MIT Technology Review

The water issue

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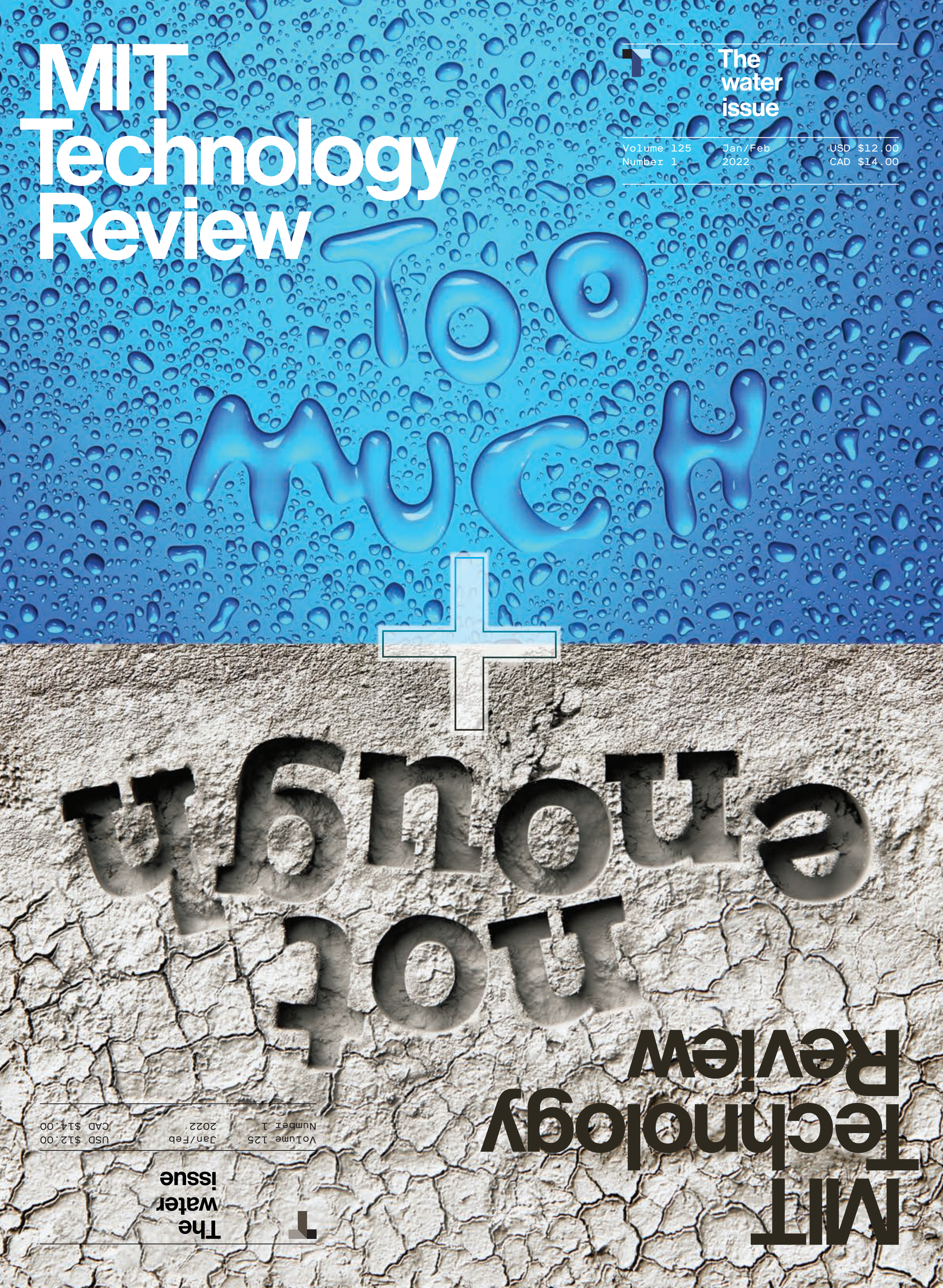

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Not a drop to drink

As we were closing this issue, I came across a video on Twitter of a highway just outside Vancouver, submerged in water. It wasn't the only one. The densely populated urban heart of British Columbia was cut off from the rest of Canada by flooding and mudslides after an atmospheric river barreled through. The country's busiest port lost access to rail service, stranding containers. Hundreds of motorists had to be rescued from slide-isolated highways on military helicopters. The only way to get to the rest of the country by road was to detour through the United States.

The deluge followed a hot, dry summer that saw the numerous cities throughout the region blast through long-standing temperature records as a heat dome blanketed much of the Pacific Northwest. By the end of August, drought had settled in across the province. Vancouver Island, home to old-growth temperate rainforests, hit level 5 drought conditions, British Columbia's most severe categorization. Hundreds of wildfires left the region covered in ash and the city itself choking in smoke. The charred landscape left by the summer's drought made the fall's floods that much worse. Watching that video of a highway covered in brown, muddy water, it occurred to me that I was viewing a sad microcosm of the premise of this issue: The way very many of us will initially experience climate change will be through water—either too much of it or not enough. We will flood. Or burn. Or both. This issue brings you stories of the way changes to the water cycle are playing out all over the world as we begin to experience climate change.

MIT Technology Review senior editor James Temple tackles the complexity and uncertainty of this change in his feature story on how warming waters are disrupting the Atlantic currents, and the scientists who are attempting to understand what may be coming next. It may not be *The Day After Tomorrow*—but, well, it ain't gonna be great.

Other stories look at a parched American West. Mark Arax takes us on a beautiful if heartbreaking tour of California, where people spent much of the past 150 years capturing water and piping it to support farms and cities, only to have the well run dry. Casey Crownhart traveled to El Paso, Texas, the "drought-proof city," where she found burst pipes and empty reservoirs side by side with desalination plants.

Changes to water and climate affect all of us, and sometimes in surprising ways. Kendra Pierre-Louis exposes rising groundwater, an often overlooked threat in coastal areas that's intricately linked to sea levels. It could have devastating consequences for our infrastructure, from sewers and gas lines to seawalls themselves.

For her book on water and climate change, Devi Lockwood spoke to more than 1,000 people in 20 countries about the ways they are experiencing change firsthand; she explains why it's important for the scientific community to listen to those voices. It's also why you'll find stories from Cape Town, Mexico City, the Volga River, Zimbabwe, and Karachi in this issue.

Mat Honan is editor in chief of MIT Technology Review

ROBYN KESSLER

From the outset, we didn't want this issue to be a paean to doomerism. Erica Gies went to China to meet with Yu Kongjian, the influential landscape architect whose vision for "sponge cities" would restore the ebb and flow of the water cycle to urban areas. Maria Gallucci takes us to space, where satellites are measuring water in the Congo River basin. And Megan Tatum has the details on Singapore's ambitious plans for water independence.

Finally, in this issue's fiction, Robin Sloan takes on the question of how it's all going to work out. I'll leave it up to you to interpret his ending.

As always, I appreciate your feedback. You can reach me at mat.honan@technologyreview.com or on Twitter, where I am @mat.

Thank you for reading.

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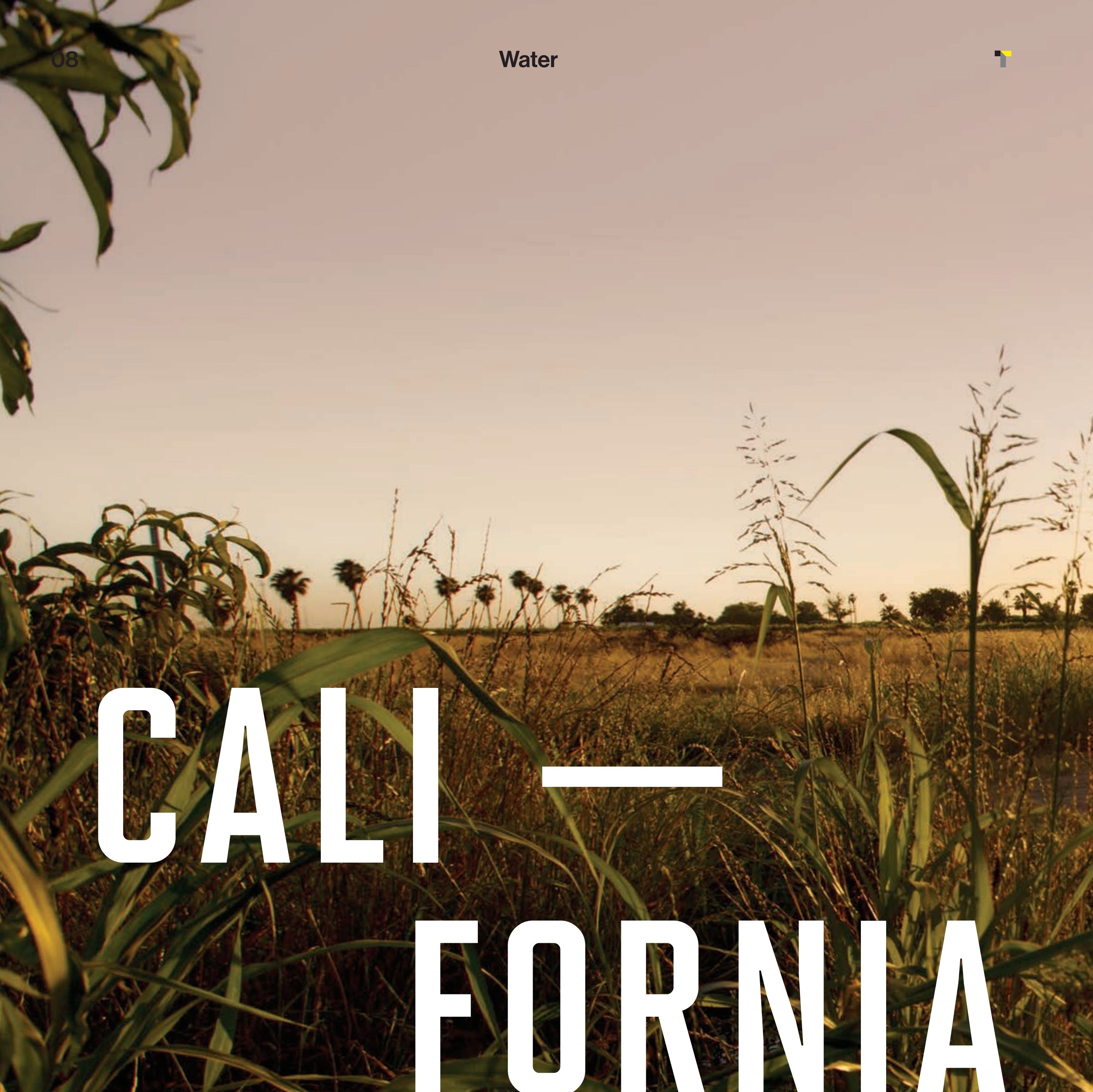


CALI— FORNIA DRY

HOW WE REMADE THE LAND AND TOOK THE WATER UNTIL THERE WAS NO MORE TO TAKE

BY
MARK ARAX

Photographs by Tomas Ovalle

The wind finally blew the other way last night and kicked out the smoke from the burning Sierra. Down here in the flatland of California, we used to regard the granite mountain as a place apart, our getaway. But the distance is no more. With all those dead pine trees in thrall to wildfire, the Sierra, transmuted into ash, is right outside our door.

We have learned to watch the sky with an uncanny eye. We measure its peril. Some days, we breathe the worst air in the world. On those few days when we can walk outside without

Masumoto, who has 80 acres in Del Rey, is nearing 68. "I think of our farm as being alive," he says.

risking harm to our lungs and brains, we greet each other with new benedictions. May the shift in winds prevail, I tell my neighbor. May there be only the dust clouds from the almond harvest to contend with. In the meantime, I don't dare quiet the turbo on my HEPA filters, hum of this new life.

The most brutal of summers in the San Joaquin Valley has come to a rest at last. Since June, the temperature has broken the 100° mark for 67 days, a new record. Drought won't let go its grip on the land. Eight of the past 10 years have been ugly dry. This October morning, after a month holed up, I decided to leave my house in the suburbs and roam the middle of California, the irrigated desert at its most supreme. Out in the country, I smell fall in the air. To celebrate its arrival, I'm going to visit an old friend, a farmer named Masumoto, who has 80 acres in Del Rey and is putting the last of his raisins in a box.

There is no way to make this drive out of Fresno at harvest's end, through the dog-tired fields of the most industrialized farm belt in the world, without thinking about water: the idea of it, the feel of it; the form as it falls from the sky as rain and snow, that man captures with his invention and implementation, his magic and plunder, the dam, the ditch, the canal, the aqueduct, the pump, the drip line; the water that gives rise to every animate and inanimate thing that now stretches before my eyes, the vineyard, orchard, cotton field, and housing tract; the water whose too much can destroy us, whose too little can destroy us, whose perfect measure of our needs becomes our superstition and story.

You should know that I have written about the matter of California and water a few times before, and I'm not above borrowing from old refrains. In my hunt for new words, I have driven Highway 99 a thousand times through a valley that geologists call the most-altered landscape by human hands in history. I now see the gashes of fresh alterations. What has been done here, by any means necessary, has been done for the want of water.

The taking of California was no small project. It relied on the erasure of the most prolific flowering of indigenous people in the United States. The civilization standing in the way was at least 10,000 years in the making and 300,000 strong. They were Yokuts, Maidu, Miwok, Klamath, Pomo, Chumash, and Kumeyaay, to name a few. Looking back at the fevered pace of our footprints over the past 175 years, we tend to idealize the modesty of theirs. And yet it is more than likely true given their numbers, given the bounty and heft of the land, that they did not war with each other over its prize. They lived light on the earth. They moved when nature moved. Flood took them to one place, drought another. When the forest load needed thinning, the fires they set burned brush and lower branch and quickly smothered out.

As genocides go, the wiping clean of California's indigenous culture was protracted, playing out in three acts: Spanish mission, Mexican occupation, American settlement. The atrocities were only as efficient as the tools of the time—blanket, smallpox, syphilis, torch, knife, Colt .45—allowed. First came the robed Franciscans led by Father Serra, slaver and saint, whose possession of the Indian body gave him the workforce to erect the first crude dams and canals that took rivers to places they'd never been: his 21 missions, from San Diego to Sonoma. At the Mission San Gabriel, the catch of water grew a profusion of grains, vegetables, exotic fruits, and the 170-acre "Las Vina," mother vineyard.

Next came the dons from Mexico, freed from Spain's yoke, whose dalliance with California lasted but a quarter-century, from 1821 to 1848. Blending European, Mexican, and American lineages, they called themselves Californios. Rather than tame California's many states of nature, they amassed millions of acres and tamed themselves. On far-flung rancherias, they slaughtered a calf a day to feast on, drank vast quantities of wine and brandy, and threw royal weddings in which daughters who'd been locked away in finishing schools all their lives finally came out into the sun. In a moment of goodwill, they pledged that the mission lands, and their flow of water, would be turned over to the remaining natives, but the pledge never amounted to a thing.

American settlers had been nosing around for decades—mountain men, fur trappers, scouts and surveyors. When they finally made their intentions known, in the summer of 1846, the government standing behind them grabbed the western edge of a continent, 1,000 miles long, without firing an official shot. What are a people to do when the land they conquer covers 11 regions of topography and 10 degrees of latitude, where rain measures 140 inches on one end and two inches on the other end? Another people might have taken the stance that each region ought to exist within its own plenitude and limit. These people drew a line around the whole, declared it one state, and began their infinite tinkering to even out the difference.

Manifest destiny would have had its way with California, sure and steady, but the shout of gold, in 1848, was heard around the world. Gold's cataclysm was a force of a different magnitude. Overnight they sailed ashore by the tens of thousands, mad miners from all over the globe, most of whom had never mined a day in their lives. They went at mountain and river with claws. Mining gold, they discovered, was mining water on an industrial scale.

"Water! Water! Water!" shouted James Mason Hutchings, an Englishman who published a quarterly of unparalleled excellence, Hutchings' Illustrated California Magazine, in the 1850s. "Not water to drink, for that can be found bubbling up on every mountaintop, but water to work with. Working men dig gold.

Gold, thus dug, would be put in circulation. That circulation would give prosperity. We will therefore, with the same language as the horseleech, cry, 'Give, Give,' but let the gift be Water! Water! Water!"

By the time the great deluge of 1862 rained down, Hutchings's magazine was no more. It would be left to William Brewer, who studied at Yale and came west to survey California's natural resources, to describe what the floodwaters had done. "Nearly every house and farm over this immense region is gone," he wrote. "America has never before seen such desolation by a flood as this has been." Brewer had come to recognize the Californian's peculiar fortitude to outlast everything: "No people can so stand calamity as this people. They are used to it."

The people forgot about flood with the same nonchalance that they forgot about drought. Their failure of memory became a strange resilience. They went back to their digging with newfound lust. They erected 6,000 miles of ditches and built a dam 100 feet tall. The flows of Northern California rivers were now dictated by a handful of industrialists. To reach the deeper veins of gold, they invented hydraulic cannons that shot out water at such force that it blew the walls off mountains. Into the rivers washed the tailings, more than a billion cubic yards of boulder, rock, pebble, and mud. Tens of thousands of acres of new crops planted in the alluvial plain began to choke on the retch of the mines.

THE PEOPLE FORGOT ABOUT FLOOD WITH THE SAME NONCHALANCE THAT THEY FORGOT ABOUT DROUGHT. THEIR FAILURE OF MEMORY BECAME A STRANGE RESILIENCE.

As to the future of California, the industrialists who lived atop San Francisco's Nob Hill had a choice to make: gold or grain? Isaac Friedlander, six foot seven and 300 pounds, whose stride was said to be that of two men, who had made his fortune by cornering the market on flour for the mining camps, snatched one million acres of valley soil for practically nothing. He became the Wheat King.

I am sailing across the desert, that is true, but it isn't the Mojave. The San Joaquin Valley, 260 miles long and 50 miles wide, qualifies as desert only by measure of average rain—less than 10 inches a year. Five rivers, two of them mighty, run down from the Sierra across its breadth. The best of the dirt, a loam that blends sand and clay, grows beets the size of an ogre's head. The sun shines 280 days a year, and the sky doesn't generate any rain from May to September. The blanket of fog that sets down in winter holds the chill of hibernation close to the fruit and nut trees. The importance of these chilling hours was a lesson my father's father, Aram Arax, a poet-farmer, thought I should know: "The apricot is a picky thing. It has to feel the kiss of the death in winter to hold on to its fruit in spring." He would need to go back to the Mediterranean, he told me, to find a clime where all manner of vegetables, fruits, nuts, and grains grew with such ease.

The 49ers who had made their way down the hill knew what to do with this fecundity. So did the cotton growers from the South who were chased off their plantations by the boll weevil. They corralled the rivers with a lattice of ditches and made them run backward. They drained dry the great inland marsh and Tulare Lake, too, the largest freshwater body west of the Mississippi. They wiped out the last of the elk, antelope, and mustang and emptied the sky of geese. They flattened the hillock and hog wallow with the Fresno Scraper and turned 6 million acres into tabletop. That's how the water of furrow irrigation glided.

Their seize of the snowmelt—"first in line, first in right"—had no parallel in agriculture. They did not take half the flow of the rivers. They did not take three-quarters. By the time the farmers were done, they had taken nine out of every 10 drops. When their garden was ready for showing, their promotional brochures fairly boasted, "Fresno County: A Wonderfully Prosperous District in California. The Land of Sunshine. Fruits and Flowers. No Ice. No Snow. No Blizzards. No Cyclones."

It would be easy to dismiss the lure of such hype. But word of their feat—"the first great experiment in irrigation by the Anglo-Saxon race"—reached all the way to Istanbul, to the attic where my grandfather Arax was hiding from the Turks in 1918. His uncle, who had lost his wife and children in the massacres and had fled to Fresno, was writing him letters describing an Eden in a valley at the edge of the Sierra: "You must see it with your own eyes to believe it."

My grandfather was plotting his way to the Sorbonne, to study French literature and become a writer, but the letters kept coming, each one more full of sadness and hope than the one before. In the summer of 1920, after a 7,000-mile-long journey, he found himself at the train depot in downtown Fresno. Nephew and uncle, survivors of genocide, hugged and climbed into a gleaming Model T Ford and rode from river to river, across an expanse already known as the "Raisin Capital of the World." They passed grapes, peaches, and plums and lingered on 12,000 acres of figs that a Kansas preacher was planting in the red hardpan. My grandfather, awestruck, kept muttering the same words: "Just like the old land."

As I approach the Kings River—emptied of river, nothing but sand—I can hear the words he used to describe our last farm, the one *embroidered* with pomegranate trees that my father, Ara, and his brother, Navo, to my grandfather's regret, sold a few years before I was born. I grew up in the suburbs not a dozen miles removed from those 60 acres, but it might as well have been an ocean away, for who we were and what we had done to make the desert bloom wasn't a topic we discussed.

We had the Cotton King, Grape King, Melon King, and Tomato King right in our midst, men who possessed the lion's share of our water, but how this dominion had happened remained a civic mystery. Irrigation canals full of snowmelt knifed through our neighborhoods, but it never occurred to me to ask where the water was coming from, to whom it was going, and by what right. The canals were completely unfenced, and one or more children of the Mexican farm workers, looking to cool off in summer, drowned in them every year. "Don't go next to those canals," my grandmother Alma warned. "If you fall in, they won't fish you out. They won't stop the flow until the harvest is over."

water to the dying farms in the middle. This is how the state of California, in the 1960s, built the State Water Project, installing more pumps in the delta and a 444-mile-long aqueduct to move more water to grow more farms in the middle and more houses and swimming pools in Southern California.

This is how we've come to the point today, during the driest decade in state history, that valley farmers haven't diminished their footprint to meet water's scarcity but have added a half-million more acres of permanent crops—more almonds, pistachios, mandarins. They've lowered their pumps by hundreds of feet to chase the dwindling aquifer even as it dwindles further, sucking so many millions of acre-feet of water out of the earth that the land is sinking. This subsidence is collapsing the canals and ditches, reducing the flow of the very aqueduct that we built to create the flow itself.

How might a native account for such madness?

"I'M NOT SAYING WE DON'T FIGHT CLIMATE CHANGE AS A SOCIETY. WE HAVE NO CHOICE BUT TO. BUT OUT HERE, IT'S FOLLY TRYING TO CONTROL NATURE."

The new land was nothing like the old land.

Not a year after my grandfather arrived, the raisin went bust. The Armenian and Japanese farmers had planted so many grapes to dry into raisins that Sun-Maid couldn't sell half of them. Who would buy the other half became a question of such wonderful theater, tragic and comic, that even Fresno's sage, William Saroyan, would weigh in. If we could only persuade every mother in China to put a single raisin in her pot of rice, we'd have the glut solved, he mused.

Just as the bust hit, the great drought of the 1920s hit too, revealing the folly and greed of California agriculture. It wasn't enough that the farmers had taken the five rivers. They were now using turbine pumps to seize the aquifer, the ancient lake beneath the valley. In a land of glut, they were planting hundreds of thousands more acres of crops. This bigger footprint wasn't prime farmland but poor, salty dirt beyond rivers' reach. As the drought worsened, the new farms were extracting so much water out of the ground that their pumps couldn't reach any lower. Their crops were withering.

A cry went out from the agrarians to the politicians: "Steal us a river." They were eyeing the flood flows of the Sacramento River up north. If the plan sounded audacious, well, just such a theft had already been accomplished by the City of Los Angeles, reaching up and over the mountain to steal the Owens River.

This is how the federal government, in the 1940s, came to build the Central Valley Project, damming the rivers and installing mammoth pumps in the Sacramento–San Joaquin Delta to move

No civilization had ever built a grander system to transport water. It sprawled farmland. It sprawled suburbia. It made rise three world-class cities, and an economy that would rank as the fifth largest in the world. But it did not change the essential nature of California. Drought is California. Flood is California. One year our rivers and streams produce 30 million acre-feet of water. The next year, they produce 200 million acre-feet. The average year, 72.5 million acre-feet, is a lie we tell ourselves.

I am sitting on the porch of a century-old farmhouse, eating kebabs and pilaf with David "Mas" Masumoto. We're looking out in near silence at his 80 acres of orchards and vineyards not far from the Kings River. His small work crew has gone home. His wife, Marcy, is doing volunteer work overseas, and their three dogs, all stinking, know no bounds. The whole place looks exhausted, like a farm where the farmer has died. But Mas, nearing 68, is as alive as ever.

We got to know each other 25 years ago on the occasion of his first book, *Epitaph for a Peach*, a memoir about a farm passed down from father to son and the son's determination not to plow under an old variety of the fruit. The heirloom was called Sun Crest, and it had fallen out of favor with the market because it bruised too easily. Golden, sweet, and juicy, it was worth saving, Mas thought. "You take one bite, and it throws you back in time," he had told me then. "Fruit is memory."

I hadn't heard a farmer talk that way since my grandfather, and so I wrote a story about him in the Los Angeles Times, and he handed me a young Sun Crest to plant in my own backyard, and it bore so many peaches next to the swimming pool that my wife, after our divorce, declared the tree a "mess" and pulled it out. Mas, on the other hand, had saved the peach. Chef Alice Waters, for one, read his book and started serving Sun Crests, all by themselves, as dessert at Chez Panisse.

He points to a spot in the orchard where they're still standing, more gnarled and weather-beaten but still producing. He counts himself among the lucky. His father, Takashi, chose this land well. It sits inside an irrigation district with an early call on the river. Even in low-runoff years, his water table gets recharged.

"We're irrigating right now, matter of fact," he says. "The water table has dropped some, but out here that means we're sitting at 70 feet [deep]. Up and down the valley, it doesn't get much better than that."

"How'd the harvest go?

"It's the middle of October, and it's still going," he says with disbelief.

Talking about the weather with a farmer isn't like talking about the weather with anyone else. It's prying into the soul of things. I venture the opinion that this long dry spell isn't only California returning to drought form. It's climate change hitching onto drought, creating an altogether new havoc. Mas isn't like most farmers. He grows his fruit organically and drives a Prius. "Climate" and "change" are words he speaks together.

"I've seen things this harvest I've never seen before," he says.

We finish our kebabs and walk the century-old rows. The Thompson seedless vines look ready to kiss winter and fall asleep. But the amber grapes laid out on paper trays in the terraced loam are only half baked. I know the rhythm, and the rhythm is off. Thompsons are put down in early September to avoid fall's first rain. It takes but 12 days for the valley sun to wrinkle a grape into a raisin. Mas's raisins are a month late in drying. They've already been rained on once.

"It's a mystery," he says.

He bends down into the crouch that raisin farmers assume when they are about to examine their crop. He sifts through the bunches with his sunburned hands, feeling for that sticky. He puts a couple in his mouth, feeling for that chewy. It's not there.

"Not a raisin yet? How do you figure?" I ask.

He looks to the sky. "This summer was record hot. They should have ripened right up. But the sun didn't shine the same."

I don't know what he means.

"All that smoke and ash from the forest fires. It changed the rays, I figure. It bent them somehow. They didn't come through the same."

I nod and keep listening. He is talking about nature's cycle. Drought helped kill the trees in the forest. Desiccated by thirst, they were whittled out by bark beetles. Lightning lit that kindling. Kindling became smoke and ash. Smoke and ash occluded the sky. This slowed the ripening of grapes on the vine. This slowed the baking of grapes into raisins.

Thanks to the wind, the sky is now clear, but it's too late. October has changed the angle of the sun hitting the rows.

"We've lost our oven," he says. "I'll likely be sending these raisins to the mechanical dryer. That's never happened before. They won't taste the same."

It was hard to find a sweeter spot on earth for farming. Mas had the soil, he had the river, he had the aquifer, and he had the sunshine, or at least he thought he did. He did not have the science to explain it, but climate change had found him too.

"I think of our farm as being alive," he says. "Nature is alive. Climate is alive. Is the idea to try and kill it? I'm not saying we don't fight climate change as a society. We have no choice but to. But out here, it's folly trying to control nature."

We walk past the giant concrete standpipe, filling up with water that will give a last drink to the farm before winter. He talks proudly about his daughter, Nikiko, and his son, Korio, who will take over these acres sooner rather than later.

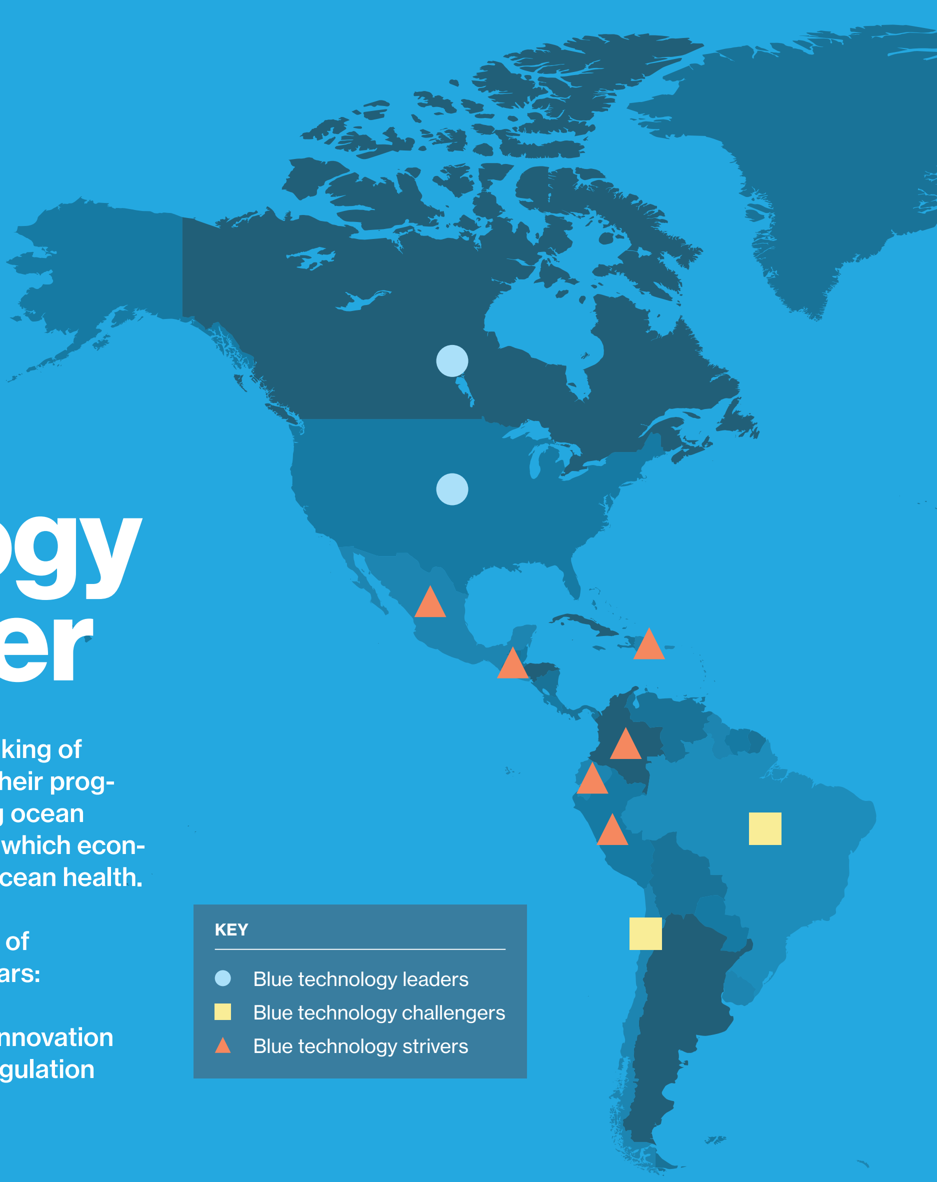
"Out here, everything is going to take time," he says.

