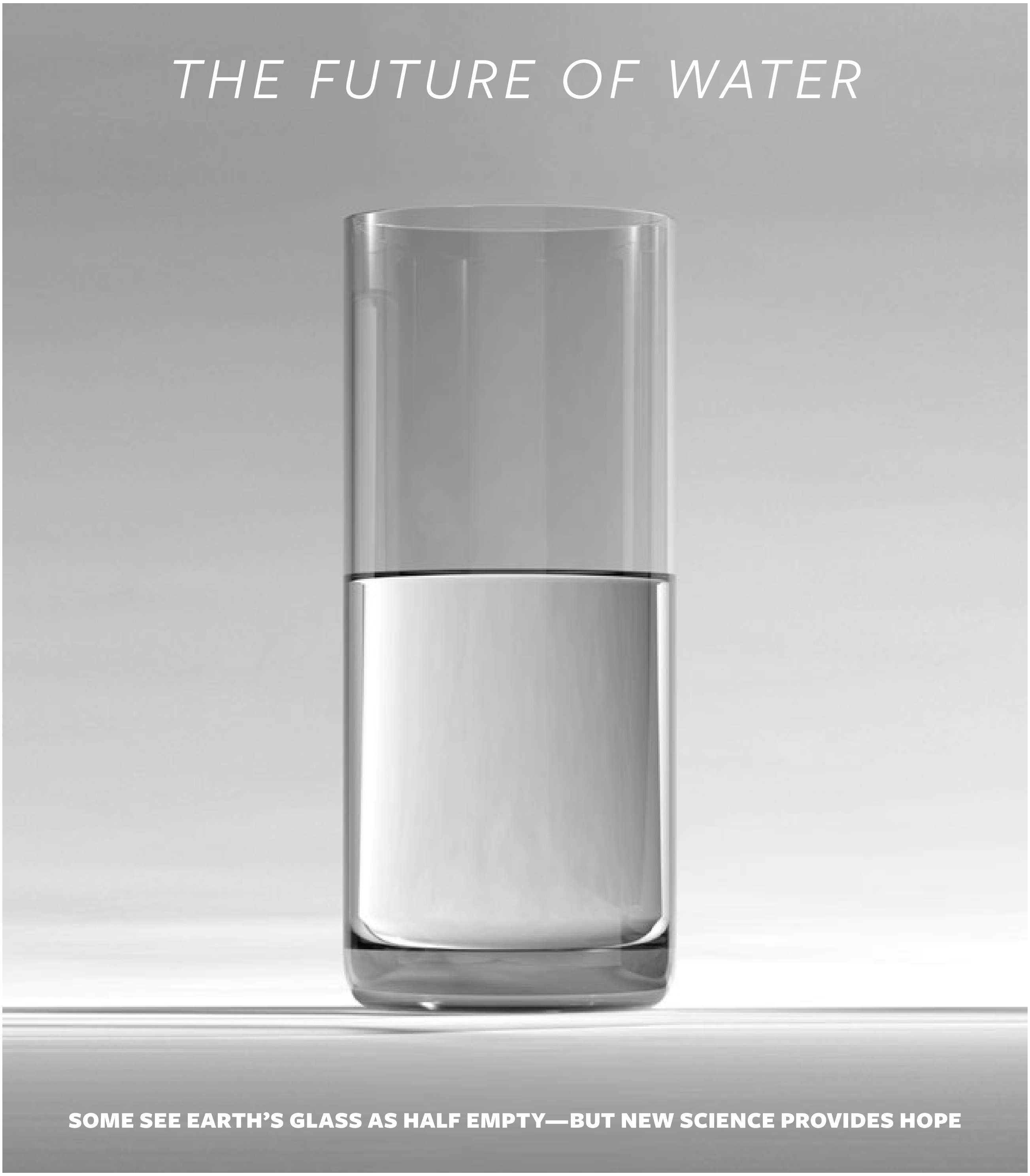
TREND

Analysis of the Facts, Numbers, and Trends Shaping the World
THE PEW CHARITABLE TRUSTS



SPRING 2019 / 04

wa·ter

[wȯ-tər]

noun

1. a compound of oxygen and hydrogen
2. a colorless, transparent, odorless liquid that forms the seas, lakes, rivers, and rain
3. a finite resource essential for life on Earth

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NOTES FROM THE PRESIDENT

THE FUTURE OF WATER

"Water," Leonardo da Vinci said, "is the driving force of all nature." And anyone who has seen the power and beauty of rushing water in its natural state would likely agree. But over time, people and industry became the driving force of water. Dams have turned rivers into lakes for energy, reservoirs for drinking, and canals for shipping. Wetlands have been drained for houses, hotels, and crops. Flood-prone rivers have been tamed. And just in the last half-century, modern drilling and pumping technology has allowed groundwater to be tapped on an industrial scale for agriculture and personal uses.

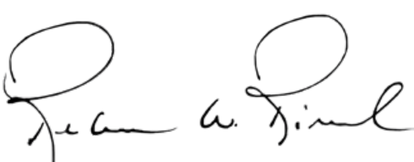
In this fourth issue of *Trend*, Charles Fishman describes the last 100 years as "a golden age of water" that helped increase life expectancy, cut infant mortality, and control waterborne illnesses in the United States. Now this golden age of plentiful, free, reliably safe, and mostly taken-for-granted water has given way to a new era that requires careful stewardship of our water resources, a policy imperative that we explore in this edition.

As hydrologist Jay Famiglietti explains, wet regions of the globe are getting wetter and dry regions are getting drier. The effects can include severe flooding, extreme drought, longer fire seasons, and water-driven conflict. And the challenges we face don't end with the water we can see. In some parts of the world, water below the ground is being taken out of aquifers at unsustainable rates, water tables are dropping, and reserves are shrinking. As a result, some food-producing areas are threatened and the natural cycle of replenishment is disrupted.

Policymakers, business leaders, and individuals all have a role to play in managing our interconnected water supply. The good news is that some progress is being made.

Hydrogeology professor Graham E. Fogg points out that new advancements "now allow us to monitor groundwater levels across a groundwater basin in real time nearly as easily as we can a surface reservoir." And 1995 Pew fellow in conservation and the environment Sandra Postel offers examples of innovations in the U.S. and abroad to better use, manage, and value water—from drip irrigation in Arizona and projects in Philadelphia designed to prevent runoff, to more efficient appliances and healthier soils that can store more moisture.

In the 21st century, we can no longer assume we'll always have enough clean water. Instead, we must learn to manage, protect, and replenish our water supply. So read along and learn more about the history and future of water—and the policy changes we need to consider to preserve nature's life-sustaining resource.



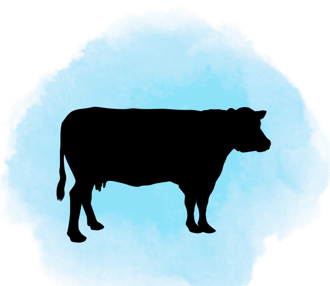
Rebecca W. Rimel, *President and CEO*

PLEASE SHARE YOUR THOUGHTS ON THIS ISSUE OF *TREND* BY WRITING US AT TREND@PEWTRUSTS.ORG, OR JOIN THE CONVERSATION ON TWITTER WITH #PEWTREND.

CRUNCH

What Is a Water Footprint?

It takes just over 2,000 gallons of water a day to keep the average American's lifestyle afloat. That's because everything we use, wear, eat, or buy takes water to make. A product's water footprint consists of the volume of water from soils, rivers, and groundwater consumed in making it, plus the water needed to absorb the pollutants from manufacturing. So the water footprint of a cotton T-shirt consists of the water from rainfall and irrigation consumed in growing the cotton plant, plus the water needed at the shirt-making factory, plus the water needed to dilute the factory's pollution. Applying a consistent methodology, the Water Footprint Network—a collaboration of companies, organizations, and individuals aimed at promoting smarter use of water—has developed water footprint estimates for many common products. = 100 gallons



1 LB. OF BEEF

1,840 gallons

MARGHERITA PIZZA

330 gallons

A CUP OF COFFEE

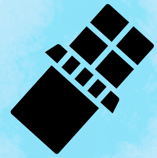
34 gallons

6 OZ. GLASS OF ORANGE JUICE

53 gallons

COTTON T-SHIRT

713 gallons

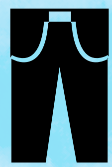


1.5 OZ. CHOCOLATE BAR

220 gallons

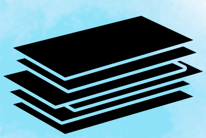
A PAIR OF LEATHER SHOES

4,385 gallons



A PAIR OF JEANS

2,113 gallons



1 REAM OF PAPER (500 SHEETS)

349 gallons

1 LB. OF CHICKEN

450 gallons

THE REDISCOVERY OF WATER

BY CHARLES FISHMAN

Water is reminding us of its power. We have spent a century domesticating water, or fooling ourselves into imagining that we had.

Let's look at the United States. Three-quarters of California's rain falls in the northern half of the state, but three-quarters of the people live in Southern California. So we move the water from one end of that vast state to the other.

We built Hoover Dam to supply water across the American West. We re-engineered the Mississippi River because we didn't like the way it flooded. We re-engineered the swamps across the southern third of Florida to create land for homes and hotels.

When we got frustrated with our own pollution backing up in Lake Michigan, we decided that the waste could be flushed away if the Chicago River flowed out of Lake Michigan rather than into it. So at the start of the 1900s, we re-engineered the river, and it has spent the past century draining Lake Michigan instead of filling it.

Most important, at the start of the 20th century, we figured out how to make water reliably clean and safe: run it through a sand filter, add a little chlorine. In the space of 10 years, drinking water in cities across the U.S. and Europe went from being an odious font of disease to a source of health, providing a foundation for big cities to flourish.

From 1900 to 1940, life expectancy in the U.S. increased from 47 years to 63 years. Infant mortality was cut in half. Much of that progress owed to a simple revolution: clean water.

That water revolution did something surprising: It gradually made water invisible. Our mastery of water allowed us to mostly ignore it.

But now, every week, there is a disaster that comes from water. Drought-fueled wildfire in California burns down most of two towns. That happens 29 days after hurricane-driven storm surge reduces to splinters an entire community in the Florida Panhandle. The result: three U.S. towns destroyed by water-caused disasters in less than a month.

The slower-moving changes are equally arresting. The water supply for Miami could be permanently contaminated as sea-level rise forces salt water into what has been the city's pristine drinking water aquifer.

The city of Charleston, South Carolina, now floods more than 50 times a year—twice the rate of a decade ago—and the flooding is changing daily life in the city. A dozen Charleston officials recently spent a week in the Netherlands to see what it looks like for a place to re-engineer, to re-imagine its relationship with water.

Everywhere we look, on every continent, water is reasserting its power to shape how we live and also, sadly, how we sometimes die. That can make it seem as if, all of a sudden, we don't know what we're doing when it comes to water.

In fact, it's the world that's changing. Except for the danger from extreme heat waves, every element of climate change is about water: too much, too little, melting glaciers, rain instead of snow, rain that falls in one place when we're accustomed to it falling in a slightly different place.

We have built our civilization—our cities and towns, our roads and reservoirs, our farms—based on our understanding of water, and our relationship with it, our ability to manage it.

Water has become the key utility in our personal lives—we use it to brush our teeth and wash our clothes—as well as in the world's economy. It is essential to making nearly everything from concrete to microchips. Water is also a source of comfort; we swim in it, sail on it, and baptize our children with it. And we gravitate to it: Just 10 percent of the United States' counties touch water, but 40 percent of Americans live in those counties.

We have this unspoken intimacy that leads us to think we know what to expect from water. The past 100 years have been a golden age of water, particularly in the developed world: We've put it where we wanted it. It has been unlimited, virtually free, and unthinkingly safe.

