CHAPTER 11

Aqueous Solutions

Drilling to China — More water than rivers — Saving the aquifer — Drying with Xeriscapes — Everywhere in the house — Rainwater and graywater — Creating urban watersheds — Wastewater equals food — Watering the community

WE LIVE ON THE WATER PLANET. THREE-FOURTHS OF THE EARTH'S SURFACE is covered by water. Yet fresh, clean water is scarce and getting more so. Of all the water on earth, less than 3 percent is fresh, and all but three-thousandths[1] of that is locked up in glaciers and icecaps or is too deep in the earth to retrieve. The freshwater available in rivers, lakes, and accessible groundwater is increasingly polluted.[2] Despite nearly 200,000 square miles of reservoirs to store more than 1,400 cubic miles of water — a redistribution of natural flows that has measurably changed the orbital characteristics of the planet[3] — even whole cities the size of Mexico City are steadily becoming shorter of water, and water scarcity has changed global patterns of grain trade.[4] As the land's water-holding green skin changes to water-losing brown scabs, water tables are retreating on every continent, with 70 percent of the pumping to irrigate crops.[5] Tucson's water table is retreating toward the People's Republic, while Beijing's water table is getting closer to the United States.[6] The consequences are not merely local. Water is becoming a significant cause of international conflict.[7] To make matters worse, global climate change could intensify the droughts that have sporadically devastated and desertified subcontinental areas.

The answer to decreasing supplies of freshwater is not to try to supply more.[8] Human beings already use one-fourth of the earth's total water in natural circulation, and over half of the accessible runoff.[9] New dams might modestly increase available runoff but are costly and environmentally damaging. Even if most of the good sites had not already been taken long ago, no supply strategy could keep pace with the present rate of population growth and demand.[10] While population will probably increase 45 percent in the next thirty years, increases in accessible runoff are projected to be only 10 percent. Even after investing some $400 billion in water supply over the past century,[11] the United States, with all its wealth and technical prowess, faces shortages that have no easy remedies. As one authority put it in 1984, "The water supply of the West is nearly fully utilized. It is difficult to see major construction projects which will add significantly to the current supply."[12] Moreover, America's eighty thousand dams and reservoirs were not entirely benign: During the boom years of water-capturing projects, the United States lost over 60 percent of its inland wetlands, polluted half its stream-miles, and lost or badly degraded many major fish runs.[13] At home and abroad, with water as with energy, the only practical, large-scale solution is to use what we have far more efficiently.

Most, especially industrialized, countries, still make all the same mistakes with water that they made with energy.[14] They deplete nonrenewable supplies and seek more water instead of using inexhaustible sources more productively and enhancing their capture by restorative grazing, farming, and forestry. They rely on the highest-quality water for every task, flushing toilets and washing driveways with drinking water. They build big dams and water projects by reflex, rather than asking what's the best solution and the right size for the job.

Fortunately, this mind-set is changing. A host of available and emerging techniques is making it possible to increase radically the productivity of water directly where it's used. These technologies and management methods, and new ways to implement and reward them, can enable countries to deliver worldwide on South Africa's water-policy promise, "Some, for all, for ever." These breakthroughs come none too soon. All the water that can reasonably be obtained will be needed to feed the world in the coming century while protecting the natural capital on which all life depends.[15]

RUNNING DRY

Agriculture is responsible for about twice as much of total U.S. water withdrawals as all buildings, industry, and mining combined. It accounted for 81 percent of all 1995 consumptive use. Eighty-eight percent of the nation's 1995 irrigation water went to 17 western states, where the great majority of all water districts were mining groundwater faster than it was being recharged. This is a long-standing pattern. Freshwater flows from rivers are provided to agriculture under a program of federal subsidies that go back to the nineteenth century. California has built a vast agribusiness sector on water so heavily subsidized that 57 percent of its agricultural water grows four crops that produce only 17 percent of its agricultural revenue.[16] Arizona has long used subsidized water to flood-irrigate cotton and alfalfa in a desert. The states along the Colorado River, including five of the ten fastest-growing states in the United States, have already allocated on paper more water than is actually in the river, and in many years, the river never reaches the sea.

Many gargantuan water projects have failed to pass the giggle test. The Army Corps of Engineers wanted to pump the Missouri River uphill to recharge aquifers in and beyond west Kansas, even though there was no legal crop that farmers could grow with that water to earn enough to afford the pumping energy.[17] The 1968 Texas Water Plan would have needed seven Chernobyl-sized power plants to pump water about 3,000 feet up from the Mississippi River to a region of west Texas. The ultimate wet dream, the North American Water and Power Alliance, would have replumbed western North America. It proposed to dam the 500-mile-long Rocky Mountain Trench near Banff and Jasper National Parks, and to divert the major rivers of Alaska, the Yukon, and British Columbia to supply water to all of Canada, the western and midwestern United States (pumping over the Rockies as needed), and northern Mexico. This massive project, which was ultimately killed, would have cost the best part of a trillion dollars. Proposed with a straight face, this plan was the ultimate expression of how far some people are willing to go to put water where it isn't.