We hug goodbye. I get into my little Chevy, turn on the electrical engine, and drive home through the dust. The pomegranates are turning red, and I can't help thinking: How much time do we have? ■

Mark Arax is the author of several books, most recently <u>The Dreamt Land: Chasing Water and Dust Across California</u>.

MIT Technology Review Insights

The Blue Technology Barometer



The Blue Technology Barometer is a ranking of 66 coastal countries and territories on their progress and commitment toward protecting ocean sustainability. It measures the degree to which economies are prioritizing the protection of ocean health.

The index ranks the "blue" performance of countries and territories across four pillars:

- Ocean environment
- Marine activity
- Technology innovation
- Policy and regulation

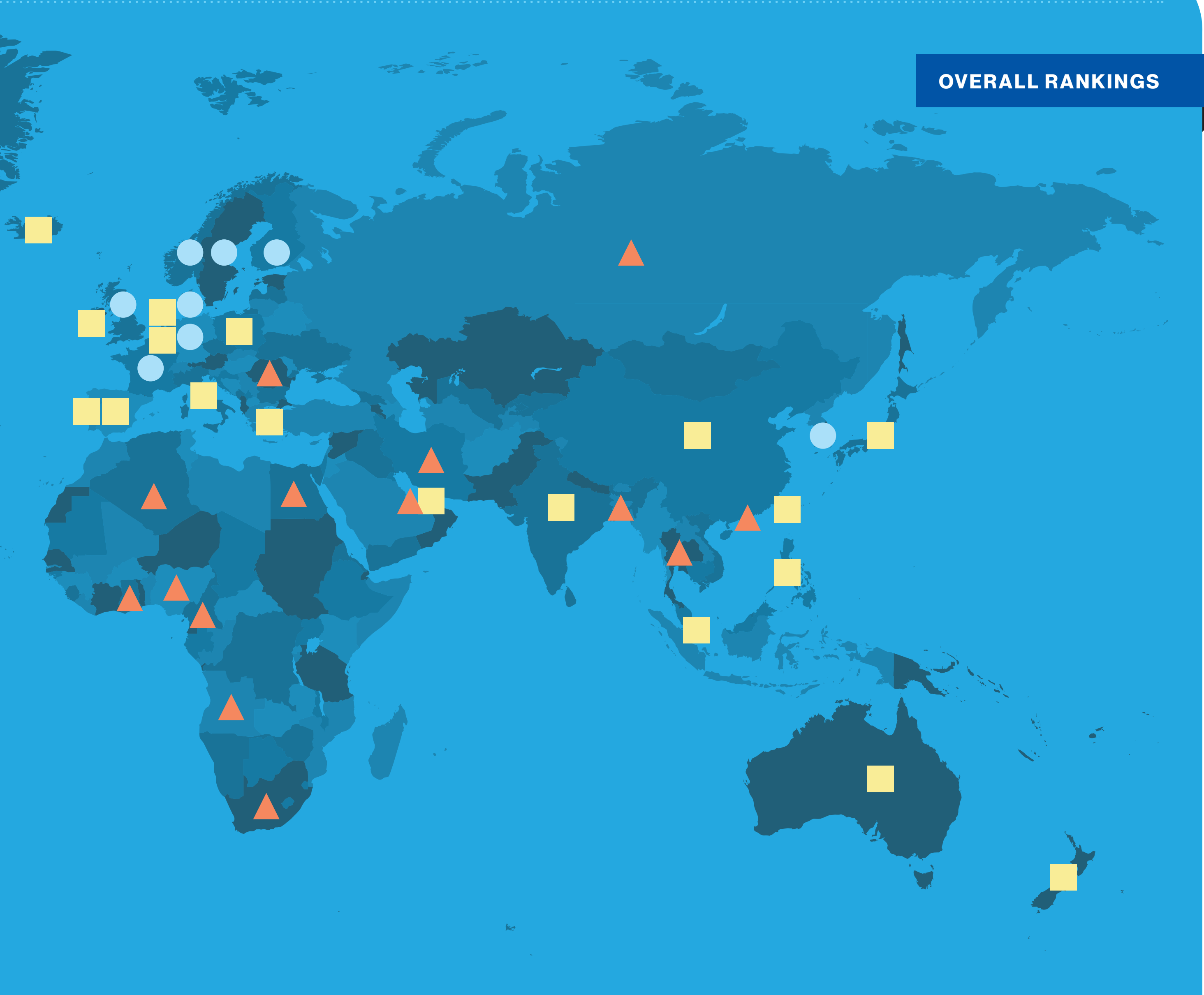
Overall top 10

Rank	Country	Score
1	**United Kingdom**	7.8
2	**Germany**	7.5
3	**Denmark**	7.4
4	**United States**	7.2
5	**Finland**	6.9
6	**Norway**	6.9
7	**France**	6.9
8	**Sweden**	6.7
9	**South Korea**	6.4
10	**Canada**	6.4

- Korea has registered nearly 9,700 patents for ocean sustainability tech – more than the next seven economies combined.
- The UK is one of the most committed developers of offshore renewable energy, with the world's largest offshore windfarm.
- Four Nordic countries are in the top 10 due to their deep digital technology innovation ecosystems and collaborative governments.

Experience the interactive index, view the data, and

OVERALL RANKINGS



Marine activity top 10

Rank	Country	Score
1	**Dominican Republic**	10
2	**Finland**	9.9
3	**UAE**	9.6
4	**Ecuador**	9.2
5	**Chile**	9
6	**Colombia**	8.7
7	**Denmark**	8.3
8	**Brazil**	8.2
9	**UK**	8.2
10	**Poland**	8.1

- This pillar ranks each country on the sustainability of its marine activities, including shipping, fishing, and protected areas.
- A startup in Chile processes 800 tons of discarded fishing nets annually, recycling them into hats, bicycle parts, and furniture.
- Baltic Sea port Gdansk is a hub for e-navigation and environment management companies, some of which monitor the port's emissions.

RE
PORT

Three cities grapple with the effects of climate change on the water supply.

Dispatch : Singapore

Singapore's push for water independence

The tiny city-state has set its eyes on self-sufficiency.
By Megan Tatum

The Keppel Marina East Desalination Plant is capable of producing 30 million gallons of clean water every day.

Every day, the Linggiu Reservoir does quiet battle with the ocean, feeding rainwater into the Johor River in southern Malaysia to keep its salt levels low enough to treat. Singapore, which built the reservoir in 1995, had been entitled to extract some 250 million gallons per day from the 123-kilometer-long river, meeting more than half its national needs. But a prolonged dry spell in 2016 saw reservoir levels fall to just 20% of capacity, leaving it shrunken and shallow.

"There was a real risk to our water supply," Singapore's prime minister, Lee Hsien Loong, later said. "It was a vivid reminder of why we have to be obsessed with saving water, and making every drop count."

Water security isn't a new concern for Singapore. The city-state's tiny land mass and lack of natural lakes or aquifers have made water a priority ever since it gained independence in the 1960s.

"Though we are located near the equator and blessed with abundant rainfall, we are a severely water-stressed country due to a lack of land to collect and store all the rainwater that falls within Singapore," explains Harry Seah, deputy chief executive

In Singapore, treated wastewater satisfies up to 40% of the country's needs. The goal is to reach 55% by 2060 ... In late

for operations at the Public Utilities Board (PUB), Singapore's national water agency. In 2015, the World Resources Institute ranked the country as among the most vulnerable to water stress, on a par with the arid states of Bahrain, Qatar, and Kuwait.

For decades, Singapore has satiated a significant amount of its demand through agreements to import water from neighboring Malaysia. One of those agreements expired in 2011. The second—the one that enables the country to draw water from the Linggiu Reservoir—is ongoing.

But that source is vulnerable—not only to drought but to politics. "In the past, there were multiple times when the relationship between the two countries [Malaysia and Singapore] had some friction, with water being a matter of dispute," says Stuti Rawat, a postdoctoral fellow in the Department of Asian and Policy Studies at the Education University of Hong Kong. In 2018, Mahathir Mohamad, then Malaysia's prime minister, signaled his plans to renegotiate the Linggiu agreement, calling it too costly and the current terms—which have Singapore paying just three sen (less than one cent) per thousand gallons—"manifestly ridiculous." "Because of that, it has been very important for Singapore to try to carve out its own independent water supply," adds Rawat.

The rise in global temperatures has added new urgency to the situation. "With climate change, we are expecting more extreme weather with more intense rain and longer dry spells, as experienced in the US, China, India, and many other parts of the world," Seah says.

These volatile patterns mean that the country can no longer rely on rainfall to predictably fill up its reservoirs.

PUB has rallied households to conserve water. By 2023, it plans to have installed some 300,000 smart water meters in homes; they will use digital technologies to monitor usage and flag leaks.

But the country is also rapidly accelerating efforts to expand on its own water sources. PUB has committed to doubling the domestic supply of clean drinking water by 2060, a feat that would take Singapore close to self-sufficiency. Crucially, it aims to do so without increasing energy use.

The Keppel Marina East Desalination Plant, which sits on reclaimed land in the Marina East area of Singapore, is a sprawling monument to that effort. Opened in June 2020, the plant is capable of producing 30 million gallons of clean water every day. The facility, which was built with a government contract estimated at S$500 million (US$345 million), generates fresh water using significantly less energy than a typical desalination plant. That is because the plant operates in two modes, drawing in and treating rainfall that collects in a nearby reservoir during wet periods and processing seawater only when the weather is dry. Both sources are transformed into drinking water through a combination of ultrafiltration, reverse osmosis, and ultraviolet radiation.

The plant, one of the first in the world to use such a dual-mode system, is an example of how Singapore has continually "pushed the envelope" on water management, says JianYuan Ling, energy industries division manager for Singapore at ABB, the company behind some of the tech that underpins the plant. In doing so, it has challenged suppliers. "Efficiency is definitely their top priority," Ling says. "This is a national project, so the whole country is watching." But Keppel, he adds, is just "part of the grand plan" to make Singapore self-sufficient when it comes to water.

"We have to be obsessed with saving water, and making every drop count."

The other element is the country's massive wastewater recycling campaign. Singapore already derives 40% of its water from wastewater. By 2060, it's hoped, that contribution will have risen to 55%.

The jewel in the crown of this plan is the Changi Water Reclamation Plant, which opened in 2009. Much of the facility sits underground (some parts 25 stories deep), drawing in wastewater through a 48-kilometer-long tunnel linked to the country's network of sewers. It's capable of treating up to 900 million liters of wastewater a day using membranes to filter out microscopic particles and bacteria, reverse osmosis to remove tiny contaminants, and finally UV disinfection to destroy any viruses or bacteria that remain. The reclamation effort is "the key in helping us to overcome our land constraint for storage," says Seah, referring to the fact that space to stockpile water in Singapore is in short supply.

The next step for Singapore is to further slash energy use. At a research and development facility in the industrial area of Tuas, for instance, PUB is testing new desalination technology that uses an electric field to pull dissolved salts from seawater, a less energy-intensive process than reverse osmosis. Also in development is a biomimetic membrane that uses natural proteins found in cells to accomplish the same task.

Such energy-saving strategies will be needed if Singapore hopes to achieve water independence. An expanding population and industrial growth are set to double water demand in the country by 2060. ■

Megan Tatum is a freelance features journalist based in Penang, Malaysia.

2017, a severe drought compounded by several years of subpar rainfall left Cape Town with freshwater dams below 25% of capacity.

Residents queue for water at a natural spring in Cape Town, South Africa.

AP PHOTO

Dispatch : Cape Town

The long shadow of Day Zero

Cape Town hasn't forgotten how close it came to running out of water.

By
Joseph Dana

In the waning weeks of 2017, many residents of Cape Town, South Africa, lined up day and night to fill old jugs with water from the city's few natural springs. Palpable angst hung in the air. After months of warnings through an anomalously long drought, Cape Town was on the verge of becoming the world's first major city to run out of water. Freshwater dams had dipped below 25% of capacity, and levels continued to fall. If the dams fell to 13.5% of capacity, the municipal water network would shut down, and millions of residents would face severe water restrictions.

The dams never reached that critical 13.5% level, dubbed Day Zero. The city instituted water restrictions, increased water tariffs, and spent the majority of its R1.4 billion ($86 million) drought-related budget to construct three emergency desalination plants, which delivered critical water supplies. Residents also took matters into their own hands, collecting water from the natural springs and installing rain catchment systems if they had the means.

Four months later, the rains returned, and dam levels rose. But the shadow of Day Zero still lingers over the city. "The citizens of Cape Town have not forgotten the fear caused by the drought and potential for the city to have run out of water," says Kevin Winter, a lecturer in environmental and geographical science at the University of Cape Town.

Thanks to the memory of Day Zero, Winter says, average daily water use in the city is between 700 and 800 million liters, about half what it was in 2014. But even if consumption remains low, the next drought could challenge those efforts. And scientists believe that Cape Town will face more sustained droughts over the next 100 years because of climate change.

Although drought instigated the water crisis, experts say it was exacerbated by existing issues, including poor water management and infrastructure problems at dams and other collection points.

The city has a plan to address the situation. In consultation with researchers and scientists, it outlined a new water strategy in 2020 that aims to make the city's water supply more resilient to future droughts. The planned approaches include diversifying water sources to include groundwater from wells and boreholes, recycled stormwater, treated wastewater, and household gray water, which could be reused for gardening and other applications that don't require something clean enough to drink. There are also plans for more desalination, controls on water use, leak reduction, and infrastructure investment.

While the path is laid out, finding the political will to execute these reforms might be difficult. Expanding access to water has been a point of contention for the ruling African National Congress since the fall of apartheid in 1994. In most shantytowns, at least 2 million residents (out of Cape

Three Cape Town desalination plants commissioned in 2017 are being dismantled ... Karachi, Pakistan's most populous city,

Town's total population of about 4.6 million) can use city water only at communal access points. The government has routinely promised—and failed—to improve essential services like these for millions of poor South Africans.

All told, the city's plan for better water resiliency calls for an investment of R5.4 billion ($335 million). As part of its water strategy, the city wants to build a new R1.8 billion ($112 million) desalination plant with a capacity of 50 million liters per day by 2026. At the same time, the three desalination plants commissioned in 2017 to combat Day Zero are being dismantled. Both the city and its contractors have been tight-lipped as to the exact reason why the plants have been decommissioned, but one contractor said there was higher demand in "other areas."

The private sector is not necessarily waiting for the city to remedy its water woes. The wine industry, for example, was hit exceptionally hard by the drought. Since then, many vineyards have established state-of-the-art water management systems designed around the concept of self-sufficiency. Tactics include reusing treated wastewater, collecting rainwater, and using elaborate irrigation systems that focus on reducing water waste. Vineyards have also spent heavily on internal research to ensure they are employing the best methods science has to offer.

Even so, Gerard Martin, the executive manager of Winetech, a nonprofit that receives funding from the South African wine industry, feels that at this stage he doesn't know if either the city or the industry is ready for the next drought. "We are certainly preparing ourselves to address this in the future," he says. ■

Joseph Dana is a writer based in Cape Town, South Africa.

"This is like a competition where eventually everyone loses."

Data from sensors, like this probe from Crop2X, could help farmers use less fertilizer and water.

COURTESY OF CROP2X

Dispatch : Pakistan

Finding water for the city

A push to help farmers conserve water around Karachi could improve yields—and help the city's residents.

By
Mariya Karimjee

When Ahsan Rehman graduated from one of Pakistan's top engineering universities in 2016, he knew he wanted a job that would help people. He did not have to look far for ideas. At his home in Karachi, his family often went days without getting any water from the city's pipes. Initially, they had dug a well, boring into the aquifer that runs beneath the city. When that began drying up, they turned to the city's system of water delivery trucks to supplement their supply. Ultimately, his family chose to dig an even deeper well, knowing as they did so that if everyone around them did the same thing, the city's groundwater supply would be further imperiled. "This is like a competition where eventually everyone loses," Rehman says. "I personally feel really bad that I have to do this, but I don't have a choice."

Pakistan is consistently listed as one of the countries most at risk from a water crisis. Rain falls more heavily there than it once did but not as often, a situation that makes replenishing groundwater reserves difficult. Hotter temperatures are increasing evaporation and creating thirstier crops. Eventually, snowmelt and glacier melt—two important sources of water for the country—will dwindle to a trickle.

But Pakistan isn't facing a water problem purely because of climate change. Water conservationists say a mix of resource mismanagement, groundwater depletion, and inadequate water storage have pushed the system to a precarious point.

Nowhere is that more apparent than in Karachi, Pakistan's most populous city, which has a daily water shortfall of hundreds of millions of gallons. Despite that, water has a daily water shortfall of hundreds of millions of gallons.

is consistently underpriced: usage isn't metered, and many sources are unregulated.

Worried about the future of water in the city, Rehman started working for AquaAgro, a tech startup formed in 2016. The company's premise was simple: use data to help farmers make better choices about irrigation schedules. Their device, which included a solar-powered box and a thumb-size soil meter, could monitor weather conditions like temperature, humidity, and pressure and measure the soil's moisture content. The data was all uploaded to a portal, and farmers then received mobile alerts informing them when to water their crops.

At AquaAgro's pilot farms, crop yields increased by 35% and water usage reduced by 50%. But when Rehman and his colleagues reached out to farmers about their product, they found few were interested. "It wasn't a viable financial model," Rehman says. "Because the price of water was so cheap, farmers weren't motivated in cutting down their water consumption."

But water is no longer the abundant resource it used to be. Farms around the Karachi area that relied on groundwater to grow their crops now use everything from sewage streams to water trucks to stolen surface water. Karachi's primary water utility company complains that a large amount of the city's water is stolen from a 3,200-kilometer canal system that distributes water from a lake about two hours outside the city. "There's a general perception that there is unauthorized use of water ... by farms, theme parks, and people in informal settlements, among others," says Farhan Anwar, a Karachi-based urban planner. But, he adds, "documentation is hard to find."

Rehman hoped that AquaAgro could help with Karachi's water crisis. If farms around the city used less water, perhaps there would be some left over for his children, and his children's children. But by the end of 2019, the team at AquaAgro had concluded that their product might never be profitable. Their funding streams had dried up, and they disbanded soon after.

The team's ideas haven't been forgotten, though. Crop2X, a startup that grew in the same incubator as AquaAgro, is also working on data-driven ways to help farmers modernize. The company uses sensors and satellite imagery to help them identify which parcels of land aren't operating at their maximum yield. "We've been able to use the satellite imagery to help identify pests and reduce the amount of fertilizer that's being used," says Laeeq Uz Zaman, the founder and CEO. "Those are things that are valuable for farmers."

Uz Zaman hopes he can pull off a bait-and-switch: if he convinces farmers to buy in to a product they want—one that would help them reduce spending on fertilizer—perhaps they will eventually incorporate water-reduction strategies as well. In its weekly reports to clients, Crop2X includes water prescriptions, in part building on the data-based program AquaAgro developed.

The company's general approach seems to be working for now. Currently, it has more than 1,500 acres of farmland using its services and it's targeting 4,000 acres by 2025. The startup has started rolling out pilot programs at large corporate farms, hoping owners will see the utility of its methods. Still, Uz Zaman says, the major obstacle to its plan is the average farmer, who doubts that less water could ever result in more crops. ■

Mariya Karimjee is a freelance writer living and working in Karachi, Pakistan.

¡AGUAS, CDMX!

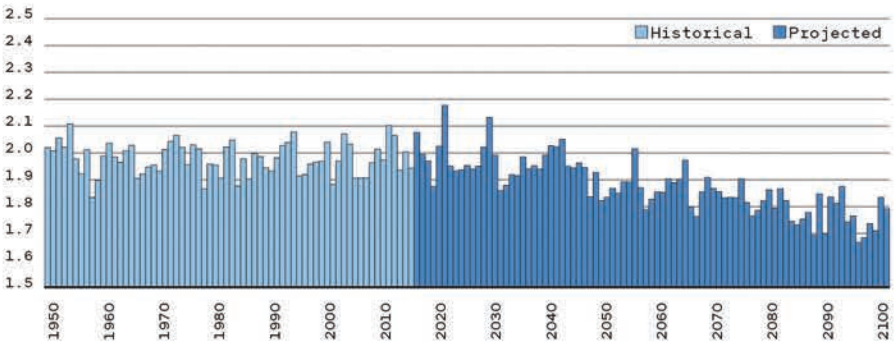
Climate change is helping sink Mexico City, but residents aren't ready to give up.

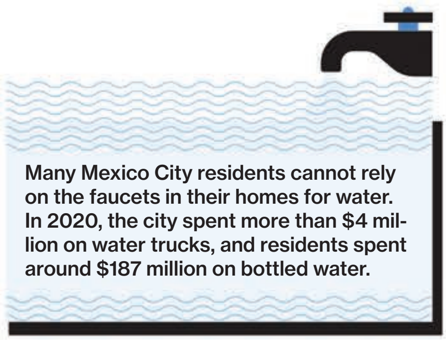
The comings and goings of water define Mexico City, a mile-high metropolis sprawled across three dry lake beds. The city floods in the wet season and thirsts during regular droughts. CDMX, as the city of 21 million styles itself, pumps more water from the aquifer below it than it replenishes: the city sank some 12 meters in the last century and may sink another 30 meters before hitting rock bottom. Scientists predict that climate change will exacerbate these problems.

But residents are taking charge of water—and their climate futures—in a variety of ways that promise to buoy the city's hydraulic balance and perhaps promote equitable access to safe drinking water. —*Lucas Laursen*

TOTAL RAINFALL WILL DECLINE

The IPCC projects that total daily rainfall in the region (in mm) will fall.

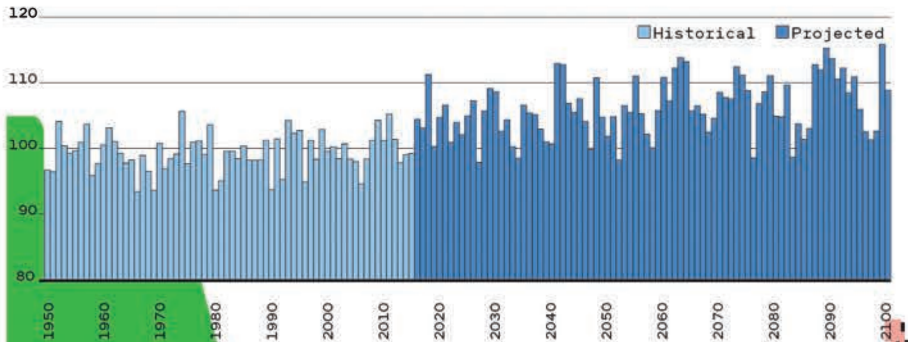




Many Mexico City residents cannot rely on the faucets in their homes for water. In 2020, the city spent more than $4 million on water trucks, and residents spent around $187 million on bottled water.

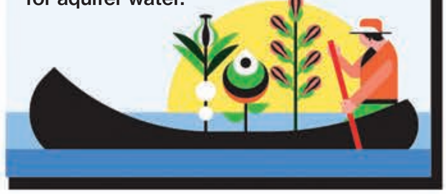
BUT WHEN IT DOES RAIN, IT WILL POUR

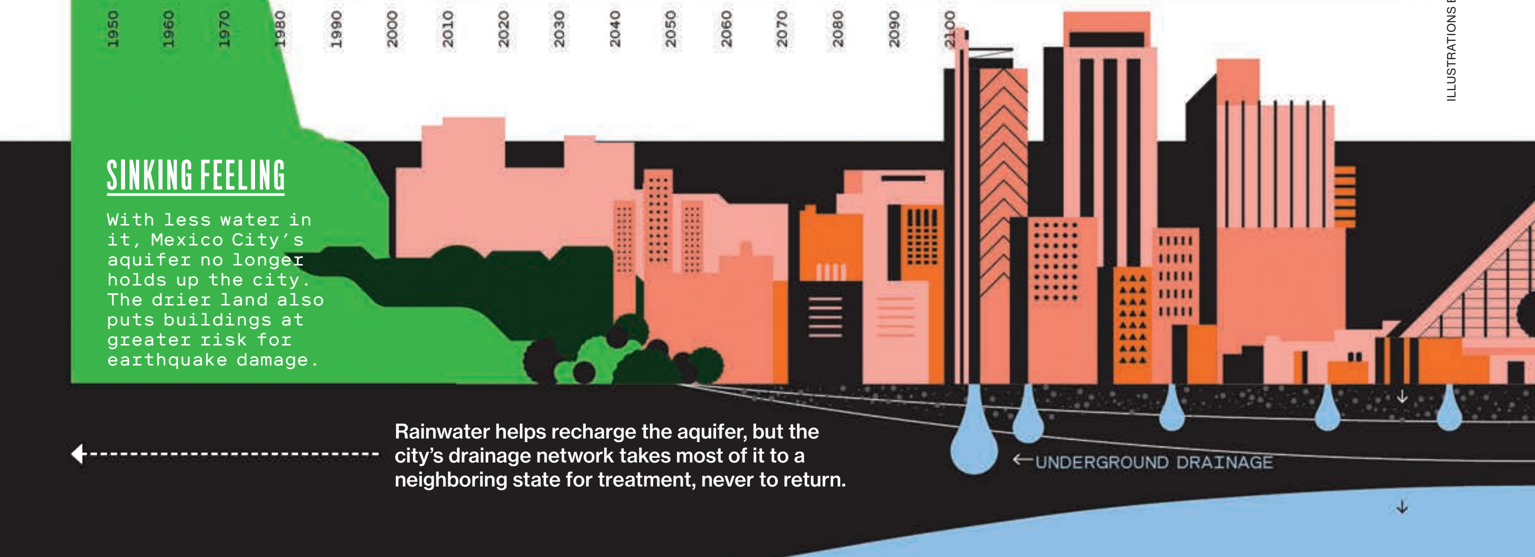
The IPCC projects stronger bursts of rainfall (in mm) in any given five-day window, a proxy for storms and flooding.



INDIGENOUS TECH: CHINAMPAS

The indigenous Mexica fenced in and filled lake areas, creating waterlogged farms to feed their island city. A collective of researchers, city planners, and farmers is adapting the approach to filter water for irrigation and reduce demand for aquifer water.



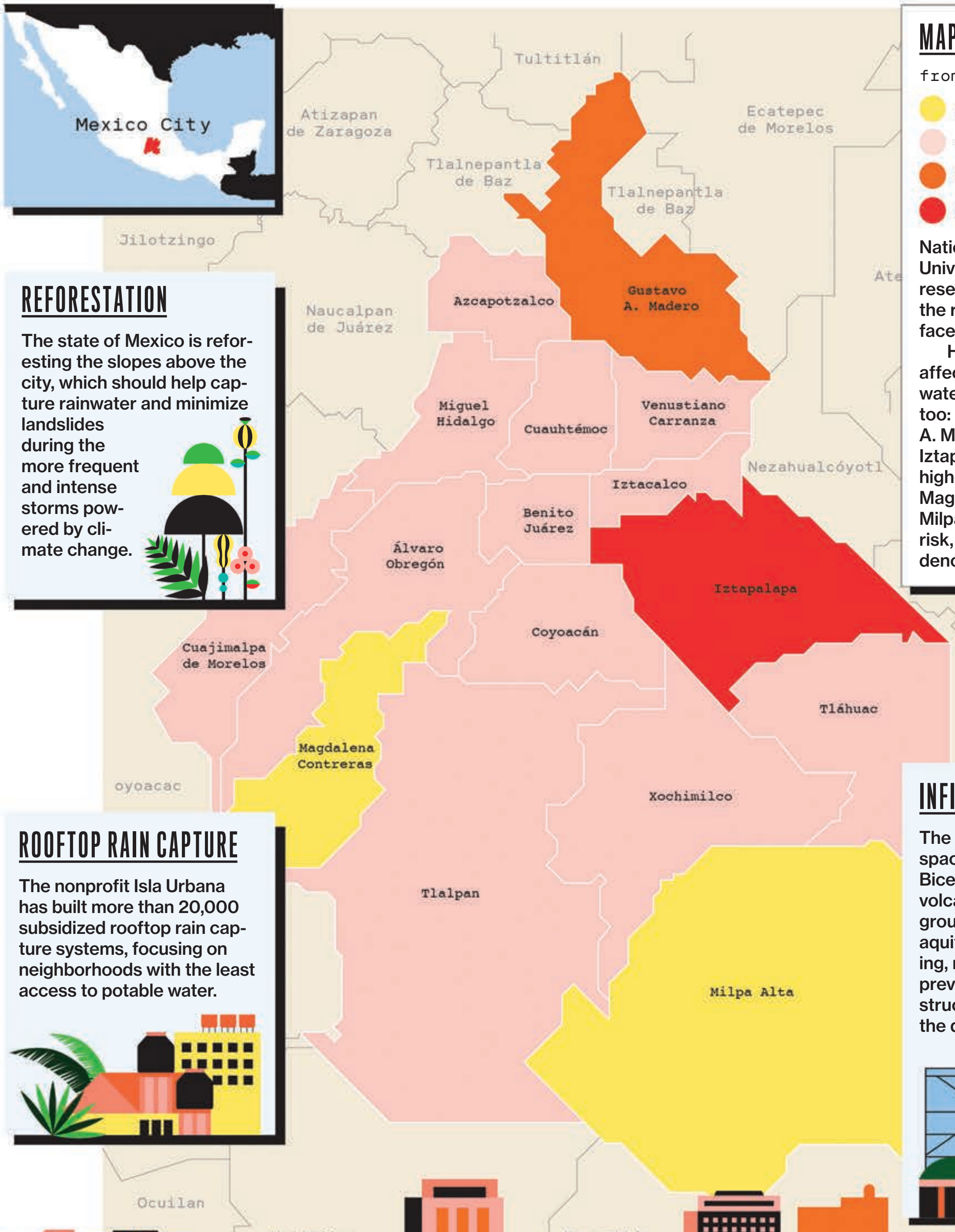


SINKING FEELING

With less water in it, Mexico City's aquifer no longer holds up the city. The drier land also puts buildings at greater risk for earthquake damage.