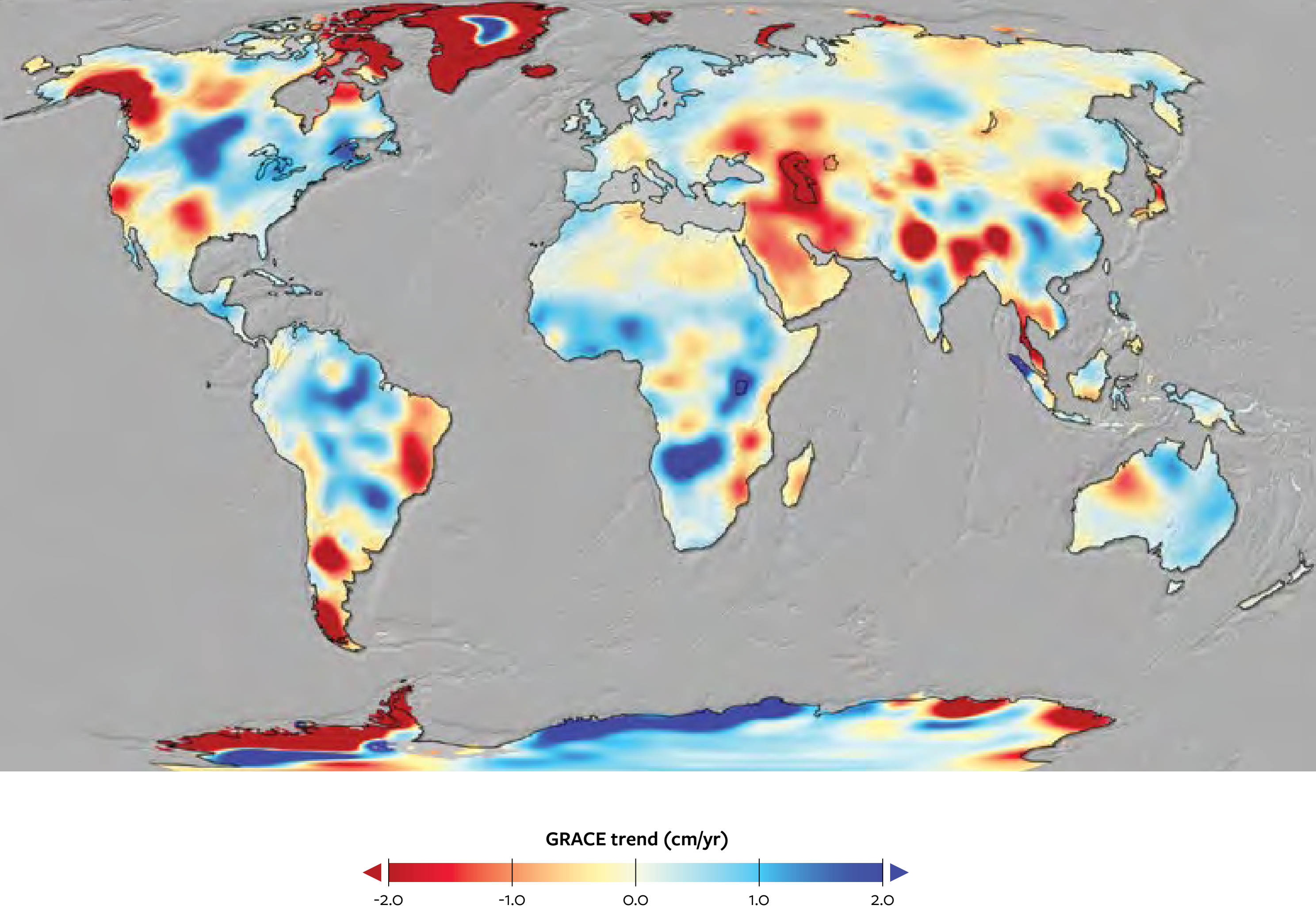
But that golden age of water is over. The invisibility it created is a luxury we can no longer indulge. If we're going to succeed in the next hundred years, we're going to have to pay attention to water in a way that we haven't had to in a long time.

In the next century, we're going to have to rethink everything we do with water: how we grow our food; how we build our homes, our parks, our cities; how we get the water we need every day for showers, and what we do with it when we're done; and also how we live, safely, alongside water.

We often forget that the chief quality of water is its resilience. All the water on the planet has been here forever; we use it over and over again. That's the key of the next era of water: our own resilience in how we use it.

The starting point should be a fresh respect for water, and a renewed curiosity about it. Our domestication of water has always been an illusion—it's all on our side of the relationship. Water is a partner in how we live, but it remains a wild and unruly, if sometimes beautiful, natural force.

WE HAVE SPENT A CENTURY DOMESTICATING WATER, OR FOOLING OURSELVES INTO IMAGINING THAT WE HAD.



A MAP OF THE FUTURE OF WATER

BY JAY FAMIGLIETTI

Global changes are altering where and how we get fresh water—and may even offer a new opportunity for worldwide cooperation and diplomacy.

The availability of fresh water is rapidly changing all over the world, creating a tenuous future that requires attention from policymakers and the public.

We know this thanks to 14 years' worth of satellite data collected by a unique NASA Earth-observing mission called the Gravity Recovery and Climate Experiment—which has the gratifying acronym GRACE. Unlike some satellite missions that rely on images, GRACE, which was launched in 2002 and decommissioned at the end of 2017, was more a "scale in the sky." It measured the very tiny space-time variations in Earth's gravity field, effectively weighing changes in water mass over large river basins and groundwater aquifers—those porous, subterranean rock and soil layers that store water that must be pumped to the surface.

As complex as that sounds, the results are actually quite simple to understand. The data quantified the rates at which all regions on Earth are gaining or losing water, allowing my colleagues and me to produce the accompanying map. And what the map shows is also simple to understand but deeply troubling: Water security—a phrase that simply means having access to sufficient quantities of safe water for our daily lives—is at a greater risk than most people realize.

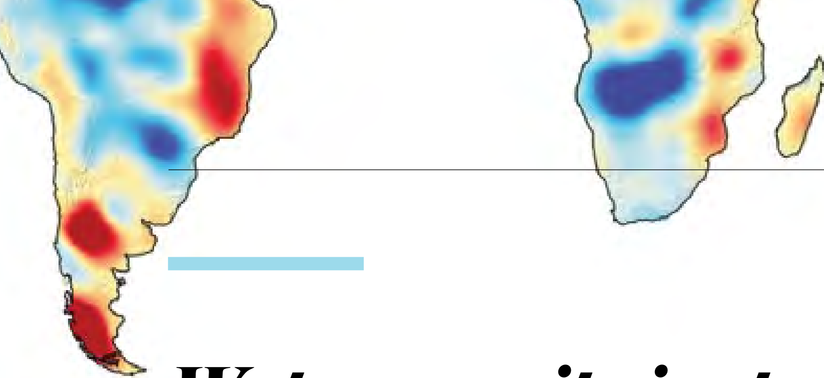
We spent more than a decade studying the data and published our map and report in 2018. Perhaps the most concerning feature throughout the years of the map's development has been persistent, distinct patterns that define emerging classes of water "haves" and "have-nots" around the world. These patterns aren't seen in previous water maps, most of which were built from ground-based data.

For example, we found that the world's high-latitude regions, including the northern half of the United States, as well as the global tropics, the low latitudes, are getting wetter. Simultaneously, the mid-latitudes—the arid to semiarid belt sandwiched in between—are getting drier. This pattern of wet getting wetter, dry getting drier, has long been predicted in a series of Intergovernmental Panel on Climate Change (IPCC) reports. However, IPCC-predicted changes extend through the end of the 21st century. Our latest study, and an earlier report from our team, show that it is happening now.

With less than two decades of data from the GRACE mission, we cannot say conclusively that these patterns are driven by climate change. But their similarity to the patterns predicted by the IPCC is striking and should be cause for great concern.

Against this broad backdrop of high- and low-latitude wetting and mid-latitude drying, the map is dotted with numerous "hot spots"—places where rapidly increasing (deeper blue spots) or rapidly decreasing (deeper red spots) amounts of water pose major threats to human and environmental well-being in a variety of ways.

Some of the hottest of the red hot spots are located where the world's ice sheets and mountain glaciers are steadily melting in response to rising temperatures. The Greenland and Antarctic ice sheets and the Alaskan, Patagonian, and other mountain glacier systems are disintegrating at alarming rates, pouring billions of tons of fresh water into the oceans each year, driving sea levels to dangerous new heights.



Water security is at a greater risk than most people realize.

At the same time, one of the more startling findings of our work with the GRACE data concerned the water we cannot see but increasingly rely upon: groundwater. Over half of the world's major aquifers are past sustainability tipping points, meaning that the rates at which groundwater is being withdrawn are far greater than the rates at which it is being replenished.

These aquifers appear as bright-red hot spots on the map, and they are found on every continent except Antarctica. The Central Valley and Ogallala aquifers in the U.S.; the Northwest Sahara aquifer system; across the Middle East, northwestern India, and northern Bangladesh; the North China Plain aquifer in Beijing; the Pilbara basin in northwestern Australia; and the Guarani aquifer in southern South America are all being overly exploited. These great aquifer systems are being mined, primarily for irrigation in the overlying, mega-food-producing regions of the world. This disappearance of groundwater places regional and global water and food security at increasing risk.

The changing climate is also leading to changing extremes in flooding and drought. Our map identifies where these shifts have been the most severe, and other work from our team shows that we can also quantify the rates at which these extremes are being altered. Key regions where increases in flooding have been most severe include the U.S. Upper Midwest and southern Alberta, Canada, where major flooding occurred in the Missouri River basin (2011) and Calgary (2005 and 2013); the Amazon and Orinoco River basins in South America; and the Okavango Delta in southern Africa.

Hot spots in which drought extremes have been intensifying at dangerously high rates are also apparent on the map. Key regions include California (with the 2006-10 and 2011-15 droughts) and Texas (the 2005-06, 2007-08, and 2010-15 droughts), and the 2014-17 drought in southeastern Brazil when Sao Paulo—with more than 12 million people, one of the world's most populous cities—nearly ran out of water. There have been chronic droughts in Eastern Europe, while in the Caspian-Aral Sea region in Asia, long-term drought is drying out once great inland seas. The hardships, damage, and loss of life caused by increases to both flooding and drought can be expected to continue in these or other future hot spots if changing extremes become "the new normal" under climate change.

The shifting patterns of water availability, along with falling groundwater levels, will further limit access to drinking water and water for irrigation, presenting new socio-economic and political implications. Over 2 billion people already lack access to safe drinking water at home, and by 2025 over half of the world's population will reside in water-stressed areas. These numbers will increase significantly if climate change and population growth follow or exceed predicted trajectories.

The disappearance of water from several hot spots on the map raises important questions: Is the world prepared for potential waves of displaced people, like those from Syria, where drought plays an important role in the conflict and the refugee crisis? How will the billions of residents across South Asia respond when disappearing glaciers and groundwater begin severely limiting the availability of fresh water and disrupting livelihoods? Will they become water refugees, and will migration be haphazard, event-driven, or managed? Are neighboring countries willing and prepared to accept potentially displaced populations?

Several of the hot spots for groundwater depletion cross state or international borders, and many such regions are already prone to conflict. Will the history of water-driven conflict continue or worsen in the Middle East or along the Tunisia-Libya or India-Pakistan borders? Will China's great thirst spark new conflict beyond its boundaries as it takes water from the Mekong River, which flows through five other nations?

Water scarcity may ultimately also limit food production. The food industry is the largest user of water worldwide, consuming far more than is available on an annual renewable basis. In fact, most of the world's food-producing regions are in a state of chronic water scarcity, with no end in sight given current rates of production and levels of agricultural efficiency.

If most food production remains in its current, drying mid-latitude locations, it will require water imported from wetter areas. States such as California and nations such as China, India, and Argentina are already doing this or considering it. But in many places, proposals to move water from one region to produce food in another meet great resistance. In the U.S., for example, discussions to build freshwater pipelines from water-rich regions like Alaska, the Great Lakes, or the Mississippi River to food-producing regions like the Central Valley or the southern High Plains—to grow food for Americans—have always been politically charged. However, given the reality of disappearing groundwater, the next questions we face could be: Will more long-distance water transport be required to support food production in its current locations in the U.S.? Or will food production migrate to where more water is available?

THE HARDSHIPS, DAMAGE, AND LOSS OF LIFE CAUSED BY INCREASES TO BOTH FLOODING AND DROUGHT CAN BE EXPECTED TO CONTINUE.

The ultimate goal of sound water management is to provide a reliable supply of water of the appropriate quality for a range of needs: drinking and sanitation, food and energy production, industrial and municipal, economic growth, and environmental biodiversity. Can water managers continue to ensure reliability as the amount of water entering a region as precipitation, snowmelt, or stream flow becomes much more variable and uncertain?