Under America's High Plains, extending from north Texas to the Dakotas, lies the Ogallala Aquifer, a deposit of Pleistocene groundwater spanning an area larger than California. By 1990, it was being drawn down at a rate of 3 to 10 feet a year to provide 30 percent of America's groundwater-based irrigation.[18] Recharged at a rate of less than a half inch per year, parts of the aquifer were getting badly depleted; half to two-thirds of the economically recoverable Texas portion was already drained by 1980.[19] Nevertheless, two-fifths of America's feedlot cattle were being fed grain made of Ogallala groundwater. Growing enough of that grain to add sufficient weight on a feedlot steer to put an extra pound of beef on the table consumed up to a hundred pounds of lost, eroded topsoil and over eight thousand pounds of Ice Age–vintage groundwater.[20]

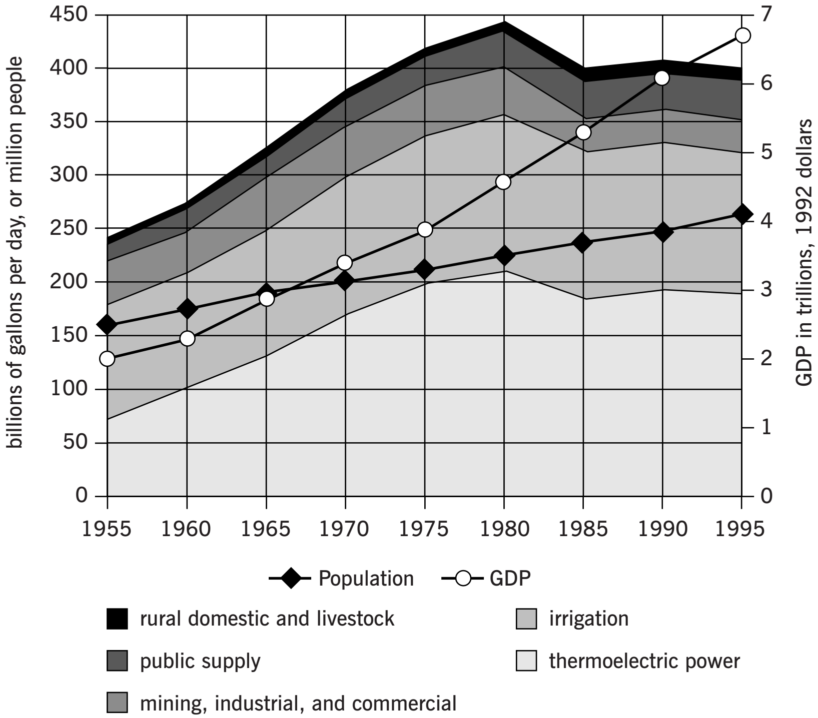
The initial "water rush" that dotted the High Plains with center-pivot irrigation (those are the circular areas of irrigated land you see when flying across the country) from the 1950s to the 1980s presumed that water resources were inexhaustible. A study of High Plains farmers and ranchers found that only half had adopted as many as three of thirty-nine available irrigation-efficiency practices.[21] By the early 1990s, depletion and pumping costs had forced hard-hit towns to rediscover dryland farming. Some, like Hays, Kansas, where water was considered abundant twenty years ago, are now turning toward water efficiency for their very survival.[22] Often the problem is not just whether the groundwater exists but also whether one can afford to pump it to the surface.

Dependence on increasingly scarce supplies is not limited to agriculture: Providing water to Las Vegas has become a regional obsession. Every drop that can be saved, bought, borrowed, or otherwise appropriated from other areas in Nevada or the rest of the West is used to fuel the city's subsidized sprawl, creating, in effect, a second Los Angeles in a country that has one too many. Even in the rainy eastern states, most cities, even those with relatively static populations, have recently suffered water shortages.

THE EFFICIENCY SOLUTION

The combination of dwindling federal water subsidies, the end of the big-dam era, energy and environmental constraints, and growing population and economic-growth pressures is creating a future of scarcer and costlier water, even in a country as rich in available water, money, and technology as the United States. Fortunately, demand-side solutions are emerging that can not only avert most water shortages but, as in the case of energy, turn deficits into abundance.

Almost unnoticed by nonspecialists, and in a radical deviation from the beliefs and experiences of water planners,[23] American farmers, landscapers, building operators, industrial engineers, and communities are making impressive progress in using water more productively. The graph opposite[24] shows that in all sectors — especially agriculture, industry, and power generation — the overall efficiency of water use has been improving since about 1980. Even as the population and the economy grew, the amount of freshwater withdrawn per American fell by 21 percent during the years 1980–95, and water withdrawn per dollar of real GDP fell by a startling 38 percent — over twice as fast as energy efficiency improved.



This success is starting to be mirrored worldwide: 1995 world water withdrawals were only about half what planners had predicted thirty years earlier by extrapolating historical trends.[25] And this is only the beginning. In every sector and every society, far larger opportunities beckon for saving water, money, and natural capital.[26]

AGRICULTURE

Nobody is more cost-conscious than an informed farmer. As Wayne Wyatt, manager of the High Plains Underground Water Conservation District in Lubbock, Texas, said, "The nerve to the hip pocket is mighty sensitive." Farmers in his district are starting to water their crops only when they need it, rather than on a regular schedule. A common technique uses a one-dollar block of gypsum, the size of a lump of sugar, buried at the root zone. Wires embedded in the gypsum run back up to the surface to a clip-on meter that indicates soil moisture. In many areas, such readings are saving one-third to two-thirds of the water with no change in crop yields, and are allowing farmers both to distribute water more evenly across a field and to schedule irrigation more efficiently. This technique also cuts pumping costs and reduces runoff of soil salts and agrichemicals.

