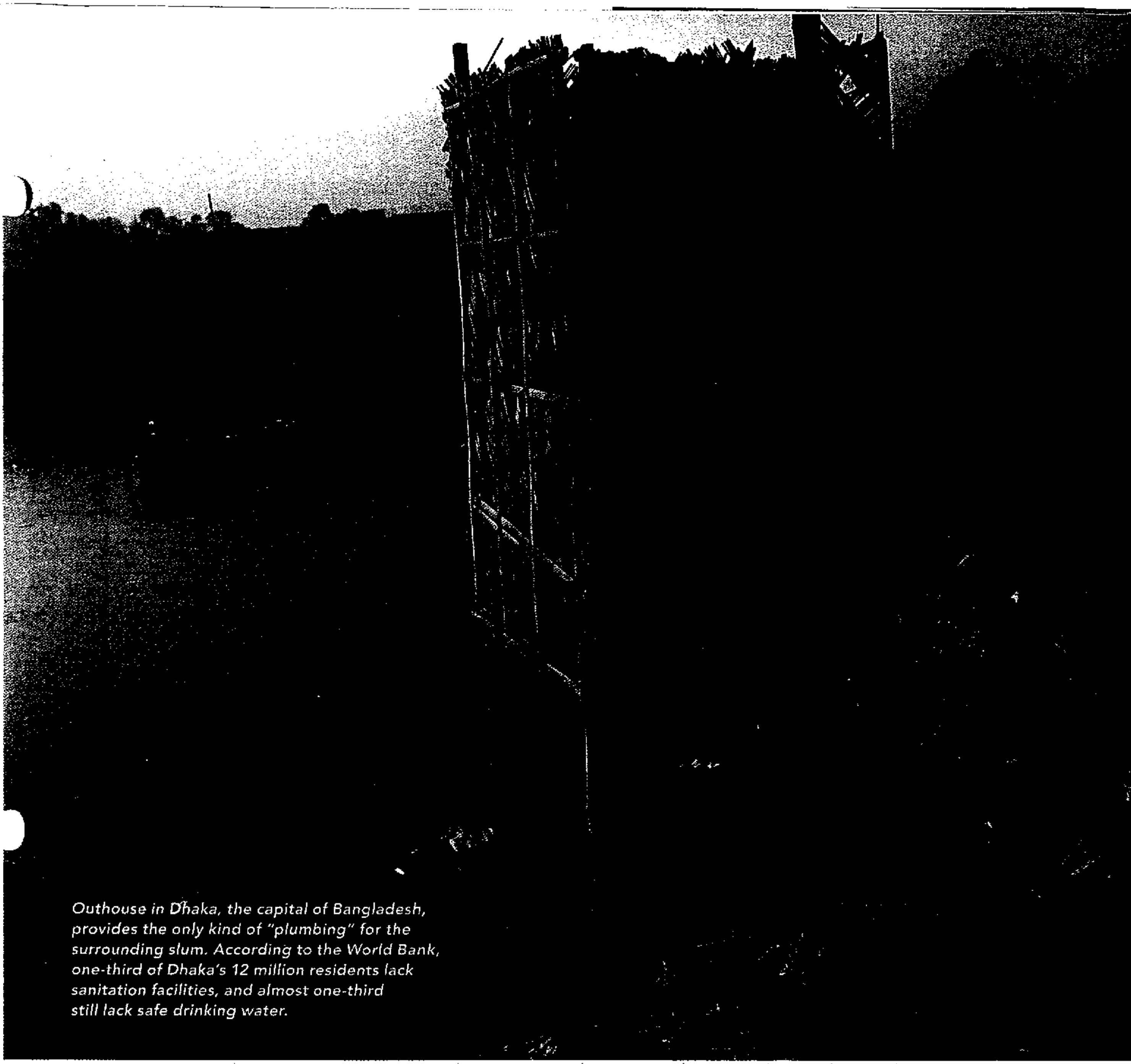


Outhouse in Dhaka, the capital of Bangladesh, provides the only kind of "plumbing" for the surrounding slum. According to the World Bank, one-third of Dhaka's 12 million residents lack sanitation facilities, and almost one-third still lack safe drinking water.

DANGEROUS WATERS

Twenty percent of the people on Earth lack access to clean water. And even that dismal number is likely to grow.

by Sharon P. Nappier, Robert S. Lawrence, Kellogg J. Schwab

An estimated **1,000 new synthetic compounds** are introduced **every year**—
some of them inevitably **seep into drinking-water** sources.