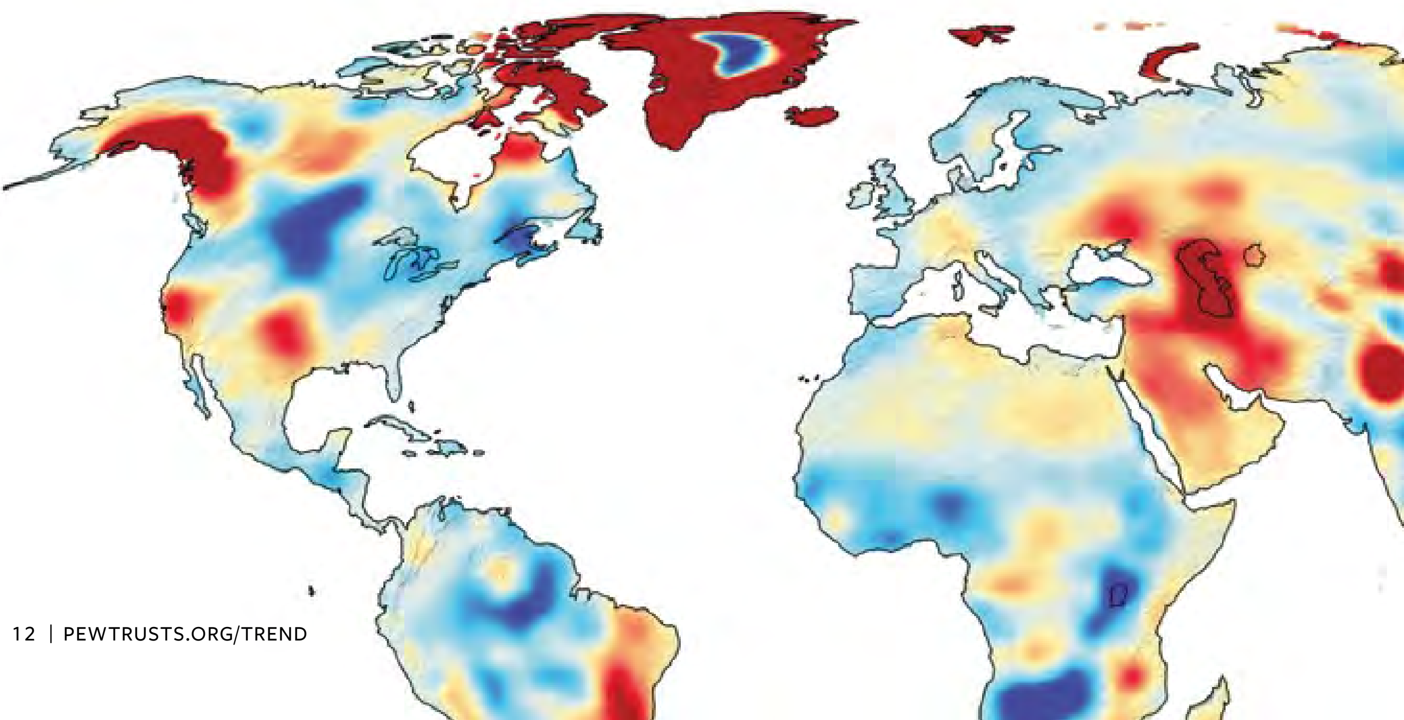
Technological innovations alone will not meet the coming global water challenges. But there are areas in which we can make progress. Agriculture has great potential for water saving by improving efficiency through more precise and focused irrigation and by breeding plants for drought tolerance.

Around the world, surface water—our rivers, lakes, and reservoirs—and our groundwater must be managed jointly, as components of one interconnected water supply. Poor monitoring and management of groundwater relative to surface water, as is typical in much of the world, has resulted in its rapid disappearance. As a critical element of national and international water supplies, groundwater should be included in interstate and international transboundary water discussions.

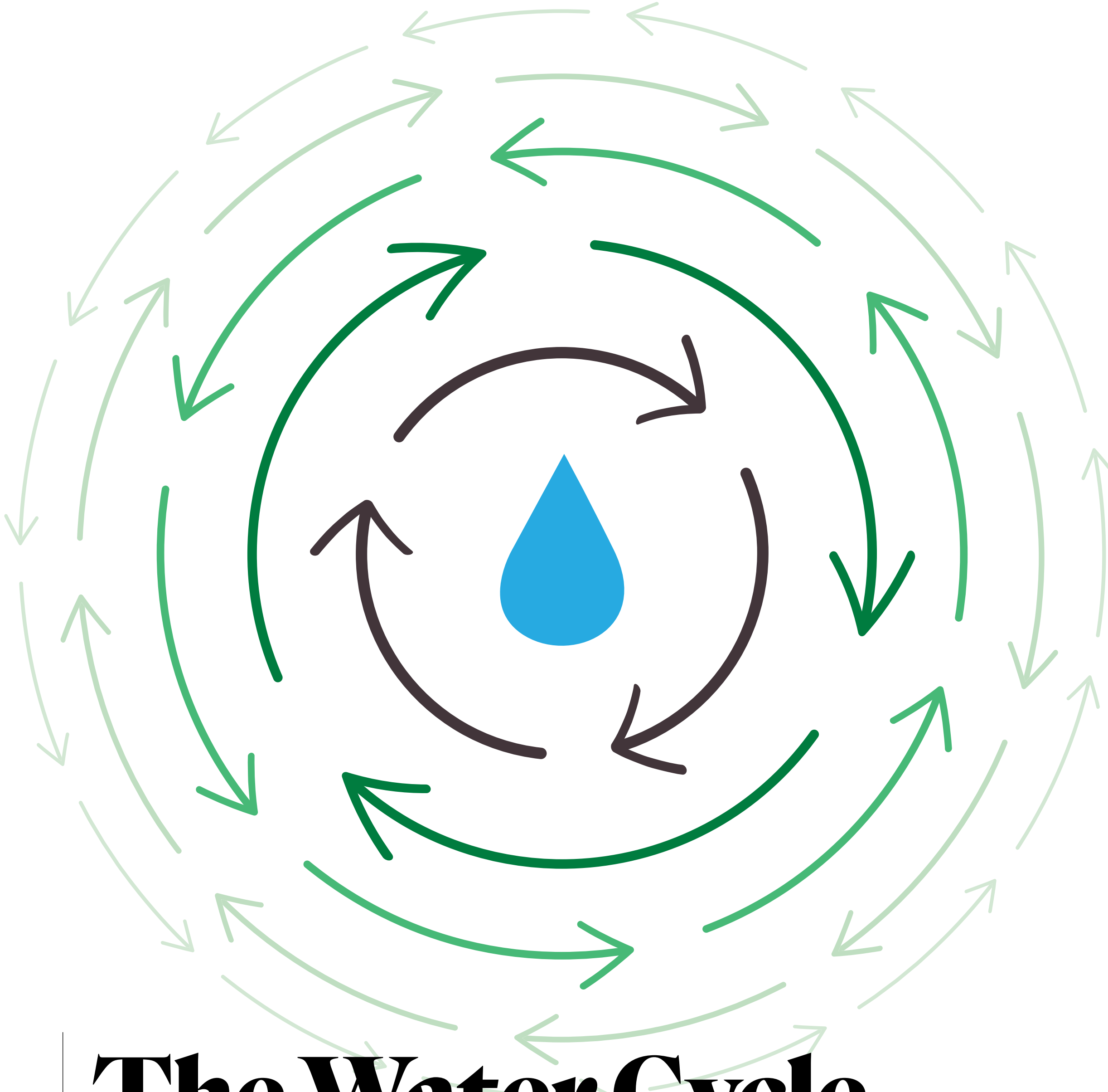
Of course, there is also action each of us can take as individuals. We can use more efficient plumbing and reduce outdoor watering at home. And we can adjust our diet, turning to foods that require less water. A pound of beef, for example, requires roughly four times as much water to produce as a pound of chicken.

As individuals we also we must require our elected officials to commit to solving our water concerns. Fortunately, reliable scientific information exists to help guide them. The May 2018 launch of GRACE Follow-On, a continuation of the original GRACE mission, will ensure a steady flow of additional data in the years to come.

If governments, nonprofits, development banks, academic researchers, industry, and policymakers can come together, we may be able to turn our freshwater challenges into a net positive. By opening venues for discussing water policy, by sharing data, by developing new physical—and social—infrastructure, we can create a new worldwide water diplomacy that treats this universal, vitally needed resource as an inspiration for cooperation rather than conflict.



The world's wet regions are getting wetter and its dry areas are getting drier much more quickly than previously thought, changes that threaten the availability of fresh water and create new risks to people's health, the food supply, and the environment.



The Water Cycle Is Broken, but We Can Fix It

By working with nature, rather than against it, we can replenish the world's water supply.

BY SANDRA POSTEL

When it comes to water, the past is no longer a good guide for the here-and-now, much less for the future.

In the spring of 2018, Cape Town, South Africa, narrowly escaped shutting off drinking water taps for its 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. At that point, residents would need to retrieve their rations of drinking water from one of 200 distribution stations around the metropolis.

Fortunately, nature bailed out Cape Town just in time. Stricter conservation measures combined with the purchase of agricultural water enabled the city to keep pushing Day Zero out—and then, luckily, the rains returned. But the scare was a wake-up call for mayors and utilities everywhere: When it comes to water, the past is no longer a good guide for the here-and-now, much less for the future.

Nothing is more critical to the success of a society than its ability to supply water where it is needed, when it is needed, and, on the flip side, to keep floodwaters at bay. History is studded with enterprising cultures that failed this basic challenge—from the Sumerians of ancient Mesopotamia, the first irrigation-based society, to the Hohokam of the American Southwest, which enjoyed a 1,000-year run in what is now central Arizona.

On the face of it, global society today would seem to have licked the water-security challenge. Some 58,000 large dams capture flood runoff, store water for later use, and allow engineers to turn major rivers on and off like plumbing works. Cities worldwide import the equivalent of 10 Colorado Rivers to meet their annual water needs; if positioned end to end, the canals and pipelines transporting that water would stretch halfway around the world. Huge pumps draw water from beneath the earth to irrigate crops that help feed the world. Indeed, it is hard to imagine our world of 7.6 billion people and $75 trillion in annual economic activity without this vast network of impressive water engineering.

Yet the command-and-control style of water management that took hold during the 20th century entails a Faustian bargain: While it has brought much of the world enormous prosperity, it has broken the water cycle—the natural storage and movement of water between the land, sea, and air that sustains life and is critical to that human prosperity. An unsettling number of large rivers—including the Colorado and Rio Grande in the U.S. Southwest, the Ganges and Indus in South Asia, the Amu Darya in central Asia, the Yellow in northern China, the Nile in northeastern Africa, and the Murray in southeastern Australia—are now so over-tapped that they drop to a trickle or dry up completely for long periods of time. Globally, dams and reservoirs now disrupt 48 percent of the volume of river flows, up from 5 percent in 1950. This flow disruption is a major reason freshwater vertebrate populations have declined by 83 percent since 1970. Dams have also trapped more than 100 billion tons of sediment that rivers would otherwise carry toward the sea to replenish deltas and sustain ecosystems critical to fisheries.

The depletion of groundwater—those hidden reserves beneath the earth—is now the sleeping tiger of global water risks. In many parts of the world, groundwater pumping exceeds recharge, causing water tables to drop and underground water reserves to shrink. Groundwater depletion is rampant across important food-producing regions of China, India, Pakistan, the Middle East, Mexico, and the United States. About one-tenth of global food production depends on the depletion of groundwater—a hidden water debt that threatens food security and agricultural economies.

The world's soils, another critical part of the water cycle, can theoretically hold eight times more water than all rivers combined. Yet the deep plowing and monoculture cropping methods employed by industrial agriculture have led to severe soil erosion and loss of organic matter, shrinking the natural soil reservoir. This means farmers have less resilience to dry spells. As Jerry Hatfield, director of the U.S. Department of Agriculture's National Laboratory for Agriculture and the Environment in Ames, Iowa, has put it: "We're losing 20 percent of our crop 80 percent of the time due to temporary water shortage."

WE CAN'T SOLVE PROBLEMS BY USING THE SAME KIND OF THINKING WE USED WHEN WE CREATED THEM.

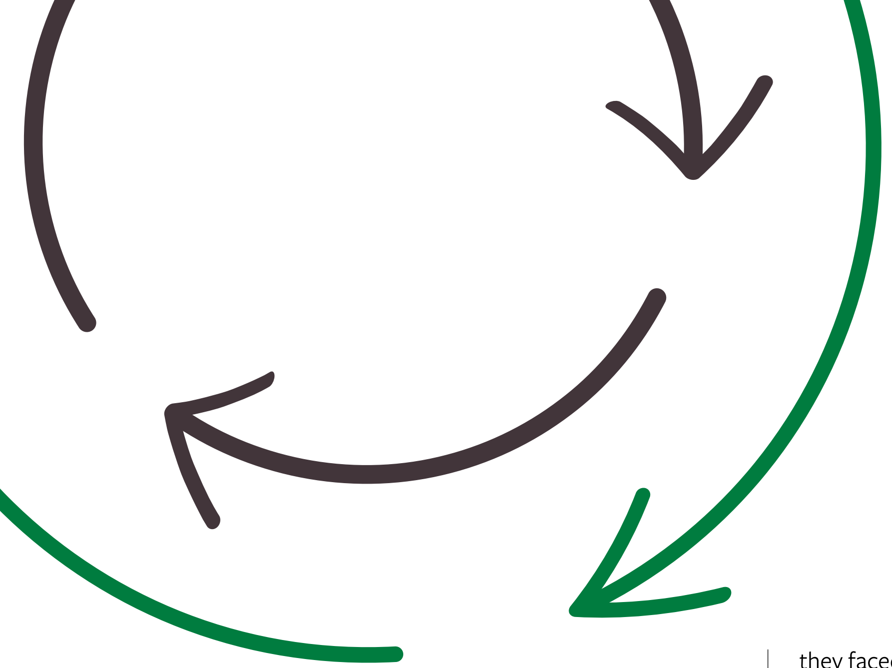
With more than half the world's wetlands sacrificed to development and cropland expansion, nature's way of capturing, storing, and purifying runoff has been lost in many locations. Besides worsening both floods and droughts, this wetland loss has allowed large quantities of nitrogen and phosphorus from farm fertilizers to drain directly into rivers and streams, which then carry these pollutants to the coasts. There, they fuel algal blooms that deplete oxygen levels as the algae decompose, threatening fish and other aquatic organisms. More than 400 dead zones now line the coasts, most in the Northern Hemisphere.