Education in water-saving techniques is a powerful tool. A 1990–91 survey in Oregon showed that a typical three-hour visit by a consultant quickly saved a tenth to a fifth of farmers' water, and sometimes twice that amount, just through better management.[27] After making those "good housekeeping" improvements, farmers had available to them a longer list of other refinements worth investing in. In Lubbock, a decade of applying these methods saved a quarter to nearly half of the water and nearly halted aquifer depletion.[28]

Better pricing structures can provide rational incentives to invest in savings that cost less than new supplies. In California's San Joaquin Valley, the Broadview Water District set a 1989 water-intensity target at 10 percent below its 1986–88 average for each crop, and enforced a stiff surcharge on excess water use. Water use per acre fell by 17 percent and total drainwater by nearly 25 percent.[29] In California, the world's largest water wholesaler, the Metropolitan Water District of Southern California, buys back "saved" water from its distributors; just one, the Imperial Irrigation District, has invested in water-saving technologies that have allowed it to sell back 32 *billion* previously wasted gallons a year.

For the big farms that in many cases demonstrably waste half their water, the most powerful efficiency response is based on technology. Many farmers are switching to a technique that waters more than half of Israel's farmland and a million acres of California's.[30] It uses calibrated "emitters" attached to buried plastic tubes to deliver water directly to plant roots one drop at a time, as needed. Howard Wuertz's Sundance Farms grows 2,360 acres of cotton, wheat, barley, milo, corn, watermelons, cantaloupes, and sweet corn with this method in Arizona's blistering Casa Grande Valley. When Wuertz started his subsurface-drip conversion in 1980, his furrow-and-flood irrigation, though better than most, made use of only half of the water applied. His durable drip system raised this to 95 percent, and resulted in higher crop yields and other valuable benefits.[31]

Subsurface drip irrigation could be a critical factor in increasing the world food supply. Two-thirds of the freshwater withdrawn for human use worldwide goes toward irrigation. Ninety-three percent of the irrigated acres receive the water by flooding, the least efficient method of delivery. Converting just half those acres to doubled-efficiency drip and sprinkler irrigation[32] could save enough water to provide the irrigation needed to feed the extra 2.6 billion people expected by about 2025.[33]

Another Israeli innovation, developed by Arava R&D, enriches its agricultural water by growing edible fish in it under evaporation-blocking and temperature-controlling giant plastic "Aqua-Bubbles." The fish don't consume water, and add nutrients that subsequently fertilize crops. Such systems can produce about 150 pounds of fish per thousand gallons per year — an impressive use of space in the desert.[34] Researchers in Israel and at Arizona's Desert Research Institute are also making exciting progress with "halophytes" — crops that prefer brackish water, which in many countries is all too plentiful.

LANDSCAPING

Parks, gardens, and landscapes need water chiefly in midsummer when it's scarcest and costliest to provide. They often account for two-fifths to four-fifths of a water utility's peak demand. But even relatively modest improvements can reduce outdoor water use by up to 50 percent.[35]

The Xeriscape movement, a design practice that creates elegant and water-efficient landscapes, now boasts state associations from California to Florida. Well-designed low-water landscaping can be not only beautiful but also provide natural cooling, fire protection, and bird and wildlife habitat. It doesn't demand radical steps like turning lawns into cactus farms; water-frugal grasses have been developed that are as attractive as traditional varieties.[36] A state-of-the-art assessment by Jim Knopf shows that landscapes costing half as much as standard irrigated ones could almost eliminate water use in Denver's yards yet lose nothing in beauty.[37] Water-efficient landscaping also saves such inputs as labor, fertilizer, herbicides, and fuel, plus agrichemical runoff, noise and fumes, cracking of pavement and foundations, and generation of yard wastes. Water-efficient median strips in Palm Desert, California, which have been well received by the public, cut water and maintenance costs by 85 percent, and have reduced road deterioration and traffic accidents (caused by skidding on wet pavements). Savings multiply further when well-chosen plants are watered with efficient technologies managed in efficient ways, and ideally using stored rainwater.

The simplest way to eliminate the need for watering landscapes is to replant them with flora that evolution actually fitted to grow there. Shared-savings retrofits have transformed corporate campuses in much of the American Midwest from standard turf lawns into plots of diverse native grasslands,[38] creating a tourist magnet — a "panorama of grasses and wildflowers, producing a . . . diverse mixture of colors and textures throughout the seasons."[39] AT&T found that both initially and over time, such a planted prairie near Chicago would cost far less[40] than bluegrass. In addition, bluegrass was bred in moist Kentucky, so it has shallow roots that trap so little water that most rain runs off, requiring irrigation even after a rain. Prairie grasses, toughened for drought and hardpan, have soil-anchoring roots over ten feet deep that water the plants for free.

BUILDINGS

Houses and commercial buildings, including their outdoor uses, account for 12 percent of America's freshwater withdrawals. A typical U.S. single-family home uses about 70 gallons per person per day indoors. This would fall to about 52 with minimal improvements, or to 40 (of which 20 can be returned as graywater[41] reusable for watering outdoor plants) by introducing a more efficient toilet, clothes washer, dishwasher, showerheads, and bathroom faucets, plus graywater toilet flushing. Even more impressive improvements are now becoming available in every one of the following fixtures and appliances.

