and bushes rise out of the water close to us. Beyond lie flooded fields that TNC is restoring to native habitat. This flood was augmented because engineers in 2014 removed 750 feet of levee to help the Cosumnes River fill this part of its floodplain when waters run high.

Last winter was the first real test of the removal. Hydrogeologist Graham Fogg of the U.C. Davis Center for Watershed Sciences set up instruments to measure the groundwater recharge. When the floodwater receded, Fogg's students calculated that the flooding had recharged groundwater three times more than typical from rain and irrigation. The area that flooded is relatively small, only about 285 acres, yet this past winter's storms resupplied more than 2,000 acre-feet of water. Upstream, the work has already inspired people to begin similar projects. And at a nearby site Viers is also studying how native fish are benefiting from this type of floodplain habitat.

FARMING WATER

BECAUSE MUCH OF THE CENTRAL VALLEY is now farmed, scientists are studying how to safely flood farm fields. A good agricultural recharge site has various qualities, including a fairly flat surface so water can infiltrate evenly; permeable soil that moves water underground quickly; and soil relatively free of salt, pesticides or nutrients that could taint groundwater. And before growers get onboard, they need assurance that water applied to fields at carefully orchestrated times will not harm their land or crops.

U.C. Davis's Dahlke is conducting test floods that measure plant and root health, water infiltration rates, and salt and nitrate levels. On an alfalfa field in northern California's Scott Valley, she applied water across three- to four-acre test patches at different frequencies: one to two days a week, three to four days a week, or continuously from February through April. Over the course of the winter's trials on the entire 15-acre field, she recharged about 135 acre-feet. "More than 90 percent of applied water went to deep percolation," she says. And the alfalfa yield was not affected. An unexpected side benefit: the flooding flushed out gophers, who "really like to eat alfalfa," Dahlke laughs.

She is testing other crops on working farms, including almonds, even though conventional wisdom says they are sensitive to water sitting on their roots. After deliberate flooding in winter and early spring the onset of blooms, as well as the timing of leaf out, was consistent with adjacent nonflooded groves. "This is already a good sign," Dahlke says.

Keeping nutrients and pesticides out of recharged groundwater is another challenge. That will require timing fertilizer applications away from flooding "so you're not creating a monster in the process," says Thomas Harter, another hydrologist at U.C.

Davis, who co-authored a seminal report to the state on groundwater pollution.

One grower has been way ahead of the scientists, inspired when he noticed that a neighboring vineyard, flooded for months after heavy rains in 1983, still reaped a good harvest. Don Cameron manages Terranova Ranch, a 7,000-acre farm southwest of Fresno in the San Joaquin Valley that grows 25 different conventional and organic crops, almost entirely with groundwater. In 2011 and again this past winter, the local Kings River Water Association allowed Cameron to take high water that its members were not using. He funneled it via canals to fallow fields and to those full of alfalfa, wine grapes, walnuts, almonds and pistachios. It worked: crops were unharmed, and sensors installed by an engineering firm showed that at least 70 percent of the water passed below plants' root zones, en route to the aquifer. State and federal grants are allowing Terranova Ranch to add canals and pumps so it can flood its entire acreage in the future.

Farmers wishing to follow Cameron's lead could face more difficulty in taking winter water. In most places, farmers will need a permit, and getting one is a lengthy process. Part of the delay is antiquated data. "Information about water rights is contained in 10 million paper files stored at the State Water Resources Control Board and scattered among 58 county courthouses around the state," says Michael Kiparsky, director of the Wheeler Water Institute at the University of California, Berkeley, School of Law. It is not an accident that water rights languish on paper in an epicenter of digital culture. Rights holders tend to think the less others know about their water usage, the better. Kiparsky and Richard Roos-Collins of the Water and Power Law Group in Berkeley, Calif., are now working with the state to develop a database that would make it easier for regional water boards to look up water rights for a given stream and to understand which water is already spoken for—or not—when considering new permits.

PAY DIRT

OTHER INNOVATORS ARE GREASING the wheels by paying farmers to participate in groundwater storage. On a sunny, clear day last September, I visited a submerged fallow field on Knaggs Ranch northwest of Sacramento with Matsumoto and Mark Reynolds, lead scientist for TNC's California migratory bird program. Water burbling from an irrigation pipe tapped into the nearby Sacramento River creates something of an "instant habitat: just add water" effect across 129 acres, attracting birds, insects and frogs. A flock of dowitchers swoops in for a landing. Fat, orange-brown dragonflies buzz by, and a dramatic V of sandhill cranes sweeps overhead.

Migratory water birds depend on flooded agricultural land for 60 percent of their needs. But because they are just passing through, the birds need the water for only a few weeks. The Knaggs Ranch flooding is part of a TNC program called BirdReturns that rents flyway habitat from farmers and floods them for two-week periods during the fall and spring migration seasons. "It's an Airbnb idea," Reynolds says.

TNC is expanding its program, now partnering with farmers over severely depleted aquifers. For example, a 206-acre flooding of a rice farm last fall, postharvest, helped Merced Irrigation District recharge an estimated 180 to 250 acre-feet of groundwater, using permits it already held for winter water. Over four years TNC conservatively estimates that BirdReturns has recharged about 20,000 acre-feet of water.

Along the coast, U.C. Santa Cruz hydrogeologist Andrew Fisher came up with another creative solution to pay farmers for recharge. Later in February, I drove to his pilot project in Pajaro Valley, south of Santa Cruz, taking my mom's advice by detouring around the area's washouts via Highway 129. The rolling hills and farmland here supply artichokes, berries and leafy greens around the world. But there is little surface water; growers rely almost exclusively on pumped groundwater. In the 1980s overpumping was already a big problem, so the state created the Pajaro Valley Water Management Agency and empowered managers to charge water users to pump groundwater. The money is used to build and manage infrastructure that improves water supply and quality and to meet environmental and legal rules.

Fisher's project diverts excess rainwater from fields and surrounding foothills into a four-acre recharge basin. Last winter his team recorded about 140 acre-feet of infiltration. The storage earns farmers credit against their future groundwater pumping charges, much as utilities credit customers with rooftop solar panels for surplus power that they send to the grid.

On Fisher's advice, the Pajaro Valley Water Management Agency credits growers 50 percent of the infiltration rate, a cautious figure to account for water that would have seeped down without their efforts and for infiltrated water that is "lost" underground to the wider hydrologic system. "Instead of arguing about who owns water, why don't we claim the win based on the hydrologic benefit?" Fisher asks. "It's everybody's water because it goes into the basin that everyone is pumping from. Everybody wins."

Because that collective spirit has been the exception in California's fractious water scene, people running these pilot projects expected resistance. But they were wrong. "There's way more interest than we can handle," Fisher says. With BirdReturns, initial hesitance gave way after word from early adopters got out in the community. After four years, Matsumoto says, the project has gotten twice as many bids as it can use.

These successful early projects show that groundwater recharge can have multiple benefits, and their success encourages others to follow. They also illustrate that if anything can change dysfunctional water culture, it is community empowerment. "Hydrology is as much about understanding people as it is about science," Harter says. "Communities are much more open if they can take ownership of the idea." Along with the pressures of SGMA to actually manage groundwater, these innovators are revealing that the culture of scarcity can evolve into something more holistic, where cities, farms and nature have enough. SA

MORE TO EXPLORE

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