Water Unsustainability

Jerald L. Schnoor

Abstract: Water is a vital renewable resource that is increasingly stressed by multiple and competing demands from people, industry, and agriculture. When water becomes unavailable or unusable, life itself cannot be sustained. Changes in supply and demand for water are driven by population growth, climate change, and our energy and land use choices. Poverty frequently precludes the ability of many people to respond and adapt to water insecurity. In this essay, we discuss the effects of these drivers on the diminution of rivers, aquifers, glaciers, and the severe pollution that renders some water resources unusable. While technologies for water reuse, desalination, aquifer replenishment, and better water pricing are important solutions, the recognition of water as a profoundly threatened resource and as a basic human right is essential for providing sustainable water for future generations.

JERALD L. SCHNOOR is the Allen S. Henry Chair in Engineering, Professor of Civil and Environmental Engineering and Occupational and Environmental Health, and Codirector of the Center for Global and Regional Environmental Research at the University of Iowa. He is a member of the National Academy of Engineering, the winner of the National Water Research Institute Clarke Prize for water sustainability, and the author of *Environmental Modeling: Fate and Transport of Pollutants in Water, Air, and Soil* (1996). He has published in such journals as *Science*, *The Bridge*, and *Environmental Science and Technology*.

Water *unsustainability* is more easily understood than water *sustainability*: you know when you do not have it. When water is unavailable or when it is of unusably poor quality, life itself is unsustainable.

So how do we define water sustainability? Definitions usually involve the concept of long-term water availability for all uses. Supplying water to people for the duration of their lives is one definition, but is limited by a rather ethnocentric point of view. More broadly, we may define water sustainability as *the continual supply of clean water for human uses and for the use of all other living organisms*. This definition neither specifies exactly how much water is needed, nor does it require the unconstrained, infinite availability of water. Rather, it refers to a sufficient quantity of pure water for the foreseeable future for all biota, including humans.

Water is, after all, a renewable resource; sustaining its uses should be relatively easy. But in reality, we can have too much water or too little water at different times, and the water available may be of too poor quality. Water availability is often constrained by natural processes associated with the hydrologic cycle and geologic setting, or by jurisdictional boundaries of governmental authorities and

doi:10.1162/DAED_a_00341

water law. Water supply is also constrained by existing infrastructure to deliver available water. Our ability to ensure enough clean water for human uses is strongly influenced by the cost of water delivery and the price of and demand for water. Thus, many factors and trends affect the availability of water in space and time.

Because H_2O does not cross the boundaries of our atmosphere, either to or from outer space, Earth has held the same quantity of water for eons. Earth's hydrologic cycle is driven by the sun, which evaporates water from oceans, lakes, and streams, and causes vegetation to transpire water. Thus, water is in a continuous flux from evaporation to precipitation, resulting in the recycling, purification, and redistribution of it. However, the *quality* of water and the *fraction of* H_2O *in each water phase* (gaseous, liquid, solid) at a given location are subject to change.

Currently, more than 99 percent of all water on Earth is unavailable for human use because it is too saline (in the form of seawater) or is frozen as glaciers, ice, or snow. With a stored volume of about two million cubic miles, groundwater remains the largest component of freshwater available for humans. Lakes and streams represent the next largest stores at approximately thirty thousand cubic miles.[1] But the volume of freshwater stored in glaciers is diminishing as a warmer climate begins to melt continental glaciers and the Greenland and Antarctic ice sheets. Many changes in water quality and quantity are driven by human activities – not nature.

There are five "driving forces" of change that threaten water sustainability:

1) Population growth (and migration patterns to megacities). According to United Nations projections, the global population will expand from 7.1 billion to 9.2 billion by 2050, further diminishing the quantity of water available per person. Further, when millions of people migrate to megacities, it concentrates the demand and stresses local water supplies, again resulting in less water available per capita. Humans are also increasingly moving to coastal cities where seawater is too saline for drinking and desalinization is too expensive. As we pump freshwater aquifers more fervently to supply water for increasing population growth and urban development, salinity can intrude from the sea and despoil groundwater supplies.