TOILETS (26 percent of indoor household use, excluding leaky toilets). One flush of a standard U.S. toilet requires more water than most individuals, and many families, in the world use for all their needs in an entire day.[42] But toilet technology has already reduced new U.S. units from the old 5–7 U.S. gallons per flush (gpf) to 1.6 or fewer, with no degradation of performance.[43] There are also three different methods to implement functional and attractive toilets that use *no* water: waterless urinals, separating toilets, and composting toilets.

Most toilet flushes are for urine alone, which can run down the drain unaided. Public-building urinals are traditionally water-flushed by always-open valves, timers, or infrared people-sensors (1–3 gpf). But the latest waterless fiberglass models[44] use liquid-repellent coatings, subtle contours to facilitate complete draining, and a special lighter-than-urine biodegradable trap liquid to prevent odors. They work well, have a lower installed cost than water-guzzling urinals, and save about 40–60,000 gallons per unit per year.[45]

Since Thomas Crapper invented the water closet, many sanitation experts have come to view it as one of the stupidest technologies of all time: In an effort to make them "invisible,"[46] it mixes pathogen-bearing feces with relatively clean urine. Then it dilutes that slurry[47] with about 100 times[48] its volume in pure drinking water, and further mixes the mess with industrial toxins in the sewer system, thus turning "an excellent fertilizer and soil conditioner"[49] into a serious, far-reaching, and dispersed disposal problem.[50] Supplying the clean water, treating the sewage, and providing all the delivery and collection in between requires systems whose cost strains the resources even of wealthy countries, let alone the 2 billion people who lack basic sanitation. The World Health Organization has stated that waterborne sanitation cannot meet *any* of its declared objectives — equity, disease prevention, and sustainability[51] — and suggests that only with more modern (waterless) techniques can the world's cities be affordably provided with clean water for drinking, cooking, and washing.[52] Meanwhile, a new, village-affordable solar-powered water purifier can stop the tragedy of waterborne disease.

A more sensible design than obsolete flush toilets has been introduced by modern Swedish toilets. These feature a two-compartment bowl to separate urine, which contains most of the nutrient value in human wastes,[53] from feces: The two leave the body separately, and should be disposed of that way. It is then a straightforward procedure to collect or sell the urine (stored in a small tank) from a tap outside the building as a valuable fertilizer,[54] and to dry and bag, compost, or otherwise treat the 20-odd pounds of feces per person per year. In Sweden, a country noted for hygienic and aesthetic refinement, more than 50,000 such dry systems have been sold in 42 models from 22 manufacturers; they cost scarcely more to buy and can cost less to install than a nonseparating toilet plus its sewer connection.[55] If perfected in a form attractive to the American market, separating toilets could greatly reduce toilets' water use, perhaps even to zero for dry or composting solutions. The toilets would save sewage-collection, sewage-treatment, and agricultural costs and would improve topsoil.

SHOWERS (18 percent of indoor use). The great American shower traditionally used about 6–8 gallons per minute (gpm), and many still do. Since 1992, the legal maximum for new units has been 2.5 gpm. But today you can take a shower just as pounding, needly, or whatever pattern you prefer by choosing from over 30 marketed models of high-performance showerheads that use only 1.0–1.5 gpm or even less.

A high-performance showerhead retails for about $13 but pays for itself in mere months from water-heating energy savings alone.

Some advanced showerheads[56] have only a single orifice made of slippery plastic, so they can't clog even in the hardest water. Their mixing chamber emits a powerfully wetting and massaging combination of air and water. One variant offers a satisfying shower with just a few pounds of pressure per square inch — produced by the gravity head from an attic tank — yet uses only 1.5–2.0 gpm.[57] Also available for the frugal or curious are clip-on "taximeters" that measure flow and temperature and display elapsed dollars.

SINKS (15 percent of indoor use). Sinks are another big water user, but faucet retrofits are among the cheapest and easiest savers. A screw-on one-dollar gadget combines the water with air to make a foamy mixture that wets better with about half as much water. A little flip-valve allows the flow to be turned off momentarily, then return to the preset temperature without wasting water readjusting the hot/cold mix. Alternatively, internal baffles and channels in a 1.5–2.5-gpm "laminar flow" device[58] deliver a smooth, solid stream of water that sticks to and wets things just as well with half the water, but turning it up to full flow can fill a pot with no delay.

CLOTHES WASHING (23 percent of indoor use) and dishwashing (1 percent). Washing machines have changed little in a century. The standard American vertical-axis design agitates clothes in a big tubful of water. In contrast, horizontal-axis machines, common overseas and in U.S. laundromats, put about 40–75 percent less water into the bottom of a tub and rotate the clothes through it.[59] Soap works better in these machines because it's more chemically concentrated. Clothes last longer because they're not agitated; tangling is also eliminated, and more space is available for bulky items. Spin cycles become shorter, better balanced, and more effective. These advantages, and the spur of federal standards, led most U.S. manufacturers of washers to introduce horizontal- or diagonal-axis machines in 1996–98. Such resource-efficient machines recently yielded a 3.5-year payback in a Portland, Oregon, laundromat, whose customers report lower wash costs and cleaner clothes.[60]

The widely available enzymatic detergents that eat fat, protein, and starch are able to clean dishes better and faster with less and cooler water. Dishwashers are improving, too, with some models adjusting water use to match the dirtiness of the load.[61] In the late 1980s, one firm[62] even invented a small countertop dishwasher needing *no* electricity — just the line pressure of hot water from the kitchen sink faucet — to needle-spray hot water onto the dishes in a several-minute cycle followed by self-drying. Running so silently that it can be used one course at a time during the meal, that "Ecotech" could reduce water use by severalfold. That product didn't make it to market, but ultrasonic dishwashers are already being installed in American kitchens, with ultrasonic clothes washers probably close behind.