Drought in Australia. Water shortages in northern China. The desertification of western Africa. Almost daily, such headlines roll off the presses and issue from the airwaves.

Undoubtedly, diminished access to freshwater is a dire threat to people around the world. But consider the condition of the water when it finally trickles down people's throats. Infectious pathogens and harmful chemicals—from parasites to poisons—contaminate the world's freshwater and contribute to the deaths of millions of people worldwide every year. Understanding the effects of those contaminants holds the key to protecting our drinking water. And figuring out how we are exposed to harmful agents is the first order of business in choosing proper water-treatment techniques.

The burden of those agents weighs heavily on communities around the world. Nearly 2 million people—most of them children under five—die every year from diarrheal diseases. That statistic is not surprising when you realize just how much dirty water flows, or in many cases lies stagnant, across the continents. Nearly 20 percent of the 6.6 billion people in the world lack access to a supply of clean water, and 40 percent lack safe sanitation facilities. No new headlines there: as far back as 1981 the United Nations recognized the need for improved water supplies and sponsored a water-themed decade through 1990, in hopes of rallying international aid. Yet the percentage of people who have sufficient access to clean water supplies has remained fairly static.

Arguably, the battle is uphill. As quickly as innovative filters and water-transport systems enter the market, new contaminants and diseases arise, populations grow, and competing demands for water increase. Certain microorganisms can be elusive, causing severe illness at doses as low as one infectious organism per drink of water. And those disease-causing organisms don't stand still while we figure out how to combat them: dirty water can lead to increased virulence, as in the case of antibiotic-resistant bacteria. Battling, let alone eliminating, those ever-changing organisms, along with the plethora of synthetic contaminants, seems only to be getting more difficult.

One thing will never change: people need water for survival. Circulating inside, outside, and across our cells, water constitutes as much as 70 percent of our body weight. Although we may survive four weeks without food, our bodies last, at best, only a few days without water. Furthermore, we use water for the most basic daily activities: drinking, cooking, bathing, washing, and sanitation.

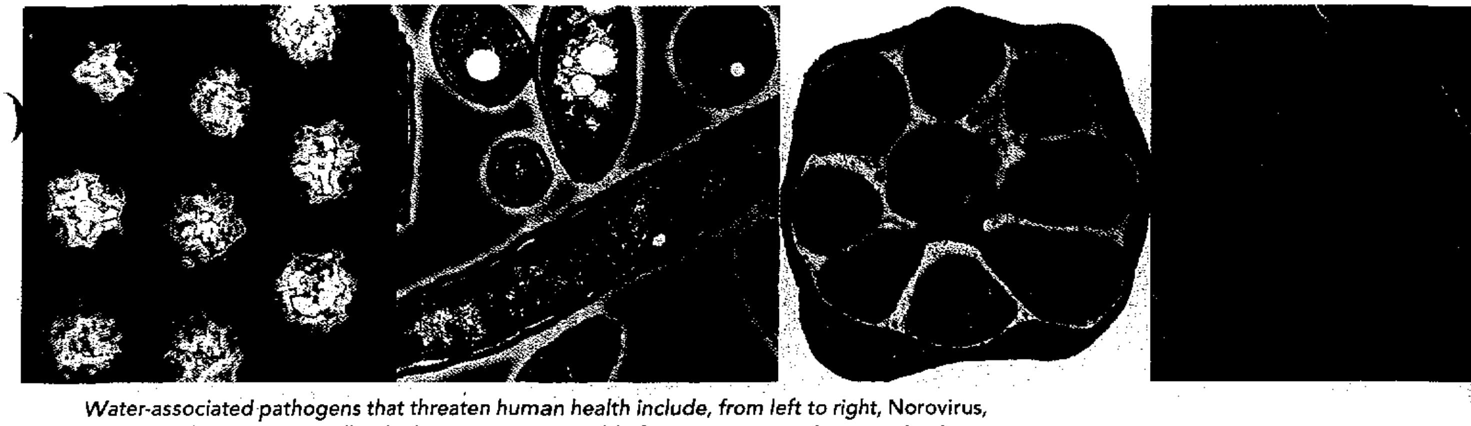
For at least the past six thousand years, civilizations have understood the need to engineer water treatment techniques. Greek and Sanskrit texts discuss approaches to water sanitation that include boiling, straining, exposing to sunlight, and charcoal filtering. The ancient Egyptians employed coagulants—chemicals that are frequently used even today to remove suspended particles in drinking water—and other methods of purification. The earliest large-scale water treatment plants, such as the one built in 1804 to serve the city of Paisley, Scotland, used slow-sand filtration. By the 1850s London was sending all of its city water through sand filters and saw a dramatic reduction in cholera cases.