2) Climate change (changing precipitation patterns and drought). Due to our shifting climate, dry areas are generally becoming dryer and wet areas are becoming wetter all around the world.[2] In arid areas, the relatively small amount of soil moisture evaporates quicker under hotter conditions, resulting in more frequent and profound droughts. Conversely, humid areas are becoming wetter with more intense precipitation events and floods: the warmer ocean evaporates more water, and a warmer atmosphere can hold more moisture, increasing clouds and bolstering global rainfall rates. Too little water and too much water are twin juggernauts of climate change that result in water unsustainability.[3]

3) Land use change (increasing agriculture, irrigation, and urban sprawl). Food and water are intimately connected. To feed an expanding global population, we employ increasingly intensive agriculture on expanded acreages, requiring more chemical inputs and further diminishing water quality. Runoff from agricultural land delivers soil particles, fertilizers, and pesticides into streams. Fertilizer nutrients, in turn, over-enrich coastal waters, causing eutrophication, harmful algal blooms, and hypoxia (low dissolved oxygen), which impairs water quality for humans and aquatic ecosystems alike.

Urban sprawl – which causes greater imperviousness, heightens stormwater runoff, and prevents infiltration to recharge aquifers – is shrinking groundwater supplies. Groundwater supplies are also diminished by the burgeoning water withdrawals demanded by expanding populations and global agriculture. Irrigation is by far the largest water user in the world. Its impact on aquifers and rivers is particularly acute because withdrawals are a "consumptive" use of water: the water is mostly lost to evaporation. In cases in which water is not entirely evaporated, agricultural return flows allow some reuse options, such as recharging aquifers through percolation (spreading) ponds. But often the return flows are of such poor quality (laden with salt or toxic leachates) that they are useless for groundwater recharge.

4) Energy choices (power production, biofuels, and unconventional extraction of oil and gas). Our energy choices to satisfy the needs of growing populations and development are loaded with water repercussions. For example, electric power production withdraws more water worldwide than any other use except irrigation. Fortunately, the cooling water from electric power plants can be returned to the receiving stream with less evaporative losses than irrigation. But if the temperature of the returned water is too hot, or if it contains anticorrosion chemicals or chlorine disinfectant, it may cause deleterious effects on downstream ecosystems and fisheries.

The so-called energy-water nexus describes this tension between developing energy and water supplies. It is axiomatic that one cannot have water without large energy inputs, or energy without significant water impacts. Development of new fossil fuels (natural gas, oil, and coal) may impact the quality of nearby surface and groundwater. Some energy development options extract considerably more water than others. "Unconventional" oil includes oil shales, oil sands, coal-to-liquids, gas-to-liquids, and deep-drilled ocean oil. Conventional oil drilling and processing uses about 8 – 20 gal/MMBTU (gallons of water per million BTU of energy produced), while unconventional development of oil sands uses significantly more: 27 – 68 gal/MMBTU according to Chesapeake Energy.[4] But the largest water user is irrigated corn used to produce ethanol biofuels, requiring more than 2500 gal/MMBTU, or roughly two hundred gallons of "virtual" water required to produce every gallon of ethanol fuel burned![5] That is in addition to the environmental impacts of fertilizers, eroded soil, and pesticides required for growing the feedstock.