Rainwater helps recharge the aquifer, but the city's drainage network takes most of it to a neighboring state for treatment, never to return.

ILLUSTRATIONS BY LAURA CATTANEO / RAINFALL: IPCC WGI ATLAS; EXTRA WATER SPENDING: REPORTE ÍNDIGO AND THE NATIONAL AUTONOMOUS UNIVERSITY OF MEXICO (UNAM); CHINAMPAS: UNAM AND ORU OFICINA DE RESILINCIA URBANA.



MAP OF CLIMATE RISK

from 0 to 10

- 2 – 3.9
- 4 – 5.9
- 6 – 7.9
- 8 – 10

National Autonomous University of Mexico researchers have estimated the risks Mexico City will face from climate change.

High temperatures will affect all municipalities, but water will make its mark too: landslides in Gustavo A. Madero and flooding in Iztapalapa drive their risk higher than their neighbors'. Magdalena Contreras and Milpa Alta enjoy the least risk, thanks to their low incidence of flooding.

REFORESTATION

The state of Mexico is reforesting the slopes above the city, which should help capture rainwater and minimize landslides during the more frequent and intense storms powered by climate change.

ROOFTOP RAIN CAPTURE

The nonprofit Isla Urbana has built more than 20,000 subsidized rooftop rain capture systems, focusing on neighborhoods with the least access to potable water.

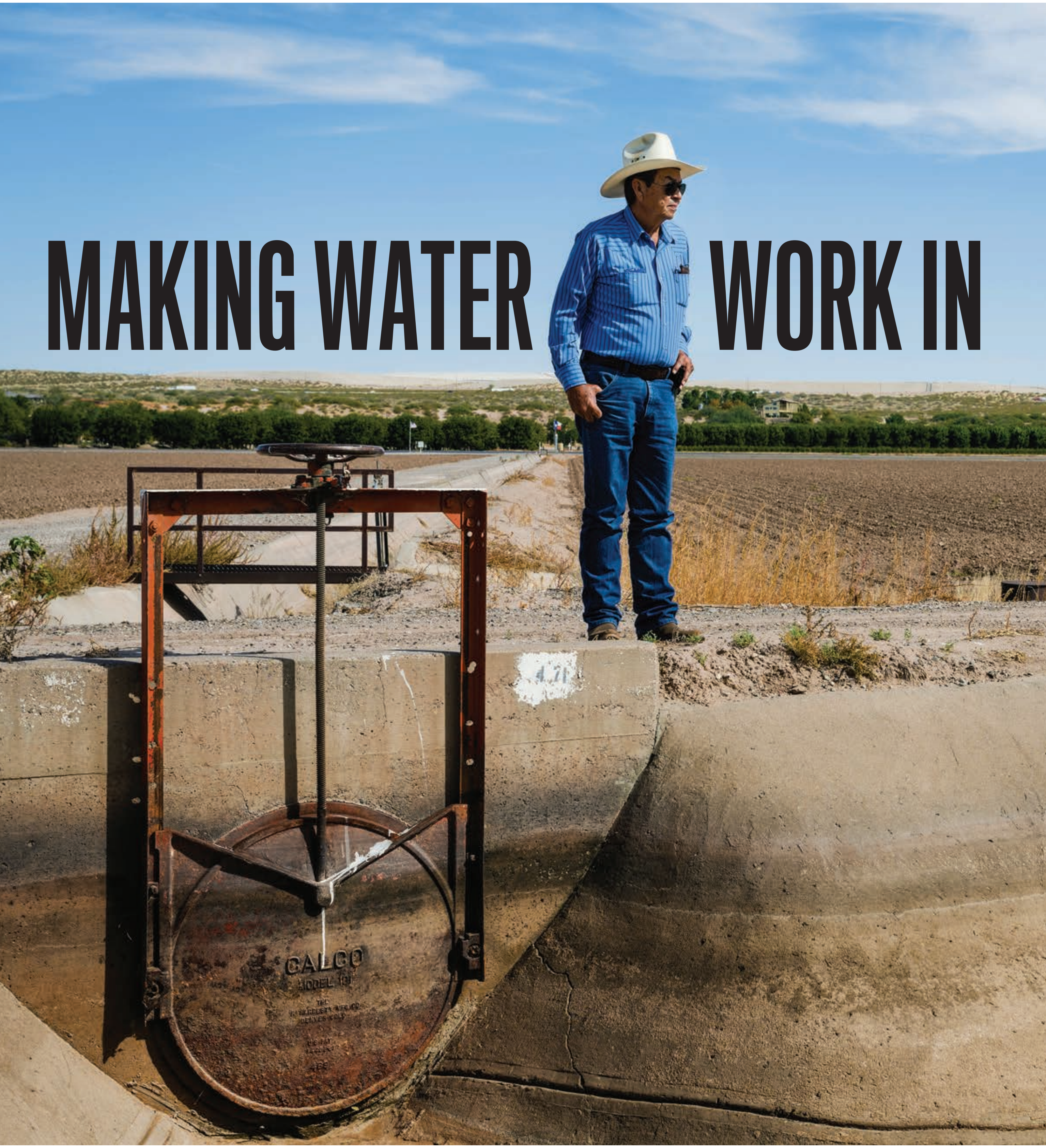
INFILTRATION

The city has built public spaces such as the Parque Bicentenario, which boasts volcanic soil. Its porous ground directs rainfall to the aquifer, heading off flooding, reducing subsidence, preventing damage to infrastructure, and replenishing the drinking water supply.

REFORESTATION: STATE OF MEXICO; CLIMATE RISK: MAC GREGOR-GAONA ET AL. 2021 INT'L. J. OF DISASTER RISK REDUCTION; INFILTRATION: MAÑON DE LA CRUZ ET AL. 2018 REVISTA IBEROAMERICANA DE CIENCIAS

Ramon Tirres Jr. has been farming just outside El Paso, Texas, for over 40 years. His pecan trees love the heat, but without water, everything falls apart.

MAKING WATER WORK IN



THE "DROUGHT-PROOF" CITY

By CASEY CROWNHART

EL PASO HAS LONG BEEN KNOWN FOR ITS WATER CONSERVATION.

NOW CLIMATE CHANGE IS PUSHING ADAPTATION TO ITS LIMITS.

Photographs by JUSTIN HAMEL

About 20 miles outside El Paso, Texas, on a warm afternoon just before the fall harvest, Ramon Tirres Jr. turns his truck between two fields covered in nothing but dirt. Both should be lush with cotton by now, but these 70 acres—a fraction of the nearly 1,000 that Tirres left unplanted this year—are bare. All told, about two-thirds of his cotton fields lie empty.

Tirres has been farming here for 47 years. His pecan trees love the heat, and the soil in the valley where he farms is fertile. But without water, everything falls apart. And the past few years have been especially dry.

Most of the water that Tirres and his neighbors use on their crops arrives via the Rio Grande, a river that snakes from the mountains in southern Colorado through New Mexico and along the Texas-Mexico border. But in years like this one, when there's not much snow and rain, water is in short supply. Tirres can pump groundwater to make up some of the difference, but it's expensive, and not all fields have pumps.

Farmers like Tirres have been among those hit hardest by water shortages affecting the region. Their predicament may not seem surprising given where they are: El Paso juts into the Chihuahuan Desert from the western tip of Texas. While annual rainfall across the US averages about 30 inches, El Paso gets under nine.

But El Paso has long been a model for water conservation. The city of 700,000 people has found a way to exist, and even thrive, in the desert. Other cities have for years looked to El Paso for solutions as population growth and climate change stress water resources worldwide.

El Paso has done all the right things—it's launched programs to persuade residents to use less water and deployed technological systems, including desalination and wastewater recycling, to add to its water resources. The city has invested hundreds of millions of dollars in these adaptations and earned an international reputation for its planning. A former president of the water utility once famously declared El Paso "drought-proof."

Now, though, even El Paso's careful plans are being challenged by newly intense droughts. As climate change accelerates and cities everywhere scramble to adapt, it's clear that technological solutions can improve quality of life in water-stressed places and prevent people from being displaced. However, every new measure comes at a cost, and all of them risk leaving people out. As the pressure ratchets up, El Paso, and places like it, force us to ask just how far adaptation can go.

Like a ring in a bathtub, a stripe in the rock marks the history of water in the Elephant Butte Reservoir, an artificial lake created by the Elephant Butte Dam and tucked into the mountains about two hours' drive north of El Paso. Snowmelt from mountains in Colorado flows here before being released down the river. Portions are then distributed by the US Bureau of Reclamation to different groups, called irrigation districts, in New Mexico and Texas. Eventually, some makes its way to fields like Tirres's.

Today the water level is far below the stripe; exposed rocks and the dam rise hundreds of feet on every side. In October, the reservoir held only about 5% of its capacity.

Elephant Butte has provided the river basin to the south with a mostly steady supply of water for over 100 years. But "you can have a really long stretch of really bad years, like we're having right now," says Ben Kalminson, the power plant supervisor at Elephant Butte. When that happens, the reservoir empties out.

Between January 2020 and August 2021, the southwest US endured a historic drought. Only about 17 inches of rain fell across the region; the 20-year average is 24 inches. According to climate models, there's about a 2% chance of having as little rain in any given year as the amount that fell in 2020. In other words, the 2020 drought was a one-in-50-years event, says Isla Simpson, a climate researcher at the National Center for Atmospheric Research.

She says there's no evidence that climate change caused the lack of rainfall. Dry spells happen every once in a while. Add heat into the mix, however, and both the drought's magnitude and the role of climate change become more obvious.

Since hot air holds more moisture than cold air, more water will evaporate if the temperature is higher. One way to measure this effect is through vapor pressure deficit, or VPD, which is the difference between how much water vapor the air could hold and how much is actually there. A high VPD means the air is hungry for moisture, and a drought's effects are likely to be worse: water evaporates more quickly from rivers, lakes, soil, and even plants.

There's only about a 0.4% chance in any given year of the VPD levels that struck the Southwest in 2020, according to climate models, making it about a one-in-200-years event. And it simply would not have happened when it did without climate change, Simpson says. High VPDs will become more common as temperatures rise—the levels seen in 2020 will become a one-in-10-years event in the Southwest by 2030. "We're really at the point now where we can start to see these climate-change signals in the real world," Simpson says.

↑ Wells scattered throughout Ramon Tirres's fields supplement what he gets from the river. The water is more expensive, but during a drought, it saves both his crops and his livelihood.

→ Between June 1994 and July 2013, drought severely affected water levels in the Elephant Butte Reservoir, the results of which are visible in these before-and-after satellite images.

While farmers rely on the Rio Grande for irrigation, much of the water that El Paso's residents drink actually comes from aquifers deep below ground. These critical water sources are also in jeopardy.

In 1979, the Texas Water Development Board projected that El Paso would run out of groundwater by

2031. At that time, each resident was using, on average, over 200 gallons of water per day. Most of that water was being pulled from the city's two aquifers—the Hueco Bolson to the east and the Mesilla Bolson to the west.

For the next two decades, the water utility launched a campaign encouraging residents to use less water by, among other things, replacing their lawns with native plants. Today, average water use is down to 134 gallons per person per day. That's still higher than the US national average of 82 gallons but lower than usage in some other places in the country with similarly dry climates, like Arizona (145 gallons) and Utah (169 gallons).

The aquifers are in better shape as a result—somewhat. "The water level is dropping, but it's not dropping like a rock," says Scott Reinert, the resources manager of El Paso Water. Still, more water is coming out of the aquifer than going back in.

El Paso Water pumps between 40,000 and 50,000 acre-feet of water from the Hueco Bolson every year and replaces about 5,000 acre-feet annually. (An acre-foot is an unwieldy unit of measurement used by water utilities—it's enough water to cover an acre of land, or just over half a soccer field, with a foot of water.) There's also some natural recharge from other groundwater and the river, but it's likely not enough to keep up with pumping.

El Paso Water plans to keep pumping from the aquifers for at least the next 50 years. But some researchers think the Hueco Bolson could be exhausted sooner, especially because El Paso isn't the only city depending on it.

The city of Juarez, Mexico, hugs the Rio Grande just to the south of El Paso. Juarez currently uses about half as much water per capita as El Paso. But because its population is rising and the city is almost entirely dependent on the Hueco Bolson, it also has a significant impact on the aquifer levels.

With both cities pumping and growing, some wells could start to run dry in about 40 years, says Alex Mayer, a civil engineer at the University of Texas at El Paso. But there might be trouble even before then, because all the pumping is changing the water quality underground.

Tirres hops out of his truck and walks over to what looks like a utility pole. He opens the door to a metal box and flips a switch. A pump roars to life, and brown-tinged water starts spewing from a pipe into the concrete canals that line the property.

Wells like this one supplement what Tirres gets from the river. They're scattered through his fields and pull water from up to hundreds of feet underground. This water is more expensive than what Tirres can get from the river, but during a drought, it saves both his crops and his livelihood.

Tirres ducks back into his truck and pulls out the lower half of a plastic water bottle he had fashioned into a sampling cup, along with a device that looks a little like an EpiPen. After letting the well run for a couple of minutes, he fills the cup and dunks one end of the gadget into the water sample.

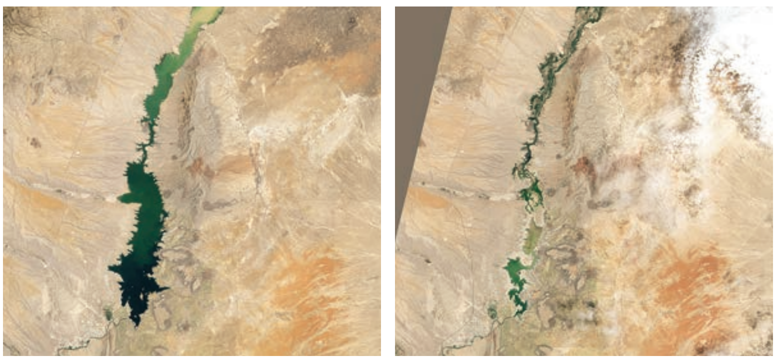
He shakes his head as he watches the small screen, where the numbers are ticking up. The meter, which measures salt content by detecting how electricity moves through the water, reads nearly 2,400 parts per million, up from the 1,600 he measured two summers ago.

Pecan trees, in particular, can be harmed by too much salt, growing scraggly and producing less fruit. Tirres has noticed a few trees on the edges of some of his groves looking a little worse for wear. He's worried—if the groundwater gets too salty, he won't be able to use it for his crops.

The Hueco Bolson holds about 10 million acre-feet of fresh water and about three times as much brackish, or semi-salty, water. Every time a pump switches on to retrieve fresh water, saltier water moves closer to the city.

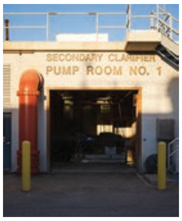
Pumping from El Paso has actually reversed the area's natural flow of groundwater, which used to move from north to south, following the Rio Grande. Groundwater moves slowly, on the scale of decades, but if farmers and larger water users in the city continue to pump as they have been doing, the brackish water could eventually eclipse what's left of the fresh water, leaving wells all over the area useless.

Before that happens, El Paso is trying to put some of that brackish water to use.



NASA EARTH OBSERVATORY IMAGE BY JESSE ALLEN AND ROBERT SIMMON, USING LANDSAT DATA FROM THE U.S. GEOLOGICAL SURVEY.

"We're really at the point now where we can start to see these climate-change signals in the real world."



Using salt water for much of anything used to be next to impossible. But reverse osmosis and other filtration methods developed in the 20th century created new possibilities.

Desalination, pulling salt out of water, accounts for a small but growing fraction of human water use worldwide. Global capacity tripled between 2005 and 2018, and today nearly 300 million people get some of their water from desalination plants. Most are near the sea: about 60% of desalination is done with seawater, and nearly half the world's desalination capacity is in the Middle East and North Africa. But in 2007, El Paso opened the world's largest inland desalination plant to make use of the brackish water in the Hueco Bolson aquifer.

"We're an on-demand plant," says Art Ruiz, the facility's superintendent, as we walk into the control room, where monitors display flows and pressures and pump speeds. Through windows on the far wall, I can see the entire $90 million facility, housed in a building not much larger than a high school gymnasium. Orderly pipes and pumps line one of the walls underneath an oversize American flag. A dull hum is the only clue that the plant is running.

By on-demand, Ruiz means that the desalination plant can increase its output to take the edge off during the highest-demand days, like summer scorchers, or holidays like Christmas, when everyone is home and turning on the taps. If the facility were running full-out, it could produce over 27 million gallons per day of fresh water. But most of the time it does much less, accounting for about 5% of the city's annual water needs, which range from 85 million to 145 million gallons per day.

The system uses reverse osmosis: brackish water is forced through a membrane with openings so small even salt can't make it through. It's an expensive process. While pumping fresh water out of the ground and disinfecting it costs about $250 per acre-foot, desalinating brackish groundwater blows the price up by nearly three times, to about $700.

Despite the cost, desalinated groundwater has become a critical part of the city's water portfolio—and an important contingency plan for the future. The desalination plant is one of two major infrastructure projects El Paso has undertaken to make its water supply more resilient to drought, and the second is arguably even more ambitious.

More water managers are looking at wastewater and seeing a valuable resource—once it's cleaned up, anyway. New wastewater recycling plants are being developed across the American West, most notably a potential multibillion-dollar project in Southern California planned for around 2030.

El Paso has been treating and recycling some of its wastewater for decades, using it to water grass in parks and golf courses, or to cool machines at factories and power plants. Today, most gets injected back into the aquifers. But Gilbert Trejo, the chief technical officer at El Paso Water, has an even grander vision.

Direct potable reuse, often referred to as toilet-to-tap recycling, is the pinnacle of wastewater recycling. Wastewater from showers and sink drains and, yes, toilets is collected and treated as it normally would be: after solids are separated out, the water is disinfected with chlorine. Then it goes through additional processing, getting filtered and cleaned with chlorine again and disinfected with UV light before being piped back out to be used in kitchens, bathrooms, and gardens across the city.

Most water recycling today passes water through a natural source like a lake or river; few sites in the world employ direct potable reuse. A site in Namibia is the longest-running and largest. El Paso is now designing a plant that would be the largest such facility in the US. It should come online in 2025 and is likely to cost about $100 million, Trejo says.

Trejo hopes the new plant will provide another stable water source and help take the burden off the aquifers when the river runs low. Residents are largely accepting of the idea—if they object, it's often not to the "ick" factor but to the cost. But the plan isn't infallible. In August, two pipes bringing wastewater to the city's existing recycling plants broke in western El Paso.

The lines were supposed to be backups for each other—so when both broke, wastewater backed up into bathtubs and yards. With more breaks appearing

El Paso is unlikely to run out of water in the coming decades. Water may just keep getting harder to pull together, and more expensive as a result.

←

El Paso has invested hundreds of millions of dollars in technological systems, including desalination (left) and wastewater recycling (right). It also runs programs to persuade people to use less water.

↑

The city already uses wastewater on parks and golf courses—after the "organic matter produced by residents" is removed, as Art Hernandez, deputy superintendent of the RR Bustamante Wastewater Plant, delicately puts it.

in the pipes every day, the city had to find somewhere for all the wastewater to go. So they turned to the only place that could hold the millions of gallons leaking from the pipes each day—the Rio Grande.

El Paso is unlikely to run out of water altogether in the coming decades. But it will keep getting harder, and thus more expensive, to pull together as much as it needs. Though technological solutions like desalination and wastewater recycling can help, the solutions many people need will get more complex as conditions continue to worsen. Scaling them up may also introduce new risks that tend to come with relying on such highly engineered systems—such as when the city had to dump untreated wastewater meant for recycling directly into the river.

El Paso's city officials will keep trying to plan ahead. In fact, El Paso Water is now the proud owner of about 66,000 acres of land 90 miles to the east in Dell City, Texas. The land comes with water rights, and if the city's own resources ever fall short, the utility plans to drill wells in Dell City and pump the water back to El Paso.

Pumping the water from Dell City to El Paso and treating it would cost \$3,000 to \$5,000 per acre-foot. That's at least twice the cost of wastewater recycling, and over 10 times the cost of local groundwater or surface water in the Rio Grande.

These costly solutions will likely be reflected in El Pasoans' water bills soon. Trejo says rates already need to go up just to maintain the existing systems.

For some, the increases won't be significant—the 2021 rate hike including water, wastewater, and stormwater fees amounts to \$1.37 a month for an average user. Waiver programs for low-volume users should help people who can't pay. About 19% of El Paso residents live in poverty, compared with about 12% nationally.

That increase was just the beginning, Trejo says. There's been public pushback against more increases, but the agency can't keep putting them off. "Rates in El Paso are going to get more expensive," he says, "and they're going to get expensive quick."

Across the river, El Paso's sister city Juarez may need similar infrastructure fixes and upgrades to deal with the dwindling water supply but has even less money to fund them.

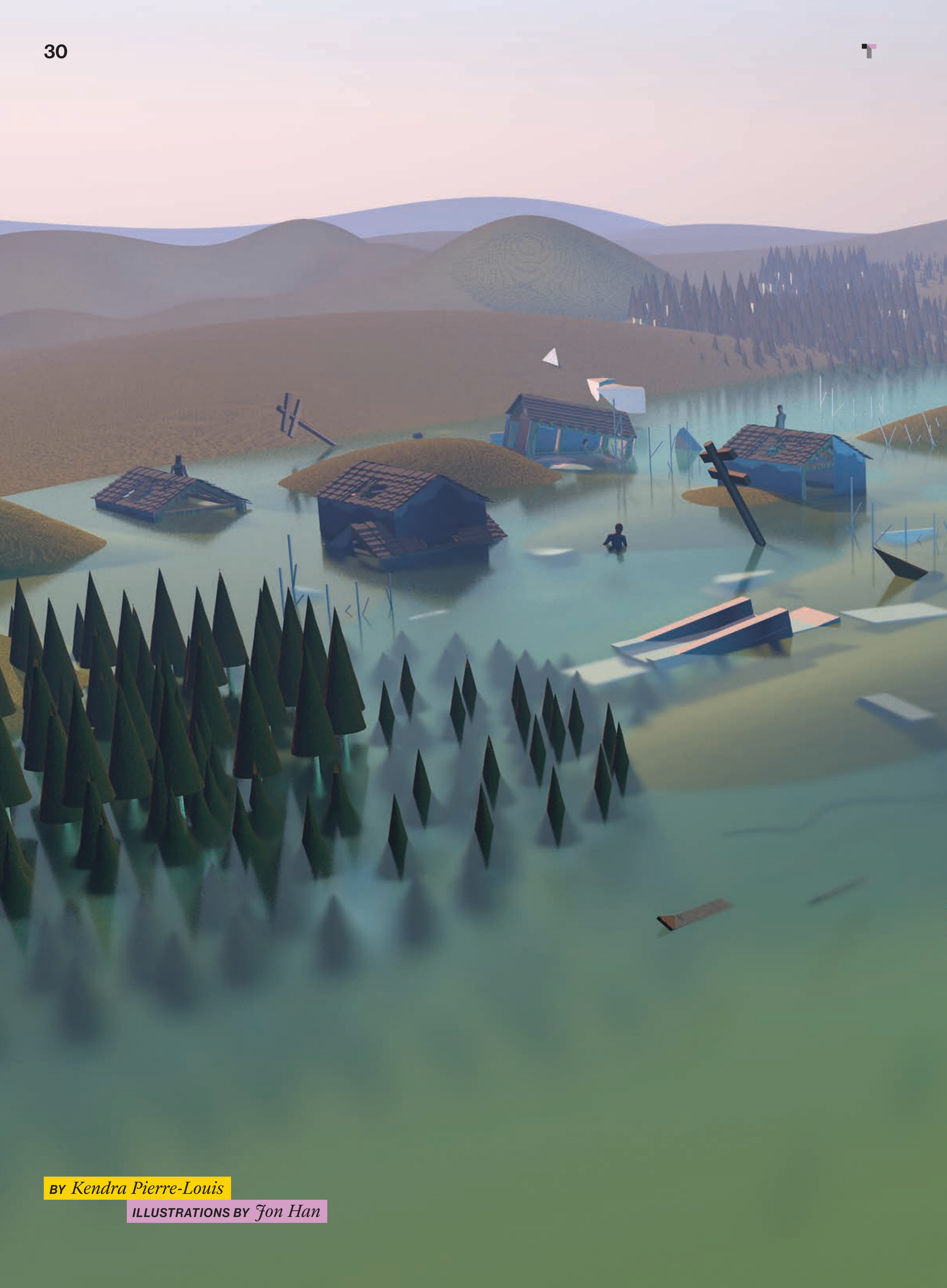
Making these adjustments may seem like a small price to pay to keep water flowing in the desert. But as populations grow, droughts stretch longer, and the planet continues to warm, the task ahead can begin to look more daunting.

The West expects to see another year of La Niña weather patterns into 2022, which likely signals a dry winter for the region and another year with a mostly empty reservoir. People who rely on river water, from Tirres and other small farmers to officials in the city of El Paso, probably won't get their expected allotment next year either.

Many El Pasoans will stay put despite the water woes. Tirres plans to keep farming as long as he can—it's in his blood, he says. Farming in the desert may be getting harder, but it's never been easy.

"Farmers have always fought this battle, forever," he says. "You adjust to it. You have to adjust to it." ■

Casey Crownhart is an editorial fellow at MIT Technology Review.



BY *Kendra Pierre-Louis*

ILLUSTRATIONS BY *Jon Han*

THE CREEPING MENACE: RISING GROUNDWATER

RISING SEA LEVELS DUE TO CLIMATE CHANGE ARE PUSHING UP GROUNDWATER, OFTEN MILES AWAY FROM THE COAST. THE RESULT IS WIDESPREAD FLOODING—A LARGELY UNSEEN AND IGNORED CRISIS THAT IS RAPIDLY GETTING WORSE.

Fae Saulenas does not want your sympathy.

Saulenas, along with her 46-year-old daughter Lauren, spent last winter—their covid winter—in Saugus, Massachusetts, in a house without a working furnace. Saulenas is in her 70s. Lauren, because of brain injuries she experienced in the womb, is quadriplegic, blind, and affected by a seizure disorder, among other disabilities. In winter, it's not unusual for overnight temperatures in Saugus to dip into the teens. The two could not long survive without heat, so absent a furnace, they relied on a space heater. But the cost of electricity to power it was $750 in February alone, and it warmed only a single bedroom.

Saulenas doesn't tell this story to engender sympathy but, rather, as a warning. The water table, she says, is rising—seeping into gas lines and corroding furnaces from the inside out. That's what happened to hers. And she wants you to know that if you live anywhere near a coast—even one, two, three miles away—that water might be coming for you too.

For something you've probably never heard about, rising groundwater presents a real, and potentially catastrophic, threat to our infrastructure. Roadways will be eroded from below; septic systems won't drain; seawalls will keep the ocean out but trap the water seeping up, leading to more flooding. Home foundations will crack; sewers will backflow and potentially leak toxic gases into people's homes.

Saugus is a small town roughly 10 miles northeast of Boston. On maps, water is one of its defining features, with the Saugus River and its tributaries meandering through the town and heading through marshland to the Atlantic Ocean. Among those salt marshes, blocked from the Atlantic by the peninsula of Revere Beach, is where Saulenas bought her house in 1975.

Given the proximity to the ocean, the source of her recent woes would seem obvious: sea-level rise. Since 1950, sea level in the region has risen by eight inches, and that change has not been linear. The sea is rising faster now than it did a generation ago—about an inch every eight years. But the water that left Saulenas out in the cold did not come from the sea, at least not directly.

Her problems began in 2018, when she lost gas—and thus heat—because of water entering an underground main. It was a problem that would persist, intermittently, for several years. Water would enter the gas main, and her utility, National Grid, would be forced to shut off the gas. National Grid would then try to find where the water was coming from, patch the leak, and pump the water out.

Officially, National Grid has not named the source of the problem. But Saulenas thinks the culprit is groundwater.

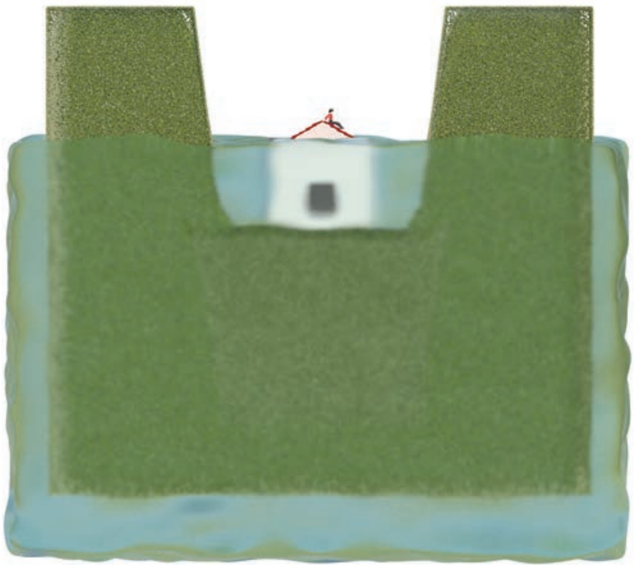
Even under normal circumstances, the cast iron pipes that make up roughly a third of National Grid's infrastructure in Massachusetts are prone to rust and corrosion. She thinks these pipes, which once sat comfortably above the water table, are finding themselves intermittently swamped during seasonal high tides that essentially push up the groundwater. And it's that elevated groundwater that she thinks seeped into the gas main, flooded out her gas meter, and eventually corroded her furnace.