Virtually all of the consequences of this broken water cycle will worsen with climate change. As rainfall intensifies, flood damage will rise. As droughts worsen, river flows will further diminish. As wildfires burn hotter and spread farther, runoff filled with sediment and debris will threaten drinking water for communities downstream. These kinds of threats are not hypothetical: In 2017, the costs of U.S. climate- and weather-related disasters totaled a record-breaking $306 billion.

It's tempting to try to solve our water problems with bigger dams, deeper wells, and longer water transfers. But as Albert Einstein reminded us decades ago, "We can't solve problems by using the same kind of thinking we used when we created them." That means thinking differently about how we use, manage, and value water. And it means figuring out how to repair and replenish the water cycle even as we prosper. It's a tall order. But some pioneers are showing the way.

In the Verde Valley of Arizona, as in much of the western United States, farmers irrigate their fields much the way their late 19th-century predecessors did: They divert most of the flow from their local river into a ditch system that delivers water to their farmland. In the case of the Verde River, a tributary to the Colorado and a lifeline for migratory birds and wildlife in the American Southwest, those diversions often left five or more miles of the river nearly dry.

When tasked by The Nature Conservancy of Arizona with protecting this biological hotspot, hydrologist Kim Schonek worked closely with local irrigators to establish mutual trust and to search for a solution. The result was the installation of a solar-powered, automated head gate on the ditch system that enabled the irrigators to take just the water they needed while leaving the rest for the river. Parts of the Verde now have twice as much summertime flow as before. The result was a triple win: The irrigators got a system upgrade, the local community got a healthier river for recreation and tourism, and birds and wildlife got healthier habitat.



That success fostered other creative solutions—such as switching from flood to drip irrigation, and diverting water from different locations—to keep the Verde flowing. One entrepreneurial conservationist motivated farmers to plant barley, which requires less summertime irrigation than many other crops, by building a local barley malting facility that supplies Arizona craft breweries.

As a result, the Verde River has become a model for smarter water management. But it took collaboration, not only between farmers and conservationists, but also with corporations wishing to invest in a healthier river. Some half a dozen companies with operations in the greater Phoenix area—including Coca-Cola, Intel, and REI—have invested in projects to keep the Verde flowing in order to enhance water security, ensure good recreational opportunities for their employees, and advance water stewardship by returning some water to the environment.

In nature, the saying goes, there is no waste.

Six years into the record-breaking Millennium Drought that hit much of Australia between 1996 and 2010, the managers of the Pennant Hills Golf Club near Sydney took this sentiment to heart. With reservoirs around the city at record low levels, they faced the prospect of dramatic water cutbacks that could turn their beloved greens to ugly browns. So club managers took an unusual step: They requested permission to tap into the sewer line that ran beneath the golf course, treat the sewage on-site, and use it to irrigate the greens.

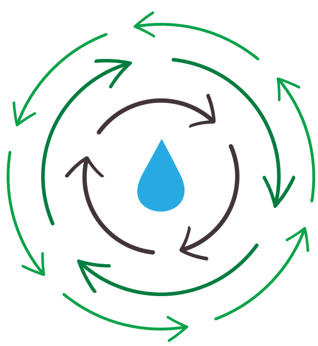
Despite its yucky name, “sewer mining,” as the Aussies call it, is catching on, not only in Australia but around the world. It’s a way of closing the urban water loop and taking the waste out of wastewater. The pipe beneath Pennant Hills runs to the coast, where the sewage gets only basic treatment before being dumped into the Pacific Ocean. So the golf club not only decreased its potable water use by 92 percent, it reduced pollutants headed to the sea.

In contrast to conventional wastewater reuse projects, which typically collect urban wastewater and send it some distance to a large treatment plant, sewer mining is decentralized and localized, which saves energy as well as water. Stuart White, director of the Institute for Sustainable Futures at the University of Technology Sydney, sees “small-scale, modular, localized wastewater treatment” as a core element of the next generation of water infrastructure.

The Pennant Hills system involves a membrane bioreactor that treats the waste biologically and then sends the resulting product through a membrane that blocks all but the partially treated sewage. The sludge, about 2 percent of the original sewage, returns to the sewer while the treated wastewater is disinfected and sprinkled onto the gardens and greens.

Although the membrane bioreactor process has been in use for several decades, its costs and energy requirements have come down substantially in recent years. It is now treating wastewater for reuse in an apartment complex in the Battery Park neighborhood of New York City, in a mixed-use development in Victoria, British Columbia, and a high-end community in Fulton County, Georgia, to name a few.

As water supplies tighten and droughts and floods worsen, many cities are embracing a concept known as One Water—a more holistic approach to the planning and management of water supply, wastewater, and stormwater. China, for example, has launched a "sponge cities" initiative that aims to turn stormwater from a nuisance into an asset. Over the past 35 years, Chinese cities have more



than tripled in number, and the nation's urban landscape has grown by 15,400 square miles—equal to 327 times the area of San Francisco. As a result, vast areas of impermeable roads, buildings, and parking lots now sit where lakes, wetlands, and woodlands once were. So instead of stormwater soaking into the earth, it now floods streets and communities—a problem common to many of the world's cities and towns.

In 2013, when severe flooding hit some 230 Chinese cities, President Xi Jinping announced that cities should act more like sponges, absorbing rainwater instead of allowing it to surge down streets and sidewalks. Within two years the government had selected pilot sites in 16 cities, including Beijing, Guangzhou, Shanghai, and Wuhan. The goal, an ambitious one, is to have 20 percent of each pilot city meeting sponge-city standards by 2020.

Outside of China, the adoption of green infrastructure to repair the urban water cycle is rapidly catching on, as well. In the U.S., Philadelphia plans to invest some $2 billion in rain gardens, tree trenches, wetlands, permeable pavement, vegetated swales, and other projects that encourage rainfall to infiltrate rather than run off the cityscape. The city hopes to reduce storm-related sewer overflows by 85 percent within 25 years. Green infrastructure is also a major component of Los Angeles' effort to reduce its long-distance water imports by half by 2035. Engineering professor Richard Luthy of Stanford University estimates that by that time, the retention and underground storage of stormwater could meet 14 to 28 percent of the city's water needs.

While big dams and desalination plants are flashier solutions to water shortage, conservation and efficiency measures remain the most cost-effective and environmentally sound ways to meet new water demands—and they are far from tapped out. In the United States, domestic water use per person fell 18 percent between 2000 and 2015, and will continue to fall. The major reason is the 1992 passage of national water efficiency standards that required plumbing manufacturers to reduce the volume of water used by toilets, urinals, faucets, and showerheads. These requirements effectively built conservation into new and remodeled homes and buildings and are now saving the nation 7 billion gallons per day, according to water conservation engineer Amy Vickers, who wrote the efficiency standards. That's equivalent to seven times the daily water use of New York City.

With the addition of efficiency standards for clothes washers and dishwashers, along with the 2006 launch of the Environmental Protection Agency's WaterSense, a voluntary labeling program that helps consumers choose water-efficient appliances, the savings continue to grow. In the coming decades, researchers expect indoor water use per person to drop an additional 37 percent or more. In residential areas, the new conservation frontier is outdoors, since watering grass and landscaping often accounts for half or more of home water use. Many utilities, especially in the drier west, offer incentives for homeowners and businesses to shift away from thirsty grasses toward native, drought-tolerant plants.

As water supplies tighten and droughts and floods worsen, many cities are embracing a concept known as One Water—a more holistic approach to the planning and management of water supply, wastewater, and stormwater.

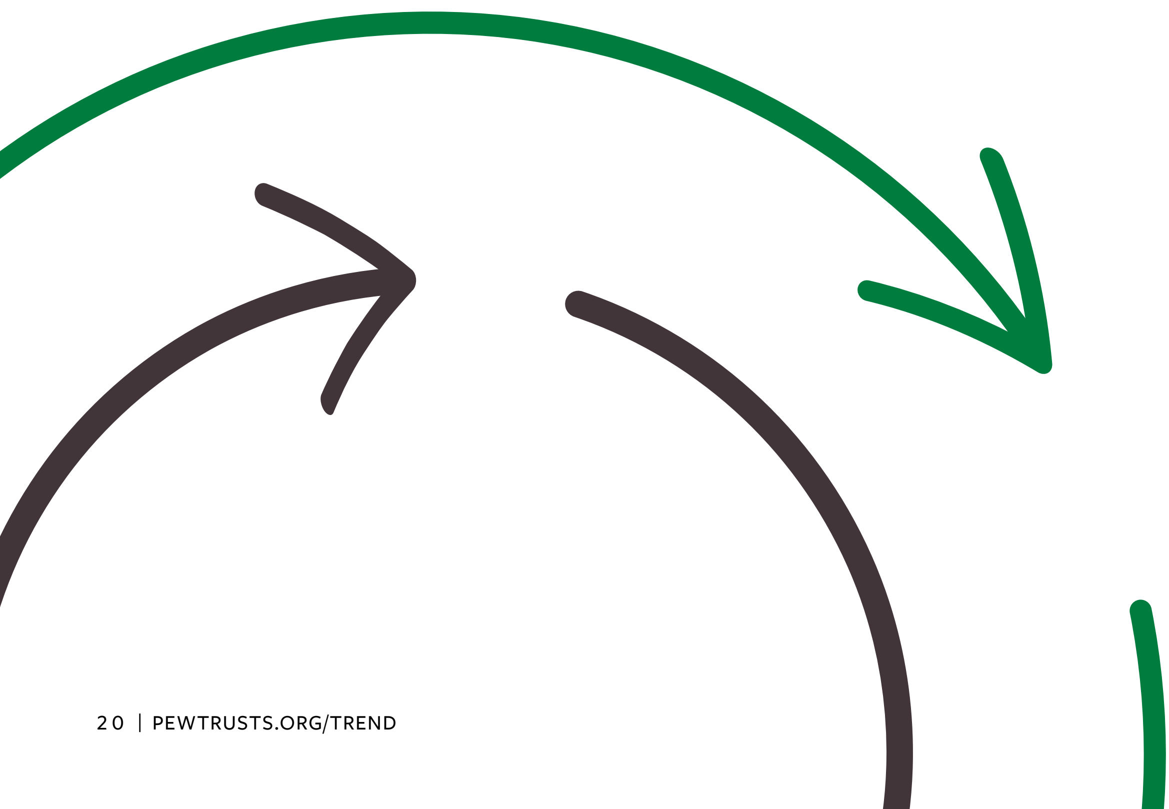
With agriculture accounting for 70 percent of global water use, improving nutritional value per drop is critical to feeding the world while repairing the water cycle. Healthier soils with higher carbon content are capable of storing more moisture, reducing the need for irrigation and building resilience to drought. Rain-fed croplands in particular can benefit from the planting of cover crops that improve soil health and hold soil in place. Only about 3 percent of the nation's farmland has cover crops now, suggesting a big window of opportunity.

In the southeastern United States, where rivers and streams are home to some of the most biologically diverse fish and mussel populations, researchers are partnering with farmers to test smarter irrigation systems that tailor water delivery to actual field conditions.

In the lower Flint River Basin of southwestern Georgia, for example, heavy groundwater pumping to irrigate cotton and peanuts depletes the base flows of rivers and streams, jeopardizing threatened mussel populations. Researchers are trying variable rate irrigation, which involves programming a center pivot sprinkler equipped with a GPS system to stop spraying when it passes over a rocky section, a wetland, or any area not growing crops. That alone can often reduce water use by 15 percent. Adding soil moisture sensors to the field and setting the sprinkler to deliver only as much water as the crops actually need also boost savings. Experiments at cotton and peanut farms by University of Georgia researchers have found that these systems can increase water productivity—crop per drop—by as much as 40 percent.

Fixing the water cycle requires scaling up these promising methods, which in turn requires economic incentives and support. Government policies that incentivize more sustainable agriculture could make a big difference, as could better zoning and land-use planning that conserve and restore floodplains and wetlands. Many businesses support these efforts because they recognize that a secure water supply is critical to their bottom lines. General Mills, for example, is supporting restoration projects in watersheds where its facilities are located and investing $3.2 million to improve the health of soils on farms in its supply chain. Coca-Cola partners with conservation organizations to restore depleted rivers and wetlands to balance the water used in making its beverages.

All of this shows that our broken water cycle can be fixed if we change our thinking and encourage these new methods. The 20th century was the age of dams, diversions, and depletion, but the 21st century can be the age of replenishment, the time when we apply our ingenuity to working with nature rather than against it. With droughts, floods, and wildfires poised to worsen and spread, investing in a healthier water cycle may be the best insurance policy money can buy.