"Unconventional" energy development affects water quality to a much greater extent than conventional drilling and processing. A blowout of a deep-ocean well, such as the BP Macondo Well at the Deepwater Horizon platform in 2010, causes an outright water-quality disaster. Approximately two hundred million gallons of crude oil spilled along the Gulf of Mexico coast directly into a sensitive fishery and a substantial tourism industry. Oil sands, another unconventional oil resource, require steam to liberate bitumen (a tar-like substance), resulting in discharge ponds of petroleum-contaminated water that both is harmful to wildlife and scars the landscape. Deep directional drilling and hydraulic fracturing for shale oil and gas deposits, which requires three to seven million gallons of water per well, are still other methods.[6] In hydraulic fracturing (popularly known as fracking), drillers inject a highly pressurized water, sand, and chemical solution into shale formations to fracture the rock and allow natural gas to flow more freely to the surface. The water solution, however, returns to the surface as flowback and produces water with extremely high salt concentrations and trace contaminants (toxic metals and radionuclides). Usually such flowback and produced waters are reinjected into deep wells, far below any aquifers used for water supply. Instead of deep-well injection, some oil and gas companies are trying to recycle this water for use in hydraulic fracturing at another well. But if it is left on the surface, the flowback and produced waters form ponds of exceedingly poor-quality water that are difficult to treat to an acceptable standard for discharge into receiving waters. Unfortunately, some unscrupulous gas companies abandon these ponds for others to clean-up or for nature to absorb.

5) Poverty (physical and economic water scarcity). Water scarcity afflicts poor people more gravely than those with resources to respond or adapt. Poor communities cannot migrate to a better location, pay to import safe drinking water, treat contaminated water to meet safe drinking standards, repair a dry well, or pump water across great distances. Volunteer foundations and nongovernmental organizations (NGOs) recognize this dire need and seek collaborative solutions. Goal 7 of the United Nations Millennium Development Goals – "Ensuring Environmental Sustainability" – seeks to reduce the proportion of people without access to safe drinking water by half between 2000 and 2015.[7] Indeed, the achievement of the safe drinking-water goal is a major success story of the UN program. Yet there remain eight hundred million people in the world who still do not have an adequate water supply; clearly much work remains. Nor has the related development goal of adequate sanitation facilities (toilets and conveyance of sewage) for the more than one billion people in need been met. The United Nations has adopted a post-2015 development agenda, with "Water and Sanitation for All" a stand-alone goal. Such a comprehensive global effort is absolutely essential for water sustainability.

All five drivers are highly interrelated. We cannot mitigate climate change without making the energy choices needed to transition out of the fossil fuel age. We must use land and energy wisely to help create jobs and raise people out of poverty. We cannot solve water problems related to urban sprawl without curbing population growth and migration to megacities. And we cannot ensure clean water for an expanding population without a global social agenda that builds strong communities and empowers them to meet future challenges.

Water unsustainability is becoming increasingly evident in impoverished countries, megacities, and large-scale arid regions. We see it in the water stress of the Middle East, North Africa, and South Asia. We see it in the investment of billions of dollars for water reclamation plants in Singapore and desalination plants in Tianjin, China, and San Diego, California. Every day, newspaper headlines attest to human struggles of having too little or too much water. We see it when lakes become so polluted that they can no longer be used for drinking, and when coastal waters turn into dead zones devoid of fish. We see it when water is no longer available for irrigating immensely valuable food crops, and when major cities are frequently flooded by storms. We see evidence in mudslides and wildfires, in one-hundred-year floods and five-hundred-year droughts. Let us now examine a few poignant examples of water unsustainability that have become all too familiar: rivers that no longer flow to the sea, wells that run dry, the extinction of glaciers, the loss of critical groundwater supplies, and economic water scarcity throughout the world.

The Colorado River is born from snowmelt in the Rocky Mountains of Colorado, Wyoming, and Utah. It twists through Nevada, Arizona, and California on its way to a final hurrah in Mexico, where it forms a twenty-four-mile borderline with the United States and travels seventy-five miles through Baja, Mexico, to discharge in the Gulf of California. The last remnant of freshwater flow is captured in Baja by the Morelos Dam, whose waters irrigate rich farmland in the Mexicali Valley.

But the Colorado River has experienced a steady decline in discharge volume over the past century; in most years since 1960, it has not even reached the Gulf of California. Dams, diversions, and irrigation have caused most of the water loss, including increasing withdrawals for an expanding population of forty million people living both inside and outside the Colorado River Basin. Millions of acres of expanded agriculture and the irrigation required to grow cash crops in the middle of the desert consume most of the incoming water.