Kristina Hill, an associate professor at the University of California, Berkeley, whom Saulenas reached out to in pursuit of answers, agrees. "She was asking me, is this something that comes from sea-level rise? And obviously, the answer is yes," says Hill.

Hill is one of a number of researchers trying to get the public and policymakers to take the risks of rising groundwater seriously. Unlike rising seas, where the dangers are obvious, groundwater rise has remained under the radar. Hydrologists are aware of the problem and it's all over the scholarly research, but it has yet to surface in a significant way outside of those bubbles. Groundwater rise is only briefly mentioned in the most recent edition of the National Climate Assessment, released in 2018; it's absent from many state and regional climate adaptation plans, and even from flood maps.

A 2021 study in the journal Cities found that when coastal cities conduct a climate vulnerability assessment, they rarely factor in groundwater rise. "They talk mostly about sea-level rise, storm surges," says Daniel Rozell, an engineer and scientist affiliated with Stony Brook University, who wrote the 2021 paper. "But there haven't been a lot of questions about what's going to happen to the groundwater."

Impacts on existing infrastructure and planned climate adaptations could be catastrophic. Remediation efforts that haven't planned for groundwater rise will be rendered useless. Billions of dollars in infrastructure will need to be upgraded. And it will likely affect an area much larger than



"THE PROBLEM IS HUGE. WE'VE WAY UNDERESTIMATED THE FLOODING PROBLEM."

what's captured on most flood maps. A 2012 study by researchers at the University of Hawaii that factored groundwater into flood risks found that nationwide, the area threatened was more than twice the area at risk from sea-level rise alone.

Any coastal area where "the land is really flat, and the geology is [the kind of] loose material that water moves through really easily," says Hill, is "where this is really going to be a problem." This includes places like Miami, but also Oakland, California, and Brooklyn, New York. Silicon Valley communities like Mountain View are susceptible to groundwater rise, as is Washington, DC. Worldwide, the area at risk includes portions of northwestern Europe and coastal areas of the United Kingdom, Africa, South America, and Southeast Asia.

"The problem is huge," says Hill. "We've way underestimated the flooding problem."

And because of how groundwater moves, people who are at risk may not know it until it's too late. "One of the most important things about the groundwater is that the rising groundwater level precedes any inundation of the surface," says Rozell. Put another way, we will experience groundwater flooding long before the ocean comes lapping at our front door.

The water beneath our feet

It might seem puzzling that rising seas could cause groundwater to rise. At first blush the two seem unrelated, but the connection is actually simple. That it has long been ignored reflects our bias toward addressing problems we can easily see.

To understand the link, it first helps to understand a bit about groundwater. The water nestled in sediments underground started as surface water, like rain or snow, and eventually seeped down. A layer of saturated soil rests below a layer of unsaturated soil; the boundary between the two is what's known as the water table. And in many coastal areas this layer of saturated soil, which can be meters thick, rests atop salt water from the ocean. As sea levels rise, the groundwater gets pushed up because salt water is denser than fresh water.

And this isn't the only way that the ocean and groundwater are connected.

"Groundwater normally flows out to the sea," says Rozell. "All along the coast, there's what they call submarine groundwater discharge. You might even notice it if you go to the beach at low tide. If you stand in the water, you might feel really cold water right at the edge, in the sand. And that's groundwater just running out continuously into the ocean."

Thus, any protection designed to keep rising seas from encroaching onto land must also factor in how to let groundwater out.

Arguably the first big study in a prominent scientific journal that looked at what sea-level rise might mean to groundwater levels was published in 2012 in the journal Nature by researchers Kolja Rotzoll and Chip Fletcher of the University of Hawaii. The study came on the heels of a report by the United States Geological Survey and Yale University researchers who looked at what would happen to groundwater in coastal New Haven, Connecticut, as sea levels rose. In both cases researchers found that the two would rise in concert.

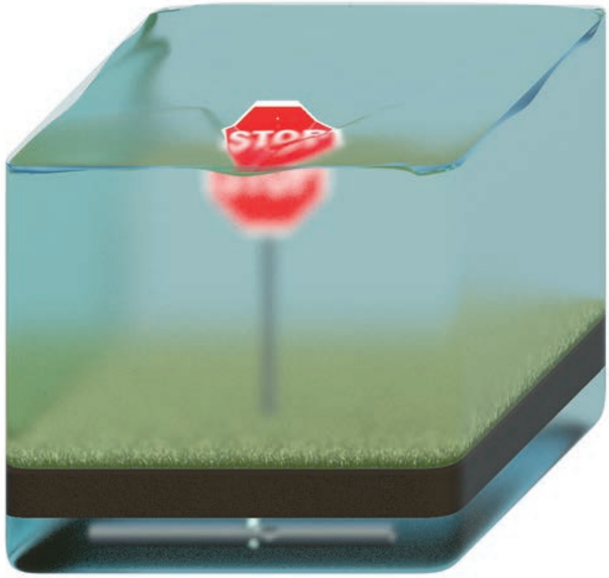
"We looked at well records and found that the water table in the coastal zone goes up and down with the tides," says Fletcher. "And so we realized there's a direct connection between the ocean and the water table. And as the ocean rises due to climate change, the water table is going to rise and eventually flood the land. So we're gonna have all these wetlands in urbanized areas and around roads, where we don't really want them. And it turns out this is a form of sea-level rise that in many areas is more damaging than what people classically think of as the ocean flowing over the shoreline and flooding."

And we're already seeing the effects.

Danger to human health

In talking with experts about groundwater rise, what often comes up is that it's more complicated and harder to adapt to than sea-level rise. Any solution to one aspect of the problem can create a cascade of others. Take, for example, something as straightforward as sanitation. Ordinarily, in most parts of the United States, when you flush the toilet one of three things happens, depending on where you live: it goes out to a cesspool, a septic system, or a sewer line. But groundwater rise presents increasing challenges for all three.

Cesspools are essentially concrete cylinders with an open bottom and perforated sides. Especially in coastal areas, the cesspools, which should be dry, instead find themselves constantly inundated, says Josh Stanbro, a senior policy director for Honolulu's city council, who until last January was the city's chief resilience officer. "They're now sort of always wet," he says. Microbes stay alive because they are wet, and because there's so much more water around, they can leach out.



"IT HAS THE CAPACITY TO AFFECT MILLIONS, AND NOBODY'S PAYING ATTENTION."

And Honolulu is not the only city with this issue. Miami-Dade County is facing similar problems with septic tanks, which in theory provide a layer of filtration that cesspools do not. But to do that filtration, the systems require a layer of soil two feet deep, and that layer shrinks as water tables rise. Already, 56% of the county's systems are periodically compromised during storms. By 2040, estimates suggest, that number will rise to 64%. Failed septic systems can contaminate the local aquifers that a community depends on for drinking water.

One workaround is to switch those households and businesses currently on septic or cesspool systems over to sewer lines. In Miami-Dade County, the estimated cost for that shift is $2.3 billion.

Nor are sewer systems a panacea, cautions Berkeley's Kristina Hill. "Most American sewer pipes, both sanitary and storm sewer pipes, are typically cracked, because we do such bad maintenance. We're like an international joke," she says. "People start conferences in civil engineering in Europe with slides of how bad American systems are, to loosen up the audience." Those cracked sewer pipes let groundwater in. And in places like New York City and Boston, which have what are known as combined sewer systems, water from rain and water from raw sewage mingle, so there's less space in the pipes. This is why as groundwater rises, places like New York City's Jamaica Bay community end up with liquid bubbling up from storm drains during high tide.

Newer cities tend to have systems where rainwater goes into one pipe and sewage into another. But if the pipes are full of groundwater when it rains, there's still nowhere for that rainwater to go. So in both cases, according to Hill, you'll get more flooding.

There's another way, too, in which rising groundwater can turn our sanitation systems into killers.

"In the Bay Area there's so much legacy contamination under the ground from military use, from the Silicon Valley tech booms—it left a lot of nasty stuff," says Kris May, a coastal engineer and climate scientist who founded Pathways Climate Institute. "And what often happens is we put low-income houses in those areas after they're remediated. But they still leave a certain amount of contamination in the ground, and those regulations were based on no rising groundwater table."

Now the groundwater table is rising. And as it does, it saturates the soil, unlocking contaminants such as benzene. These chemicals are highly volatile, and as gases they can easily find their ways through sewer lines and into homes.

This is the impact of groundwater rise on just one system—sewage. But it could affect many more. Buried electrical lines that aren't properly sealed will short out; foundations will start to heave from the pressure. Some fear that seismic faults could even be put under pressure.

How water finds a way

To protect themselves against rising seas, cities are turning to the same tools they have used for centuries: levees and seawalls. Boston has proposed a 175-mile seawall called the Sea Gates Project. Miami has a proposal for a $6 billion, 20-foot-high seawall. New York has proposed its own $119 billion, six-mile-long project called the New York Harbor Storm-Surge Barrier. Homeowners from Florida to California are erecting barriers to keep the ocean out. But the fundamental problem with all these interventions is the same: a seawall holds back the sea, not groundwater.

In some areas, if the underlying ground is relatively impermeable, it is possible to build a seawall or levees that slow groundwater rise. But then you're left with other problems. Recall that water moves toward the ocean. A barrier that stops groundwater from rising with sea level will also keep stormwater from, say, recent rainfall from flowing to the sea.

"If you don't let the water run out to the ocean, then you have to basically pump it over the wall. And that's essentially what the Netherlands has been doing for several centuries," says Stony Brook's Rozell. But this too can create problems, because so many of the places these seawalls are working so hard to save—much of Lower Manhattan, large parts of San Francisco and Boston—were built on wetlands, landfill, or both. "If they pump, the land is going to sink," says Hill.

And even if cities were willing to pursue such a path, not every place can. "There are lots of conditions where you can pump all day long and the water table won't go down," says the University of Hawaii's Fletcher.

Recall that groundwater is water that makes its way into the spaces, or pores, in sediment. In some places, like Miami, "the pores are so large that you're just pulling in water from the estuary from the ocean," says Fletcher. "You can pump as hard as you want and it just keeps coming in from an endless body of water"—the sea.

Planners are often oblivious to the problem. In 2009, the Maldives, a low-lying island nation, held the world's first underwater cabinet meeting to draw attention to the harm big climate polluters, like the United States, were perpetuating through climate inaction. The message was clear: You're drowning us. These days, already dealing with the consequences of rising seas, the country is consolidating its outer island communities onto a new island called Hulhumalé. It's designed to withstand sea-level rise. But the project did not factor in rising water tables.

"They did not understand that the water table will rise with sea-level rise," says Fletcher. If the sea rises only two more feet—which some estimates say will happen as soon as 2040—most of this brand-new island will be uninhabitable wetland.

When he explained this to the project's lead designer, "he just stared at me—he was speechless. It's like he couldn't comprehend what I was saying," Fletcher says. "All the billions of dollars they had spent on this thing, and they didn't build it high enough."

Eroding away history

There is at least one place where you can see people reckoning with rising groundwater in close to real time. Strawbery Banke Museum is in Portsmouth, New Hampshire, near the banks of the Piscataqua River, just a few miles from the Atlantic Ocean. The buildings were preserved to let us see three centuries into the past, but they are also giving us a glimpse into the future. Some of the structures, including the city's second-oldest house, are flooding from below.

"We're getting these super tides, king tides, that elevate the water over two feet higher than typical. And so we're starting to see this water get into our basements," said Rodney D. Rowland, Strawbery Banke's director of facilities and environmental sustainability, on a tour of the museum in late September. When you crouch down in basements with their ceilings too low for most adults to stand, it's easy to see the water marks from past groundwater incursions.

The museum has taken a two-pronged approach. The first element is educating the public. "One of the exciting things that we're gonna add is a kiosk that is attached to sensors that were placed in the ground around the museum," said Rowland. "And they will track the movement of the groundwater, [plus] salinity, temperature, water height. And so visitors will see that there's water under their feet."

But the museum also needs to preserve the buildings. And that goal must now be balanced with the fight against rising water. In one of the houses, "we made the decision to take out what was called a summer kitchen," said Rowland. "There was a hearth down there where they cooked in the summertime. We took it out, and we put in a granite block." They had to do that because the old hearth was acting like a candle wick, drawing water from the basement into the rest of the structure.

"So now the rest of the chimneys are preserved," he added. "The water can't get through that. But we lost that piece of history. And this is going to be a constant battle with how much are we going to lose to save what we can."

In some ways Rowland is lucky. His state, New Hampshire, is at least aware of the risk of groundwater rise and is factoring it into plans. But New Hampshire is an exception. Many other states, with more extensive coastlines, are going to have to face the issue in the coming years as not only buildings but lives are threatened by this unseen risk.

Less than 50 miles down the coast in Saugus, Fae Saulenas plans on leaving for higher ground— but not without making some noise. She's written legislators, National Grid, and the press to try to draw attention to the issue. "Groundwater is really important to me. And it's important to me not only because it has affected my life profoundly, but because I think it has the capacity to affect millions of people," she says. "And nobody's prepared, and nobody's paying attention." ■

Kendra Pierre-Louis is a senior climate reporter with the Gimlet/Spotify podcast "How to Save a Planet."

You can find Dubna, a small town three hours away from Moscow by train, both on a map and in the periodic table: dubnium, element number 105, was discovered at a research center there, and named after the town. A hasteless town, Dubna is defined as much by the surrounding forests as by the water: it sits on the banks of the Ivankovskoe Reservoir, the first part of a massive hydropower project called “Big Volga” whose construction spanned decades during the Soviet era. The complex, consisting of 11 dams on the Volga and its largest tributary, the Kama, is responsible for about 5% of the total electricity production in Russia. The Ivankovskoe Reservoir is both the oldest part of the complex and the farthest upstream, situated almost at the Volga’s headwaters.

About 2,300 miles long, the Volga—sometimes referred to as “*Volga-matushka*,” or “Mother Volga”—is the longest river in Europe and the biggest by water flow, arcing from northwest of Moscow around and down to the Caspian Sea. Some 60 million people—about 40% of Russia’s population—live in its basin, which spans almost a tenth of the country’s vast territory. Moscow, with its 12 million people, gets most of its drinking

HEALING

THE SOVIETS TURNED RUSSIA’S MOST IMPORTANT RIVER **INTO A MACHINE.**

THEN THE MACHINE **BROKE.**

CAN IT BE **REPAIRED?**

water from the Volga via the Moscow Canal. About 1,500 miles downstream, the strategic port city of Volgograd, formerly known as Stalingrad, was the site of World War II's most decisive, and arguably bloodiest, battle. As an artery of commerce, a source of energy and drinking water, and a conveyor of history, the Volga touches nearly every aspect of life in Russia. It is what the Mississippi is to the United States or the Rhein to Germany.

When the station in Dubna was designed, in the early 1930s, the young Soviet state had just decided to catch up with the capitalist states of the West by rapidly accelerating its industrial development—but in order to do so, it needed to generate energy on a massive scale. By the time the last station was built, in the 1980s, the Soviet Union, having just hosted the Olympics for the first time, was about to launch *perestroika*, a program of large-scale democratic reforms intended to end an era of stagnation and revitalize the flailing state. The history of the Big Volga project is, in a sense, the history of Soviet industrialization. It is also a history of rivalry with the US, which for decades raced the Soviets to build bigger, more impressive dams.

The project was one of the largest nature-transforming schemes in history: put together, the artificial reservoirs on the Volga are about as big as Lake Erie. It tried to harness the river

THE MOTHER RIVER

BY
OLGA
DOBROVIDOVA

PORTFOLIO BY
STOYAN
VASSEV

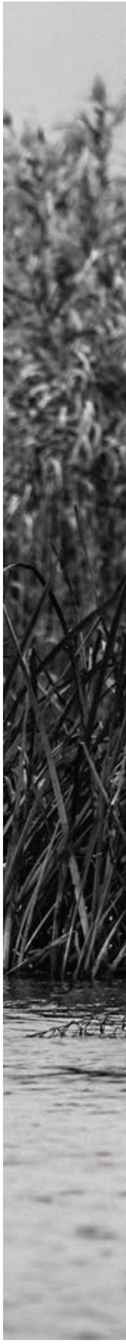
to provide the Russian people with necessary things: energy, transportation, and water. But it tried to do too much.

The river has become polluted, silted up, and overwhelmed by invasive species. Water flows at a tenth of the speed it did before the dams were constructed, according to estimates by researchers at the Institute of Ecology of the Volga River Basin, in the central Russian port city of Togliatti. Widespread toxic algal blooms are now common.

As global temperatures rise, the Volga basin is getting less and less rainfall in the spring and summer, and more snow in the winter. Igor Mokhov, chief scientist at the Obukhov Institute of Atmospheric Physics of the Russian Academy of Sciences, points out that the intensity of spring and summer precipitation is expected to increase, making post-high-water planning more difficult. A team of Russian hydrologists, writing in an August 2021 paper in Ecohydrology & Hydrobiology, argued that because of climate change, "there will be more water in those regions [of Russia] where it is sufficient, and less where it is most needed." The Volga basin is one of the regions most at risk, they wrote.

It is not an exaggeration to say that Russia's mother river is broken.

THE RIVER HAS BECOME POLLUTED, SILTED UP, AND OVERWHELMED BY INVASIVE SPECIES. WIDESPREAD TOXIC ALGAL BLOOMS ARE NOW COMMON.



I visited Dubna on a windy November morning. Runners in colorful clothing zipped by people walking their dogs along an unkempt reservoir front. I found myself in a grayscale photo of milky clouds and water like quicksilver, interrupted by the odd patch of evergreen and autumn brown. The opposite side of the reservoir was an impenetrable wall of coniferous trees, shrouded in a light mist.

I was trying, in vain, to orient myself to figure out how exactly one of the better-known stories about this reservoir must have unfolded. The story goes that in late November 1941, German forces were closing in on Moscow and had planned to cross the frozen body of water. The hydropower station workers reportedly decided to drain the reservoir, dropping water levels abruptly by two meters, crushing the ice and buying the city some time by stopping the invaders in their tracks. Eighty years later, though it was the same time of year, there was no ice in sight.

The hydropower station itself is a restricted site, encircled with an abundance of barbed wire, warning signs, and towering cranes so enormous there are small buildings on top of them. The noise of the water was pierced by seagulls and the occasional car as I walked along the dam. It was Unity Day, a modern Russian holiday devised to supersede a Communist holiday celebrating the 1917 revolution. Some of these people were driving to the Vladimir Lenin statue, a spot beloved by locals.

I could see Lenin's back at the end of the road. The statue was surrounded by ceremonial blue-green fir trees, and looked across the water at nothing in particular. The corresponding monument to Joseph Stalin had been demolished in 1962, after the Soviet government decided to "de-Stalinize" itself. The two monuments, each almost 40 meters tall, once guarded the entry point to the Moscow Canal, a Soviet engineering marvel connecting the Volga and Moskva rivers.

About the artwork:
A former velodrome racer for the Russian National Cycling Federation, Stoyan Vassev quit his sports career and began making photographs professionally in 2009.

The images accompanying this story are from his ongoing series *No Fish,* in which he documents the effects of environmental exploitation on life in Kirovsky, a small fishing village in the Volga Delta.

Beside the complex, there is a memorial hardly taller than I am. It looks like a random granite building block, tilted to the side, seemingly thrown out by the mighty waters to the foot of the Lenin monument and behind its back. The stone was placed there in 2013 to commemorate the more than 22,000 prisoners who died building the canal. Flowers and wreaths at the bottom were still fresh from the annual ceremony, held on October 30, when Russians remember those persecuted and murdered by the state, usually by reading their names aloud in front of countless similar memorials across the nation.

A young boy in a yellow jacket asked his mother, who was putting their things into the car parked near the memorial, "Mom, what's written on the stone?"

To the builders of the canal, she responded without looking.

This only made him ask her another question: "Why builders? Isn't the Volga a real river?"

In a way it isn't really a river anymore—it no longer flows naturally. It is now so mediated by human intervention that it is better thought of as a machine.

Just two months after the first gulag prisoners had arrived at the future dam site in Dubna, in November 1933, research bigwigs at the Academy of Sciences of the Soviet Union gathered in Moscow to discuss the state of the Volga and the Caspian Sea. Evgeny Burdin, a historian in the Volga town of Ulyanovsk, some 900 miles downstream from Dubna, read to me from one of the reports presented at the meeting. The report predicted that reservoirs would cause "swamp formation due to flooding, poor conditions for soil self-restoration, flooding of cellars in homes, changing microclimate, algae blooms and stale water, pollution, slowing down of water flow, and local risks of malaria."

"Even if there wasn't deep public awareness and discussion, surely many of the hydrologists and engineers knew that there would be significant and unavoidable impacts … Many people were aware of it, but it was very difficult, I'm sure, to say anything," Paul R. Josephson, a professor of Russian and Soviet history at Colby College, told me.

It was, indeed, quite difficult: one could be sentenced to hard labor for daring to criticize the government. In fact, one could even be very much in line with the government and still end up purged. That was what happened to Konstantin Bogoyavlensky, a turn-of-the-century engineer who designed the first known hydropower station project on the Volga, in the Samara region, a little downstream from Ulyanovsk, in 1910. The local authorities and clergy protested Bogoyavlensky's idea, which required flooding a lot of land, and it was shelved until after the 1917 revolution. Described as a fanatic, the engineer spent years lobbying the national government to build his station—and succeeded, only to be declared a spy and an enemy of the revolution shortly afterward and sent to a gulag camp in Siberia, where he eventually died.

"The important things to get from the Volga were energy for industry and good conditions for shipping to and from Moscow," Burdin told me. The technocratic, goal-oriented thinking of the time had no patience for polite objections from scientists or anything that could interfere with industrial development.

In April 1941, about two months before the USSR was attacked by Germany, bringing it fully into World War II, engineers started to fill the Rybinskoe Reservoir, the third one in the cascade, around 50 miles northeast of Dubna. (The second reservoir was also being filled at the time, but it was about a 20th the size.)

The Rybinskoe Reservoir would become the largest artificial body of water in the world at the time. More than 130,000 people had to relocate to make room for it, including some 6,000 residents of Mologa, a settlement first mentioned in historical chronicles in the 12th century. Mologa's churches, the tallest buildings in town, had to be blown up. The dam and reservoir were also built by gulag prisoners, who worked through the war to make sure the unfinished station could still power Moscow.

The Rybinskoe Reservoir destroyed thousands of square miles of arable land for a relatively small amount of electricity—after upgrades, the hydropower station now produces 376 megawatts, less than a fifth of what America's Hoover Dam puts out. By the 1980s, it began to look like a questionable bargain even for the USSR. Gosplan, the state planning agency, explored draining it. Experts concluded that "any consequences of draining the Rybinskoe Reservoir would be more drastic than those of filling it in the first place," says Victor Danilov-Danilyan, head of research at the Water Problems Institute (WPI) of the Russian Academy of Sciences. It would take at least several hundred years for the area, covered in sediment that had accumulated industrial and household pollution, to recover on its own, he adds, while cleaning it up would essentially mean "relocating this awful mess elsewhere" at a cost that Russia couldn't afford. And so the reservoir remains.

Decades later, the last surviving Mologa townspeople and their descendants still come to the nearby town of Rybinsk for an annual get-together in mid-August. Some of them visit the ruins that occasionally resurface when the year is particularly dry. That happened again in 2021, when summer left water levels in the reservoir low, causing alarm about potential water shortages downstream. In aerial photographs, the streets and foundations of Mologa formed an eerie geometry emerging from the lakebed.

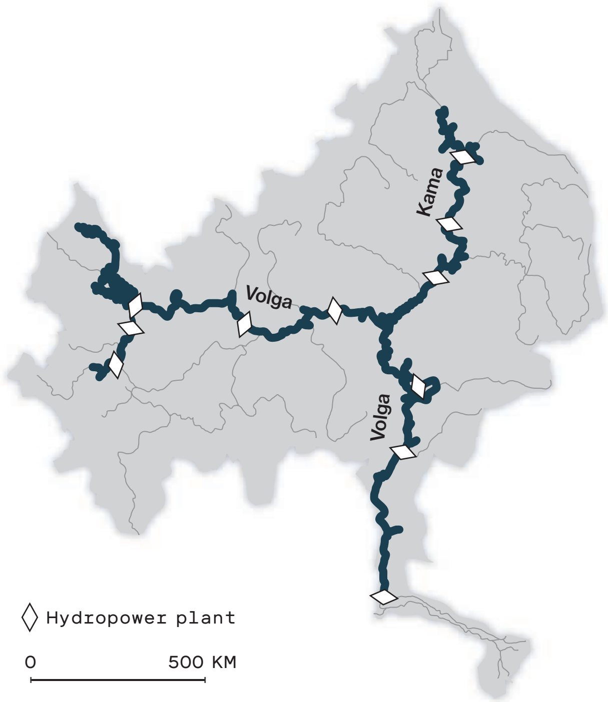
Gosplan, the USSR state planning agency, is notorious for completely destroying Mologa, a town almost as old as Moscow. When the Volga is low, its ruins can emerge from the water, drawing many Atlantis comparisons.

ISTOCK

The dam cascade has effectively turned the Volga into a chain of reservoirs. How much water gets through from the upper parts to the lower parts now hinges on a complex technical process that involves wrestling both innate uncertainty and worrying global trends. Natalia Frolova, a hydrologist and

A river no longer runs through it

The Volga, with its largest tributary, the Kama, is a massive cascade of 11 reservoirs with hydropower plants responsible for about 5% of the total electricity production in Russia.



geographer at the Lomonosov Moscow State University, explains how the trend of shifting precipitation played out in 2021: the spring high water on the Volga was more or less normal and well predicted, and the reservoirs were full, but the drier conditions that brought out the Mologa ruins this past summer caused water levels in all the reservoirs to fall below normal levels.

For the Volga cities, it's not just about the quantity of water but also the quality. The Volga is consistently among the three most polluted rivers in the country, accounting for nearly 40% of all polluted wastewater in Russia. Alexander Demin, a river researcher at the Water Problems Institute of the Russian Academy of Sciences, says only about 10% of all wastewater from point sources like sewer pipes is treated to levels required by Russian regulation. There are also many diffuse sources of pollution that are not effectively regulated: agricultural runoff, rainwater, meltwater, wastewater from ships, and even polluted soils and other detritus that wash into the river as sediment.

Since nearly all Volga cities and towns—and Moscow, via the canal—end up using the river for their water supply, this pollution comes with a hefty bill for water treatment. "The worse the water in the Volga, the costlier it is to make it potable," Demin notes. Given that the Volga basin is home to 60 million people, about half of Russia's industry, and a comparable portion of its agriculture, the costs add up.

A recent analysis compiled by Carbon Brief, a UK-based climate media outlet, puts the USSR and Russia third in the world in all-time historical greenhouse-gas emissions. A national assessment report compiled by Russian climate scientists in 2014 said that at a time of human-caused climate change, average annual temperatures in the country have been increasing twice as fast as the global average. The report also stated that the trend is expected to continue. Impacts of climate change fueled in part by Soviet industrial development are already visible around Russia, from permafrost degradation to desertification in the agriculture-heavy southern reaches of the country. The same large-scale industrial development that spawned Big Volga and was powered by the river's waters also contributed to the global problem of climate change—which has now brought the threat of water scarcity to millions of people living in towns along the Volga.

When I visited the final node in the cascade, the Cheboksarskoe Reservoir, about 370 miles east of Moscow, in 2010, I saw algal blooms that made the water look like a witch's brew.

The nearby city of Cheboksary, the capital of Chuvashia, one of several ethnic republics in Russia, was leafy, quiet, and welcoming when I visited. I was part of a press tour organized by RusHydro, the owner of the cascade, which had been lobbying the government to increase the water level in the reservoir. Years later it is still five meters below where RusHydro wants it to be, because the Cheboksarskoe Reservoir is where, after four glorious decades, the Big Volga project finally stumbled.

By the mid-1980s, with *glasnost*, Mikhail Gorbachev decided the Soviet Union could do with a bit more freedom of the press and transparency, letting citizens discuss and even criticize the decisions of their government. And so the irreversible environmental damage to the Volga gradually became part of a wide public conversation too. A 1989 book about the river called out the people behind the construction of reservoirs that led to "the life-giving water of the Volga turning into dead water, with nothing for us to do about it." "Boasting around the world that the Volga-*matushka* [mother-river] has been tamed several times, still calling themselves her sons, those who tamed her also condemned her to a long, horrible, and painful illness," the book reads.

It was also apparently no longer possible to simply give thousands of people two months' notice to leave their ancestral land, as was the initial plan for Mologa (the relocation ultimately took four years). Two nearby regions in European Russia, bordering Chuvashia, would be most affected by projected flooding: the Nizhegorodskaya Oblast to the west and the republic of Mari El to the north stood to lose territory, along with treasured historical landmarks such as gravesites and city churches, to rising waters. The republics protested and imposed delays, counting on central government funding to run out, which it did. In 1989, the Soviet government decided to keep the water level in the Cheboksarskoe Reservoir at a level that meant the hydropower station there could produce only about 60% of its designed electricity-generating capacity. The reservoir ended up about 380 square miles smaller than planned.

Because of the Cheboksarskoe debacle, the Volga-Kama cascade is, on paper, still unfinished. In a sense, the Soviet Union lost one of the more curious Cold War races: in the 1930s, as part of the New Deal, the US government started building a cascade of hydropower stations in the Columbia River basin in Washington state. For

a while in the late 1950s, the giant Kuibyshevskaya station on the Volga was the largest in the world by capacity, a title it snatched from the Grand Coulee Dam in Washington. Both projects were being touted as the greatest of their kind, and there are a few parallels, Paul Josephson says: "They've really turned both rivers into machines."