OTHER INDOOR AND SYSTEM SAVINGS. Old, neglected pipes tend to leak. Even good urban distribution systems lose a tenth of their water; the average U.S. city, about a quarter; Bombay, one-third; Manila, over half.[63] During fiscal year 1990–91 alone, New York City put 26 people and $1.5 million to work in a survey of more than 90 percent of the city's 57,000 miles of water mains. This resulted in repairs to 66 breaks and 671 leaks, and saved 49 million gallons per day.[64] Since then the whole system has been rescanned every three years, and leaks have decreased by 75–80 percent. Magnetic locking caps on fire hydrants have also reduced tampering rates to less than 10 percent, saving upward of 100 million gallons on hot summer days (if disappointing neighborhood kids). Such efficiency improvements are steadily shrinking losses, making costly supply expansions unnecessary.[65]

A tenth of typical U.S. household usage[66] is leaks from toilet valves, dripping faucets, and aging pipes.[67] Toilets are the biggest offenders, often wasting as much as 750 gallons a month versus 300 for a typical leaky faucet.[68]

Automated building leak-monitoring techniques are now becoming available, often integrated with cost-saving automatic meter-reading. In this system, acute leaks trigger alarms to customers, utilities, or plumbers.[69] Insurance companies like this concept and may ultimately share its cost or waive deductibles for customers who adopt it.

TECHNOLOGY *PLUS* BEHAVIOR. Efficiency technologies that are already commercially available can in combination double or triple water efficiency, with no loss of service or convenience, no change in the source of water, and no reliance on recovery of departing wastewater.[70] Yet water efficiency depends not only on technology but also on behavior — which in turn is influenced partly by letting people know how much water they're using, for what purposes, at what cost, with what consequences.

Over the past decade, previously unmetered cities like Denver and much of New York have been installing water meters. Charging households for their actual use, rather than a flat rate, typically saves up to a third of their water. Charges that rise with consumption ("inverted" tariffs), rather than quantity discounts, can save even more.[71] Santa Barbara's emergency tariff increased price geometrically with usage, up to 27 times the base level.[72] Often the best strategy is charging marginal cost *and* educating customers. Palo Alto saved 27 percent of its water use in drought years not only by surcharges but by hiring college students to teach high-usage homeowners about their efficiency opportunities.[73] A 1994 experiment in South Africa's arid Kruger National Park[74] used simple, unsophisticated technologies, education, and metered charges to save 74 percent of the water and 52 percent of the electricity compared with standard technologies, no education, and a flat rate. The combined effect appeared to be greater than the sum of its parts. In contrast, providing only written educational materials without introducing better technologies or price signals didn't help (water use *increased* by 3 percent).

WATER-QUALITY BENEFITS. Overpumping groundwater not only depletes the resource but also tends to draw chemical contamination toward wells. This created a water crisis for Fresno's 360,000 people, who had to shut down 35 wells and retrofit water efficiency into 125,000 homes to slow the creep of the agricultural biocide dibromochloropropane.[75] In San Simeon, California, efficiency that reduced groundwater pumping by 28 percent in one year alleviated the intrusion of salt water into freshwater wells.[76] Irrigation efficiency in Nebraska's Central Platte Natural Resource District reduced the leaching of nitrogen fertilizer into aquifers, cutting dangerous nitrate levels in wells.[77]

Water efficiency can likewise relieve an overloaded sewage-treatment plant without costly upgrades or expansions, and can usually allow the plant to function better, because of reduced flows. Efficiency enables individual septic systems to work better, too. One 12-house survey found that saving a quarter to a half of household water use greatly reduced malfunctions of septic systems, made their treatment more effective, and would probably lead to lower long-run operating costs.[78] In states like Florida, where about two-fifths of households use individual, on-site wastewater treatment, this triple bonus — better water quality as well as more secure and more affordable supplies of water and energy — is of strategic importance.

INDUSTRY

The graph on page 217 likewise illustrates the dramatic water savings that have been achieved by American industry. These have often included reductions in pollutant discharges too. In 1995, nonagricultural businesses withdrew 38 percent less water than in 1970, while producing 69 percent more real output, which represents a 63 percent reduction in water intensity.[79] California's industries achieved even faster savings in the 1980s — a 46 percent reduction in water intensity in only ten years.[80] Further examples suggest that far greater savings are still achievable:

- Pacific Coca-Cola reduced a can line's need for rinsewater by 79 percent by using air instead of water to clean the insides of cans before filling.[81]
- A Calvert County, Maryland, senior citizens' center proposed to build 50 more apartments. New water and sewer hookups were going to cost $135,000. Instead, retrofitting 1.6-gpf toilets into existing units saved 58 percent of the center's water, which freed up the needed capacity at a cost of only $16,000.[82]
- A North German manufacturer of paper products for packaging almost ***eliminated*** its water use by completely recycling its base supply in a sophisticated process that successively sediments, floats, and filters the fiber and particulate loads from the water. Only 1.5 pounds of water per pound of paper is still needed to offset evaporation and provide the water content of the paper itself. This residual water requirement is 600 times smaller than the European norm in 1900, or about 15–20 times below the recent German norm.[83]
- During the years 1972–93, Gillette Company reduced the water used to make a razor blade in its South Boston Manufacturing Center by 96 percent. During the years 1974–93, Gillette's water use to make a Paper Mate pen also fell by 90 percent.[84]
- Armco's Kansas City steel mill, now called the GST Steel Plant, uses its water at least 16 times over, purifying it in between uses in settling ponds. It now takes in only 3.6 million gallons a day even though it uses 58 million gallons a day. Additional clarifiers and settling ponds are planned to increase water recycling still further and achieve zero discharge ahead of tightened standards.[85]
- Even in making microchips — one of the industries with the most stringent requirements for water purity — water recycling up to 85 percent has been effectively achieved.[86]