Lake Mead is a main stem reservoir of the Colorado River near Las Vegas. It is the largest dammed water body in North America, though – as a victim of repeated droughts and rising withdrawals – it has not been full since 1983. It provides power for more than one million people and recreation for many more, but spreading the Colorado River over a large desert area has increased evaporative losses significantly. Since 2000, the surface of Lake Mead is down almost 130 feet, leaving a "bathtub ring" on the rocky catchment and divulging where water was once stored. Climate change has exacerbated evaporation from Lake Mead (and its upstream sister Lake Powell) and has decreased flow from the river upstream.

The Colorado River is not alone: the Indus River in Pakistan, the Yellow River in China, the Murray River in Australia, the Amu Darya River in Central Asia, and the Theertha River in India are just a few watersheds that terminate before reaching their destination. All are located in arid regions where temperatures and evaporation are increasing, and where excessive withdrawals of water for people and agriculture combine to promote water unsustainability.

Big Spring, Texas, doesn't spring anymore. The town lacks a big spring or even adequate surface water. Its wells have run dry and its residents face frequent drought and water shortages. In 2014, nearby towns Wichita Falls, Lubbock, and Amarillo, Texas, declared a stage five emergency for exceptional drought. It was the driest year on record – even drier than the Dust Bowl. Other towns in Kansas, Oklahoma, and Texas on the Ogallala Aquifer in the Southern High Plains of the United States have recently experienced "game changing" drought and overwithdrawals. That they all lie on the largest aquifer in North America turns out to offer them no insurance against drought. Although torrential rains and flooding in May 2015 finally broke the Texan drought, the need for innovative technology and investment in new water infrastructure had become clear to everyone.

Big Spring responded by building a $14 million treatment plant to treat wastewater and recycle two million gallons directly to nearby towns for drinking water. By June of 2014, the Wichita Falls water treatment plant followed suit and became just the second facility in the United States to practice *direct potable reuse* (DPR): the treatment of wastewater for direct reuse in drinking-water treatment plants without an environmental buffer. Texans never thought they would drink treated domestic sewage, but direct potable reuse is an increasingly common solution for water-short areas.

California had a near-record drought in 2008. That one broke, but the state has routinely been short of precipitation since

2011. Now, in 2015, about half the state is in exceptional drought (the most severe category) and virtually all of the state is abnormally dry. Governor Jerry Brown put mandatory restrictions on urban areas to curb water use, but 80 percent of the water in California is used by agriculture. Farmers have volunteered to reduce their consumption by 25 percent in an effort to prevent steeper mandatory cuts later on. In many parts of California, groundwater is all that remains, but in areas like Kern County near Bakersfield, it has been pumped-down by more than fifty feet since 2011. Fortunately, water is a renewable resource and nature stores freshwater in many places: aquifers, lakes, soils, glaciers, and snowpack. But in California, all are in short supply. Snowpack levels in the Sierra Nevada are less than 25 percent of normal levels, and reservoirs contain only a fraction of their capacity.

More broadly, the California drought is emblematic of a global problem: wells are simultaneously being depleted in Pakistan, India, Sub-Saharan Africa, China, and the Mediterranean region. Wells run dry through the interplay of excessive withdrawals for population growth, climate change, agriculture, industry, and energy projects. The combination of these drivers with widespread poverty inevitably causes water scarcity. Impoverished communities suffering from water scarcity cannot recover or adapt; they lack the "resiliency" to respond to the disruption of their water supply. Water may be available in the new market at a higher price, but many simply cannot pay.

Land-based glaciers are melting worldwide. And tropical glaciers are melting the fastest. In mountain ranges near the equator, tropical glaciers are our canaries in the coal mine, early warning agents of climate change. While it is true that glaciers have been melting ever since the Little Ice Age (circa 1650 to 1730), the melt rate is much faster now and has only accelerated since 1980. We are witnessing the demise of low-elevation tropical glaciers within our lifetime; it is not simply a climate change story but an important water supply story for this generation and the next.