After the collapse of the Soviet Union, the newly formed Russian government was left trying to fix the Soviet machine. The federal Volga Revival program, a conservation and restoration effort launched in 1996, met its demise just two years later during a bout of deep economic crisis and government turmoil. The newest iteration of these efforts, the Healthy Volga program, started in 2018; the government plans to spend 205 billion rubles ($2.9 billion) over six years cleaning up the gargantuan wastewater flow to the Volga.

"WHOSE LAND IS BEING DESTROYED AND WHOSE WATER IS BEING POLLUTED SO THAT SOMEONE ELSE CAN MAKE MONEY?"

But Healthy Volga is already being criticized for failing to make a dent in the problem: in late 2020, the Accounts Chamber of Russia, a state audit authority, issued a report titled *Unhealthy "Healthy Volga,"* chastising the program managers for an excessive focus on point source pollution and a convoluted management structure. Water quality in the Volga, the report found, hasn't improved substantially over the last three decades.

Josephson, the historian, says the first necessary step is to enforce existing regulation and abandon the Soviet habit of making it cheaper to send untreated wastewater into the river and pay any resulting fines than it is to actually clean the water.

A frank and open conversation about the risks of projects such as Big Volga is essential beyond the Volga basin, argues Josephson. Many "zombie" Soviet projects have been coming back to life in modern Russia. Near Kamchatka, in Russia's far east, a proposed 100-gigawatt tidal power complex that was once thought too expensive is now being reevaluated as a potential hydrogen factory. Two more large hydro stations, also discussed in the Soviet era, are planned for the Angara, the only river flowing out of Lake Baikal in eastern Siberia; with six stations in total, activists fear, the Angara will turn into "a cascade of dead reservoirs." The Amur, a river on the Russia-China border, recently flooded, causing almost $7.5 billion in property damage and reviving plans for lowland dams and stations that had been made in the 1970s and '80s.

In 2017, when the Moscow Canal turned 80, the CEO of the state-run company that manages it told the media, "It's hard to imagine, but the Moskva River is about 80% Volga at this point." He went on to say that before the construction of the canal, in the early 1930s, the situation was so dire the Moskva had been reduced to a trickle; right near the Kremlin, one could simply walk across it. As the Volga cities downstream face increasing water risks, the capital water authorities report that for the foreseeable future, Moscow is out of any danger.

It is telling that the Volga has been put to use to provide for the Russian capital. As Josephson muses: "Whose land is being destroyed and whose water is being polluted so that someone else can make money? The Volga serves the Kremlin. It is Moscow's. It no longer belongs to the people along the Volga." ■

Olga Dobrovidova is a science journalist based in Moscow.

BONE DRY

Drought in Zimbabwe has forced tens of thousands of farmers to migrate to the country's Eastern Highlands. How many more can the region support?

Growing maize—Zimbabwe's staple crop—is becoming unfeasible, leaving millions of farmers without enough food.

Julius Mutero has harvested virtually nothing in the past six years. For his entire adult life, he has farmed a three-hectare plot in Mabiya, a farming community in eastern Zimbabwe. There he grows maize and groundnuts to feed himself, his wife, and their three children. He sells whatever's left for cash.

But over a decade ago, his area started getting less rain and the rivers dried up. What was already a hot climate, with temperatures that could reach 30 °C (86 °F), began recording summer highs up to 37 °C (99 °F) on a regular basis. Now the rainy season begins in late December instead of early November, and it ends sooner too. In the driest months, dust billows across sunbaked farmlands where only thorny shrubs remain.

Years of severe droughts have wiped out all Mutero's crops. He tried planting maize varieties that mature early, but even they didn't survive. And with no pastures for his livestock, he watched helplessly as all seven of his cows died.

TSVANGIRAYI MUKWAZHI/AP PHOTO

By
Andrew
Mambondiyani

“Life is now extremely hard here,” Mutero says. His family survives largely on food aid supplied by nonprofits or Zimbabwe’s government, but it’s not enough.

He feels he has no choice but to abandon his home in search of water. He’s fortunate—a traditional leader has promised him a small piece of land about 30 kilometers from Mabiya in the country’s Eastern Highlands, which get more rain and heavier mists than the rest of the country.

When we spoke in October, Mutero was planning to build a new home and relocate his family by year’s end. But he was nervous. “I don’t know what my family and I will face and how we will be received,” he said.

Mutero is just one of the 86 million people in sub-Saharan Africa who the World Bank estimates will migrate domestically by 2050 because of climate change—the largest number predicted in any of six major regions the organization studied for a new report.

In Zimbabwe, farmers who have tried to stay put and adapt by harvesting rainwater or changing what they grow have found their efforts woefully inadequate in the face of new weather extremes. Droughts have already forced tens of thousands from the country's lowlands to the Eastern Highlands. But their desperate moves are creating new competition for water in the region, and tensions may soon boil over.

Running out

Zimbabwe has endured droughts for the past three decades. But they're happening more often and becoming more severe as a result of climate change. Up to 70% of people in Zimbabwe make a living from agriculture or related rural economic activities, and millions of subsistence farmers there depend entirely on rain to water their crops. Over the last 40 years, average temperatures have risen by 1 °C, while annual rainfall has decreased by 20 to 30%.

At the height of the most recent drought, which lasted from 2018 to 2020, only about half as much rain fell in Zimbabwe as usual. Crops were scorched and pastures dried up. People and livestock crowded around hand-pumped boreholes to find water, but the wells soon went dry. Some people in the driest areas had so little to eat they survived on the leaves and white, powdery fruit of baobab trees.

More rain fell during the last growing season, but many farmers still feel uneasy about the future. Maize—Zimbabwe's staple crop, which was aggressively promoted by the former colonial government beginning in the 1940s—is becoming impossible to grow.

Over 5 million Zimbabweans—a third of the population—don't have enough to eat, according to the World Food Program. A study in 2019 of how vulnerable countries were to agricultural disruption due to drought ranked Zimbabwe third, behind only Botswana and Namibia.

As Mutero and other climate migrants know, conditions are somewhat better in the Eastern Highlands. This mountainous region stretches for around 300 kilometers along Zimbabwe's border with Mozambique. Many of the region's major rivers, including the Pungwe and Odzi, begin there as streams. The area's climate and fertile soils are perfect for growing crops such as tea, coffee, plums, avocados, and a sweet pinkish-red fruit called lychee.

When climate migrants started showing up in the Eastern Highlands a decade ago, they settled without permission on state land, and the government was swift to evict them. But they returned in even larger numbers, and officials have more or less given up trying to stop them.

By 2015, the government estimated that more than 20,000 migrants had settled in the Eastern Highlands. Though no more recent official estimates exist, anecdotal evidence suggests the number has continued to climb.

Today in some parts of the highlands, migrants occupy any vacant land they can find. In others, traditional or community leaders like the one helping Mutero, who are known in local dialect as *sabhuku*, have taken up the task of allocating land to migrants. The leaders—whose roles are largely ceremonial—are doing this in defiance of government orders. They've earned praise from migrants but disdain from local farmers who were there first.

Two senior government officials in the Eastern Highlands' Manicaland province—Edgars Seenza, the provincial coordinator, and Charles Kadzere, the provincial lands officer—declined to comment for this story. Vangelis Haritatos, Zimbabwe's deputy minister for lands, agriculture, fisheries, water, and rural resettlement, didn't respond to questions sent to his WhatsApp number.

"Soon people will fight"

Leonard Madanhire, a farmer who lives in what's known as the Mpudzi area in the Eastern Highlands, is worried. He grows mostly maize on his five hectares of land. His herd of cattle has dwindled from more than 20 a decade ago to five. Most nearby grazing lands, which he has long shared with other farmers, are now occupied by climate migrants.

In September, Madanhire took me on a long hike along the banks of the Chitora River. Freshly built dwellings stood on land that was once pasture; other structures dotted the river's banks. A couple of seemingly frustrated herdsmen were trying to steer cattle and goats through the narrow patches of pasture that remained.

A few kilometers up river, migrants had planted vegetable gardens on the river's edges. Madanhire says farming along the banks that way causes erosion and puts more silt and debris in the water for everyone downstream.

He fears that resources will soon run out as more people come to the area. Rivers that originate there, like the Mpudzi, Mushaamhuru, Murare, and Wengezi, are now running dry halfway through the dry season, he says.

"Soon people will fight for the little water left," he says. Already, skirmishes have broken out between farmers, migrants, and traditional leaders over who settles where and who gets to decide.

Madanhire isn't alone in his concerns. Josphat Manzini is a banana farmer in Burma Valley, a lucrative farming area in the Eastern Highlands that's long been renowned for producing the best bananas in the country. He's been anxious as climate migrants settle on nearby river banks and tap the water he needs to irrigate his more than 20 hectares.

Manzini says migrants have overrun several local rivers, taxing water supplies and stirring up so much silt that the debris is obstructing three dams as well as many smaller streams in the area.

Now, for the first time in his life, the prospects for banana farming in the Eastern Highlands are looking bleak. "There is no future here," Manzini says.

By 2050, the World Bank estimates, as many as

86 MILLION people in SUB-SAHARAN AFRICA

49 MILLION people in EAST ASIA AND THE PACIFIC

40 MILLION people in SOUTH ASIA

Living alone in Zimbabwe's arid Mudzi district, 90-year-old Leah Tsiga sometimes goes for days without a solid meal.

TSVANGIRAYI MUKWAZHI/AP PHOTO

Too little, too late

In scorched parts of Zimbabwe, some farmers have tried to cope and stay put. They've returned to planting drought-resistant traditional grains like finger millet, pearl millet, and sorghum. Others have switched from irrigating their crops by flooding entire fields to using systems that drip only the necessary amount of water right next to each plant.

And some, including Blessing Zimunya, a farmer in Chitora, have tried to harvest rainwater for irrigation and other uses. Zimunya uses a 5,000-liter container to collect water from his roof and a 100,000-liter tank to collect runoff on the ground. He supplements these systems with water from a nearby river.

Natalie Watson, the managing director of Bopoma Villages, a nongovernmental organization that runs a clean water and hygiene project, says rainwater harvesting has great potential to make a difference. She cites a well-known Zimbabwean farmer named Zephaniah Phiri Maseko, who before he died transformed dry land into lush fields using methods that Watson's organization now teaches.

Her program is currently focused on the Zaka district in southern Zimbabwe, where hundreds of farmers are taking part. Some in the nearby province of Midlands have also begun to experiment with rainwater harvesting.

The total number of farmers in Zimbabwe who have taken up the practice is still very low, though. Of the more than 7 million small farmers across the country, only a few thousand in the driest provinces have tried it. Despite the efforts of organizations like Watson's, most farmers don't have the money to build large tanks to store water. Many more still don't know what rainwater harvesting is, or how to get started.

Other nonprofit programs are underway to help farmers adapt by learning new practices to preserve soil moisture and finding ways to diversify their incomes beyond agriculture. And last year, Zimbabwe's government announced a plan to

19 MILLION people in **NORTH AFRICA**

17 MILLION people in **LATIN AMERICA**

5 MILLION people in **EASTERN EUROPE & CENTRAL ASIA**

will be forced to migrate as a result of climate change.

create 760,000 new "green" jobs in four years in fields like solar, hydropower, energy efficiency, and sustainable agriculture. But these efforts are still in their infancy.

Gift Sanyanga of Haarlem Mutare City Link—a twin-city arrangement between the city of Haarlem in the Netherlands and Zimbabwe's Mutare that commissioned a 2019 report on climate migration in the Eastern Highlands (and paid for me to travel to Haarlem to speak that same year)—says adaptation measures have largely failed, and the only practical option left for many farmers is to migrate. Anna Brazier, an independent climate researcher, thinks it's time for Zimbabwe's government to actively encourage people to move out of dry areas before conditions get even worse.

"As climate change intensifies, it is going to make some of these areas uninhabitable," she says. "Rather than having to deal with a rushed mass migration, which will put severe pressure on the areas that people migrate to, we should be planning for a gradual evacuation of the most vulnerable areas now."

She says the government should do a nationwide land audit to figure out where space is available for migrants and create a process by which people can legally resettle there—perhaps with a bit of money or other support to get them started. While the government is doing a lot to properly relocate people from flood-prone areas, it's doing little to relocate farmers from places prone to drought.

For many, though, it's already too late.

Despite the uncertainties that await him in the Eastern Highlands, Mutero has already made up his mind. "I'm moving; nothing will stop me," he told me. "That's my only option." ■

Andrew Mambondiyani is a science journalist based in Zimbabwe and a former MIT Knight Science Journalism Fellow.

Making friends with flooding

By
Erica Gies

Above:
Qunli Stormwater
Park in Harbin City

Opposite:
Nanchang Yuweizhou
Wetland Park

Our attempts to control water have been a disaster, says one influential Chinese designer.

His radical theory: we should work with it instead.

Above:
Shanghai Houtan Park

Opposite top:
The Floating Gardens at Yongning River Park, before (inset) and after

Opposite bottom:
Beijing Yongxing River Greenway before (inset) and after

For years, Beijing landscape architect Yu Kongjian was ridiculed by his fellow citizens as a backward thinker. Some even called him an American spy—a nod to his doctorate from Harvard's Graduate School of Design and his opposition to dams, those symbols of power and progress in modern China.

Yu's transgression: he advised working with water, rather than trying to control it.

Yu is at the forefront of a movement that aims to restore the ebb and flow of water to urban environments. His landscape architecture firm Turenscape, which he cofounded in 1998, creates flexible spaces for water to spread out and seep underground, both to prevent flooding and to be stored for later use. His vision is to heal the natural hydrology that we've disrupted by tightly confining rivers with levees, putting buildings or parking lots where water wants to linger, or erecting dams that have, to varying degrees, dried up 333 rivers in the Yangtze area. "Those gray infrastructures are actually killers of the natural system, which we have to depend on for our sustainable future," Yu has said. By trying to solve one problem at a time—flooding here, water scarcity there—the 20th-century approach to water management has undermined itself. "Drainage is separated from the water supply; flood control is separated from drought resistance," he wrote in 2016 for a paper he presented at a Harvard symposium.

Since the 1700s, we've filled or drained as much as 87% of the world's wetlands, which would otherwise be flexibly absorbing and releasing water. It's a key reason urban flooding is increasing worldwide: as populations grow and cities expand, builders pave floodplains and farmland, fell forests, and channelize rivers, leaving stormwater that once filtered into the ground with nowhere to go. The land area lost to cities has doubled worldwide since 1992. When a city increases the area of roads, sidewalks, or parking lots by 1%, stormwater runoff boosts annual flood magnitude in nearby waterways by 3.3%.

In dense cities, only around 20% of rain actually infiltrates the soil. Instead, drains and pipes carry it away—lunacy, Yu thinks, in places with water shortages.

In the early 2000s, Yu and a research team created a map of Beijing showing where land was at high risk for flooding, which he called the "ecological security pattern." His recommendation was that this land should remain undeveloped, and should be used instead to absorb stormwater.

Government officials ignored him. But then, in July 2012, disaster struck. Beijing's largest storm

PHOTOGRAPHS THROUGHOUT COURTESY OF TURENSCAPE

Two views of Tongnan Dafo Temple Wetland Park in Chongqing City. Below, a structure inspired by the Dafo Temple.

At right, an aerial view of the park. In 2020, Chongqing faced a 100-year storm, but the landscape protected nearby farms from flooding.

Opposite: Another view of Beijing Yongxing River Greenway.

in more than 60 years chucked down as much as 18 inches of rain in places, flooding roads three feet deep and filling underpasses. Yu barely made it home from work. “I was lucky,” he says. “I saw many people abandon their cars.” Almost 80 people died, most of them drowned in their vehicles, electrocuted, or crushed under collapsed buildings. The damage stretched across 5,400 square miles and cost nearly $2 billion.

“The 2012 flood gave us the lesson that the ecological security pattern is a life-and-death issue.” Yu says.

Climate change has worsened these threats. With every 1 °C increase, the atmosphere holds 7% more water vapor. So when clouds burst into rain, it pours. Meanwhile, dry areas get drier as the warmer air evaporates more water out of soil and plants.

Now we’re starting to see the impact on the water cycle. Summer and fall 2021 brought deadly flooding to New York, New Jersey, Tennessee, Alabama, Germany, Belgium, India, Thailand, and the Philippines. At the same time drought, crop failures, and forest fires plagued the American West, Syria, Guatemala, Greece, and Siberia. Global economic losses from flooding rose from $500 million annually, on average, in the 1980s to $76 billion in 2020. When it comes to drought, more than 2 billion people around the world already live with severe or high water insecurity. Researchers predict that as the climate continues to warm, two-thirds of the global population—more than 5.25 billion people—will experience progressively worse and more frequent drought conditions.

These recent disasters have brought home to many people the truth of what climate scientists have been saying for years: climate change is water change.

Less than a year after the 2012 storm, President Xi Jinping announced a nationwide program dubbed “sponge cities” (because a sponge absorbs water and then releases it slowly). The idea of giving water space was thus elevated from fringe concept to national mission. In 2015 the central government began demonstration projects in 16 cities, and it added 14 more in 2016. Each project covered at least five square miles, although some were larger, with the goal of retaining 70% of the average annual rainfall on site by 2020.

In November of that year, the state-controlled broadcaster China Central Television reported completion of the 30 pilot projects. It said they were preventing and mitigating urban disasters, increasing environmental benefits to waterways, and reducing water pollution. CCTV further reported

that between 2016 and 2020, the sponge city concept had been implemented in 90 provincial-level cities and included in the master plans for 538 cities. A new goal aims for 100 cities with more than 1 million people to meet the 70% rainwater capture target by 2030.

"It is, of course, a success story," says Chris Zevenbergen, an expert in urban flood-risk management at the IHE Delft Institute for Water Education in the Netherlands and a visiting professor at China's Southeast University. Chinese government reports are best viewed with skepticism, but Zevenbergen says he's cautiously optimistic that the rosy assessment will be borne out.

Sponge cities are part of a worldwide movement that goes by various names: green infrastructure in Europe, low-impact development in the United States, water-sensitive urban design in Australia, natural infrastructure in Peru, nature-based solutions in Canada. In contrast to industrial management, in which people confine water with levees, channels, and asphalt and rush it off the land as quickly as possible, these newer approaches seek to restore water's natural tendency to linger in places like wetlands and floodplains.

Because of that common thread, I've come to think of them collectively as the "Slow Water" movement. As in the Slow Food movement, solutions are tailored to local ecology, climate, and people. The most ambitious Slow Water projects involve conserving or restoring wetlands, river floodplains, and mountain forests, simultaneously safeguarding carbon storage and protecting homes for threatened plants and animals. But there are also small urban projects, shoehorned between buildings or in narrow corridors along streets.

In April 2018, on a day with a "very high" air pollution rating, I visited Yu at Turenscape's headquarters in Beijing. A slim, intense man with shrewd eyes and just a bit of gray at the temples, he told me that his passion for repairing humans' relationship with water comes from his childhood during the Mao years, spent on an agricultural commune in Zhejiang province southwest of Shanghai. The youngest of five children, he spent his days observing Chinese "peasant wisdom" for managing water, techniques that had been practiced for thousands of years. To cope with scarcity, farmers maintained little ponds and berms to help rainfall infiltrate the ground, storing it for a dry day. The seasonal creek next to his village swelled and retreated with the seasons. "For me, flood is a time of excitement because the fish come to the field, the fish come to the pond," he said. But as the country urbanized, the Chinese abandoned that knowledge and followed the Western path. Now, he believes, they need to reclaim that ethos: "We need to make friends with flooding."

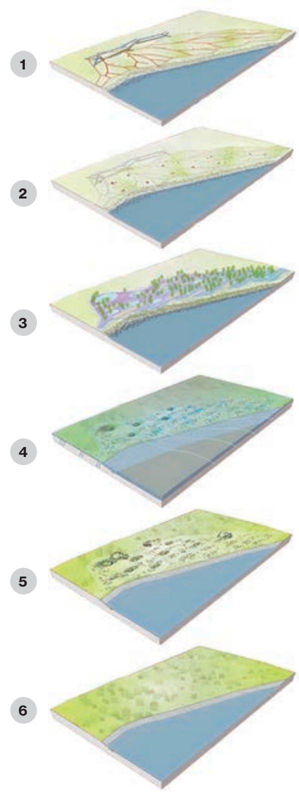
Yu has built Turenscape into an empire, with 600 employees in three offices. The company has more than 640 projects completed or underway in 250 Chinese cities and 10 other countries. Turenscape also publishes a magazine called Landscape Architecture Frontiers, in both Chinese and English, and supports master's and PhD candidates and postdocs who are researching hydrology or ecology, or measuring the efficacy of completed projects.

The founder and dean of the College of Architecture and Landscape at Peking University, Yu has also taught periodically at Harvard. He lectures regularly at the Ministry of Housing and Urban-Rural Development, and his 2003 book *Letters to the Leaders of China: Kongjian Yu and the Future of the Chinese City* is in its 13th printing. He's been asked to consult in other countries: Mexico, for example, is hoping he can help solve Mexico City's water problems, which are similar to Beijing's.

When planning a project, designers first must figure out what water did before people built a city. In a large white room at Turenscape's offices, young men and women sit at desks separated by a jungle of plants, focused intently on that question. They construct models of how water behaves within the built environment, factoring in each place's specific ecology, geology, hydrology, and culture—a kind of computational geography. The data allows Yu and other Slow Water practitioners to model how reshaping the land and available space in various ways affects how water flows and slows.

Yu is now something of a hero to young landscape architects. Accompanying us to various sites was Geng Ran, an employee who exudes intense excitement to be working for him. Throughout the day, we were perpetually trotting after Yu as he rushed ahead. "He's always like this," said Geng, laughing.

While Yu retains his farmer's values, he is a man of modern China. He bought and renovated a building in one of Beijing's few remaining historic *hutong* neighborhoods, turning it into a private club for fellow Harvard grads, Beijing politicians, and other power brokers. This move is in keeping with



1 Pedestrian & artifact
2 Dewdrop
3 After runoff
4 During runoff
5 Cut & fill
6 Previous site

When planning a project, designers build models of how water behaves within the built environment, factoring in each place's specific ecology, geology, hydrology, and culture—a kind of computational geography.

his modus operandi, according to Niall Kirkwood, a professor of landscape architecture and technology at Harvard's Graduate School of Design who has known Yu for many years. Kirkwood says Yu is a political animal, and that this—along with his vision and ambition—accounts for his success.

I got a chance to observe Yu in his natural habitat that evening. He escorted me and Geng into the club through a set of engraved metal doors and across the courtyard, where the traditional stone floor had been replaced with thick glass. Inside he ushered us downstairs to a massive table underneath that transparent floor. As we sat in ornate, carved chairs sipping bright-green cucumber juice, I looked at the moon above. Finance ministers were also visiting the club that evening, so Yu rotated between our tables. Before we left, he gave me a souvenir: a heavy tome titled *Designed Ecologies: The Landscape Architecture of Kongjian Yu*. After dinner, his driver chauffeured us in a brand-new Mercedes minivan to my hotel, where Yu got out to walk home—his daily constitutional.

A week later I visited one of Turenscape's projects in progress: Yongxing River Park, located in Daxing, a far-flung exurb of Beijing. "Before" satellite pictures from three years earlier showed a river straightened and confined by steep concrete walls. "Now" pictures were chock-a-block with buildings around a more generous, meandering path for water.

Yu is concerned that China may be applying a cookie-cutter approach to sponge cities: "Every patient needs a different solution."

The project was nearly complete when I saw it. About two and a half miles long and perhaps two city blocks wide, the park follows the river. Workers removed concrete along the river channel and excavated soil to widen the riverbed. That dirt was then molded into a large berm running down the center, creating two channels. The river flows on one side; the other channel has big holes of varying depths that act as filtration pools. During the dry season, the filtration side is filled with partially cleaned effluent from a sewage treatment plant. Wetland plants in the pools clean it further, and the slow pace allows some water to filter underground. During the monsoon season, that channel is reserved for floodwaters, and the effluent is treated industrially.

Geng and I walked a slim concrete path atop the central berm. Many of Turenscape's designs feature walkways such as this, soaring above wetlands, so people can enter the landscape year-round and appreciate changes from season to season. The broader riverbanks, newly freed from concrete, are dotted with thousands of small sedges planted in closely set rows to hold the earth, like a pointillist-rendered landscape. We passed young willows, a native streamside plant that can survive flooding. Elsewhere, reeds, dwarf lilyturf, and other native plants stabilize the soil. Turenscape mostly uses native plants in its designs because they thrive on the water, weather, and nutrients available.

In summer 2020, during heavy summer rains, Yu sent me photos of Yongxing River Park. The trees and grasses had grown up considerably since I'd visited. The channel contained a lot of water but was nowhere close to overtopping. Turenscape does not yet have data on Yongxing's flood capacity, infiltration rate, or water-cleaning services, but Yu called its management of that year's monsoon a "great performance."

It can be hard for people to conceive of making space for water in a populated area, but it's possible. Taking advantage of space in growing exurbs like Daxing is one approach. Another is to stop building atop protective wetlands and coastal habitats—absorption capacity that is continually squandered.

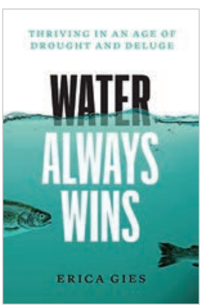
Other opportunities to make space for water and reduce future losses are found even in city centers, where buildings are torn down more frequently than people assume. Disasters can also be a catalyst, such as when governments use emergency funds to buy and remove flooded buildings and convert the area to an absorbent park. Cleaned-up former industrial sites can offer up a lot of space too—often right alongside rivers. Other techniques to accommodate water in compact cities include bioswales (ditches lined with water-loving plants), infiltration ponds, rain gardens, and seepage wells. Where human space is nonnegotiable, designers sometimes use features such as permeable pavement and green roofs that can absorb water.

Yu has converted his house, a duplex he shares with his sister, into a living laboratory for some of these techniques. In the hallway are photos of his family back on the farm, Yu and his Harvard mentor, Yu with two Chinese presidents. Between the apartments, he built a living wall of porous limestone. Water captured from the roof dribbles down its face, from which maidenhair ferns and philodendrons sprout. The green wall cools the two homes enough to make air-conditioning unnecessary, although he concedes that it gets a bit warm in summer. Plants

Above:
Yanweizhou Park in Jinhua City

Below:
Yu Kongjian

Opposite:
Sanya Mangrove Park



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on decks off the bedrooms are watered with roof-caught rain, stored in tanks under the raised plant beds. "We collect 52 cubic meters of stormwater [annually], and I grow 32 kilograms of vegetables," Yu says proudly. His efforts also reduce runoff from his building's roof and decrease his personal water usage from city sources.

Though Xi's sponge cities initiative is based on principles that mirror his own ideas, Yu fears that in some cases, China may be doing it wrong. The country has sometimes used cookie-cutter solutions for other programs, Yu says, but for sponge cities to be successful, each project must be place-specific. As Yu puts it, "Every patient needs a different solution."

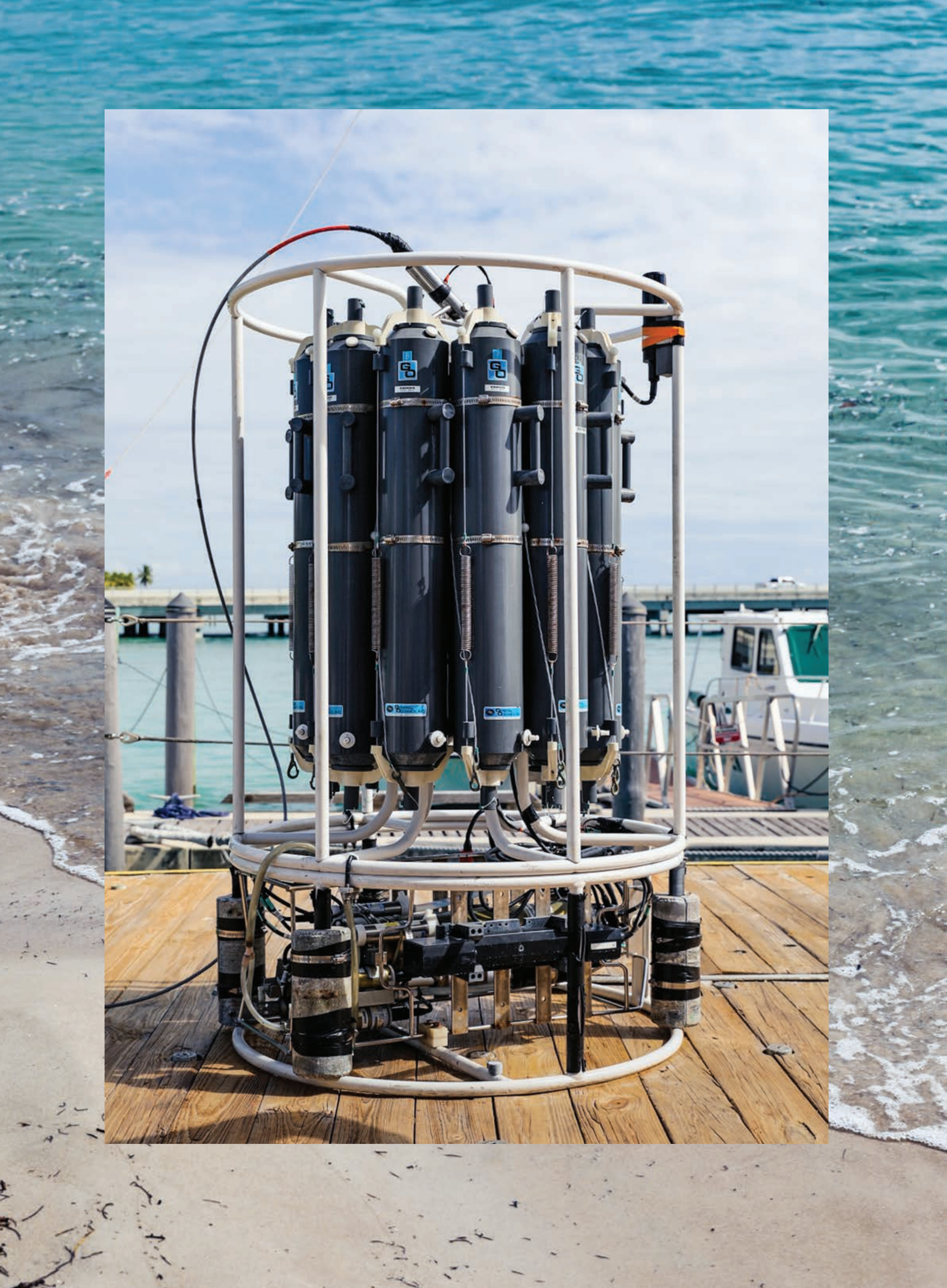
Monsoon rains across China have been heavy the last couple of summers, challenging not only standard water infrastructure, such as dams—several of which have failed or come close to it—but also the fledgling sponge cities. In summer 2021, one pilot project city with a population of around 7 million, Zhengzhou, suffered significant flooding when more than eight inches of rain fell in one hour and almost 300 people died, leading some to ask whether sponge cities were working.