RECOVERING RAINWATER AND GRAYWATER

Whenever it rains, naturally distilled water falls on buildings. It flows off their impervious roof surfaces, is guided into gutters, is quickly sent into sewers to be combined with human and industrial wastes, and is then "taken away" at great expense.

In contrast, the roof of Mike McElveen's house in Austin, Texas, collects the local average of 32 inches of rain a year into two 8,400-gallon tanks. When full, they can provide a hundred gallons a day — enough for two people in his moderately water-efficient household[87] — even if it doesn't rain for five and a half months. Unlike the region's well water, rainwater is soft and pure, and requires no treatment.[88] The system has met all the needs of his two-person household since 1988, and even worked well during a three-year drought. The capital cost of the tank, plumbing, and enhanced water-catching surface was less than the cost would have been for redrilling the well or tapping into a newly formed rural water district. The water bills are zero, and the tanks, obviously oversized, have never fallen below 70 percent full.[89] Such on-site systems may even yield other savings because their big containers, which are often positioned at a height that can gravity-feed a hose, can reduce fire-insurance premiums.

Harvesting rainwater, common in the nineteenth-century United States, remains standard practice today even for affluent households in Hawai'i and in such islands as Bermuda, where many areas have no public water supply. In many regions of Australia, rainwater collection systems are mandatory. Rainwater-holding cisterns are affordable when measured against the water-supply and storm-water-drain investments they make unnecessary. A case study[90] in Byron, Australia, found that cisterns devoted half to supply and half to storm-water detention — the cisterns are normally kept half empty to leave room for storm water — would be cost-effective for the drainage authority to pay for. They could reduce sewer-pipe sizes, and would be almost cost-effective for the water supplier compared to other supply alternatives. These savings together could finance private cisterns from avoided public costs.

Rainwater could even be captured at the scale not just of a single house but of a whole basin. One day in August 1998, while the rest of Los Angeles sweltered under a clear summer sky, Mrs. Rozella Hall's 1920s bungalow in the South Central inner city suddenly experienced an isolated 28-inch cloudburst — 8,000 gallons in 20 minutes.[91] It came from fire hoses. A project led by Tree People was demonstrating several retrofit techniques. Two 1,700-gallon electronically controlled cisterns,[92] redirected downspouts, retention grading (slightly sunken and bermed lawn areas to hold rainwater until it can percolate into the ground), a driveway drywell (to recharge groundwater but first catch engine-oil drippings), and a grassy or mulched swale for further filtration kept all the surface water on-site. Such measures can sponge up deluges from winter storms and make them last all year. Replicated citywide, this could cut the city's water imports by 50–60 percent, help control flooding, and reduce toxic runoff to the ocean. It would improve air and water quality, save energy, cut by 30 percent the flow of yard wastes to landfills (it would instead be mulched and composted as a water-catcher and soil-builder), beautify neighborhoods, and create direct jobs (perhaps including 50,000 "urban watershed managers"). An interactive software package now enables city managers to quantify the multiple benefits of such management practices.[93] In a city like Los Angeles, where two agencies that hadn't talked to each other are spending a billion dollars a year to import water and a half billion dollars a year to take it away ("flood control"), closing the water loop could save money at both ends.[94]

Another ubiquitous but normally wasted water resource is the "graywater" from showers, sinks, tubs, and washing machines — in effect, all of a household's discharged water except "blackwater" from toilets. After widespread droughts in the 1980s and 1990s, the California legislature, following the lead of Santa Barbara and other localities, passed statewide guidelines in 1994 for the safe use of graywater for subsurface irrigation. The California Plumbing Code[95] now defines how graywater should be controlled to protect public health, keeping it underground and off food crops. Typical recovery and reuse rates average about 50 gallons per house per day, cutting total water use about in half, and saving even more in multifamily and commercial buildings where graywater is used to flush toilets. Such a system at the Roseland III office park in Essex County, New Jersey, cut the 360,000-square-foot complex's water use by 62 percent.[96]

Many buildings in Salt Lake City deliver brackish water in a separate plumbing system specifically for flushing toilets. The utility in St. Petersburg, Florida, developed a similar dual distribution system to use reclaimed water for nonpotable needs, providing about 20 million gallons a day, or one-third of the city's total consumption, for such functions as irrigation and cooling. This plan will eliminate the need for new water sources and expansions to water facilities until 2025.[97] In the Los Angeles area, sanitation districts resell an annual average of 63 million gallons per day of reclaimed tertiary-treated effluent that is virus-free and meets or exceeds bacterial and other drinking-water standards. It's used at more than 140 sites for such nonpotable purposes as irrigating parks, golf courses, and food crops, watering livestock, filling recreational lakes, running industrial processes, supplying cooling towers, construction, and for groundwater recharge.[98] In early 1998 San Diego announced America's first major municipal project to reroute reclaimed tertiary-treated wastewater directly back into reservoirs. Throughout the United States, more than a thousand projects reclaim water, but they provide less than one percent of total usage. In contrast, Israel's reclaimed total was 4 percent in 1980, and 8 percent (reclaiming 40 percent of total wastewater) in 1998.[99]