THE TAKEAWAY

A century of water management by dams, pipes, and pumps has upended the natural movement and storage of water between the land, sea, and air that sustains life and human prosperity—and now requires new thinking.

GROUNDWATER:

THE RESOURCE WE CAN'T SEE, BUT INCREASINGLY RELY UPON

BY GRAHAM E. FOGG

We are pumping groundwater from many aquifers at unsustainable rates, but thanks to new technologies, we can now make these hidden reservoirs more visible and manage them more effectively than ever before.

People have used groundwater for thousands of years, especially in arid regions such as the Middle East and North Africa, where hand-dug wells and subsurface tunnel systems collected and diverted it for early societies. These ancient methods amounted to skimming the shallow groundwater off the top of massive aquifer systems—the vast stores of invisible groundwater beneath the continents that account for more than 95 percent of all circulating fresh water on Earth.

That early skimming was limited by the primitive know-how of the time. But beginning in the 19th century, technological developments were opening our access to groundwater as advancements in drilling for extracting petroleum were spun off and developed for the water well industry. Still, even into the 1940s, most pumping reached only shallow depths of less than 30 feet, removing water at modest rates. That changed radically after World War II, when more sophisticated pumping technology, as well as the cheap, petroleum-based energy to power it, came to the fore. Soon we were pumping so much water from aquifers that we were beginning to "overdraft" them—taking out more than could be replenished at sustainable rates. Today, a little more than a half-century later, the world gets about 35 percent of its fresh water this way, making it a sizable—and quite new—development in world history.

This new availability of water, especially in arid regions, together with the advent of relatively cheap chemical fertilizers, has helped fuel the Green Revolution, increasing agricultural production around the globe, especially in the developing world. But it has come with a cost that cannot be sustained without new ways of managing our water resources.

Think about it this way: All your money is in two bank accounts—accounts A and B. You know what your balance, deposits, and withdrawals are in Account A. But you don't know much about Account B—except that when A gets depleted, large amounts of cash are withdrawn from B. Even if B has lots of money and you don't immediately feel the impact, it's hardly the path to financial security. But that's how civilization has been managing water—Account A representing surface water and B, groundwater. And because of the vast volume of groundwater beneath the continents, we didn't always notice the impact and correct our mismanagement. Now we have entered an era of scarcity as a growing world population is increasing demand and creating a drain on groundwater in aquifers across many regions, including the United States, China, India, the Middle East, and Australia.

There were clues we were making mistakes, but too often water users and managers didn't know enough about the consequences of their overexploitation to connect cause and effect. Just as accelerated pumping is a relatively new development in human history, the science of groundwater and how to manage it—known as hydrogeology or groundwater hydrology—is even more recent, beginning to mature in the past 20 to 30 years. For example, in California's Central Valley, which contains one of North America's largest aquifers, intensive pumping in the mid-20th century dried up massive wetlands that once covered 20 percent of the area. But most water managers didn't yet understand the connection between groundwater and surface water and didn't attribute the disappearance of wetlands to the pumping.

Despite the vast volume of fresh groundwater on Earth, we can pump only a relatively small fraction of it before overdraft occurs and the subsequent problems arise, even if they may not seem immediately alarming or connected to the pumping. Groundwater overdraft almost always causes groundwater level declines and surface water depletion, and sometimes leads to degradation of groundwater quality and land subsidence.

It may take decades for these changes to become obvious and even longer for an aquifer's "tank" to become empty. It has taken some 70 years of steady, unsustainable pumping for portions of the Ogallala Aquifer under the Great Plains to become nearly desiccated.

But we are learning the errors of our ways and are slowly starting to change our practices.

In California, which has seen the harsh consequences of overpumping exacerbated by climate change in recent years, proactive groundwater regulation is being enacted. These initiatives—together with earlier regulatory efforts by other states and countries, including Australia—mark a change in how we think about groundwater, treating it less like an extractive resource, which we pump limitlessly and hope for the best, to one that is managed and replenishable. This approach employs science-based methods, many of them relatively new, to determine how to bring groundwater basins into balance by reducing the pumping, increasing recharge, or both.

What has become known as managed aquifer recharge involves diverting alternative sources of water—usually surface water, including storm flows, or treated urban wastewater—onto land where the water can be infiltrated in ponds or injected into wells. Studies by the University of California and the California Department of Water Resources indicate that recharge can be increased enough to eliminate overdraft in some aquifers. But research from the Public Policy Institute of California cautions that in other places it will require large reductions in pumping and with it significant changes in land and water use.

Still another potential recharge idea involves crop irrigation. An unintended consequence of irrigating crops above many aquifer systems has been the substantial increase in recharge. This is because just 50 to 90 percent of irrigation water is typically consumed by the crop; most of the rest soaks downward to recharge the groundwater supply. Studies by the University of California, Davis have shown that diverting high river flows onto

It has taken some 70 years of steady, unsustainable pumping for portions of the Ogallala Aquifer under the Great Plains to become nearly desiccated.

farmland in winter, when fields are fallow, may substantially increase recharge.

But these efforts are not enough by themselves. Throughout the world, the consequences of decades of high pumping rates necessitate new approaches to manage groundwater, which unlike surface water is difficult to observe and measure. Fortunately, development of new hydrologic technologies is showing the way.

By gathering data from water wells, along with geological and geophysical measurements, we can apply our knowledge of physics and the chemistry of water as it moves underground to determine flow rates and directions. This allows hydrogeologists to create mathematical models to determine what we cannot see: changes in the amount of water underground and the impact our management of pumping and recharges is having so we can avoid overdrafts.

Just as importantly, our ability to do this has improved dramatically in the last 20 to 30 years thanks to technological advancements. While we have been able to monitor individual wells for decades, new and relatively easy-to-deploy wireless sensor networks now allow us to monitor groundwater levels across a groundwater basin in real time nearly as easily as we can a surface reservoir. As articulated recently by NASA and the National Research Council, this, along with improved satellite monitoring and analyses of groundwater storage, can provide us with more knowledge of these underground reservoirs than we've ever had before.

Now that scientific developments make it much more feasible to manage groundwater nearly as intuitively and transparently as we do surface water, we can embark on a new phase of groundwater development in which we devote as much effort to recharging aquifers as we do to pumping from them.

This is true not only for more developed countries but also for the rest of the world. The worldwide problem with overdrafted aquifers exists because those with the best technology for pumping exported it while doing little to expand new, innovative management methods for groundwater. The biggest challenge will be to export and help deploy those methods globally.

These improved methods of monitoring groundwater, as well as advancements in surface water monitoring, will help us develop more accurate and reliable models of the entire water system—giving us the big picture that will help avoid overdrafting aquifers. But key to that is ensuring an integrated approach to managing groundwater and surface water—those two "bank accounts" that are essential to maintain as we enter this looming time of water scarcity. We must be creative. For example, we can turn the negative of overdrafted aquifers into a positive by using them for underground water storage. In California, where every major river has been dammed, the available space for underground storage of water in the Central Valley is about three times greater than the total surface reservoir capacity in the entire state. More capacity is literally just below our feet.

This integrated approach will require some new thinking and planning on our part. Until now, for example, surface water reservoirs have primarily been operated with the objectives of maximizing water storage, generating hydropower, and providing flood control. To jointly manage surface water and groundwater means we must think of the total watershed storage and the infrastructure requirements, such as conveyance canals to move water where it is needed not just for immediate use but for aquifer replenishment.

It may be a challenge to determine where the water will be found to accomplish the recharge our aquifers require, but some promising potential sources include the alternative management of river flood flows where it can be accomplished wisely, the redistribution of some surface reservoir stores to the groundwater systems, and of course conservation and water reuse. While the recent decades of water resources management have been influenced by groundwater overexploitation, we are facing a dynamic transition in which important changes are in store. If we keep working on modern groundwater regulatory initiatives, apply the right technologies, develop water conveyance infrastructure, and work to replenish aquifer systems, the future for water could be very different from the past.

THE TAKEAWAY

We must employ new technologies and devote as much effort to recharging aquifers as we do to pumping from them while also managing groundwater and surface water as an integrated system.

HOW DEVELOPMENT OF AMERICA'S WATER INFRASTRUCTURE HAS LURCHED THROUGH HISTORY

And why we may be at another key turning point in the safety of public water

BY DAVID SEDLAK

Throughout history as cities grew, new water infrastructure was built to supply this vital resource to increasing numbers of people. Initially, urban dwellers carried water from hand-dug wells and lakes and streams that ran through the city. As cities advanced, engineers built aqueducts and canals to import water from great distances. Among the engineering marvels of the ancient world, the Roman water system of elevated aqueducts, underground piping, and the world's first sewer network is an iconic example of the ingenuity that made possible Europe's first city of a million people.

Modern water systems owe a lot to the Roman innovations from 2,000 years ago. But instead of celebrating the technology that has allowed millions of people to survive in places where the local water supply is limited, we hide our water infrastructure underground and go about our daily lives oblivious to these lifelines. Today, we talk about urban water systems only when they fail. And therein lies our current problem: Much of the water infrastructure in the United States, Western Europe, and many other places is aging and in serious need of replacement or upgrading, especially to address the effects of a changing climate and new generation of man-made contaminants.

Due to our complacency, only a serious crisis that could leave people without access to tap water is likely to free up the financial resources needed to bring water infrastructure—which in many places still includes pipes from the 1800s—into the 21st century. Absent an emergency, cash-strapped water utility managers will continue to deal with aging water systems by economizing on routine maintenance and deferring upgrades for as long as possible. This chronic funding shortage is so dire that the American Society of Civil Engineers has awarded the drinking water infrastructure of the United States grades of D-minus or D for over a decade.

Our reluctance to invest means that we allow our water systems to deteriorate until they nearly fail and invest in them only after the public decides that the status quo is unacceptable. Our water systems' shortcomings were brought to the public's attention by Flint, Michigan's, recent experience. But it doesn't end there: Water systems are teetering on the edge of viability in numerous cities. We have seen this pattern before—and the present-day warning for us all is that the past is often prologue.

As the United States grew during the 1800s, it transformed from an agrarian nation to an industrialized one as populations increased and built drinking water infrastructure on a grand scale. But these developments had less to do with real planning than with reacting to crises. The first crisis occurred when the rapid population growth overwhelmed the water infrastructure of the period—typically shallow wells or small reservoirs located within the city—leaving it unable to provide sufficient quantities of drinking water.

The clearest example of this was in New York, where the population more than tripled, from about 60,000 people to more than 200,000 people, between 1800 and 1830. After decades of denial by city leaders during which the wealthy drank water provided by the Manhattan Water Co. (the predecessor of Chase Bank) while the poor drank well water of dubious quality, New York's leaders invested $9 million (about $850 per person in today's dollars) to import water to the city using a system of canals, pipes, and reservoirs situated about 40 miles to the north.

Building upon this early success, New Yorkers spent another $177 million (about $500 per person today) to expand their water system out another 60 miles in search of more clean water as the city grew in the subsequent decades. This pattern of population growth outstripping the capacity of local water supplies, followed by investments of hundreds of dollars per person to import water from great distances, also took place in Boston, Washington, Philadelphia, and other cities during this period. The periodic crises of growing East Coast cities taught the young country some valuable lessons. The technological know-how gained from the construction of dams and reservoirs helped our nation's westward migration that began several decades later when leaders of Seattle, San Francisco, and Los Angeles were able to build massive imported water systems before their cities reached a state of crisis.

MUCH OF THE WATER INFRASTRUCTURE IN THE UNITED STATES, WESTERN EUROPE, AND MANY OTHER PLACES IS AGING AND IN SERIOUS NEED OF REPLACEMENT OR UPGRADING

These solutions to the nation's first water crisis, though, spawned its second one. Once city dwellers had access to large quantities of water, per capita water consumption increased as they indulged in stay-at-home baths and replaced their outhouses with indoor toilets. The sewage produced by city dwellers flowed to the nearest rivers, which often served as the drinking water supply for the next downstream city. By the late 19th century, typhoid fever and other waterborne diseases had increased to epidemic levels.

The new challenge was to develop treatment plants that could make sewage-contaminated waters safe to drink. By the early 1900s, billions of dollars had been invested in the new technology of drinking water treatment. The corresponding decrease in waterborne disease and lengthened life spans resulting from these advances has been hailed as one of the top five technological achievements of the 20th century by the National Academy of Sciences. Thanks to water filtration and chlorination, the second water crisis was averted.