Zevenbergen notes that designs may need to be tweaked to better match local needs. But the bigger factor may be that the interventions simply aren't ambitious enough. Absorbing 70% of rainfall across five square miles of a city that spans 2,900 square miles won't prevent flooding. Slow Water projects work best when they can absorb water across the full landscape, so planners need to think beyond the urban footprint. A city is part of a larger watershed. Restoring space for water upstream in natural river floodplains can lower the water levels downstream.

In this, too, Yu is hard at work. He's creating a landscape master plan for all of China. At his office, he showed me a series of maps that document China's elevation, watersheds, flood paths, biodiversity, desertification, ecological security, soil erosion, and cultural heritage. As urbanization spreads, as estuaries and deltas silt up, as water starts to move differently across landscapes and cityscapes, he identifies the spots where his projects will have the biggest impact.

"This is a philosophy for taking care of the continental landscape," Yu says. "It's time to expand the scale." ■

Erica Gies is a journalist based in Victoria, British Columbia, and San Francisco. This story has been adapted from her book Water Always Wins: Thriving in an Age of Drought and Deluge, available for preorder at slowwater.world.



Global warming could shut down a crucial network of Atlantic currents, triggering a climate disaster. But new science suggests that the system is more befuddling and unpredictable than expected.

THE THREAT TO THE PLANET'S OCEAN CURRENTS

By JAMES TEMPLE
Photographs By Alfonso Duran

ON A SATURDAY MORNING in December of 2020, the RRS *Discovery* floated in calm waters just east of the Mid-Atlantic Ridge, the massive undersea mountain range that runs from the Arctic nearly to the Antarctic.

The team onboard the research vessel, mostly from the UK's National Oceanography Centre, used an acoustic signaling system to trigger the release of a cable more than three miles long from its 4,000-pound anchor on the seabed.

The expedition's chief scientist, Ben Moat, and others walked up to the bridge to spot the first floats as they popped up. The technicians on deck, clad in hard hats and clipped into harnesses, reeled the cable in. They halted the winch every few minutes to disconnect the floats as well as sensors that measure salinity and temperature at various depths, data used to calculate the pressure, current speed, and volume of water flowing past.

Opposite page: This package of bottles and sensors is used to measure temperature, pressure, and other properties of the Atlantic currents.

The scientists and technicians are part of an international research collaboration, known as RAPID, that's collecting readings from hundreds of sensors at more than a dozen moorings dotting the Atlantic roughly along 26.5° North, the line of latitude that runs from the western Sahara to southern Florida.

They are searching for clues about one of the most important forces in the planet's climate system: a network of ocean currents known as the Atlantic Meridional Overturning Circulation (AMOC). Critically, they want to better understand how global warming is changing it, and how much more it could shift in the coming decades—even whether it could collapse.

"Measuring this ocean system is vital to understanding our climate," Moat says.

The Atlantic circulation is, effectively, one leg of the world's mightiest river. It runs tens of thousands of miles from the Southern Ocean to Greenland and back, ping-ponging between the southwestern coast of Africa, the southeastern US, and Western Europe.

The system carries warm, shallow, salty water northward, transporting about 1.2 million gigawatts of heat energy across RAPID's array of moorings at any moment. That's equivalent to about 160 times the energy capacity of the entire world's electricity system. The currents, which heat up the surrounding air as they travel northward, are a major factor (though not the only one) in why Western Europe is warmer than eastern Canada even though they lie at roughly the same latitude.

The waters become cooler and denser as they reach the high latitudes, forcing the currents to dive miles below the surface, spread outward, and bend back southward. That sinking of the water deep into the ocean helps propel the system.

The problem is the Atlantic circulation seems to be weakening, transporting less water and heat. Because of climate change, melting ice sheets are pouring fresh water into the ocean at the higher latitudes, and the surface waters are retaining more of their heat. Warmer and fresher waters are less dense and thus not as prone to sink, which may be undermining one of the currents' core driving forces.

Simply put, the currents influence much of the weather we know in the Northern Hemisphere, particularly around the coastal Atlantic but also as far away as Thailand. If the currents change, so too will the weather, disrupting temperature and precipitation patterns that have shaped our lives and societies for centuries.

Some climate models predict that the currents will decline by as much as 45% this century. And evidence from the last ice age shows that the system can eventually switch off or go into a very weak mode, under conditions that global warming may be replicating.

If that happened, it would likely be a climate disaster. It could freeze the far north of Europe, driving down average winter temperatures by more than 10 °C. It might cut crop production and incomes across the continent as much of the land becomes cooler and drier. Sea levels could rise as much as a foot on the Eastern Seaboard, flooding homes and businesses up and down the coast. And the summer monsoons over major parts of Africa and Asia might weaken, raising the odds of droughts and famines that could leave untold numbers without adequate food or water.

It would be a "global catastrophe," says Stefan Rahmstorf at the Potsdam Institute for Climate Impact Research.

Most scientists say a collapse of the currents is a remote possibility this century, but even a steep slowdown would have significant impacts, potentially cooling and reducing rainfall around the North Atlantic while increasing precipitation across parts of the tropics. It might raise sea level by about five inches off the US southeast coast.

Despite the stakes, scientists have only a coarse comprehension of the currents' behavior, the balance of the forces that drive them, or their susceptibility to shifting climate conditions. That's why Moat and others are so keen to observe the Atlantic circulation.

But much of what has been discovered so far is that the Atlantic circulation is more variable, perplexing, and perhaps unpredictable than previously understood.

THE FLORIDA CURRENT

NOAA's Atlantic Oceanographic and Meteorological Laboratory is a squat, white five-story building, fringed by palm trees on Virginia Key, a barrier island just a few miles from downtown Miami.

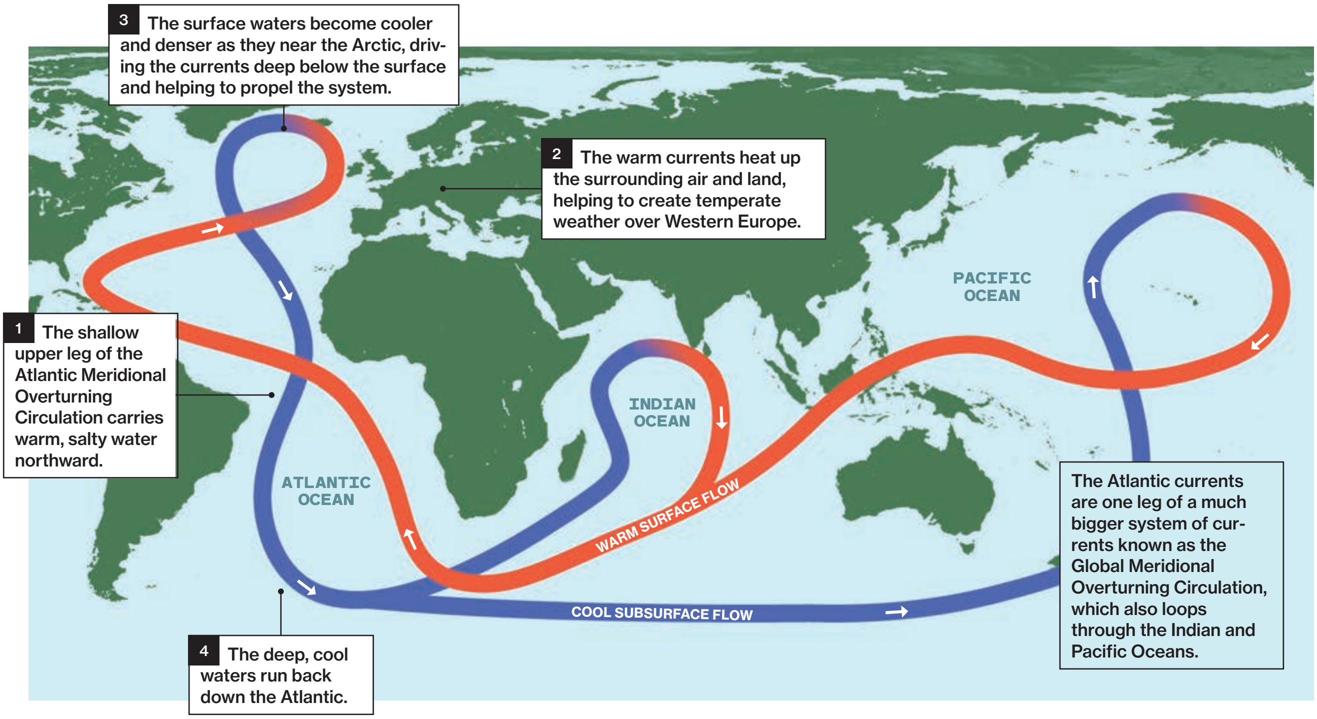
The warm upper layer of the Atlantic circulation, known here as the Florida Current, races past the island, squeezed between the state and the Bahamas. It's an ideal place to observe one of the most powerful stretches of the system, because the topography of the Florida Straits confines the currents, which can otherwise span hundreds of miles, down to dozens. (The Florida Current is part of the Gulf Stream, a stretch of the Atlantic circulation that traces the southeastern US before cutting across the ocean to Europe.)

NOAA scientists have been monitoring the Florida Straits at around 27° North almost continuously since 1982, in large part by taking advantage of underwater telephone cables. The now-defunct phone lines along the seafloor provide a cheap, unobtrusive way of observing the Atlantic circulation.

The passing seawater creates a voltage along the sides of the cables, which NOAA

"Measuring this ocean system is vital to understanding our climate."

How the AMOC works



researchers found they could reliably measure. They receive daily readings from instruments set up in a telephone trunk room on Grand Bahama Island. With careful calibration, they are able to translate those measurements into estimates of how much water flows across that line of latitude.

Meanwhile, William Johns and other oceanographers at the University of Miami's Rosenstiel School of Marine and Atmospheric Science, located just across the causeway from the NOAA lab, have used sensor-strung moorings and other instruments to study the currents east of the Bahamas since the 1980s. They've observed both the deep, cool boundary current flowing south and a stretch of the warm northward limb that forks off and flows around the islands.

These efforts began as part of a broader push to improve scientific understanding of how the oceans work and interact with the climate, says Molly Baringer, deputy director of the NOAA lab, who helped develop the cable program.

But the ongoing cable measurements and the historical records have taken on added importance as concerns have grown about the effects global warming could have on the Atlantic circulation, and the impact that could have, in turn, on the climate. "It's the way the ocean moves around heat," Baringer says. "You have to understand it to understand climate change."

Through the 1990s, there were a growing number of other attempts to measure parts of the currents, using short stretches of anchored moorings, drifting floats, shipboard observations, and other means. But oceanographers came to realize that these snapshot observations weren't enough to fully capture the system's behavior. They needed ways to continuously monitor the currents across the ocean in order to distinguish short-term fluctuations from long-term trends, among other things.

The UK's National Oceanography Centre established the RAPID effort in 2004 to do just that, anchoring cables across the Atlantic. It made obvious sense to collaborate with NOAA and the University of Miami research groups as well, taking advantage of those ongoing monitoring efforts.

Moat says the researchers are trying to shed light on how variable the currents are, how much heat they deliver, how much carbon they pull down from the air, how harmonized the southward and northward limbs are, how much local winds influence the system, and—critically—whether or not the Atlantic circulation is slowing down at the rate climate models predict.

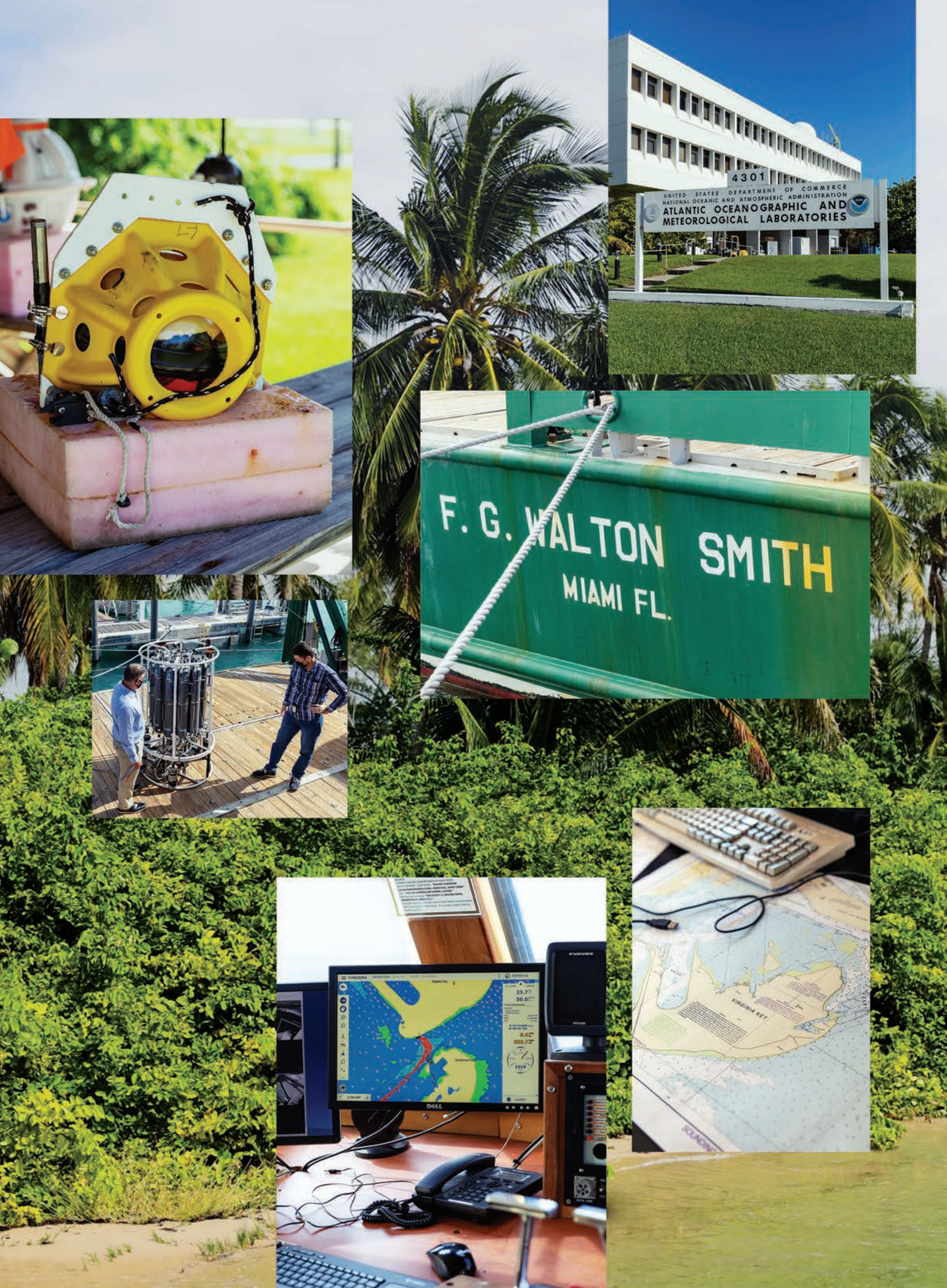
OUT AT SEA

On a sunny day in early November, I followed a pair of NOAA researchers down a pier on the southeastern edge of the Rosenstiel School of Marine and Atmospheric Science campus.

We ascended the gangway onto the *F.G. Walton Smith*, a 96-foot-long catamaran with dark green hulls and a white deckhouse, owned by the University of Miami.

Roughly every quarter, at least in pre-pandemic times, researchers from both institutions have boarded the vessel for 30-hour sprints out and back to the Bahamas. They use an A-frame and winch on the stern to lower what are known as CTDs into the waters at nine stations along the way, near the line of the old telephone cable.

The CTDs include a carousel of tubes that capture water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UNITED STATES DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
ATLANTIC OCEANOGRAPHIC AND
METEOROLOGICAL LABORATORIES
F. G. WALTON SMITH
MIAMI FL.
VIRGINIA KEY
DELL

Opposite page, clockwise from top left:

NOAA uses so-called dropsonde floats to confirm current readings from an undersea telephone cable.

NOAA's Atlantic Oceanographic and Meteorological Laboratory on Virginia Key, not far from downtown Miami.

The F.G. Walton Smith is used to monitor the Florida Current.

A map onboard the F.G. Walton Smith.

Inside the bridge of the F.G. Walton Smith.

NOAA researchers Denis Volkov and Pedro Pena check out measuring equipment on the stern of the F.G. Walton Smith.

samples, as well as sensors that measure temperature, pressure, oxygen saturation, and other water properties.

Denis Volkov, one of the principal researchers on NOAA's monitoring project, explains that these voyages, along with more frequent excursions on smaller vessels, allow the researchers to determine how much heat and salt are moving through the straits, how fast the currents are at varying depths, where the water moving through originates, and how the currents are affecting relative sea levels along the coasts of Florida and the Bahamas.

Separately, the research teams usually go out on longer voyages every 18 months, to remove and replace sensors from three or four moorings on the eastern side of the Bahamas. Their UK counterparts do the same job on the eastern side of the ocean and along the Atlantic Ridge.

Other groups have set up arrays of moorings across different parts of the Atlantic to better understand how varying components work, how tightly the system is connected, and whether changes in one part are rippling throughout.

Susan Lozier, an oceanographer at the Georgia Institute of Technology, leads an international effort known as OSNAP, which began in 2014. It has anchored cables across the Labrador Sea and from the southeastern edge of Greenland to the coast of Scotland.

The hope of the international research effort was to go to the sources of the deep-water sinking, which is largely responsible for propelling the currents in the Atlantic, to "try to get a much better understanding of the mechanisms driving change in the AMOC," Lozier says.

So far, what the monitoring programs have largely found is that the Atlantic circulation is more variable than previously believed, she says.

Its strength and speed fluctuate dramatically from month to month, year to year, and region to region. Most of the deep-water sinking in the North Atlantic seems to be occurring not in the Labrador Sea, as long believed, but rather in the basins to the east of Greenland. The northward- and southward-flowing limbs operate more independently than previously understood. Local wind patterns seem to exercise a more influential role than expected. And some findings are just befuddling.

It's very likely that the Atlantic circulation has weakened. Studies by Rahmstorf of the Potsdam Institute and others have concluded it's about 15% slower than during the mid-20th century and may be at its weakest in more than 1,000 years. Both findings are based, in part, on long-term reconstructions of its behavior using records like Atlantic Ocean temperatures and the size of grains on the ocean floor, which can reflect changes in deep-sea currents.

There's also "strong agreement" in models that the currents will continue to weaken this century if greenhouse-gas emissions continue.

But there's uncertainty about what state the system is in at the moment, and whether the direct observations are aligning with the models.

Data from the RAPID moorings showed a general weakening in the Atlantic circulation from 2004 to 2012, with a sudden 30% drop from 2009 to 2010. That was likely a major contributor to an especially cold winter in northwest Europe in 2012, as well as rapid sea-level rise in that period along the northeastern US coast, reaching about 13 centimeters around New York. The slowdown was an order of magnitude larger than global climate models predicted.

The currents rebounded substantially in the years that followed. But the strength of the circulation is still below where it was when the measurements started. In fact, it has decreased even more than climate-change models predicted.

Some say the data suggests that the system has already shifted into a weaker state. But it showed such a wild swing that others believe it was more likely an indication how much the ocean currents can vary across a decade, rather than any clear result linked to global warming.

Johns says it's simply unclear at this point. "We can't be 100% sure whether it's a longer-term trend—i.e., related to climate change—or an oscillation that can happen naturally," he said during an interview in his office overlooking the Florida Straits.

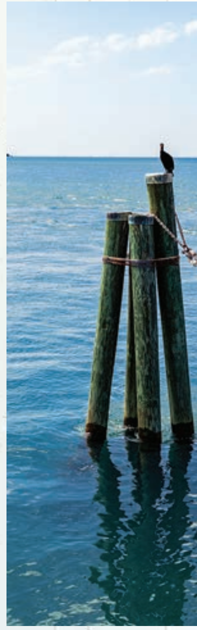
An added wrinkle is that the Florida Current flowing by in the background has only declined a small amount since 1982, and not quite a statistically significant amount at that, according to NOAA's findings. That's weird, because that powerful, concentrated flow is "the place you'd most expect" to see a weakening trend according to climate models, Johns says. The data is "showing two slightly different stories," he says.

He and others believe it's likely to simply take more time—years to decades—before the currents reveal clearly how climate change is affecting them.

A winch is used to lower instruments into the ocean.

Molly Baringer, deputy director of the Atlantic Oceanographic and Meteorological Laboratory, helped establish NOAA's effort to monitor the Florida Current using an underwater telephone cable.

Birds perch on a rope along the shores of Virginia Key.



A COLLAPSE

The reason scientists worry that the Atlantic circulation could dramatically weaken is that it repeatedly did so in the ancient past.

Nearly 13,000 years ago, as the Earth was emerging from the last ice age, the climate across the North Atlantic region suddenly began cooling again. Temperatures plunged back toward nearly glacial-era conditions for a more than 1,000-year period known as the Younger Dryas, named for a wildflower that flourished in the frosty conditions of Europe in that era.

The leading theory on what triggered it involves the Laurentide Ice Sheet, which stretched millions of square miles across North America. As temperatures rose, it rapidly melted, pouring fresh glacial water into the ocean through the Mississippi River.

At some point, ice damming a massive lake on the southern edge of the glacier may have given way, unleashing a flood that possibly rerouted the drainage to the St. Lawrence River. It would have poured fresh water into the North Atlantic through modern-day Quebec.

The massive influx of fresh water could have reduced the salinity and density of the surface water enough to undermine the mechanisms driving the Atlantic circulation at its origin, flipping it off or sending it into a very weak mode, says Jean Lynch-Stieglitz, a paleoclimate researcher at the Georgia Institute of Technology.

By the late 1980s, some scientists started to wonder: Could the effects of global warming halt the currents much as the breakup of the Laurentide likely did, bringing about a more abrupt climate shift than researchers had been considering?

For years, the UN's Intergovernmental Panel on Climate Change has called a shutdown of the Atlantic circulation this century "very unlikely," defined as a 0 to 10% probability. But as several studies note, the climate models have biases that could overstate the stability of the current, in part because they don't incorporate increasing meltwater from Greenland ice sheets.

The latest UN report, released in August, downgrades the assurance that a collapse won't occur before 2100 to "medium confidence," citing that "neglect" in the models as well as the recent findings by a pair of scientists at the University of Copenhagen.

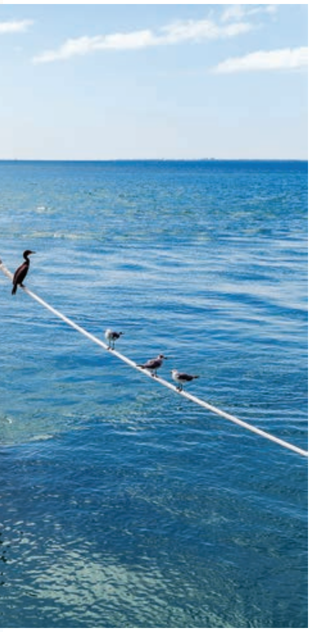
The researchers, Johannes Lohmann and Peter Ditlevsen, ran numerous scenarios on a model developed at the university, turning the knobs on the levels, rates, and time frames of runoff from the Greenland ice sheets.

The general conception of a tipping point is that there's some fixed physical threshold beyond which the system trips into a different state. But they found that a lesser-known phenomenon known as a rate-induced tipping point, triggered by a sudden increase in the system's rate of change, might halt the currents as well. In other words, too much change occurring too fast could cause the system to break down.

The Atlantic circulation could be susceptible to this if the water flowing from ice sheets increases rapidly enough, according to the study, which was published in the Proceedings of the National Academy of Sciences in March.

It's just one model and one study, but it suggests that the climate system could be more fragile than previously appreciated.

These "chaotic dynamics" mean that "we maybe cannot



expect, even if our models get much better, to be able to predict with 100% confidence whether such an element of the climate system will go into another state or not," Lohmann says.

An August paper by another researcher added to these concerns, concluding that the currents might be closer than expected to the standard sort of tipping point as well.

Scientists have found telltale early warning signs of a collapse in models and geological records from the last ice age, wrote the author, Niklas Boers, a professor of Earth system modeling at the Technical University of Munich and a researcher at the Potsdam Institute for Climate Impact Research.

The signs include decreasing sea-surface temperatures and salinity in the North Atlantic, a salinity "pile-up" in the Southern Atlantic, and a characteristic shift in current patterns known as a "critical slowing down." Boers found evidence of these warnings across eight different records, suggesting "an almost complete loss of stability."

"In the course of the last century, the AMOC may have evolved from relatively stable conditions to a point close to a critical transition," Boers wrote.

But how close is "close?"

In an email, Boers said it remains difficult to define the threshold in terms of a specific global temperature or time, given the numerous layers of uncertainty.

"The only thing we can say is that in the course of the last century the AMOC has moved toward its critical point (which on its own had not been expected by many)," he wrote in an email. "And that with every additional ton of emitted greenhouse gases, we'll likely push it further."

HOLLYWOOD VS. REALITY

So what happens if the Atlantic circulation collapses?

The Day After Tomorrow, the popular 2004 disaster film in which an abrupt halt of the currents shock-freezes the Northern Hemisphere over a few nightmarish days, is a wild Hollywood exaggeration. The changes brought about if the network of ocean currents collapsed would unfold over years or decades, not days, and there's no reason to expect tsunamis flooding Manhattan or ice entombing the city.

But a shutdown would flip the global climate system into a fundamentally different state, inflicting somewhat unpredictable consequences across large parts of the planet.

Much of Europe could turn into a starkly different world, according to a study by researchers at the Met Office Hadley Centre in the UK, which closely analyzed the effects on that continent using a high-resolution climate model. Within 50 to 80 years after a massive infusion of fresh water that halts the Atlantic circulation, sea surface temperatures drop as much as 15 °C from the Barents to the Labrador Seas, and 2 to 10 °C across much of the rest of the North Atlantic.

Sea ice drifts farther and farther south, reaching the northern tip of the United Kingdom in late winter.

The continent experiences extensive cooling as well. Winter storms intensify, become more frequent, or both. On average, most of Europe gets drier, aside from the Mediterranean during summer. But more of the precipitation that does fall arrives in the form of snow.

Given these cooler and drier conditions, surface runoff, river flows, and plant growth all decrease.

The Garonne River in southern France carries 30% less water during peak winter periods. Growth in the needleleaf forests of Northern Europe slows by as much as 50%. Crop production "decreases dramatically" in Spain, France, Germany, Denmark, the United Kingdom, Poland, and Ukraine.

Laura Jackson, the lead author of the study, stresses that it was an "idealized" model, using a large amount of fresh water to quickly shut down the Atlantic circulation and shorten the length of the experiments. "A more realistic scenario, or a different model, might show different magnitudes of change," she said in an email.

Still, other studies looking beyond Europe have concluded that a collapse or significant weakening of the Atlantic circulation would have wide-scale effects on much of the world.

Some models find that parts of Asia and North America could grow cooler as well. The slowing currents could disrupt the delivery of crucial nutrients, devastating certain fish populations and otherwise altering marine ecosystems.

As the Gulf Stream subsides and flattens, ocean levels could quickly rise eight to 12 inches along the southeastern US. The tropical rain belt could drift south, weakening rainfall patterns across parts of Africa and Asia and ratcheting up monsoons in the Southern Hemisphere.

A certain amount of weakening may act as a counterforce against climate change, mitigating to some degree the warming

"The only thing we can say is that in the course of the last century the AMOC has moved toward its critical point."

Researchers from NOAA and University of Miami use the F.G. Walton Smith, a 96-foot vessel, for quarterly voyages to take current readings in the Florida Straits.

that would otherwise take place. But how these competing forces balance out overall and over time would depend on multiple, overlapping layers of uncertainty: how much the system weakens; whether it shuts down entirely; how much less carbon dioxide the oceans, forests, and farms pull down; and how much warmer the planet gets.

THE OCEAN MATTERS

The potential for a steep slowdown or collapse of the AMOC raises difficult questions.

How worried should we be about very low-odds but very high-consequence possibilities like a shutdown will happen this century? How can we properly evaluate the risks and take appropriate actions with so much scientific uncertainty? How much should today's policy debates or climate actions be shaped by the danger of events that may not occur until the 2100s or 2200s, if they occur at all?

Some who study the AMOC believe that people, and the press in particular, are overly obsessed with the catastrophe scenario—"the drama" of *The Day After Tomorrow*, as Lozier puts it.

This, she stresses, is largely a distraction that misses the point. We don't need some danger in the distant future to underscore the risks of climate change: there are plenty of serious consequences unfolding in the present.

"I love the AMOC and have studied it forever," Lozier says. "But when we talk about what we should really be concerned with, it's ocean warming, sea-level rise, ocean acidification, hurricanes. These are the things we know are happening. Those are huge impacts. So I think we just always should keep this in mind."

When I met with Baringer, on a picnic table outside of NOAA's lab to comply with covid protocols, I asked how concerned she is about climate models predicting a steep slowdown or possible collapse of the Atlantic circulation.

Baringer said she doesn't "worry that much" about it. That's in part because she thinks it's hard to properly account for all the feedbacks in such a complex and roughly understood system—and in part because, like Lozier, she thinks there are more pressing climate concerns. She listed ocean acidification, droughts, wildfires, and sea-level rise, which she believes the field is largely underestimating.