RECOVERING WATER FROM LOCAL BIOLOGICAL TREATMENT PLANTS

The World Bank has stated that North American and European sewage-treatment practices

> . . . do not represent the zenith of scientific achievement, nor are they the product of a logical and rational process. Rather, [they] . . . are the product of . . . a history that started about 100 years ago when little was known about the fundamental physics and chemistry of the subject and when practically no applicable microbiology had been discovered. These practices are not especially clever, not logical, nor completely effective — and it is not necessarily what would be done today if these same countries had the chance to start again.[100]

Most sewage-treatment systems are large, centralized, and capital-intensive: Los Angeles alone collects a billion gallons a day through 6,500 miles of pipe. Studies have already shown that when an electrical system is similarly designed, its economics suffer, for reasons that appear equally applicable when what is flowing is not electricity in wires but water or sewage in pipes: In both cases, the connection to the customer is too long and costs too much.[101] There is growing evidence that smaller water delivery and wastewater treatment systems — often at the scale of the neighborhood or even the single building — can provide cleaner water at much lower cost and without environmental or safety hazards. An official study in Adelaide, the capital of South Australia, found that while typical large sewage-treatment plants do gain some economies of scale, they also gain bigger diseconomies because they must pay for the sewer network to collect wastes from a larger area. That network's pipes and pumps often account for about 90 percent of the total cost of wastewater treatment. Designed to capture only the advantages of treatment-plant size without counting its collection costs, standard designs are probably at least tenfold, and may even be a thousandfold, larger than an economic optimum.[102] Small-scale systems "can be more readily developed and appear able to compete against the existing systems."[103]

Some experts believe that the whole concept of sewage has been called into question by the new composting and separating toilets described above. But since most people in developed countries already use flush toilets, and probably will for a long time, the more favorable economics of smaller-scale sewage treatment[104] are leading to a rethinking of the sewage-treatment *process.* This includes measures like switching from chemical engineering to biological techniques that already — even at their relatively early stage of development — offer striking ecological and economic advantages.

The leading practitioner of this approach, Living Technologies, Inc.,[105] designs, builds, and operates innovative wastewater treatment systems called Living Machines that eliminate the need for the chlorine, polymers, aluminum salts (alum), and the other chemicals used in conventional wastewater treatment plants. A biological treatment plant costs about the same or less to construct, especially for small-capacity systems. It yields valuable fertilizers and soil amendments instead of toxic chemical hazards, looks like a water garden, greenhouse, or wetland, doesn't smell bad, and yields safer, higher-quality water.

Invented by biologist Dr. John Todd, the Living Machine treats wastewater as it moves through a series of mainly open tanks, typically located in passive-solar greenhouses. The tanks are populated by an increasingly complex series of organisms: bacteria and algae, then plant communities, and finally miniature, engineered ecosystems, including large fish and shellfish. Fixed film substrate, plant roots, and tank surfaces anchor plant roots while water moves past. The resulting controlled ecological system maximizes biological degradation of contaminants by treating them not as waste but as food. These ecosystems provide a higher degree of biodiversity than previous biological treatment technologies (which were based on only a few species), thereby treating a wider range of contaminants with greater stability and resilience. Some plants, such as bullrushes and certain flowers, sequester heavy metals, secrete antibiotics that kill pathogens, or otherwise protect human health. A simple ozone or ultraviolet treatment of the final output water (usually stored in an attractive pond or wetland habitat) would even make it potable.

Living Machines deliver higher effluent quality than conventional secondary sewage-treatment systems. Operating costs are roughly the same and sometimes less. Energy consumption is similar, but a few advances likely in blowers and system design (on the line of the "big pipes, small pumps" in chapter 6) may give Living Machines an advantage. As advanced as this technology is over conventional wastewater treatment, it represents only the beginning of what is possible. At present, only a fractionally small number of organisms are being drawn upon to produce these results. After a more complete assay of the earth's biota, we may expect to see great improvements in efficiency including a diverse array of saleable compounds and by-products.

By 1998, the company had installed twenty-three systems in the United States and six other countries. They are permitted in seven states, and existing designs serve from one household to ten thousand. Being odor-free and aesthetically pleasing, the systems should face less local resistance than conventional wastewater treatment plants, and present no chlorine or other chemical hazard. In chilly South Burlington, Vermont, a 6,400-square-foot Living Machine that reached full design flow in April 1996 is treating 80,000 gallons of municipal sewage per day, outperforming all its design targets and proving compatible with a residential neighborhood.