Lower-elevation tropical glaciers tend to be smaller than high-mountain glaciers, and they are more vulnerable to melting. Loss of these glaciers means collapse of the communities that depend on glacial melt for water supply and irrigation of crops. In the Andes Mountains of Colombia, Bolivia, Peru, and Ecuador, glaciers below 17,700 feet are melting at the fastest rate in three hundred years: a near 3 percent loss per year. Since the 1970s, the glaciers have lost an average of four-and-a-half feet of ice thickness per year from a total of about one hundred thirty feet.[8] In two or three decades, they will be history.

On the way to extinction, melting glaciers provide a lifetime of service to people below. When glaciers first begin melting, melt-water rivers are bolstered and flow-rates increase. But once enough ice has melted, the river reaches a peak flow and flow-rates begin to decline. The seasonal timing of the melt may also vary, providing little water in late summer and fall, stressing irrigation and drinking-water supplies. At lower elevations, snowmelt and precipitation also provide water for rivers, and researchers strive to unravel the precise contribution of glacial melt to total river discharge. "Glaciers provide about 15 percent of the La Paz water supply throughout the year, increasing to about 27 percent during the dry season," Alvaro Soruco, an Andean researcher, has reported. A loss of 27 percent of stream discharge can be devastating to growing populations with increasing agricultural development.

In the Peruvian Andes, glaciers are melting so fast that this critical component of stream flow is vanishing. The Santa River flows northward along the base of the Andes, the Cordillera Blanca, and then turns west toward the seaport city of Chimbote. Precipitation in the Andes has changed little since 1970, but the coastal climate of Peru is about 0.7 degrees Fahrenheit warmer – enough of an increase to melt its glaciers. Santa River has already passed "peak discharge" from glacial melt, so future streamflow is expected to decline. Some river flow remains from local precipitation and groundwater inflow, but expanding withdrawals for irrigation projects in the coastal desert are claiming an ever-increasing share of this diminishing resource. During the arid month of July, only a trickle of water now makes its way down the Santa River to Chimbote, and a declining portion of that is glacial melt.

Lake Tai (Taihu) in Eastern China is the third largest lake in the nation. Near the mouth of the Yangtze River and the city of Wuxi, the lake has been celebrated for its beauty for centuries. Yet industrialization, agricultural expansion, and population growth have in recent years given Lake Tai the dubious distinction as having among the poorest lake-water quality in the world. In 2007, a harmful algal bloom of cyanobacteria (blue-green algae) choked the lake and threatened the water supply for over thirty million people. Since the 1990s, the Chinese government has taken a variety of drastic measures to combat the lake pollution, including closing dozens of industrial plants, flushing the lake with Yangtze River water, dredging contaminated sediments, and severely reducing the use of agricultural fertilizers in the basin. Authorities even controlled the price of bottled water when the price sky-rocketed due to exponential demand from a panicked public. But none of these interventions have been successful in restoring water quality, and Lake Tai remains a poster child of water unsustainability driven by the forces of population, expanding agriculture, and rampant industrialization.

By the time it flows from the Himalayas to the Bay of Bengal, the Ganges River in India serves approximately four hundred million people. But the Ganges is plagued by proliferate sewage pollution capable of contaminating whole river basins. According to the Indian government, of the eight hundred million gallons of sewage discharged daily along the Ganges River, only 20 percent receives any treatment whatsoever.[9] Yet every day two million people still bathe in the sacred river, posing a major risk for the spread of water-borne diseases. The Ganges is overloved and overused: she provides water for drinking and washing clothes, a receptacle for raw sewage and solid waste, and a final resting place for the ashes (and partial remains) of the thousands who are cremated on the Ganges annually in religious rituals. Clearly such practices render use of the river unsustainable, but huge investment in sewage treatment plants would be required to restore the sacred Ganges and protect the health of the Indian people who rely on it.