America's third water crisis occurred as cities again grew during the economic expansion that followed World War II. As people migrated to urban areas, the increased volume of wastewater they produced overwhelmed the assimilative capacity of the nation's rivers, lakes, and estuaries, which had purified the modest amount of pollution that they had received in the previous years. For the next 25 years, foul smells emanated from urban waterways, dead fish washed up on shorelines, and runaway algal blooms became the norm in lakes. Water pollution was a nuisance, but city leaders lacked the will to tax their constituents to build sewage treatment infrastructure that might benefit downstream communities more than their own—and the state of the nation's waterways further deteriorated until the early 1970s. It was only then that the nation, fed up with water pollution, came to support the Clean Water Act—a federal law that established requirements for sewage treatment. The federal government provided cities with grants and low-interest loans to upgrade their inadequate sewage infrastructure. During the two decades ending in 1992, the federal government invested over $60 billion (about $700 per person today) to again make America's waterways fishable and swimmable.

As these investments in sewage treatment improved the environment, cities continued their struggle to keep up with the demand of growing populations. In addition to building more imported water systems, they turned their attention to conservation and passed laws that required low-flow fixtures and less thirsty landscaping in new housing developments.

But as we soon enter the third decade of the 21st century, two potential crises are again poised to threaten our ability to keep up with thirsty American cities: continued demand and the growing perception by residents of some communities that their tap water is no longer safe to drink.

The availability of water has continued to be an issue as population growth has driven demand. But what is complicating things more than before are climate change-induced shifts in precipitation patterns and a greater recognition that taking too much water from rivers and streams damages aquatic ecosystems. This means that the old model of piping water in from long distances is no longer attractive. For example, the water level in the massive dams on the Colorado River, which supplies some of the drinking water to about 10 percent of the nation's population, has been falling since 2000 due to climactic shifts and increasing demand from cities and farmers. The imminent declaration by the Colorado River's managers of a shortage means that water is about to get more expensive, and water rights lawyers will become more plentiful in cities throughout the Southwest as legal disputes increase. Recent droughts of historic duration and intensity from Texas to California also have contributed to a sense that action is needed to enhance water security—that simple notion of having enough available, clean water to meet society's needs. Atlanta, Tampa, Florida, and Charlotte, North Carolina, are worrying about the security of their existing water supplies because their populations are approaching a point where local water sources will no longer be sufficient, especially during dry years.

Some communities facing water shortages have begun to think ahead by investing in new strategies for decreasing their reliance on imported water. This movement, which is sometimes referred to as water self-sufficiency, is furthest advanced in Southern California, where water has long been a scarce resource. The 2.5 million people of Orange County now recycle nearly all of their wastewater, passing it through an advanced treatment plant and returning it to the aquifer from which they draw their drinking water. The county currently satisfies 75 percent of its drinking water needs by combining water from wastewater recycling with groundwater recharged with rainwater that falls within the city and water from an effluent-laden stream that bisects the county. If the remaining 25 percent of the region's imported water supply becomes too expensive or unreliable, the county could meet its water needs by building seawater desalination plants, just as its neighbors to the south, in San Diego, and to the north, in Santa Barbara, did in response to their water scarcity concerns.

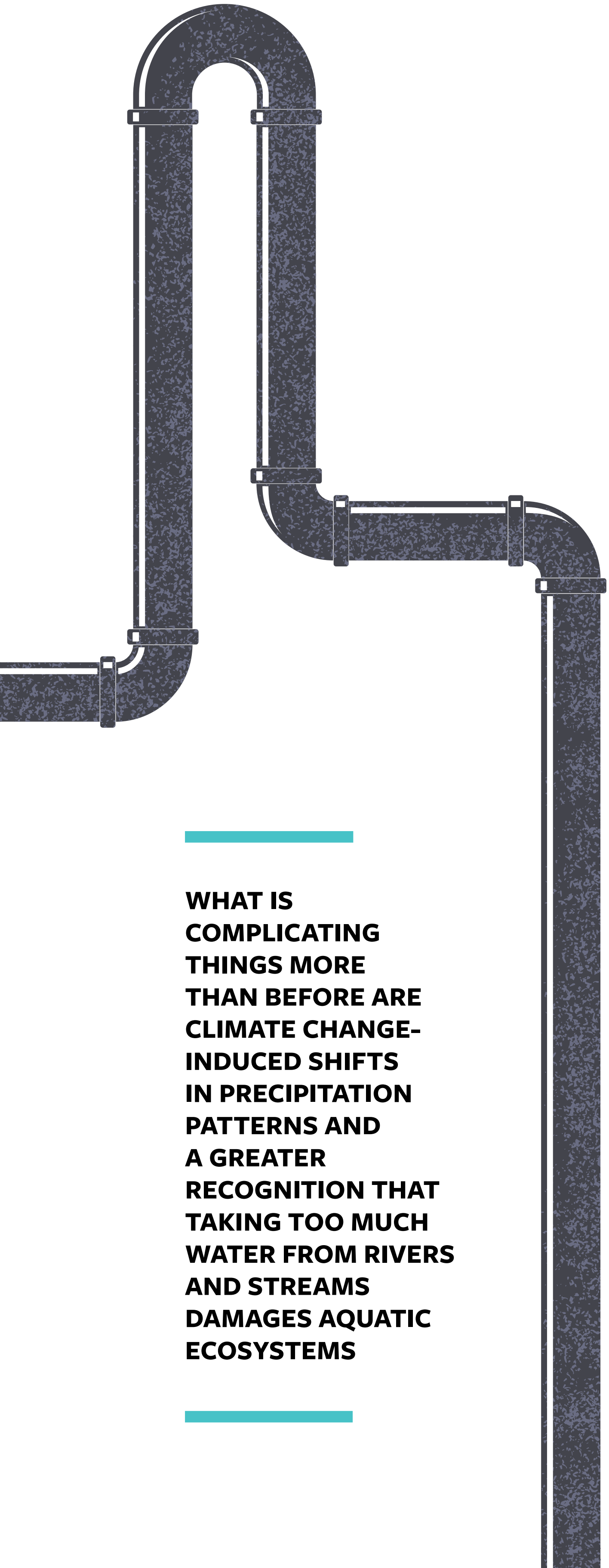
Elsewhere, the drive toward water self-sufficiency has taken a different form, shaped by local geography and geology. In California's Salinas Valley, technologies similar to those used to recycle wastewater in Orange County are being repurposed to create drinking water from a mixture of municipal wastewater effluent, runoff from city streets and farm fields, and wash water from food processing plants.

On the East Coast, in eastern Virginia, the local utility is treating wastewater with advanced technologies before using it to recharge the local drinking water aquifer. The project makes sense in that relatively wet part of the country because it eliminates the discharge of nutrient-rich wastewater to the ecologically sensitive Chesapeake Bay and counteracts land subsidence that has made the region increasingly vulnerable to flooding from rising sea levels.

The second potential water crisis is related to a growing public perception that tap water is no longer safe to drink. The failure of the municipal water system in Flint to properly manage its aging pipe network, which contaminated the water supply with lead and *Legionella* bacteria, was national news a few years ago. More recently, the discovery that chemicals used for firefighting and industrial manufacturing—the per- and polyfluoroalkyl substances referred to as PFAS—have contaminated water supplies for about a quarter of the nation has further highlighted the vulnerability of drinking water systems to man-made pollutants.

Most important, this discovery raises a significant new issue: Can our old water filtration and disinfection plants protect public health? Simply retrofitting treatment plants in places where water supplies are

LENGTHENED LIFE SPANS RESULTING FROM DRINKING WATER TREATMENT HAS BEEN HAILED AS ONE OF THE TOP FIVE TECHNOLOGICAL ACHIEVEMENTS OF THE 20TH CENTURY



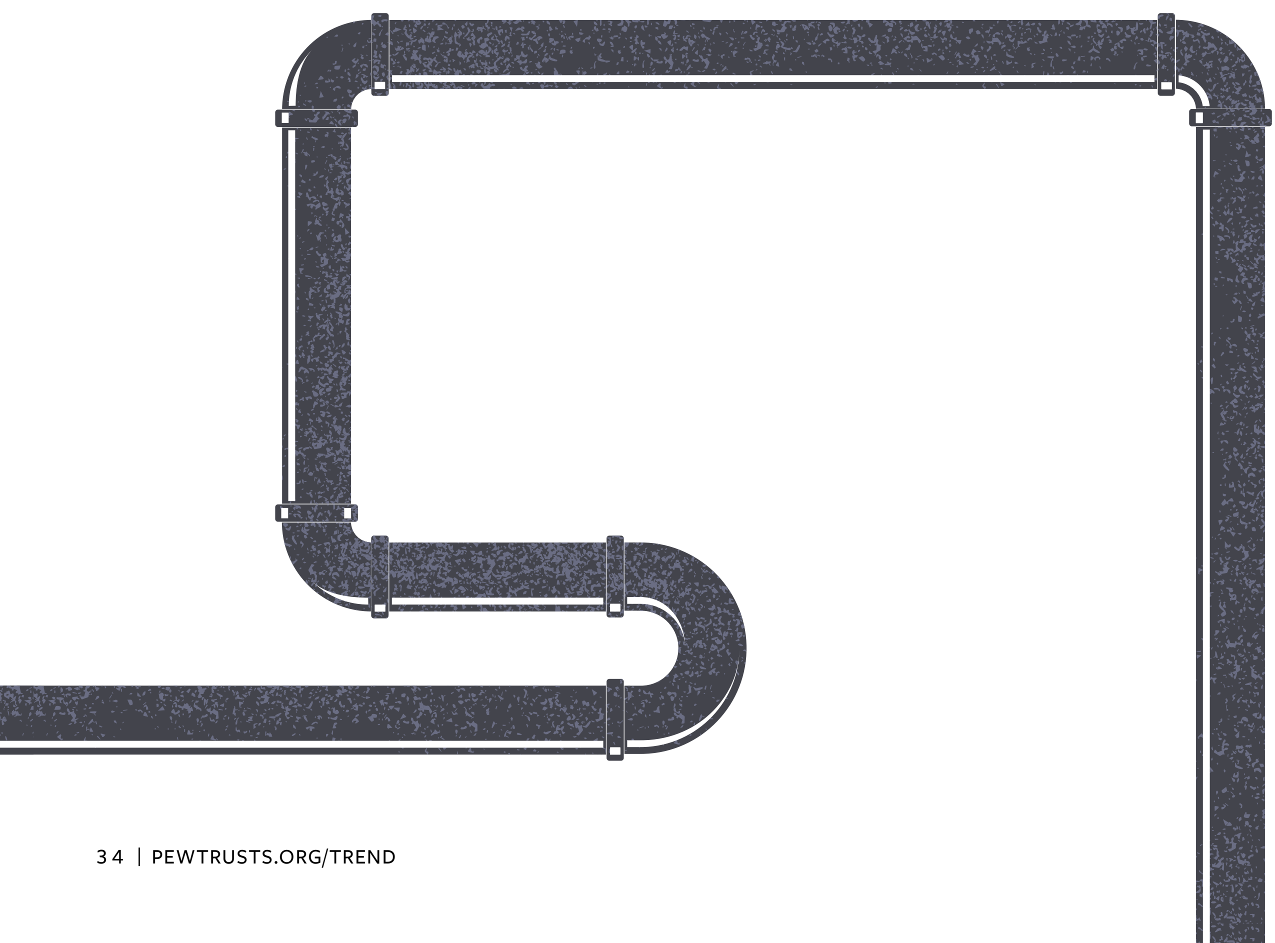
WHAT IS COMPLICATING THINGS MORE THAN BEFORE ARE CLIMATE CHANGE-INDUCED SHIFTS IN PRECIPITATION PATTERNS AND A GREATER RECOGNITION THAT TAKING TOO MUCH WATER FROM RIVERS AND STREAMS DAMAGES AQUATIC ECOSYSTEMS

known to be contaminated and banning difficult-to-treat chemicals like PFAS will not protect us from the coming quality challenges. Evidence of the systemic shortcomings of the existing drinking water system are apparent a short drive south of Flint, in Toledo, Ohio, where continued release of nutrients from farms, wastewater treatment plants, and city streets, coupled with warmer temperatures in the Great Lakes, resulted in blooms of toxic algae that made tap water unsafe for several days in 2014. The exact cause of more recent toxic algal blooms that have occurred in Florida, Oregon, Ohio, and other parts of the country is unclear, but most experts suspect that nutrients that are legally released from farms and cities are the main culprit. Simply put, our aging drinking water systems are not ready for the less forgiving future that will prevail in an era of climate change and inadequate pollution regulations.

Considering the way that change has come about in the past, it seems likely that the nation will have to weather a few more high-profile drinking water contamination incidents before public opinion forces action. When change does come about, it would be useful if the means of evolving our water systems were ready to be deployed. Using the water self-sufficiency movement as a starting point, it may be possible to rapidly adapt existing infrastructure. For example, the reverse osmosis technology used to make municipal wastewater effluent and seawater safe to drink by forcing water through a membrane that captures salts, microbes, and chemicals could be repurposed to remove PFAS and algal toxins from water supplies. With a little more development, emerging technologies that have yet to be deployed at scale, such as energy-efficient LED water disinfection lamps and treatment systems that use electricity instead of difficult-to-manage chemicals to decontaminate water, could provide new approaches for solving water-quality problems. Although advanced treatment technologies will not solve all of the problems related to decaying water pipes, aging dams, and inadequate treatment plants, they may create the means to move away from our historic reliance on massive infrastructure projects that have become too expensive to properly maintain.