The discovery of chlorine as a microbicide in the early 1900s was a turning point in drinking-water engineering. That, in turn, led to a major advance in public health. Chlorination was initiated in the United States around 1910, and during the next several decades change was evident: the previously high mortality rate from typhoid fever—twenty-five deaths per 100,000—plummeted to almost zero. Although chlorine readily inactivates viruses and bacteria, its killing power flags when faced with hardy protozoan oocysts (developing cells), such as those of *Cryptosporidium parvum*—an agent of diarrheal disease. Another, and perhaps even nastier, drawback is that chlorine and organic matter may create carcinogenic by-products when they mix in the treatment plant. Nevertheless, chlorine is still one of the cheapest and most effective disinfectants in use today.

No panacea for water disinfection exists, however. To ensure that the water supply is clean enough to drink, most modern drinking-water plants amass an arsenal of treatment options. A multibarrier approach might include physical processes such as coagulation and flocculation (creating clumps of particles), sedimentation, and filtration, in conjunction with disinfectants such as chlorine, chlorine dioxide, chloramines, or ozone.

Such systems for cleansing community water are public investments that pay dividends. Clean water improves general health and reduces health-care costs, thereby enabling greater productivity among community members and redirection of public funds to other pressing needs. Unfortunately, rural and low-income localities cannot afford the infrastructure required for large, centralized drinking-water facilities.

On a global scale, of course, an ideal filter is natural vegetation. Protecting entire watersheds could vastly im-



Water-associated pathogens that threaten human health include, from left to right, Norovirus, *the Norwalk virus;* Legionella, *the bacterium responsible for Legionnaires' disease, a kind of pneumonia;* Plasmodium, *the protozoan that causes malaria (pictured here inside a red blood cell);* Cryptosporidium, *a protozoan that causes severe diarrhea and resists treatment with chlorine;* Vibrio cholerae, *the cholera bacterium; and* Giardia lamblia, *another protozoan that causes diarrhea.*

prove water quality worldwide; benefits could come from actions as simple as maintaining hillside growth to prevent soil erosion and flooding. But because many watersheds span several states or even countries, most management plans are politically complex. A comprehensive watershed-management plan must incorporate multiple stakeholders' needs and conflicting interests.

Water scarcity goes hand in hand with disease. As renewable freshwater becomes a dearer commodity worldwide, waterborne disease agents and other contaminants become harder to control. When dealing with diarrheal diseases, for instance, the quantity of available water often matters more than the quality, both to fend off the disease and to foil its spread. Then there's trachoma, a condition that can cause blindness; today it affects 6 million people and is associated with poor personal hygiene, often resulting from a dearth of water.

Every person, every day, needs at least thirteen gallons of water for drinking, cooking, bathing, and sanitation. In 1990 more than a billion of the world's people used less than that. By contrast, average per-capita water usage in the U.S. now exceeds 150 gallons a day. That discrepancy illustrates how the level of personal use correlates not only with the economic development of a region, but also with the degree of urbanization and with the overall public health in the region.

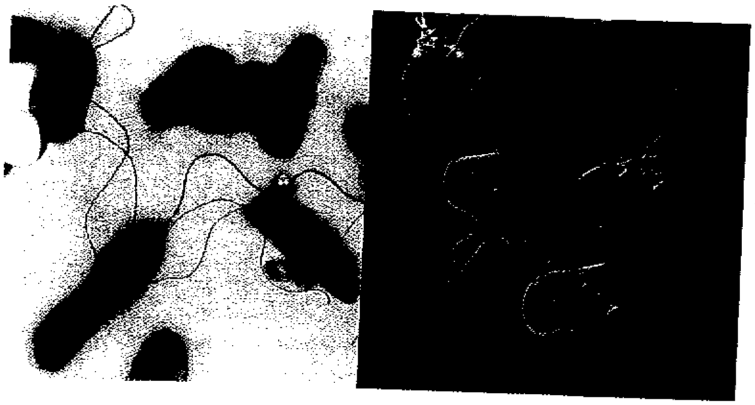
All that water filling swimming pools and soaking gardens might seem extraordinarily wasteful, but only 8 percent of the planet's freshwater supply goes toward personal, household, and municipal water use. Agriculture accounts for 70 percent, and industry for 22 percent, of current freshwater use. It takes more than fifty gallons of water to produce a single cup of milk. That's modest as virtual water content goes: consider a quarter-pound hamburger (470 gallons) or a cotton T-shirt (520 gallons). Then consider how many cotton T-shirts are tucked away in your closets. It's no surprise that demand is exceeding supply.