But it is not only underprivileged populations in developing countries who suffer from poor water quality. Rich countries have been polluting their water supplies with agricultural runoff from high-input agriculture and factory farms such as concentrated animal feeding operations. I was born and raised in Iowa, a prosperous state with the most productive agriculture in the world. Iowa rivers flow through immensely rich agricultural land, but farm runoff carries an insidious load of soil particles, fertilizers, and pesticides far in excess of what a healthy stream ecosystem requires. Further, nitrate from fertilizers moves easily from soil to stream via tile-line drainage systems. It is transported about eighteen hundred miles down the Mississippi River to the Gulf of Mexico, creating a coastal "dead zone" of low dissolved oxygen. This

Gulf Hypoxia is one of the largest of more than one hundred fifty such hypoxic zones around the world.

Increased agricultural activity to grow the feedstock to support a new biofuels industry also jeopardizes water sustainability in the United States. Biofuels are meant to provide energy security for developed countries and a high-value export for developing countries. But as an energy choice, biofuels are incredibly water intensive. Increased land and irrigation is required to grow the feedstock for biofuels (corn, canola, wheat, beets, and sugar cane for bioethanol; soybeans, sunflowers, and palm oil for biodiesel). In arid locations, large water withdrawals from aquifers are needed to irrigate crops, and more water is required at production facilities to produce the fuel. Fertilizers required to grow the feedstock crops lead to excessive nutrient runoff, which despoils water quality. At the same time, food prices may rise in response to the higher demand for corn, soybeans, wheat, and canola. In the United States at present, 40 percent of the corn crop (about thirty-six million acres of a total eighty-four million acres of corn crop) is dedicated to the production of ethanol biofuel. *Cellulosic* feedstock from perennial crops like switchgrass, miscanthus, and hybrid willow, or from crop and wood residues, hold promise for a greener future. Perennial crops do not require annual tillage and would reduce soil erosion; they would also use less fertilizers, pesticides, and irrigation water.

Physical water scarcity is defined as the lack of available water for humans and ecosystems, commonly occurring in arid areas, during droughts, and where water has been overallocated (causing unsustainable withdrawals). Economic water scarcity, on the other hand, is the lack of water infrastructure necessary to deliver water to people. It is typical of impoverished communities who cannot pay to access water from distant locations or whose water requires significant treatment for drinking. In individual families, it often falls to women and girls to find water wherever they can, including by traveling long distances to collect from wells or streams. Such sources may be contaminated, however, causing intestinal illness, especially in children.

Physical water scarcity presumes investment in infrastructure to overcome shortages during times of drought and in regions with progressively drier climates. Overallocation of water resources is common in California, where agriculture preceded other forms of development and "prior appropriation rights" dictate that farmers now control the water. When surface allocations are consumed during droughts, groundwater becomes the sole water supply and is quickly overdrawn. But the frequency and intensity of the problem is made direr by irrigation and by interbasin transfers to growing cities that may have purchased appropriative rights. The largest such transfer in recent years is the massive "south-to-north" interbasin transfer of water from the Yangtze River in China to northern megacities like Beijing and Tianjin. When the project is fully completed, it will transfer 4 to 5 percent of the annual flow of the Yangtze, the largest river in China.

Interbasin transfers may be avoided through water conservation and reuse, by recycling industrial and municipal wastewater (sewage) and treating it to drinking-water quality, and by practicing indirect or direct potable reuse. Industry is also contributing to water conservation by designing new plants with "zero water footprints" and by capturing the precipitation that falls on their property (rainwater harvesting) for treatment and recycling. But all of these measures require "getting the prices right" such that the cost of water reflects its scarcity in a free market. With higher prices, private and public water companies will develop the infrastructure necessary to conserve and reuse water and/or desalinate seawater and brackish groundwater. The cost will also incentivize citizens to learn to conserve water resources, as Californians have tried to do.