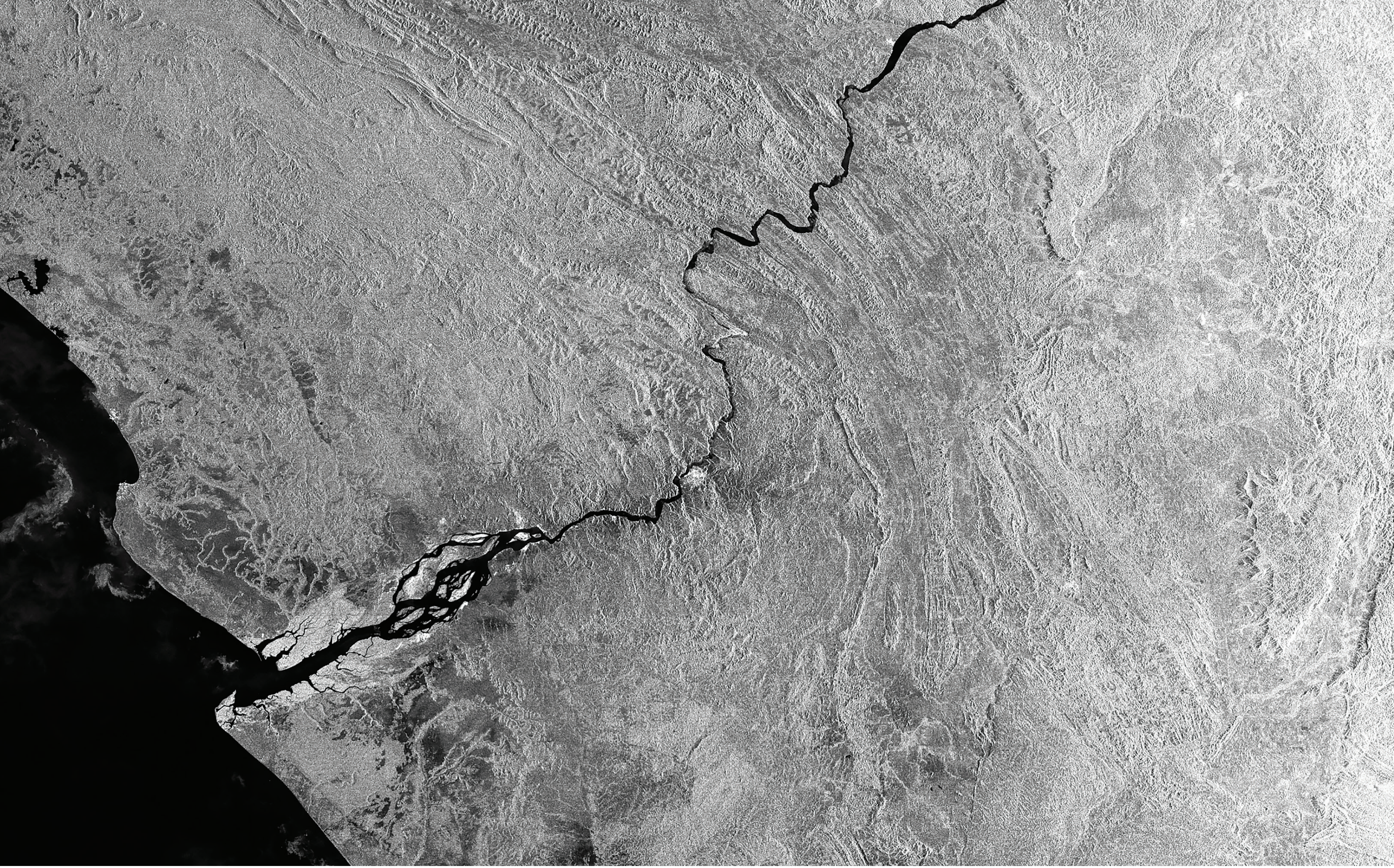
So why, I asked, is it so important to study the Atlantic circulation?

"I don't like that question," she said, "because it's sort of like asking: Why do we study oceanography in general?

"The ocean matters. The ocean carries a huge amount of heat. It sequesters carbon. It moves nutrients around. If we didn't have the ocean circulation or upwelling, you wouldn't have fish. The whole ocean matters, and the AMOC, that large circulation, is a big part of what the ocean is doing."

But that is also arguably the biggest reason to worry about how human actions could alter one of the planet's most complex—and exquisite—natural systems. There are, as Lozier and Baringer note, more imminent climate risks to worry about. But in the long term, perturbing this immensely powerful network of ocean currents could be the biggest climate risk the world is taking. ■

James Temple is MIT Technology Review's senior editor on climate change.



EUROPEAN SPACE AGENCY

▲

A synthetic aperture radar image is a mosaic of the Congo River.

MAPPING THE WORLD'S FRESH WATER FROM SPACE

It's surprisingly difficult to measure fresh water up close. So climate scientists are taking a step back.

By MARIA GALLUCCI

The Congo River is the world's second-largest river system after the Amazon. More than 75 million people depend on it for food and water, as do thousands of species of plants and animals that live in the swamps and peatlands it supports. The massive tropical rainforest sprawled across its middle helps regulate the entire Earth's climate system. The amount of water in the system, however, is something of a mystery.

Hydrologists and climate scientists rely on monitoring stations to track the river and its connected water bodies as they flow and pool across six countries, and to measure precipitation. But what was once a network of some 400 stations has dwindled to just 15, making it difficult to know exactly how climate change is affecting one of Africa's most important river basins.

"To take action, to manage water, we need to know about our water resources," says Benjamin Kitambo, a geologist with the Congo Basin Water Resources Research Center in Kinshasa, Democratic Republic of the Congo. "But we can't know something that we don't measure."

Researchers around the world are increasingly filling data gaps on the ground using information gathered from space. Satellites equipped with remote sensing instruments can peer into places where "in situ" measurements—those taken on site—are outdated, hard to gather, or kept private.

Kitambo spoke by video call from Toulouse, France, where he's conducting PhD research at the Laboratory of Space Geophysical and Oceanographic Studies. These days, he's analyzing troves of satellite measurements and hydrological models to understand how the Congo River's tributaries, wetlands, lakes, and reservoirs are changing. That includes studying records from more than 2,300 "virtual" gauging stations, which estimate two key metrics throughout the basin: "surface water height," or the water's level above a reference point, and surface water extent.

He says most of the region's field data dates back to before 1960, the year most countries in the region gained independence from European colonizers. Since then, research there has sharply declined, and collecting data on surface water has proved difficult.

About five years ago, the Congo Basin research center began installing a network of water-monitoring stations to address the "severe lack of basic knowledge" about the river's main navigable channels, which often serve as roads. But some places in the vast basin were too remote or rugged for researchers to reach. In others, people removed the newly installed instruments to sell the materials, or because they feared being spied on.

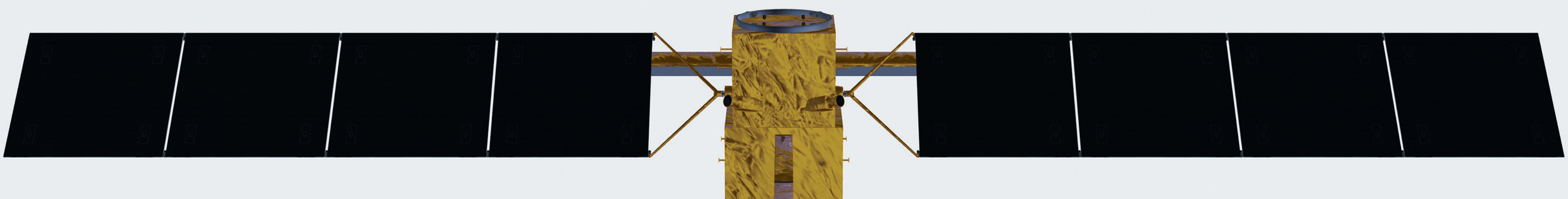
Many parts of the world face similar challenges. Countries in Latin America and the Caribbean have seen a "dramatic decline" in ground-based measurements since the 1980s, according to a 2018 assessment published in the journal Water Resources Research. In the Mekong River basin—which extends through six nations from China to Vietnam—countries closely guard their data on water availability, if they gather it at all.

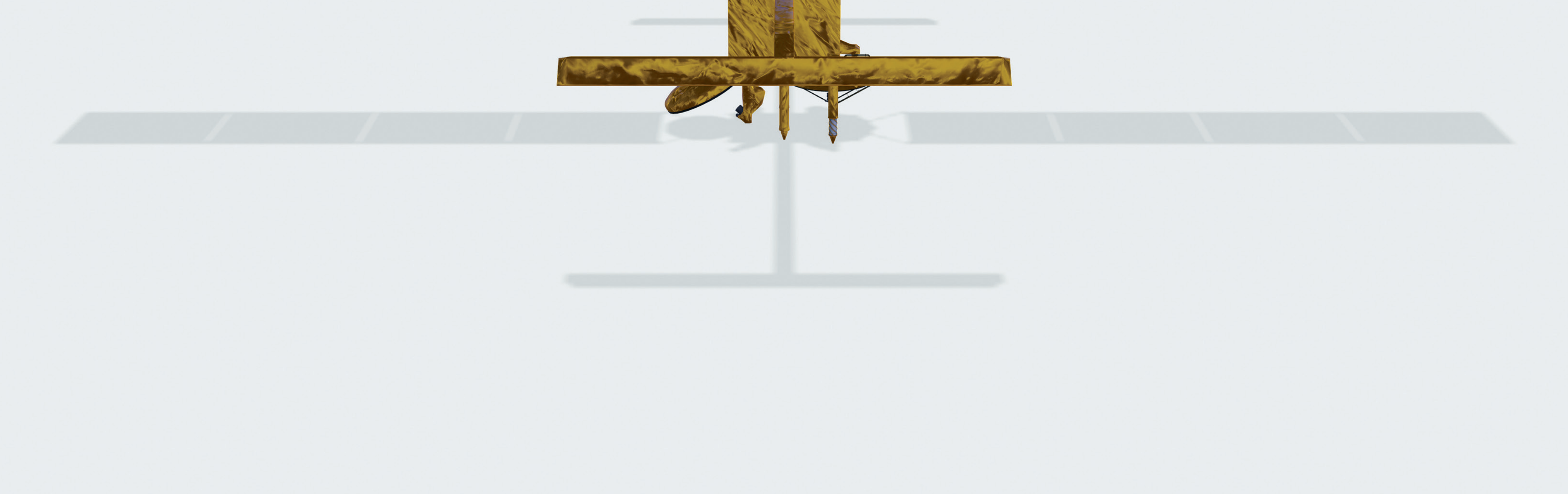
Yet measuring water is key to helping people prepare for natural disasters and adapt to climate change, experts say. Rising global temperatures are projected to increase the risk of storms and flash floods in certain areas and severe drought in others. Meanwhile, massive infrastructure projects and sprawling urban development are altering and straining freshwater resources like rivers and lakes.

This need to know is driving a series of ambitious research initiatives using remote sensing tools. As the technology for gathering and analyzing data from space evolves, scientists are gaining a clearer picture of how water flows across Earth and circulates in the atmosphere.

Satellites observing Earth's surface measure and map water using optical and radar sensors. Optical sensors form images of water bodies by detecting the solar radiation that reflects back from targets on Earth. One form of radar sensing, called synthetic aperture radar, measures the extent and height of surface water by transmitting pulses of microwave energy toward the planet and then measuring the amount of energy reflected back to the spacecraft, as well as the time it takes for the signals to return. Unlike optical sensors, radar can see through clouds and at night.

Scientists can then combine those observations to explore how a region's water resources are changing over time. One study using 30 years of satellite imagery from NASA's Landsat program found that water has shifted dramatically across Earth's surface as a result of both natural movement of rivers and human interventions like dams and irrigation. Some 44,000 square miles of land are now covered in water, and 67,000 square miles of water have become land, researchers with the Dutch research institute Deltares reported in a 2016 paper.





NASA / JPL

A computer model of the SWOT satellite that NASA and the French space agency CNES plan to launch in late 2022.

Yet even with the remote sensing technology available today, surprisingly few freshwater bodies are closely tracked for their water height; instead, many existing radar satellites mainly focus on oceans and ice sheets. To date, any single satellite has measured only about 5 to 10% of the world's largest rivers and just 15% of water storage changes in the world's lakes, according to NASA.

A new radar system built by NASA's Jet Propulsion Laboratory in Pasadena, California, will soon be able to observe much more of Earth's surface, and at 10 times the resolution of current technologies. The Ka-band Radar Interferometer uses two antennas to transmit and receive pulses over a 75-mile-wide swath as the satellite passes over a body of water. An antenna sends signals to a spot below; the system then analyzes the two return signals using triangulation. This allows scientists to gauge the height of surface water to within about 10 centimeters.

NASA and the French space agency CNES plan to launch a satellite with the Ka-band sensor in late 2022 as part of a joint mission called Surface Water and Ocean Topography (SWOT), with help from the Canadian and UK space agencies. Along with oceans, the SUV-size satellite will observe the planet's lakes, rivers, and reservoirs during its 21-day repeating orbit.

"We're going to have access to global information on surface waters in a way that we never had before," says Cédric David, a hydrologist at the Jet Propulsion Laboratory. Scientists will be able to observe changes in the amount of water stored on Earth's surface and estimate how much water flows through river systems.

Researchers like Kitambo say SWOT's observations will increase the accuracy and quality of their numerical models, which simulate and predict how water swells, drains, and flows over time. Specifically, scientists can use SWOT data to calculate daily discharge—or the volume of water flowing through channels—from the Congo's major tributaries and within the rainforest at the basin's center. This will help them understand the development of seasonal floods, which affect everything from fishing and agriculture to wildlife habitats and human safety.

David notes that along with other similar projects, the new mission will give NASA eyes on nearly every part of Earth's water cycle, including oceans, soil moisture, groundwater, ice sheets, and now surface water. "Many of us are calling this the golden age of water cycle observations from space," he says. ■

Maria Gallucci is an energy and environment reporter based in Brooklyn, New York.

ESSAYS

Three takes on our worldwide water crisis

ANDREA DAQUINO

SANDRA POSTEL

Water infrastructure needs to change

Conventional ways of supplying water and preventing floods will be no match for climate change.

In the world of water, 2021 was yet another year for the record books. Parts of Western Europe reeled from deadly floods that sent rivers surging to levels not seen in 500 to 1,000 years. Destructive floods hit central China as well, displacing more than a quarter of a million people from their homes. Meanwhile, a large swath of the southwestern United States

INFRASTRUCTURE

remained locked in a megadrought—the second-driest 20-year period in 1,200 years.

One might think that the impressive water engineering installed in the US and elsewhere over the last century would safeguard society from such catastrophic events. Globally, some 60,000 large dams now capture and store water, allowing engineers to turn rivers on and off like plumbing works. Each year, the world's cities collectively import the equivalent of 10 Colorado Rivers through vast networks of pipelines and canals. And thousands of miles of artificial levees protect cities and farms from flooding rivers.

In many ways, it's hard to imagine our world of nearly 8 billion people and $85 trillion in annual goods and services without this water engineering. Cairo, Phoenix, and other large desert cities could never have grown to their present sizes. California's sunny Central Valley would not have become such an abundant producer of vegetables, fruits, and nuts.

Yet when it comes to water, the past is no longer a good guide for the future. The heating of the planet is fundamentally altering the water cycle, and most of the world is unprepared for the consequences.

One of the most alarming wake-up calls came in 2018, when the city of Cape Town, South Africa, was nearly forced to shut off the drinking water taps of 4 million residents. Three consecutive years of drought had dried up its reservoirs. City officials began publicly announcing "Day Zero"—the date water would no longer flow to household faucets.

Conservation measures helped Cape Town push Day Zero further out—and then, luckily, the rains returned. But no city wants to rely on luck to bail it out of disaster. Scientists later determined that

TEMPTING AS IT MIGHT BE, THE SOLUTION IS NOT TO FURTHER BEND NATURE TO OUR WILL BY BUILDING BIGGER, HIGHER, AND LONGER VERSIONS OF WATER-ENGINEERING INFRASTRUCTURE.

climate change had made Cape Town's extreme drought five to six times more likely.

Droughts, floods, and other climate-related disasters come with big price tags. In 2017, three large hurricanes in the US were the primary cause of a record $306 billion in damages, more than six times the yearly average since 1980. While 2017 appears to be an outlier, climate scientists expect annual disaster costs of that magnitude to be common by the end of the century.

Tempting as it might be, the solution is not to further bend nature to our will by building bigger, higher, and longer versions of water-engineering infrastructure. It is to work more with natural processes, rather than against them, and to repair the water cycle, rather than continue to break it. Along with water-saving measures, such approaches can create more resilient water systems. They can also help solve our interconnected water, climate, and biodiversity crises simultaneously and cost-effectively.

As floods worsen, for example, instead of raising the height of levees—which often intensifies flooding downstream—we can consider ways to strategically reconnect rivers to their natural floodplains. In this way, we can mitigate floods, capture more carbon, recharge groundwater, and build critical habitat for fish, birds, and wildlife.

The Netherlands, a country renowned for its advanced water engineering, avoided major damage from the historic floods in July 2021 thanks to its new approach to flood control, which gives rivers room to spread out during flood events. The Maas River, which flows in from Belgium (where it is called the Meuse), broke its 1993 high-flow record last July, but it caused less damage than that earlier flood. One reason was a recently completed project that diverted floodwaters into a 1,300-acre wetland, which held the water and lowered parts of the raging Maas by more than a foot. The wetland also sequesters carbon and doubles as a nature preserve, offering valuable climate and wildlife benefits as well as recreation opportunities. Through its "Room for the River" program, the Dutch are implementing these nature-based flood control projects at 30 locations around the country.

Napa County, California, took a similar approach when redesigning its flood-control system for the Napa River. In the early 1900s, engineers straightened and deepened the Napa's channel and filled in its wetlands and tidal marshes. After the area endured 11 serious floods between 1962 and 1997, local officials asked the US Army Corps of Engineers to collaborate on a "living river" strategy that would reconnect the Napa with its historical floodplain, move homes and businesses out of harm's way, revitalize wetlands and marshlands, and construct levees and bypass channels in strategic locations. Residents voted to increase their local sales tax by half a cent to pay their share of the $366 million effort. In addition to gaining new trails for birding and hiking, the city of Napa has benefited from more than $1 billion in private investment that revitalized the downtown.

In an effort to scale nature-based systems, the US Congress directed the US Army Corps of Engineers in 2020 to consider them on equal footing with more conventional infrastructure. A significant shift in approach, however, will likely require changes in Corps rules and procedures, as well as additional funding.

Agricultural practices that rebuild soil health offer another strategy.

WATER WITHOUT BORDERS

Globally, soils can hold eight times as much water as all the world's rivers combined, but we rarely think of soils as a water reservoir. Scientists have found that boosting organic matter in the soil by one percentage point can increase the soil's water-holding capacity by up to 18,000 gallons per acre, creating resilience to both intense rains and dry spells.

This means farmland practices that regenerate soils, such as the planting of cover crops during the off-season, can not only boost yields and lower costs but improve water management and mitigate climate change. As an added bonus, cover crops reduce farm runoff, which means less nitrogen and phosphorus polluting rivers, streams, and aquifers. That, in turn, means fewer of the toxic algal blooms that threaten drinking water, coastal fisheries, and inland lakes around the world.

New policies and incentives that recognize the interconnections between climate, water, and agriculture are needed to expand the use of such nature-based solutions. The state of Maryland, for example, shares the cost of planting cover crops with farmers. Some 29% of the state's farmland gets planted in cover crops, compared with about 6% of US farmland overall.

Holistic solutions don't come easily, since they require thinking and acting outside of bureaucratic and professional silos. But they are key to a livable future.

While it is too late to avoid the impacts of climate change, we can avoid the worst of those impacts by investing more heavily in such nature-based water solutions. ■

Sandra Postel is the author of Replenish: The Virtuous Cycle of Water and Prosperity and the 2021 Stockholm Water Prize Laureate.

ANDREA DAQUINO

ALOK JHA

Exporting water in a time of record drought

Fresh water can and will eventually run out if we're not careful. Climate change is bringing that day along faster.

The Sulphur Springs Valley is a windswept desert in southeastern Arizona, bounded on three sides by forest-topped mountain ranges known as the sky islands. It can take an hour or more to drive between inhabited places in the valley, but the community there is tight-knit—many of the farmers went to the same high

WATER WITHOUT BORDERS

school (as did their grandparents), and today they graze their cattle on the plains and grow corn, soybeans, and grapes.

All of this relies on an aquifer underneath the valley. This layer of rock and soil accumulated its moisture over tens of thousands of years—caught during the monsoon season, or as snow on the nearby mountaintop melted. For generations, farmers—and the many others who have migrated across the country to make this epic landscape their home—have greened their desert by digging wells a few hundred feet into the ground and tapping the groundwater below.

In the past decade, however, these wells have started to run dry. Travel beyond the homesteads and family-run farms you'll see why—thousands of acres of neatly ordered trees bearing pecans and pistachios, vast fields of alfalfa and corn, huge dairy herds, and rows of greenhouses growing tomatoes cover the once-barren desert. This enormous carpet of industrial agriculture, with food grown for export to places around the world, takes deep wells to sustain. For every 100 acres or so, a corporate farm owner will dig a well as deep as 2,000 feet and pull up water from the ancient aquifer at up to 2,000 gallons per second, often 24 hours a day. The drilling rigs often resemble those used for oil.

There are almost no regulations governing the extraction of groundwater in Arizona. As long as the farms pay a permitting fee, they can pump as much as they like.

Added to the over-extraction of water from the aquifer, Arizona (along with the American Southwest in general) is now experiencing one of the worst droughts in hundreds of years, likely driven by global warming. As the region becomes hotter and drier, necessitating more extraction from the aquifer, less water trickles in from monsoons or snowmelt to replenish it.

IF THEY CAN'T FIND ENOUGH WATER WITHIN THEIR OWN BORDERS, THE THINKING GOES, WHY NOT JUST IMPORT IT (EMBEDDED IN FOOD) FROM SOMEWHERE ELSE?

What we don't get about the water cycle

In school we teach children about the water cycle, in which water moves from the oceans to the sky to the land to freshwater basins and eventually back to oceans. In this telling, the water we use never really disappears.

But these tales gloss over something important: the water cycle can take decades or hundreds of years to complete a turn. Much of the fresh water we use every day comes from groundwater, which can take hundreds or thousands of years to accumulate. If we use water faster than it can be replenished, or pollute it and dump it into the seas faster than the natural water cycle can clean it, the resource will eventually run out.

If you instead think of water as a finite material being used up in much the same way as oil or gas, you quickly start to see its presence in every part of the economy. More than 70% of the water we use is put into food production, for example. But water is also used to make everything from T-shirts to cars to computer chips.

Like its cousin the carbon footprint, a water footprint can be a useful shortcut to understanding a product's environmental impact—or your own. The water footprint of a cup of coffee is around 140 liters, for example. It takes about 15,000 liters to grow a kilogram of beef. A couple of slices of bread can rack up 100 liters. A kilogram of cotton (a pair of jeans and a shirt, say) can have a footprint of anything from 10,000 liters to more than 22,000 liters, depending on where it was grown.

This means that countries and companies, whenever they trade goods, are in effect moving massive amounts of water across borders. But because the water footprint of food or clothes or anything else is never acknowledged in this trade, the movement of water itself cannot be properly regulated.

Partly for this reason, richer countries such as Saudi Arabia and China have begun buying up land in other countries to compensate for their own lack of fresh water. If they can't find enough water within their own borders, the thinking goes, why not just import it (embedded in food) from somewhere else? The problem is that the places they've been shopping are themselves water-stressed, including countries in sub-Saharan Africa and the Sulphur Springs Valley in southwest Arizona.

Why Arizona? Because the land is cheap and well connected to airports, and because water-use regulations are almost nonexistent.

The United States is, in fact, the largest exporter of water on earth, according to Robert Glennon, a law professor at the University of Arizona and one of the country's leading experts on water policy. Glennon calculated that during a recent severe drought, farmers in the American West used more than a hundred billion gallons of water to grow alfalfa that was then shipped mostly to China.

Across the US, groundwater is regulated by the "reasonable use" doctrine, which Glennon dismisses as "an oxymoron of the first order." That policy permits "limitless use of the water so long as it's for a reasonable purpose," he says, " and everything is reasonable … It's just a recipe for exploitive use of the resources."

Faster than you think

You might expect this to be a major international priority, but it's not.

Maggie White, a senior manager of international policy at the Stockholm International Water Institute (SIWI) and a longtime water advocate, says that even though water is everywhere and is needed for everything, it has never been prioritized in regulations because it doesn't have its own formal lobbying voice. The water needs of powerful industries like agriculture and energy get prioritized over the management of global water supplies.

White told me about the pushback she faced while trying to get the water crisis mentioned in the official texts of the Paris climate agreement in 2015. The sticking point for many negotiators was that water resources were seen as a local or national issue. As soon as they were brought into a multilateral agreement, they were perceived to rub up against sovereignty issues. Water has always been a source of contention between countries, so some might feel that there's good reason to keep water out of the conversation—but whatever the reason, any discussion of water was edged aside.

To see just how global the impending crisis is, you might head into space. Since it was launched in 2002, NASA's Gravity Recovery and Climate Experiment (GRACE) mission has measured how water moves around the world. It uses two satellites, each the size of a car, sweeping over the surface of the planet and responding to gravitational tugs from the masses below. When the two satellites move over a snowstorm or floods, the gravitational attraction of that extra water pulls the satellites closer to the surface. Over dry areas the satellites are less affected. By keeping track of the ups and downs of the satellites, scientists can map out regions of the world that are gaining or losing water over time.

Scientists already knew the ice sheets in Greenland and Antarctica were melting, but GRACE showed how much. Since 2002, Greenland has shed around 280 billion metric tons of ice annually, causing global sea level to rise by 0.8 millimeters per year. The Antarctic lost around 150 billion metric tons of ice per year in the same period. The glaciers of the Tibetan plateau and in Alaska and western Canada have retreated as well. GRACE also revealed that more than half of the world's major aquifers were being depleted, including those in California's Central Valley, the northwest Sahara, the Arabian Peninsula, India, Pakistan, and the northern China plain.

The two key causes: human overuse of groundwater supplies, and the extreme droughts brought on by climate change. The climate crisis and the water crisis are therefore interlocked. GRACE showed that human fingerprints on the freshwater landscape are the dominant force changing patterns of water availability around the world, and that the threats to water security are coming faster than you think.

The locals whose families have lived in the Sulphur Springs Valley of Arizona for generations have already figured this out. With the aboveground water sources drying up, and with the aquifer being depleted, many of them have had little choice but to leave their homes and farms behind. ■

Alok Jha is science correspondent at The Economist in London and author of The Water Book (Headline, 2015).

STORYTELLING

DEVI LOCKWOOD

The power of storytelling in the fight against climate change

Stories may be the most overlooked climate solution of all.

DEVI LOCKWOOD (FIGURE); PIXABAY (WATER)

It might sound strange to think of storytelling as a climate solution, but after spending five years documenting 1,001 voices on climate change in 20 countries, I believe one of the most powerful forms of climate action is to listen deeply to people already affected by the crisis. To ensure that solutions actually help

STORYTELLING

communities most at risk, we must first hear their stories.

Climate change is an environmental justice issue. The people most harmed by the problem are often those least at fault. Solutions that ignore people already living with the impacts of climate change—most of whom live in the Global South—risk perpetuating the same systemic inequality that delivered this mess to their doorsteps in the first place.

There is a lot of shouting about climate change, especially in North America and Europe. This makes it easy for the rest of the world to fall into a kind of silence—for Westerners to assume that they have nothing to add and should let the so-called "experts" speak. But we all need to be talking about climate change and amplifying the voices of those suffering the most.

Climate science is crucial, but by contextualizing that science with the stories of people actively experiencing climate change, we can begin to think more creatively about technological solutions.

This needs to happen not only at major international gatherings like COP26, but also in an everyday way. In any powerful rooms where decisions are made, there should be people who can speak firsthand about the climate crisis. Storytelling is an intervention into climate silence, an invitation to use the ancient human technology of connecting through language and narrative to counteract inaction. It is a way to get often powerless voices into powerful rooms.

That's what I attempted to do by documenting stories of people already experiencing the effects of a climate in crisis.

In 2013, I was living in Boston during the marathon bombing. The city was put on lockdown, and when it lifted, all I wanted was to go outside: to walk and breathe and hear the sounds of other people. I needed to connect, to remind myself that not everyone is murderous. In a fit of inspiration, I cut open a broccoli box and wrote "Open call for stories" in Sharpie.

I wore the cardboard sign around my neck. People mostly stared. But some approached me. Once I started listening to strangers, I didn't want to stop.

That summer, I rode my bicycle down the Mississippi River on a mission to listen to any stories that people had to share. I brought the sign with me. One story was so sticky that I couldn't stop thinking about it for months, and it ultimately set me off on a trip around the world.

I met 57-year-old Franny Connetti 80 miles south of New Orleans, when I stopped in front of her office to check the air in my tires; she invited me in to get out of the afternoon sun. Franny shared her lunch of fried shrimp with me. Between bites she told me how Hurricane Isaac had washed away her home and her neighborhood in 2012.

Despite that tragedy, she and her husband moved back to their plot of land, in a mobile home, just a few months after the storm.

"We fight for the protection of our levees. We fight for our marsh every time we have a hurricane," she told me. "I couldn't imagine living anywhere else."

> **"WE FIGHT FOR THE PROTECTION OF OUR LEVEES. WE FIGHT FOR OUR MARSH EVERY TIME WE HAVE A HURRICANE. I COULDN'T IMAGINE LIVING ANYWHERE ELSE."**

Twenty miles ahead, I could see where the ocean lapped over the road at high tide. "Water on Road," an orange sign read. Locals jokingly refer to the endpoint of Louisiana State Highway 23 as "The End of the World." Imagining the road I had been biking underwater was chilling.

Here was one front line of climate change, one story. What would it mean, I wondered, to put this in dialogue with stories from other parts of the world—from other front lines with localized impacts that were experienced through water? My goal became to listen to and amplify those stories.