For example, point-of-entry water filters that purify only the water that comes into the kitchen and building-scale water recycling systems that clean up any contaminants that entered the water within the underground pipe network could reduce costs by allowing water used outdoors for cleaning and irrigation to be treated less stringently than drinking water. Additional savings could be realized by investments in underutilized technologies that prevent treated water from escaping from aging water pipes between the treatment plant and the user.

Given these needs, our nation's water systems are on the cusp of a once-in-a-generation change involving costs that could reach $100 billion. Whether the change is preceded by crises that compromise public health and damage local economies will depend upon the investments that are made over the next few years. Federal agencies, including the National Science Foundation and the Department of Energy, along with water-stressed cities in Southern California and Texas, have begun to invest in the research and development needed to adapt urban water infrastructure to a future with greater water scarcity and increasing threats to water quality. Elected officials and community leaders now must recognize that they have an important role to play in reforming the institutions, regulations, and financial policies that impede systemic change. Our history of crisis and response will likely continue, but the more we can anticipate and plan, the better the chance that we'll have the safe water we all need in a less forgiving future.



THE TAKEAWAY

Our aging drinking water systems are not ready for a less forgiving future of climate change and inadequate pollution regulations, and it is likely that the nation will have to weather more high-profile drinking water contamination incidents before public opinion forces action.

Sometimes Water Should Be Left Where It Is

BY TOM DILLON

Throughout history, we've altered the flow of rivers and streams. But now we're learning that water often serves both a local and a global purpose right where it is.

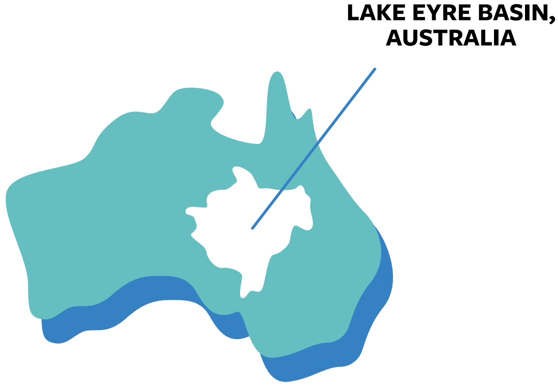
In March 2018, torrential rains poured over the Australian Outback in the state of Queensland. The water pooled and began dispersing into rivulets for a long march to the Lake Eyre basin, which bottoms out 50 feet below sea level—the lowest point in the country. Over the course of weeks, the runoff filled innumerable channels that in turn fed into three river basins—the Georgina, Diamantina, and Cooper Creek—and advanced toward Lake Eyre like one massive aquatic organism, transforming a sweltering and inhospitable landscape into one alive with plants, wildlife, and birdsong.

These floods occur on no set schedule; the waters might come annually for a time, but five years can pass between deluges. During long droughts, life there relies on waterholes that are left behind from flooding as well as on spring-fed oases that sustain fish, turtles, shrimp, and birds, and that offer drinking water to other animals.

Remarkably, millions of water birds somehow know when these rains and floods arrive, and they come, more than 80 species of them, from as far as the Asian continent. This transformation of dry desert into green, lush landscape is dramatic, almost magical—and perfectly normal.

We rightly fear floodwaters in many places on the globe, but in this area of nearly 20,000 square miles of Australia's Channel Country, along with a few other areas of the world, such as the Pantanal in Brazil and the Okavango Delta in Botswana, heavy rains such as this cause a massive natural change that illustrates the power, necessity, and the very existential nature of fresh water when it is undisturbed. Unlike most of the world's river systems, which flow to the sea, these all flow inland, creating unique ecosystems and exerting influence on the global climate in ways we are only beginning to understand.

This natural flow of water lies in contrast to much of what present-day water management entails. Around the world, as civilization has developed, people have needed fresh water for drinking and growing crops and, as history progressed, for manufacturing and other sophisticated uses. We have diverted creeks, streams, and rivers, often forgetting the natural world these waters fostered. There are harrowing lessons to be learned when shifting water ecosystems to other purposes.



THIS TRANSFORMATION OF DRY DESERT INTO GREEN, LUSH LANDSCAPE IS DRAMATIC, ALMOST MAGICAL—AND PERFECTLY NORMAL.

The Aral Sea, on the Kazak-Uzbek border, is a case study of how diversion can lead to depletion. For most of human history, it was fed by the Amu Darya and Syr Darya, rivers that together flowed through six countries. Once the fourth-largest lake in the world, the Aral Sea sustained a rich fishery that yielded 48,000 tons of catch at its peak and supported numerous shoreline communities.

But in the 1940s, all of that began to deteriorate when the Soviet government ordered the diversion of both rivers to irrigate the surrounding desert in a bid to boost a burgeoning cotton-growing industry.

That strategy had numerous flaws, outside of the obvious perils of trying to re-engineer nature. One was that most of the water diverted from the sea never made it to the cotton-growing areas, a crop that requires large amounts of water. Because the canal carrying it was unlined, as much as 75 percent of the water mostly just soaked into the surrounding desert.

Another issue came when water levels in the Aral Sea began to drop and the salinity dramatically rose, as the natural cycle of rains, floods, and evaporation was disrupted. That increase in salt made the water less usable and also accelerated evaporation.

By 1998, the level of the sea had dropped by 65 feet and the volume had decreased to 50 cubic miles from 255 cubic miles in 1960, according to a Columbia University study. This change destroyed the local fishing industry—catch dropped from 48,000 tons in 1960 to zero by the early 1980s.

The other significant impact from diverting the two rivers was less visible initially, but we've now come to see it clearly. The shallower, saltier sea warmed up more quickly in summer and cooled more quickly in winter, triggering a shift in climate cycles in the region and a drop in sea-ice cover in winter. This meant saltier soil, prompting farmers to use more fertilizer, which in turn further degraded the land. Plants and wildlife died in droves. One study concluded that 23,166 square miles of agricultural land had been destroyed. Today, dust and salt storms up to 200 miles wide occur frequently, and often deposit particles hundreds of miles away, damaging soil far from the region.

We're also coming to see how the desiccated Aral Sea is contributing to intensified climate change. When the sea had normal levels of water, it both tempered Siberian winds in winter and cooled the region in summer. Now, the area has shorter, hotter summers and longer, colder winters, along with less precipitation—a combination of factors that could be accelerating the melting of glaciers in the Tien Shan, Pamir, and Hindu Kush mountains, nearly 1,000 miles away, according to that Columbia University study.

UNRESTRAINED ALTERING OF NATURAL WATER SYSTEMS CAN HAVE LASTING AND WIDESPREAD IMPACT.

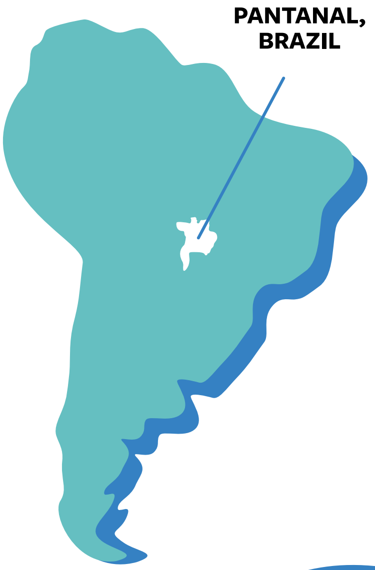
The lessons of the Aral Sea were learned the hard way and offer a caution for other regions such as Australia's Channel Country that support remarkable and critical ecosystems. These places sustain a dizzying variety of life and are so large and isolated that they seem invulnerable to significant damage.

Consider Brazil's Pantanal, which is the world's largest tropical wetland, nurtured by the 40 to 60 inches of rain that falls from November through March each year, flooding most of the region, which sits like a bowl in the Earth's crust. It is a 70,000-square-mile mosaic of grassy woodlands, savanna, and semi-deciduous forest that is home to the highest concentration of wildlife in South America, from hyacinth macaws to jaguars, toucans, and giant anteaters. The species count—3,500 plants, 656 birds, 325 fish, 159 mammals, 98 reptiles, and 53 amphibians—tops even the Amazon.

Or consider Botswana's Okavango Delta, which like the Channel Country is surrounded by desert—the Kalahari—and is fed largely by rain that falls hundreds of miles away. The Okavango's waters arrive predictably, flooding the delta every June through October. It all begins more than 600 miles to the northwest, in the humid, forested highlands of Angola, where rain falls in sheets and begins a months-long journey to the Okavango. As the water begins its final advance upon the desert, it pans out onto more than 16,600 square miles of lagoons, wetlands, and seasonal ponds that nurture grasslands, riparian forest, deciduous woodlands, and shifting sandbanks that attract the largest concentration of wildlife in Africa.

Beyond the astonishing natural life that these places nourish, we are becoming increasingly more knowledgeable about the global value of these regions in influencing weather, climate, and human well-being. A study published in 2017 in *Scientific American* found that desert basins help check global warming by storing carbon dioxide that would otherwise escape into the atmosphere. These basins, which include Lake Eyre, sequester 168 million tons of carbon each year worldwide, the study found.

Which makes the threats facing them all the more worrisome.



In Australia, industrial agriculture firms want to divert Channel Country rivers for large-scale farming of cotton and other crops while the mining industry wants to expand shale gas mining, which requires hydraulic fracturing (fracking).

The prospect of fracking is particularly concerning considering the sensitive hydrology of the region's rivers and floodplains. This type of unconventional gas mining requires a network of densely spaced wells, roads, pipelines, and wastewater ponds that could disrupt the natural flows that make for healthy floodplains. There is a further risk of river contamination from well failures, or from overspill or structural damage to wastewater storage ponds during floods.

Opening these lands to unconventional gas mining would run counter to a joint federal-state government warning, issued after a 2008 review of the Lake Eyre basin, that found that changes to natural water flows "could have severe effects" and that "natural flow and seasonal flooding are also vitally important to floodplain productivity."

ALTERING ANY ONE OF THESE PLACES, INCLUDING THE SOURCES OF THEIR WATERS, WILL IMPART SEVERE CONSEQUENCES ON THE NATURAL WORLD.

And because the Channel Country is so flat, even seemingly benign activities, such as the construction of a single road through a vast and otherwise undeveloped area, can significantly alter the pathway of the water.

Botswana's Okavango Delta is so treasured that it became the world's 100th UNESCO World Heritage Site. Yet it, too, faces threats that include dams, overgrazing, overfarming of arable land, intentionally set bushfires, overfishing, deforestation for cropland and firewood, and rampant poaching, according to a study in the *Journal of Biodiversity and Endangered Species*.

Many of the same issues weigh on Brazil's Pantanal—upstream dams, deforestation, and unregulated fishing and grazing in the watershed—with the lamentable addition of soil erosion from industrial farming and emerging policies that favor more large development over conservation. Even the construction of roads through the basin has affected the hydrological cycle, in some places leaving land on one side of the road parched, with consequences for flora and fauna that are not yet fully understood.

These threats are only more disturbing because of the harsh lessons we learned from the Aral Sea and the continuing impact it is having on the region's climate. It shows that unrestrained altering of natural water systems can have lasting and widespread impact.

As remote as the Channel Country, the Pantanal, and the Okavango Delta are, they are critical to the health of our planet. Humankind has the scientific knowledge, experience, and perspective to know that altering any one of these places, including the sources of their waters, will impart severe consequences on the natural world. Whatever short-term gain might be had will be far outweighed by both the short- and long-term suffering of people and our economies, wildlife, and entire ecosystems in and around the deltas and basins. Now more than ever, we need to protect these sensitive systems.

THE TAKEAWAY

When diverting creeks, streams, and rivers, society has often forgotten the natural world these waters fostered—and there are harrowing lessons to be learned when shifting water ecosystems to other purposes.

Gary White and Matt Damon: Bringing Water to Those Who Don't Have It

White and Damon founded Water.org a decade ago to bring clean water and sanitation to the developing world. The organization now works in Africa, Asia, and Latin America.

WATER IS ESSENTIAL FOR US ALL, BUT EVEN IN THIS MODERN AGE A SIGNIFICANT NUMBER OF PEOPLE LACK ACCESS TO CLEAN WATER AND SANITATION. WHAT MISCONCEPTIONS DO SOME PEOPLE HAVE ABOUT THE STATE OF THE GLOBAL CRISIS?

Matt: That's a good question. For those of us who grew up in the States a clean drink of water is only a few steps away at any given time. But the water in our toilets is cleaner than the water that about 800 million people have access to on a daily basis. That causes a massive number of problems, not the least of which is death. About a million kids a year are dying completely preventable deaths because they lack access to clean water and sanitation. There is also the opportunity cost of the time women and girls spend collecting water. Young girls are out of school because they are out collecting water.