One solution to water unsustainability is to recycle treated wastewater for nonpotable uses (such as using purple pipes for watering lawns and shrubs) or to practice water reuse by recycling highly treated wastewater for use as drinking water. Water reuse is actually widely practiced today, if inadvertently. By the time the Trinity River in Texas flows from Dallas–Fort Worth to Houston, every drop has passed through a wastewater treatment plant. Withdrawals from the river for drinking-water treatment and distribution use treated domestic sewage whether customers realize it or not. Because of vast improvements in wastewater treatment practices, the Trinity River is of surprisingly good quality and still supports many aquatic species. Thus, people already practice potable water reuse in one of three forms: 1) inadvertent potable reuse (as in Trinity River, Texas); 2) indirect potable reuse (as in Orange County, California); and 3) direct potable reuse (as in Big Spring and Wichita Falls, Texas).

Indirect potable reuse is the practice of reusing highly treated effluent from domestic or industrial wastewater and discharging it into a reservoir or aquifer (an environmental buffer) for storage. After a few months, the water is withdrawn and treated for drinking-water distribution. The environmental buffer tends to help users overcome the "yuck factor" that typically characterizes public opinion on drinking highly treated sewage (direct potable reuse). In indirect potable reuse, three factors are at play. First, the waters are mixed (diluted) with existing water in the reservoir or aquifer. Second, the treated wastewater is naturally filtered and purified in the reservoir or aquifer for some period of time. Finally, after the water is withdrawn it is treated once again to drinking-water standards prior to distribution.

There are only a few communities in the world that presently practice direct potable reuse of drinking water. The first use of direct potable reuse was in Windhoek, Namibia, in 1968, when 250,000 people began using highly treated wastewater for drinking. Windhoek has practiced direct potable reuse ever since with no reports of illness or long-term negative effects. Big Spring, Texas, is the first application of this process in the United States, and its success has led Wichita Falls, Texas, to follow suit.

One of the most urgent tasks for communities facing water unsustainability is to replenish their depleted aquifers. Sustainable groundwater levels offer a measure of resiliency for the future akin to water insurance. Full aquifers, reservoirs, and storage tanks all offer insurance in times of need, but aquifers are immense and – better than any other method of storage – can protect and hold more water with little loss to evaporation.

Aquifer storage and recovery (ASR) and shallow aquifer recharge (SAR) are two methods practiced today in Oregon, Washington, Nevada, California, Florida, and Texas. Shallow aquifer recharge refers to the percolation of water from a surface pond to replenish a shallow aquifer, though not necessarily for recovery and drinking-water reuse. Full aquifers are desirable themselves for the capacity to bolster streams and to restore wetlands and springs that may have drained.

California's Orange County Water District Groundwater Replenishment System (GWRS) is a leader in shallow aquifer recharge. It recycles and treats wastewater that would have otherwise been discharged to the Pacific Ocean. The wastewater is treated to very high purity and exceeds state and federal drinking-water requirements; but rather than be withdrawn for drinking, the treated wastewater is naturally filtered through sand and gravel percolation basins in Anaheim, California. There the replenished aquifer serves as the source of drinking water for 2.4 million people. The groundwater is subsequently pumped-up, treated again, and distributed to nineteen municipal water agencies.

Aquifer storage and recovery describes the process of using wells to pump water into confined aquifers under pressure below the water table (where the water pressure head equals the atmospheric pressure). These aquifers may often be brackish or slightly salty, and the fresh, highly treated wastewater forms a "bubble" on top of the aquifer that can be accessed during a drought or dry season as an emergency water supply. The South Florida Water Management District oversees the operation of dozens of injection wells with the capacity to recharge aquifers with water of various qualities, including treated and untreated groundwater, partially treated surface water, and reclaimed (highly treated) wastewater.