Daily water needs are exceedingly hard to meet in areas where rapid urbanization is taking place. Antiquated water-supply systems are simply not equipped to provide enough water and sanitation to people living in progressively crowded shantytowns or on the urban fringe. About half the world's people are now city dwellers. This new urban majority puts great stress on infrastructure, increasing the likelihood that illegal connections will be inserted into existing water systems and that, as a result, the piped drinking water will become contaminated.

Countries undergoing urban population booms often face acute microbial hazards. In countries where per-capita income is low, roughly 200 children under the age of five die every hour from a water-associated microbial infection. Many of the infections derive from the ingestion of water contaminated with human or animal feces that carry pathogenic bacteria, viruses, protozoa, or helminthes. That's the classic, but not the only, pathway for waterborne disease spread.

Exposure to contaminated water extends beyond the drinking fountain. Many diseases, once introduced into a population, can spread via person-to-person contact, in aerosol droplets, or through food preparation, rather than direct consumption of contaminated water. For example, malaria-carrying mosquitoes use stagnant water as a breeding ground; *Giardia* can be acquired during a swim in a local lake; clothing or bedding may carry scabies mites; noroviruses can be transmitted by eating oysters [*see photomicrographs on these two pages*].

Emerging infectious diseases (the ones whose incidence in humans has increased in the past two decades or threat-



ens to increase soon) have recently caused some public-health scares. Noroviruses—headlined for causing cruise ship infections—are already on the rise. *Cryptosporidium parvum* sickened some 400,000 residents of Milwaukee, Wisconsin in 1993, when the local water-treatment process was changed in what had seemed to be a minor way. *E. coli* O157:H7 is another of the more common emerging infectious pathogens in the U.S. joining the hefty ranks of dangerous bacteria, many of which are becoming resistant to multiple standard antibiotics.

Drawing copied from the wall of an Egyptian pharaoh's tomb—dated to about 1450 B.C.—depicts an early method of water purification. One person, shown on right, pours water into the purifier, while another, shown on left, appears to use suction power to draw the water through a series of filters.

But pathogenic microorganisms are not the sole cause of water-associated illnesses. Chemicals, too, pose serious risks. About a thousand new synthetic compounds are introduced every year, joining the ranks of tens of thousands more that are already in widespread use—dioxins, PCBs, and halogenated hydrocarbons included. Many inevitably seep into the water system and accumulate in the food chain. In the United States, for instance, some 700 chemicals have been detected in drinking water sources, and more than a hundred of those chemicals are considered highly toxic.

Advanced technologies enable investigators to detect harmful chemicals in the water supply, even in low concentrations—a critical step, since their effects on human health are often unknown. Several emerging chemicals of utmost concern are fuel additives, such as methyl tertiary-butyl ether, or MTBE; by-products of disinfection; antibiotics, hormones, and psychoactive drugs; the antibacterial soap ingredients triclocarban and triclosan; and persistent organic pollutants, such as perfluorinated chemicals and phthalates.

Most people have a sufficiently robust immune system to handle exposure to a certain amount of water pollutants. But some—infants, the elderly, people living with cancer or AIDS—are immunocompromised. Elderly adults often sicken on exposure to only a small fraction of the infectious dose that others require—an issue for the U.S. as it baby boomer population ages.

Just as an aging population poses a concern for public health, so too does an aging infrastructure pose a concern for water delivery. U.S. water infrastructure is outdated and deficient. In the next few decades, measures must be taken to reinforce or restore our water delivery pipes and systems, equipping them for both natural disasters and terrorist threats.

Once again the United Nations has declared a water decade: 2005 through 2015 will be the Water for Life Decade. Among the UN's Millennium Development Goals outlined for the decade are reducing the number of people worldwide who lack adequate water and sanitation by half. Additional efforts will concentrate on curbing the unsustainable exploitation of water. As with the UN's approach to increasing literacy, facilitating income generation, and curbing population growth, the focus will be on empowering women as a means of achieving its goals.

Certainly the goals are challenging. Achieving them will require cooperation among many stakeholders who are committed to expanding investments in water and wastewater infrastructure. New management strategies must embody conservation and efficiency for people everywhere, lest we find ourselves changing too slowly to quench the world's thirst. □

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