Gary: That's a huge problem—you mention the time, Matt—200 million hours will be spent by women and girls today walking to collect water, 266 million hours will be spent by them walking to find a safe place to defecate. But there are solutions that work. And we've been pioneering those types of solutions, especially with access to affordable finance, so people can get the water and sanitation solutions at the household level that best meets their needs.

AS YOU BEGAN YOUR WORK, HOW DID YOU DECIDE TO FOCUS ON AFFORDABLE FINANCING?

Matt: It started with this insight that Gary had—he'll be too humble to say it, so I'll say it for him. He spent a lot of time in developing countries and realized those living in poverty were paying a tremendous amount for their water. They were paying as much as 15 times more for water than the middle class because they weren't connected to the infrastructure. They had no savings. Gary thought about the ideas that Muhammad Yunus pioneered with microfinance and asked, "What if we apply that to the water sector?" It was a big thought leap at the time. A lot of these people are working jobs and then leaving those jobs to queue up for water and it's incredibly unproductive. Gary thought if you could front them the money to connect to the pipes that were running right underneath the slum that they were living in—a loan for about $200 or less that they didn't have in savings—they could pay that loan back and end up with more time to work. They would have more time to pay off the loan.

HOW DOES YOUR ORGANIZATION WORK AND WHAT'S AN EXAMPLE OF ONE OF YOUR SUCCESS STORIES?

Gary: I was in the Philippines recently meeting people who bring stories to life for us. This woman I met outside the slums of Manila, Leneriza was her name, she was paying $60 a month to one of these water vendors to come and deliver water to her home. She took out a loan through one of our partners. And she then got a water connection, as Matt mentioned, right into her home. If you combine her loan payments plus the water tariff she's paying each month, it's about $10. You can see from Leneriza's example that there is a huge amount of inefficiency in the system. The market is broken. And that's what we're trying to do, correct this market failure through access to affordable finance. Nearly every loan is repaid by the borrowers. And more than half of the people who benefit from them live on less than $2 a day. I was on the Global Agenda Council on Water Security with the World Economic Forum and we did the numbers. There is about $300 billion in coping costs spent by people each year because of the failure of water and sanitation systems worldwide. We work to make the system more efficient by redirecting those coping costs, demonstrating that people living in poverty really aren't a problem to be solved; they're a market to be served.

Matt: The exciting part is watching how successful this has been. It's worked better than we ever could have hoped. We reached our first million people in 2012. We're reaching more than a million people a quarter now. The model's proven.

GIVEN THE WORLDWIDE SCOPE OF THE WATER CRISIS, WHAT CAN AN INDIVIDUAL DO TO HELP?

Gary: The best way for individuals to help is through organizations that are tackling the crisis on a large scale. People can start their own fundraisers, donate, or download facts about the water crisis to share from our Water.org website. We also plan to launch a platform later this year where anyone can make a loan to someone who needs it for water and sanitation.

YOU'RE NOT ALONE IN SEEKING TO MAKE A DIFFERENCE. FROM THE UNITED NATIONS TO GOVERNMENT AGENCIES TO PHILANTHROPIC ORGANIZATIONS, A RANGE OF EFFORTS IS UNDERWAY. WHAT'S BEEN ACCOMPLISHED—AND WHAT'S LEFT TO BE DONE?

Matt: The World Bank identified 500 million people who could be reached with finance. We've projected, and we're on target, to reach 60 million people by 2022. As Bill Clinton said to us years ago—he looked at Gary's model and this was before we reached a million people—and he said, "This is going to work. Run those numbers up." And he's right. That's what we've been doing and will continue to do.

Gary: Impact investing is a powerful way to bring private capital in to fuel this market. Matt and I co-founded WaterEquity, the first-ever impact investment manager dedicated to solving the global water and sanitation crisis. Now that we have demonstrated the market beyond a shadow of a doubt, it is time to fuel it. Philanthropy alone cannot solve this crisis, but a blend of private finance and philanthropy can.

VOICES

WHEN YOU CAN'T TAKE WATER FOR GRANTED

The World Resources Institute reports that more than a billion people live in water-scarce regions around the world. Many of them are in developing nations that lack basic clean water and sanitation—and others are in American cities where aging infrastructure and mismanagement have left people unable to rely on the water that flows from their taps.

WE DUG A CANAL BY HAND TO BRING WATER TO MY VILLAGE

By Wilfred Charles

When I was a year old, our village, named Mitawa, in southern Malawi, suffered from famine. Without enough water, our village of nearly 10,000 couldn't grow crops and didn't have enough food to go around. Women used to fight for water when they went to collect it from the wells. I was hungry and underweight. Many kids were. I never want my wife and four children to suffer like that.

For decades, Malawi has experienced droughts, made worse by the effects of El Niño. Without water, we can't grow the food we need to survive. And we didn't think we could do anything about it.

Without water, we can't grow the food we need to survive.

In 2010, the U.S. Agency for International Development taught us that irrigation farming could supply water to our farms. With this system, we would be able to increase the level of the water table, keep the soil from eroding, and water our crops. That year, we began our watershed development project.

First, we needed to dig a big canal to collect the water. Pipes would divert water from the Lingoni River into the canal. Then, gravity would help the water flow

Continued on page 49

I'M IN FLINT, MICHIGAN, AND STILL CAN'T RELY ON MY WATER

By Jeneyah McDonald

A 16-ounce water bottle is my new standard of measurement.

I know how many it takes to fill up any pan I own. Cooking a bag of frozen vegetables takes one bottle. Spaghetti takes five. A pitcher of Kool-Aid for the kids requires seven. I can easily use eight cases of 16-ounce bottles on dinner for our family of four. These are the kinds of things you know when you can't trust your water.

We use bottled water for everything—brushing our teeth, washing dishes, making coffee, filling a tub.

We've seen neighborhood pets get sick and die from drinking the tap water. Parents automatically put bottled water in kids' backpacks because they can't drink the water at school. In the summer, swimming is off limits because we can't fill up the pool. My two boys can't run under the sprinkler or drink out of the water hose. Basic rites of childhood are gone.

You hardly ever think about all the ways you take water for granted. But I live in Flint, Michigan. Unlike most places in America, our water isn't safe.

A few years ago we were in the news headlines. In April 2014, the city of Flint began getting its water from the Flint River instead of Detroit to save money. The new water wasn't treated properly and corroded the city's iron water mains. That led to iron, lead, and other toxins leaching into the water supply.

The city switched back in October the next year, but the damage was done and the city didn't fix the bad pipes that were causing the problem.

In the beginning, the brownish, light tan water was scary. It smelled like sewage. I'd run a bath, then be

Continued on page 49

I'LL NEVER FORGET THAT DAY WHEN WATER FIRST BEGAN TO REACH OUR FIELDS. IT WAS LIKE A DREAM COME TRUE.

WILFRED CHARLES

THE CITY SAYS THE PIPES SHOULD ALL BE REPLACED THIS YEAR. THEY ALSO SAY THE WATER WE HAVE NOW IS SAFE TO DRINK. BUT HOW CAN YOU TRUST THAT ANSWER WHEN SOMETHING AS BASIC AS WATER HAS BEEN TAKEN AWAY?

JENEYAH McDONALD

to the fields in the village. So we began looking for volunteers for the project. In the first days, I was very happy: 296 farmers registered to help.

We quickly learned it was very hard work. We started by building a dam across the river with boulders and mortar that we mixed from sand. After that, we marked the route of the canal with wooden pegs.

We worked by hand using hoes, shovels, and picks. We dug water channels along where we marked the route and lined them with boulders and sand mortar to prevent erosion. In some sections, we placed pipes that would be used to convey water underground and covered them with soil. Our main canal is about a mile long. We also dug secondary shallow canals so that water could reach different parts of the village.

When our volunteers realized how difficult the project was, they began to give up. Soon, only six of us were left.

But our small group was determined. I had faith through reading the Bible that whatever one decides to do through prayers everything is possible. People in the village made fun of us. They thought we were crazy! Even my wife thought the project wouldn't work. But we didn't quit. It took us three years. During that time, we received food rations for our labor, but no money. It was strictly volunteer. We finished in 2013.

Once the canal was built, water began to flow through the pipes and trenches, and then to the crops. I'll never forget that day when water first began to reach our fields. It was like a dream come true. We never thought we would have this gift of water in our fields, and now the land is also protected from soil erosion when the rainy season brings floods.

Today, we are able to harvest crops twice a year, even during droughts. We grow maize, sorghum, cassava, pigeon peas, tomatoes, and vegetables. On the fields close to the river banks, farmers can even grow rice. Women are able to get water from the wells at any time of the year. There is no fighting.

Irrigation farming has helped us a lot. We can sell some of our harvest and use it to better our lives. We are able to send our children to school and pay for their uniforms and fees. We can store our excess food, so that we have enough in our reserves. Now I can see that the future for my kids is bright.

Water has made all the difference.

afraid to get in. The neighbors noticed the same thing. A couple of weeks later, the city told us to stop drinking the water.

But we had already seen effects. All my house plants died and I had to throw them away. Friends got rashes and had breathing problems. My older son, Justice, who's now 9, has eczema and the water aggravated it like we'd never seen before. He loves bath time, but I couldn't let him play in the tub. I had to tell him the water was poison so he'd know I was serious about avoiding it.

I thought fixing the problem would be easy, but when the city started handing out water that fall in 2014, it hit me: This is how it's going to be from now on. In 2015, tests by the EPA showed dangerous levels of lead in the water in our homes.

It wasn't easy to get enough water. We'd have to stand in long, long lines for hours and then only get a case or two. That's just not enough.

As a home visitor with the school district, I visit families with small children and see firsthand the effects of the water. We know exposure to lead can lead to behavioral disorders, impaired cognition, hearing problems and delayed puberty in children. I see a lot of children developing autism, including my 5-year-old, Josiah. I see language and developmental delays. But no one will confirm that it's related to our water.

The city says the pipes should all be replaced this year. They also say the water we have now is safe to drink. But how can you trust that answer when something as basic as water has been taken away?

Flint is 100,000 residents strong, living in the most sophisticated country in the world, and we can't get clean water. We're in Michigan, surrounded by four great lakes, and we don't have clean water. We sent a spaceship to the ends of the earth and I can't get clean water in my house.

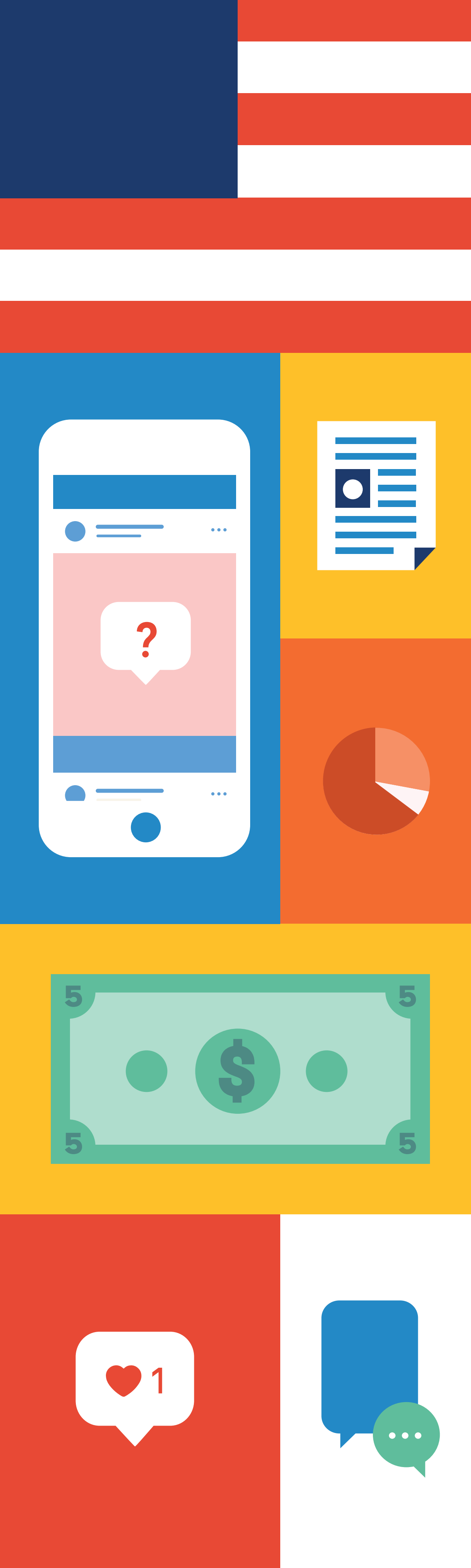
And I still pay for it. My water bill is about $190 a month for our 900-square-foot house with no leaks when I'm the only one in our family who bathes every day, with filters on my shower, and washes clothes once a week.

I don't know when I'll feel comfortable drinking the water. Right now, I have no faith that it will ever be clean again.

A THOUSAND WORDS

"The lessons of the Aral Sea were learned the hard way and offer a caution for other regions like Australia's Channel Country that support remarkable and critical ecosystems."—page 36

Paul Blackmore/Getty Images



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