In this essay we have seen that driving forces of population growth, climate change, urban and agricultural sprawl, energy development, and global poverty jeopardize future water supplies and render our present practices unsustainable. Water unsustainability poses risk for this and future generations. We should adapt to these changing conditions and mitigate them wherever and whenever we can. Adaptation takes the form of preparing for climate change, creating and refurbishing our water infrastructure, reusing water, recharging aquifers, making wise energy choices, and utilizing hyper-efficient irrigation for crops to feed the world. Mitigation requires transitioning from the fossil fuel age and improving human prospects through acts of global cooperation, as in the United Nations Sustainable Development Goals post-2015.

Many of the problems discussed herein will not be solved solely through new technologies. Economic and social issues are integrally linked to the problems of water sustainability. For example, we will not come to grips with economic water scarcity without the determined efforts of all stakeholders to eradicate poverty, improve education, and empower communities.

We are today experiencing a widespread crisis of water unsustainability throughout the world, with effects at the local, regional, and global scales. At the local scale, the drivers cause profound hurdles for individuals and families in gaining access to safe drinking water. At the regional scale, droughts and floods are increasingly frequent, inflicting human misery on a burgeoning population, while ecosystems suffer from poor water quality caused by our energy and agricultural practices. At the global scale, our efforts to reduce our greenhouse gas emissions have been stymied by competing economic and political interests. It is likely we will come to know the impacts of climate change through the effects delivered upon our most vulnerable and shifting water resources. Unless we can overcome or adapt to these driving forces, future generations will inherit a legacy of declining and degraded water resources. Our relationship with water and how we use it can evolve to meet this challenge, but it requires an understanding of the drivers of unsustainability and an acceptance of high-quality water as a human right.

ENDNOTES

[1] Franklin W. Schwartz and Hubao Zhang, *Fundamentals of Ground Water* (Hoboken, N.J.: John Wiley & Sons, 2003).

[2] Jerald L. Schnoor, "Living with a Changing Water Environment," *The Bridge* 38 (3) (2008): 46–54.

[3] Intergovernmental Panel on Climate Change, *Climate Change 2013: The Physical Science Basis (Working Group I Contribution to the Fifth Assessment Report)*, ed. Thomas F. Stocker, Dahe Qin, Gian-Kasper Plattner, Melinda M.B. Tignor, Simon K. Allen, Judith Boschung, Alexander Nauels, Yu Xia, Vincent Bex, and Pauline M. Midgley (Cambridge; New York: Cambridge University Press, 2013).

[4] Chesapeake Energy, *Leading a Responsible Energy Future: 2013 Corporate Responsibility Report* (Oklahoma City: Chesapeake Energy, 2013), http://www.chk.com/documents/media/publications/2013CorporateResponsibilityReport.pdf.

[5] National Research Council of the National Academies, *Water Implications of Biofuels Production in the United States* (Washington, D.C.: National Academies Press, 2008).

[6] Cornell University City and Regional Planning, *Hydraulic Fracturing – Effects on Water Quality (CRP 5072)* (Ithaca, N.Y.: Cornell University, 2010), http://www.cce.cornell.edu/EnergyClimateChange/NaturalGasDev/Documents/City%20and%20Regional%20Planning%20Student%20Papers/CRP5072_Water%20Quality%20Final%20Report.pdf.

[7] United Nations, *The Millennium Development Goals Report* (New York: United Nations, 2013), http://www.un.org/millenniumgoals/pdf/report-2013/mdg-report-2013-english.pdf.

[8] Antoine Rabatel et al., "Review Article of the Current State of Glaciers in the Tropical Andes: A Multi-Century Perspective on Glacier Evolution and Climate Change," *The Cryosphere Discussions* 6 (2012): 2477–2536; and Antoine Rabatel et al., "Current State of Glaciers in the Tropical Andes: A Multi-Century Perspective on Glacier Evolution and Climate Change," *The Cryosphere* 7 (2013): 81–102.

[9] Janak Rogers, "India's Polluted Ganges River Threatens People's Livelihoods," *Deutsche Welle*, November 21, 2013, http://www.dw.de/indias-polluted-ganges-river-threatens-peoples-livelihoods/a-17237276.