The technology also lends itself to integration into normal commercial settings. Visitors could enter an elegant corporate headquarters through a garden of cascading water flows, featuring a series of landscaped tanks full of flowers, fish, water plants, and other organisms — discovering only later that the garden was actually the building's sewage-treatment plant. Oberlin College's new Environmental Studies Center building and the Body Shop in Toronto have adopted this very strategy. The ability to integrate Living Machines into the landscape also suits them to industrial and food-processing use. The Mars Company's positive experience treating difficult industrial wastes in Henderson, Nevada, and Waco, Texas, has spurred the firm to order three additional systems for plants in Brazil, Australia, and the United States.[106]

IMPLEMENTATION

Many water efficiency programs had their origins in water shortages, because the threat of running dry does tend to concentrate people's minds. (Water efficiency professionals speak of the "hydro-illogic cycle": drought, concern, rain, apathy, drought, concern, rain, apathy. . . .) Nonetheless, many of the most successful efforts worked not because they exploited a teachable moment but because they, like other kinds of resource efficiency, provide better services at lower cost.[107]

In Goleta, California, drought and the threat of a multimillion-dollar expenditure to meet EPA sewage-treatment standards spurred a $1.5 million municipal program that provided information and incentives to the town's 74,000 citizens to reduce water waste. Technical improvements, plus some emergency drought measures (peak-season surcharges and a little rationing),[108] cut citywide water consumption within the single year from 1989 to 1990 by 30 percent, from an average of 135 to 90 gallons per person per day — twice the targeted savings. Sewage flow fell by over 40 percent, enabling the existing plant to run within its rated capacity and EPA secondary standards.[109] The proposed plant expansion was indefinitely deferred. The total water savings later grew to 40 percent. In the dry summer of 1990, while some nearby communities were forced to cut their water use by 30–45 percent, Goleta had only to set a 15 percent goal, avoiding disruption or hardship.

In large cities, broadly based efforts at fixture replacement, leak reduction, metering, technical advice, and rate restructuring have yielded steady improvements. Despite population growth, New York's water use is 18 percent below its peak and falling[110] — relieving pressure on sewage-treatment plants, five of which were overloaded and six about to become so. Boston has inexpensively saved 24–27 percent of its water through leak repairs and retrofitting nearly half the housing stock with leak reductions, better showerheads, faucet aerators, and toilet dams (full toilet retrofits would save even more). The more than 1,000 facility engineers and managers whom Boston trained and networked will also apply their knowledge over the course of many years, as will the next generation of Bostonians, now being educated with multimedia campaigns, teacher training, and new school curricula.

In the poor, mainly African-American and Hispanic neighborhoods of East Los Angeles, a unique partnership between community groups and a for-profit third-party firm, CTSI Corporation,[111] was formed in 1992. The coalition tackled the problem that $100 utility rebates for toilet replacements didn't help the many customers who couldn't afford to pay the balance, or those who had to wait two months for the rebate to be delivered. CTSI arranged with the utility to bulk-buy 1,000 initial toilets and use their rebates to pay for more toilets that nonprofit community groups like Mothers of East LA Santa Isabel (MELA-SI) could then give away. Soon people were lining up at convenient sites, often run by their neighbors, to bring in their decrepit, inefficient old toilets (which got recycled into road base) and exchange them for new ones plus high-performance showerheads and compact fluorescent lamps. This swap cut water and energy bills by about $30–120 per household per year, putting money back into residents' pockets and into community economies. The Metropolitan Water District of Southern California contracted with CTSI to make the program available throughout Los Angeles and Southern California. MELA-SI and eight other community groups that later joined the program earned over $1 million participating in the programs. They used these earnings to hire and train local staff, some from the unemployment rolls, and to fund such community benefits as immunizations, graffiti abatement, day care, scholarships, and inner-city business development. High-school students also marketed one-day distribution "events" at their schools — earning one school, through $15-per-toilet fees, $30,000 to re-fund student activities that had fallen victim to budget cuts. By the beginning of 1996, community groups working with CTSI had distributed more than 300,000 toilets, saving over 3 billion gallons of water per year and creating over a hundred jobs. Utility rebates in various communities citywide brought the Los Angeles total of 1.6-gpf toilet retrofits by January 1998 to about 33 percent.[112]

With indoor water as with landscape design and energy, "service contractors" are available who will choose, install, and maintain energy-efficient technologies in schools, hotels, and apartments in return for a share of the savings.[113] Denver, Colorado, is encouraging such entrepreneurs by incentivizing retail water distributors, the city's parks department, and the private sector with payments for however much water they save. Businesses and irrigators can then use the payments to hire contractors to design, implement, combine, and measure the savings.[114]

Community programs that are successful typically involve a variety of constituencies and kinds of expertise. Western Australia has mobilized plumbers, who have practical knowledge of the subject, as the vanguard of the water efficiency education and installation effort. Other potential allies include water, wastewater, energy, religious, labor, economic development, social justice, environmental, fish and wildlife, and real estate organizations. There are also new methods of implementation that create markets in saved water, and promote competition to capture the cheapest opportunities first. For example, in Connecticut, Washington, and California, different utilities that provide water, wastewater treatment, electricity, and gas are teaming up to share the tasks and costs of distribution, marketing, administration, and product selection for water-efficiency programs that benefit them all.[115]

As usual, the greatest benefits from saving water emerge from the broadest vision of connections and the widest integration of design. The natural drainage control and water storage described in chapter 5 not only saves capital and irrigation water; it creates better places to live. It also avoids vast investments in storm drains, funding reinvestments for even greater value. From Chicago to Chattanooga to Curitiba (chapter 14), this new approach to urban hydrology is starting to capture rain as it falls, put it back into groundwater, and green the city.

Letting water flow wherever it belongs on the Water Planet is a key part of the wisdom of natural capitalism. For as Carol Franklin of the landscape architecture firm Andropogon puts it, water is not, as most civil engineers assume, mere gallons of H_2O, to be taken away as quickly as possible in large concrete pipes. Water is *habitat.* Water is life.