Water is how most of the world will experience climate change. It's not a human construct, like a degree Celsius. It's something we acutely see and feel. When there's not enough water, crops die, fires rage, and people thirst. When there's too much, water becomes a destructive force, washing away homes and businesses and lives. It's almost always easier to talk about water than to talk about climate change. But the two are deeply intertwined.

I also set out to address another problem: the language we use to discuss climate change is often abstract and inaccessible. We hear about feet of sea-level rise or parts per million of carbon dioxide in the atmosphere, but what does this really mean for people's everyday lives? I thought storytelling might bridge this divide.

One of the first stops on my journey was Tuvalu, a low-lying coral atoll nation in the South Pacific, 585 miles south of the equator. Home to around 10,000 people, Tuvalu is on track to become uninhabitable in my lifetime.

In 2014 Tauala Katea, a meteorologist, opened his computer to show me an image of a recent flood on one island. Seawater had bubbled up under the ground near where we were sitting. "This is what climate change looks like," he said.

"In 2000, Tuvaluans living in the outer islands noticed that their taro and pulaka crops were suffering," he said. "The root crops seemed rotten, and the size was getting smaller and smaller." Taro and pulaka, two starchy staples of Tuvaluan cuisine, are grown in pits dug underground.

Tauala and his team traveled to the outer islands to take soil samples. The culprit was saltwater intrusion linked to sea-level rise. The seas have been rising four millimeters per year since measurements began in the early 1990s. While that might sound like a small amount, this change has a dramatic impact on Tuvaluans' access to drinking water. The highest point is only 13 feet above sea level.

A lot has changed in Tuvalu as a result. The freshwater lens, a layer of groundwater that floats above denser seawater, has become salty and contaminated. Thatched roofs and freshwater wells are now a thing of the past. Each home now has a water tank attached to a corrugated-iron roof by a gutter. All the water for washing, cooking, and drinking now comes from the rain. This rainwater is boiled for drinking and used to wash clothes and dishes, as well as for bathing. The wells have been repurposed as trash heaps.

At times, families have to make tough decisions about how to allocate water. Angelina, a mother of three, told me that during a drought a few years ago, her middle daughter, Siulai, was only a few months old. She, her husband, and their oldest daughter could swim in the sea to wash themselves and their clothes. "We only saved water to drink and cook," she said. But her newborn's skin was too delicate to bathe in the ocean. The salt water would give her a horrible rash. That meant Angelina had to decide between having water to drink and to bathe her child.

The stories I heard about water and climate change in Tuvalu

ANDREA DAQUINO / SOURCE PHOTOS: GETTY AND DEVI LOCKWOOD

reflected a sharp division along generational lines. Tuvaluans my age—like Angelina—don't see their future on the islands and are applying for visas to live in New Zealand. Older Tuvaluans see climate change as an act of God and told me they couldn't imagine living anywhere else; they didn't want to leave the bones of their ancestors, which were buried in their front yards. Some things just cannot be moved.

Organizations like the United Nations Development Programme are working to address climate change in Tuvalu by building seawalls and community water tanks. Ultimately these adaptations seem to be prolonging the inevitable. It is likely that within my lifetime, many Tuvaluans will be forced to call somewhere else home.

STORYTELLING

Tuvalu shows how climate change exacerbates both food and water insecurity—and how that insecurity drives migration. I saw this in many other places. Mess with the amount of water available in one location, and people will move.

In Thailand I met a modern dancer named Sun who moved to Bangkok from the rural north. He relocated to the city in part to practice his art, but also to take refuge from unpredictable rain patterns. Farming in Thailand is governed by the seasonal monsoons, which dump rain, fill river basins, and irrigate crops from roughly May to September. Or at least they used to. When we spoke in late May 2016, it was dry in Thailand. The rains were delayed. Water levels in the country's biggest dams plummeted to less than 10% of their capacity—the worst drought in two decades.

"Right now it's supposed to be the beginning of the rainy season, but there is no rain," Sun told me. "How can I say it? I think the balance of the weather is changing. Some parts have a lot of rain, but some parts have none." He leaned back in his chair, moving his hands like a fulcrum scale to express the imbalance. "That is the problem. The people who used to be farmers have to come to Bangkok because they want money and they want work," he said. "There is no more work because of the weather."

Migration to the city, in other words, is hastened by the rain. Any tech-driven climate solutions that fail to address climate migration—so central to the personal experience of Sun and many others in his generation around the world—will be at best incomplete, and at worst potentially dangerous. Solutions that address only one region, for example, could exacerbate migration pressures in another.

A family celebrates Nunavut Day near the waterfront in Igloolik, Nunavut, in 2018.

The author at Monasavu Dam in Fiji in 2014.

I heard stories about climate-driven food and water insecurity in the Arctic, too. Igloolik, Nunavut, 1,400 miles south of the North Pole, is a community of 1,700 people. Marie Airut, a 71-year-old elder, lives by the water. We spoke in her living room over cups of black tea.

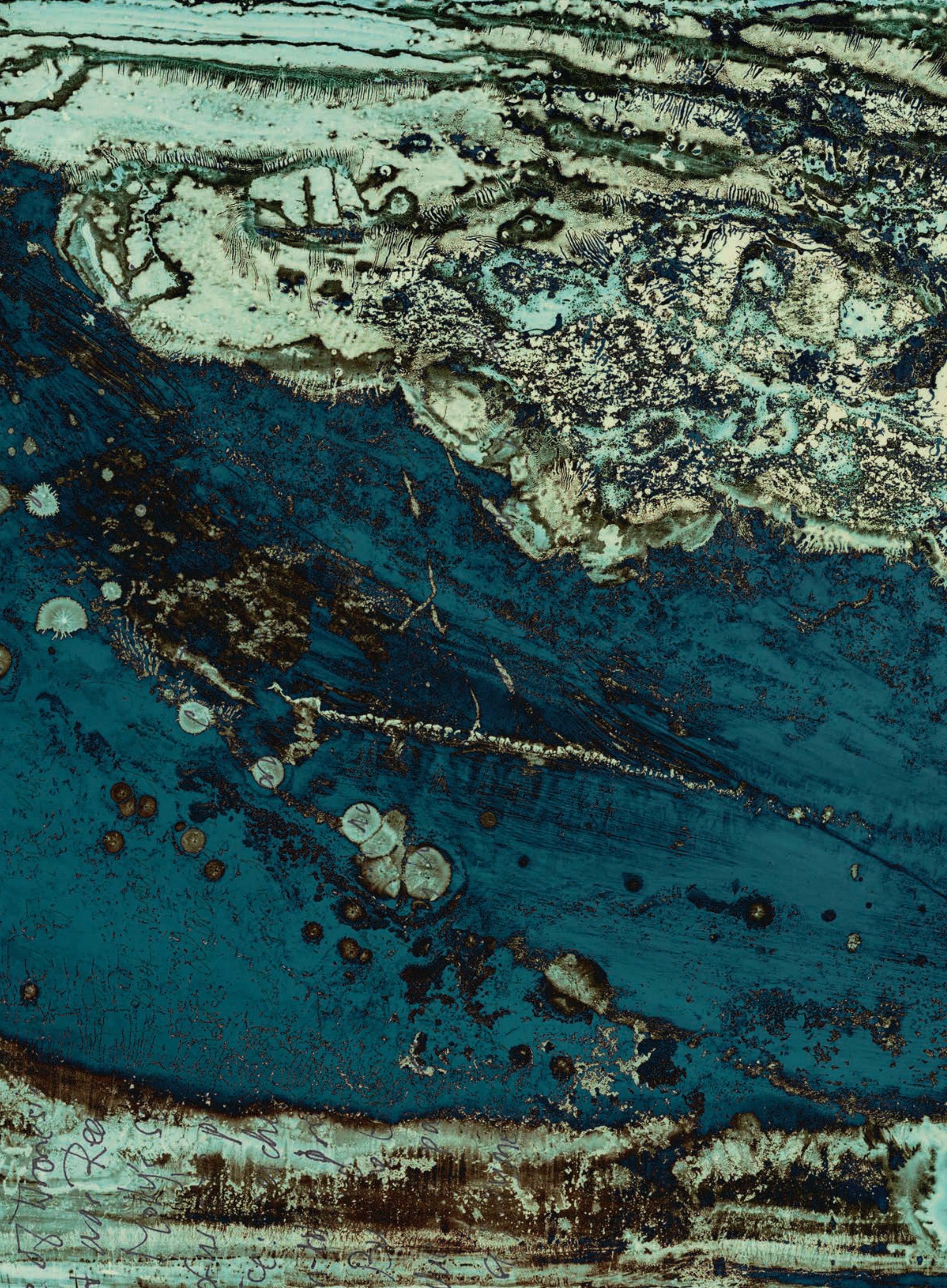
"My husband died recently," she told me. But when he was alive, they went hunting together in every season; it was their main source of food. "I'm not going to tell you what I don't know. I'm going to tell you only the things that I have seen," she said. In the 1970s and '80s, the seal holes would open in late June, an ideal time for hunting baby seals. "But now if I try to go out hunting at the end of June, the holes are very big and the ice is really thin," Marie told me. "The ice is melting too fast. It doesn't melt from the top; it melts from the bottom."

When the water is warmer, animals change their movement. Igloolik has always been known for its walrus hunting. But in recent years, hunters have had trouble reaching the animals. "I don't think I can reach them anymore, unless you have 70 gallons of gas. They are that far now, because the ice is melting so fast," Marie said. "It used to take us half a day to find walrus in the summer, but now if I go out with my boys, it would probably take us two days to get some walrus meat for the winter."

Marie and her family used to make fermented walrus every year, "but this year I told my sons we're not going walrus hunting," she said. "They are too far." ■

Devi Lockwood is the Ideas editor at Rest of World and the author of 1,001 Voices on Climate Change.

DEVI LOCKWOOD



ELYSE FLAYME AND THE FINAL FLOOD

From: Boreal, Emily <Emily.Boreal@samphire.house>

To: Picual, Jim <Jim.Picual@samphire.house>,
Joss, Lillian <Lillian.Joss@samphire.house>,
Gupta, Mohan <Mohan.Gupta@samphire.house>

Cc: Executive Committee <Ex.Com@samphire.house>

By Robin Sloan

Illustrations by Stephanie Arnett

You sent me to find the god of a dying world, and I found her, but it didn't turn out the way you expected. I'm not sorry for what I did, but I do owe you an explanation.

Those of you reading this know very well the problem we faced, but I assume this message will be forwarded to at least one board member, so I'll go over the basics.

Molly Khan had written six books in as many years, starting with *Elyse Flayme and the Ice Queen*, surprise best seller, first in the series that became the heir—at last—to Potter. Even better, this series *meant* something, because the crisis that faced Molly's mythic world of Arrenia was a clear parable for climate change. The books were urgent and serious, but also fun and charming and, as Molly's characters grew up, not a little bit sexy. They were broccoli fried in bacon fat.

Six years, six books, and a glossy TV adaptation running in lockstep: so far, so profitable. But Molly Khan's agent was good. The books were contracted one at a time rather than all at once, so with each success, her leverage increased. Furthermore, the TV show was not permitted to proceed without a book to guide it: there would be no *Game of Thrones*–ing ahead of the author's imagination. Molly Khan's agent was *really* good.

Molly's seventh book would conclude the series. There we were, proud publishers, along with our counterparts at the streaming service: perched, poised, ready to proceed into the final stage of this billion-dollar project.

But the Green Tolkien did not submit her seventh manuscript. The due date passed, and Molly was silent. We knew the book's title: *Elyse Flayme and the Final Flood*. Another month passed. That's all we knew. Three more months. The actress who played Elyse was being pursued for a Star Wars movie. Everything stood frozen, waiting on the author, her imagination, her drowning world, its fate.

She would not reply to emails; would not answer the phone. She was holed up in her house in Bodega Bay, the one she bought with the money from the first Elyse Flayme book and never left. She was, apparently, staring at the ocean.

So you sent me to California.

My mission was simple: determine the cause of Molly's delay and identify what was needed to finish the book. I was authorized to offer, as enticement, an additional 2% of total back-end across all media, which could easily amount to $20 million. On the plane to San Francisco, I imagined myself carrying a giant check. In the rental car up the coast, I imagined myself hauling a sack of gold bars.

Wonderful idea

You all warned me about Bodega Bay. I'd never been to California at all, so of course in my imagination it was Eden, warm and woozy and comfortable. This stretch of coast—cold to start and colder as I crept north, with the cliffs calving away into the black water and the geological fault line totally, hilariously apparent—this was a world ending, literally ending, in slow motion.

I found Molly's house out on the edge of town, perched on a particularly ragged and desperate cliff. The house wasn't large, but its design was very modern, a slanted box built from wood that might once have been dark but had long since been blasted pale by the salt wind.

We had met in person only once before but had corresponded at length, mostly in the comments attached to the manuscript for *Elyse Flayme in the Ocean Beyond Oceans*, her most recent book, now lingering on shelves. Molly had included my name in the acknowledgments: "My thanks also to Emily Boreal, who gets it." This had come as a complete surprise, and even now, when I think of it, my face gets hot.

Molly answered the door in sweatpants.

"Of course it's you," she said. "Smart of them."

I told her I was just here to help, if I could.

Molly nodded. "Fine. Let's see if you can."

On the flight, I wondered if Molly had suffered some kind of breakdown; the writer's agony and ecstasy that, if we're being honest, editors find sort of delicious. Encountering her, I had the sense not of a bulwark broken, but one currently loaded down almost unimaginably. Molly Khan was short and slender, swallowed up by her sweats; following her into the house, I was conscious of all the money, all the expectations, all the *emotions* balanced on that little body as if it were a fulcrum.

There were millions of readers, yes. Millions of viewers, sure. But the thing you really had to contend with was the cosplayers. Elyse Flayme had become a central symbol of the climate justice movement; at every rally, on the steps of every capitol, you found dozens of Elyses, and even more Osric Worldenders, partly because his cold wrath resonated powerfully and partly because his costume called for very short shorts. Molly had achieved the thing that had eluded a thousand earnest climate journalists; she had surpassed even the girl from Sweden. How? By transcribing, without flinching, the fears of a generation. They trusted her. Molly's readers wrote steamy fan fiction *and* they marched on their centers of government.

It was those kids who now had Molly Khan tied into a knot.

"I can't finish it," she said simply. "I've considered every possibility." She waved at a little desk that sat facing the ocean; a tower block of notebooks rose on its surface. "Arrenia can't be ruined, because I can't say, yeah, sorry, we're doomed. No way. But it can't be saved, either, because ... well, it can't. You know the story."

I knew it very well. In Arrenia, the elves who lived on the coast of the Ghost Ocean had, through their misuse of magic, wrecked the climates, plural: meteorological *and* spiritual. The ocean was rising and the stars were raining down curses. To avert calamity, the elves would have to give up magic—immediately, decisively, forever.

The real achievement of the books was that they made this seem appropriately difficult. Magic was fucking awesome! No wonder the elves didn't want to give it up. No wonder they might rather drown. In her fiction, Molly dramatized all the paradoxes. She danced inside the grinding gears of inevitability. There were revenant sharks in the Ghost Ocean. You could ride them.

"But aren't the books actually *about* that tension?" I parried.

Molly looked at me witheringly. "Yes, but I still need an ending."

I searched. "The ending could be about ... not knowing ..."

"Oh, Emily, yes! Very literary. I'll end the series with Arrenia's fate still hanging in the balance. I'll say: That's the point! We don't know the future, do we? Meanwhile, I'll haul my royalties away, go enjoy my life, because I'm part of the last generation for whom that's even possible."

She paused. I was already dead.

"Wonderful idea."

I started reading Elyse Flayme in high school and continued through college. I was one of them, the millions who mothed to this author because she saw the climate nightmare clearly; because she stood beside us in the vise grip of energy and time. But we had put off the reckoning, all of us, author and readers alike. If a happy ending was impossible, but we refused to revel in doom ... what did that leave?

Molly Khan poured wine and led me to the glassed-in balcony that projected off the back of the house. We talked while the sun dipped into the real ghost ocean. I asked her what it had been like, wrestling with the book. She told me about her notes, her experiments. Enough to fill five finales, she said. All abandoned.

I didn't push her; didn't even mention the offer I'd been authorized to make until halfway through the second bottle of wine.

"You could donate the money to climate activists," I said lamely.

You could donate the money to climate activists

Molly shot me an acid look. "You know what I think about that kind of laundering."

I did; everyone did. Elyse Flayme's best friend Meritxell was always coming up with ways in which they could keep using magic *and* delay Arrenia's destruction, and Elyse was always saying, *We have to choose what matters to us, Mer.*

We talked into the night. Mostly, I listened. I came to understand that Molly Khan had been cooped up in that house by herself for way too long. Her false starts came spilling out. The horizon faded to buzzing black as she ticked through the various versions she'd tried and rejected. She went digging in the notebooks for half-remembered lines. The truth is, they all sounded great to me, but Molly wasn't satisfied.

All along, a certainty was growing in my mind.

Molly Khan emptied the second bottle of wine, and when I probed her about Elyse Flayme—asked what Elyse had kept hidden; what this avatar was capable of, in the end—she became animated. She had been rooting in the kitchen for more to drink, but this question brought her back out onto the balcony: she said one thing, then another, and another, all while I cheered her on. I was the only witness: there, in the dark above the ocean, out of nothing, came something: an ending.

Soon after that, Molly sat at her desk and started to type what she'd just explained. I collapsed on the bed in her little guest room. My last thought before sleep was that I had succeeded in my mission: unblocked the writer, secured the future of the franchise. Maybe I deserved a commission … just a tiny cut of that $20 million.

In the morning, I found Molly in the same place exactly. She had not slept. A low-slung district of coffee mugs had joined the tower block of notebooks on her desk. Her keyboard clattered like a subway car; she barreled down the track, not stopping at any of the stations. She was absolutely focused; no part of her moved except her fingers, careening toward their destination. Is this how she had written all the books?

I padded into the kitchen, afraid to disturb her because breaking the spell would be costly, and because I was afraid she would turn around and her eyes would be like Osric Worldender's, shadowed pits crackling with black lightning.

I rustled in the refrigerator, found yogurt, and tapped out an update email, cc-ing most of the people now receiving this. As you might recall, I wrote that things were going well; that Molly appreciated our generosity; that she seemed very energized! This was all true. But I might also have added: The money was an insult; she had not slept; I was afraid to speak to her.

I fiddled with my phone while the clacking of the keys continued. While I waited, a few of you sent enthusiastic replies: *Way to go! Yeah, Emily, great news! I guess you really do "get it"!*

The clacking slowed, became a stately chug. The chug broke down into silence. Molly lifted her head and peeled herself away from her laptop. She looked out across the ocean and, from my perspective, was framed against it: a ragged silhouette, baggy sweatshirt and wild hair conspiring to make her into a witchy apparition.

In another world, she would have rolled her shoulders, put her head down, and finished the book. She would have committed to the page these events, which she had imagined and described to me the night before:

Elyse Flayme would have climbed the great tower at the center of Svanta City, using all the powers she'd accrued over the past six books to knock down the obstacles in her path, absolutely shredding the elvish security forces. Osric Worldender would have been there at her side, throwing black lightning, exultant. At the tower's top, she would have found the Ghostburn Council, the ones who profited most from the use of magic. Among them would be Meritxell, her old friend, who had been catapulted into power in book five and aimed to transform the council from within. Meritxell, who—

Elyse Flayme would have killed them all. She would have abrogated all her values, crossed all the lines established in the previous six books. She would have done precisely the thing her foe from the first book, Mauna the Ice Queen, had stood poised to do: the massacre young Elyse had prevented, in an impassioned speech that kids still quoted on the hand-written signs they carried to rallies at capitols. THEY ARE ABOVE ALL AFRAID, one sign might read. WE WILL SAVE THEM WHETHER THEY LIKE IT OR NOT, might read another.

There would be no speeches in this final scene, just blue fire and black lightning and, in the space that death opened, a glimmer of hope.

In another world, that's what Molly wrote, Final_Flood_v19_Final_ReallyFinal.docx. In this one, she—I don't know how else to say it: she crumbled. I watched it happen, like a cliff sliding into the ocean. Exactly that heavy. Exactly that final.

She put her head down on the desk, and it stayed there. I wondered if she was crying. I wondered what I should do if she was crying. Then she stood, screamed once, and stalked out of the room.

In that moment, I was terrified. Would I have to soothe her? Was that my mission? I am not a soother. I do not soothe. I annotate. I stood frozen in the kitchen and strongly considered flight, but in a pulse of character development worthy of Elyse herself, I bested my chickenshit heart and hustled to pursue Molly Khan, who had exited not only the room but the house.

Outside, thick fog had settled along the coast, and I could not locate any witchlike apparitions. I scrambled around, checked the front of the house, looked up and down the road, raked the coast with my eyes. Nothing.

Then I very gingerly approached the cliff, where I spotted a figure pacing the beach below. I hustled down switchbacking stairs to find Molly circling the sand, staring into the gray. The muscles across her face were tight. In her hair, I saw crumbs, along with a stalk of some hardy coastal grass. The wind whipped off the water, stung my eyes, extracted tears. There were tears in Molly's eyes, too.

"IT DIDN'T WORK," she shouted above the wind. "This is what happens. Like a loop, this whole year. I think I have an ending, and I get so excited, but I realize I can't publish it, because it's not what they deserve. THEY'RE BEYOND ME, EMILY! I can't write what they deserve!"

If I had found Molly's crumpled body on the beach, rather than her scowling face, I wouldn't have been surprised; and it was that realization that shook me into action.

Because, as I said before, a certainty had been growing in my mind. The idea occurred to me first on the plane, but I had smothered it. It reappeared on the drive, but again, I pushed it aside, because I understood how dangerous it was. Now, though, I saw how deeply Molly Khan was suffering, and I saw—as she did—that she would never complete this book in the way she, or any of us, had planned.

What had Ambassador Agora said to Elyse Flayme in book three? "We cannot undo these curses with the same kind of magic that created them."

I was certain what Molly Khan had to do, so I told her.

She looked at me, there on the beach, her eyes narrow. She asked for clarification: "Can I ...?"

She was the god of a dying world. Of course she could.

We climbed up to the house, where Molly prepared a proper breakfast. For the first time, I detected a lightness in her. Ever since I'd arrived—and for the whole year prior—her brain had been whirring, searching, grasping. Failing. Now she allowed it to rest. She gave me a plate of eggs, perfect, then dialed her great and terrible agent. When Molly explained my idea, her agent's reply shook the phone speaker: "THAT IS ABSOLUTELY UNHINGED. I LOVE IT. I MEAN, I HATE IT. BUT I LOVE IT!"

That is absolutely unhinged.
I love it.
I mean, I hate it.
But I love it!

I presume you know what her agent loved and hated, because you've read Molly's announcement, and perhaps some of the reactions to it, but just in case—and for the board member, hello—I'll take this opportunity to make it perfectly clear:

Molly Khan will not submit her seventh book, but the series will not go unfinished.

Remember: Molly Khan retains all rights to Elyse Flayme and her world, and those rights include the power to commit them to the public domain, which she has now done.

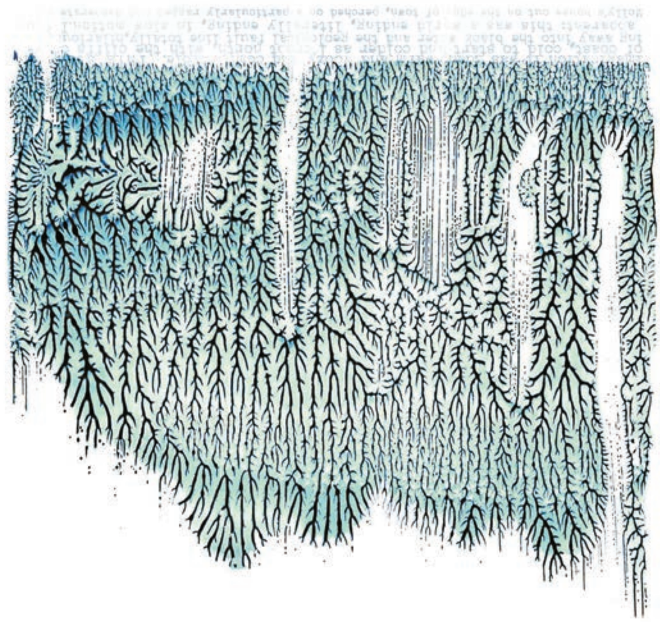
Now anyone can write their own ending—and not only in the shadowy confines of fan fiction, but in the scrum of the market. They can publish it, sell it, get it made into a movie. In a stroke, Molly Khan has given up her control over Elyse Flayme. She has turned down the sack of gold bars I carried, and all the giant checks that might have followed, and given it all to ... anyone who wants it?

We cannot undo these curses with the same kind of magic that created them.

Don't worry: you will not be denied *your* final fountain of money. The public domain, after all, is open to you, too! You can commission a conclusion from one of Molly's peers, or go hunting for the best one that bubbles up from the ferment of the fans. Every other publisher can do the same, though, so you'd better hurry.

The streaming service will now have total creative freedom, and for them it will be terrifying. Which ending will they choose? How will they justify it? They know the fans; they fear them; and they don't have Molly to protect them anymore. This makes me very happy.

Here's the last trick: Molly will write her own ending. It will be something from one of her notebooks; there's so much to choose from. She'll publish it just as she did in the very beginning, her fan-fiction days, using a pseudonym. As everyone pores over the ocean of alternatives, they'll have to ask themselves: Is this one hers? Does it matter?



When I left Molly in Bodega Bay, she was back at her desk, but it felt different. There was no demonic clacking. She typed in normal-person bursts, just a bit at a time, before standing to circle the room. The desperate energy had dissipated. She browsed her shelves, plucked books to consult. When I left, she was lying on the couch, paging through *Candide*, legs kicked up in the air. She wore real pants. The Green Tolkien is gone, banished, thrown from that cliff. She is again—will now remain—Molly Khan.

Did we really believe we could do any good, buying and selling this climate fiction inside the same system that's boiling the world? I don't excuse myself. "Thanks also to Emily Boreal, who gets it," Molly wrote—but I didn't. I took a plane to reach her. I drove a car up the coast. In the end, I wanted Elyse Flayme to kill them, the stupid greedy ones, wanted the thrill of blood on the page—and then a safe flight home.

I'm on a train right now, Oakland to Chicago. You've probably figured it out: this message is my resignation. Thank you for sending me to Molly, so I could help her open this door, which I will now walk through. I have my own vision for the end of Arrenia. It's darker than you might imagine. I came of age with Elyse Flayme, and now I have something I want to say through her. With her. I'll send you my manuscript when it's ready; maybe it will be the one you publish. Molly introduced me to her agent, who is a demon queen.

In the meantime, don't be afraid. If you ever truly believed in Molly's millions of readers—not just as consumers, but as collaborators, co-creators—then believe in them now.

She titled the book before she knew what it would become. The Final Flood is not one story you can control; it's a thousand you cannot. Control is what got us here! I met Elyse Flayme in a big chain bookstore, and for that, I'm grateful. But now we have to leave it behind. We cannot undo these curses with the same kind of magic … you get it.

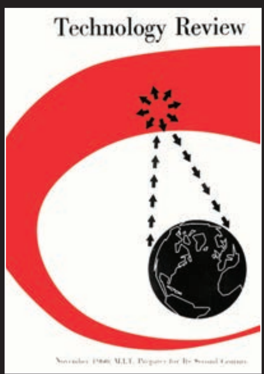
I've been on this train for two days; it's just now passing through Denver. I'm searching for "Elyse Flayme" on all the big online bookstores, and they're already appearing, all the different conclusions, self-published, totally legal, climbing the sales ranks together: Elyse Flayme and the Burning Tower; and the Last Spell; and the Moon's Promise; and the New Magic; and the Absolutely Shortest Shorts.

How did they write these stories so fast? There can only be one explanation: they were writing them already. ■

Robin Sloan is the New York Times bestselling author of Mr. Penumbra's 24-Hour Bookstore and Sourdough.

Come hell or high water

We've been messing with the oceans for many years, and for at least 60 of those, this publication has been writing about it.



NOVEMBER 1960

APRIL 1969

AUGUST 1980

From "Climate Control and the Oceans": Without a clear picture of how the ocean overturns and with no accurate time scale for interaction with the atmosphere, oceanographers and meteorologists alike are at a loss to explain adequately the general mechanism of the earth's climate. Now man, with his carbon-dioxide-producing industry, has become yet another unknown modifying factor. The influence of this new and geologically unique factor may be operating in any of several directions. It could be tending toward a new ice age or could be producing another great tropical epoch like that prevailing when coal and oil deposits were laid down. The interactions are so involved that experts do not yet know how to sort them out. One thing they are sure of—this influence is at work on a scale to dwarf all previous changes man has made.

From "A Sterile Sea": The modification is beginning. "Man, a land organism, is influencing the chemical composition of sea water more than any of the species that live within the marine environment," said Edward D. Goldberg, Professor of Chemistry at Scripps Institution of Oceanography. For example, some 3,000 tons of mercury reach the oceans each year from natural continental sources and 4,000 tons from fungicides and industrial processes; the lead input to the oceans from automobile fuel is "roughly equivalent" to that from sedimentary action; pesticides, "a recent and novel entry to the marine environment," now are widespread, and so are radioactive species; and man has introduced two new elements: sewage outfalls and accidental pollutions from man's commerce. Perhaps half of all these contaminants are introduced into the ocean by activities in the U.S.

From "Coal and Climate Stoking the Fires of Research": One thing to avoid is running around warning that the Antarctic ice cap is going to melt and flood a lot of real estate. Some scientists have suggested that this could happen quickly—a highly speculative conclusion. As J.H. Mercer of the Institute of Polar Studies at Ohio State University pointed out, the projected warming could melt enough ice to raise global sea levels some five meters, but this would likely take several centuries. More sophisticated computer models should be developed, and it would be prudent to monitor the Antarctic ice by satellite regularly. Meanwhile, there's little merit in the "scare-the-hell-out-of-them" approach typified by one prominent geophysicist, who stood on the U.S. Capitol steps indicating where the water would come to dramatize his case for restricting the use of coal.

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