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Water: Is There Enough and Is It Drinkable?

Men work on earth at many things;
Some till the soil, a few are kings;
But the noblest job beneath the sun
Is making Running Water run.

—John L. Ford, *Water and Wastewater Engineering*

Few of us think regularly about water. It seems limitless because it falls from the sky year after year. We turn on the tap and fresh, pure water comes out. Most of us have never known it to be otherwise. But problems that water specialists saw on the horizon many decades ago are now with us. Water shortages are a well-known problem not only in desert areas such as Tucson, Phoenix, Las Vegas, and Albuquerque but also in moister places like New York City. As America's population continues to grow at its current rate of 3 million each year, water shortages will creep into other large cities as well. Adding to the water problems caused by increasing numbers is the increasing concentration of our population in cities. The nation's population is increasing about 1 percent per year and the growth of cities is much faster. About three-quarters of all Americans now live in large cities. That is where most jobs and growth opportunities are.

Perhaps even more frightening than the looming shortage of water is the amount of impure water we are drinking. Despite marked improvement since passage of the Clean Water Act 35 years ago, the United Nations estimates that 5.6 million Americans (2 percent of us) drink water that does not meet safety standards. Chemical contaminants are present in all our major streams and in 90 percent of our underground aquifers. Twenty-four percent of Americans refuse to drink tap water. Sixty-five percent take such precautions as treating water in their homes by filtering or boiling it.

More than half of us drink bottled water despite a 1997 UN study that showed bottled water was in no way superior to New York City tap water. And the Natural Resources Defense Council in 1999 estimated that at least 25 percent of bottled water is in fact ordinary tap water. One bottled-water supplier was found to be drawing its water from a well in the middle of an industrial parking lot next to a hazardous waste site![1]

There probably is more than one reason more than half of all Americans drink bottled water. Not only suspicions about our city's water may be involved. Thanks to advertising, there is a certain cachet or possibly snob appeal to imbibing a glass of Perrier or Evian imported from France rather than the liquid the city supplies. But whatever the reason, bottled water is the fastest-growing major beverage category in America. On average, each of us in 2000 drank 53 gallons of bottled water (table 1.1). Sales have increased ninefold in the past 20 years, tripled in the last 10, and increased 30 percent between 2000 and 2001 and 11 percent more in 2002, despite the fact that bottled water costs 120 to 7,500 times more than tap water and 6 times more than gasoline.

Even our treasured pets can enjoy the thrill of bottled water designed especially for them. The K9 Water Company in California (of course, where else?) sells beef-, liver-, chicken-, and lamb-flavored bottled water for dogs. You can even get all four in a combo pack "so your dog can decide . . . "

Table 1.1
Beverages Americans drink in gallons per year (International Bottled Water Association)

Water	140
Tap	87
Bottled	53
Carbonated soda	59
Coffee	46
Juice	43
Milk	39
Tea	27
Alcoholic drinks	23
New age beverages	14
Sports drinks	11
TOTAL	402

Pollution from farms, factories, and even the pipes that bring the water to our homes is increasing. Underground water supplies in about half the states have been contaminated with hazardous wastewater legally injected into it. The wastewater came from chemical plants and other industrial sources that produce materials essential to the way we live.

Lead in drinking water is a problem in many major cities, including Chicago, San Francisco, Boston, New York, and Washington, our nation's capital. Water pipes in buildings built before 1960 were made of lead, and lead solder to seal water pipes was in use until 1988. It is uncertain how many Americans have health maladies caused by ingesting lead. Lead causes brain damage, among other maladies, but we do not know whether the lead in Washington's drinking water, where 16 percent of the water pipes are made of lead, has affected legislative judgment in recent Congresses. The way we waste and contaminate our water supplies has generated a new word—*hydrocide,* patterned after the more familiar word *suicide.*

The Water Cycle

> The journey of water is round, and its loss, too, moves in a circle, following us around the world as we lose something of such immense value that we do not yet even know its name.
>
> —Linda Hogan, *Northern Lights*

Most of America's large cities use surface water. The amount of surface water available to each American for all purposes (personal, industrial, agricultural, and so on) from rainfall, rivers, and lakes is 138,000 gallons per day. This number is the result of a system of water circulation known as the *water cycle.* Pure water is evaporated from the salty ocean, is carried by winds over the land surface, and as air temperatures and land elevations change, the moisture is dropped from the air onto a thirsty population. Most of this moisture falls on land, runs off into streams and rivers where it is available for our use, and eventually finds its way back to the ocean. Some of this heaven-sent moisture is taken directly into plants and combined with carbon dioxide gas from the air to produce plant tissues (biomass). Some of the precipitation soaks into the soil and continues downward hundreds or thousands of feet into empty spaces in the underlying rocks. This becomes an underground water supply known as *groundwater.* Some precipitation falls directly into lakes, such as the Great Lakes that form part of the boundary between the United States and Canada. And some of the moisture that falls to the ground evaporates back into the moving air before it can flow into streams, enter lakes, or soak into the ground. When all these gains and losses are totaled up each of us ends up with a theoretical 138,000 gallons per day to spend as we see fit, for drinking, growing crops, manufacturing steel, or flushing toilets.

The expression "each of us" is, of course, a statistical average. Obviously, some of us end up with more than others. If you live in the Western half of the country you average less than your "fair share," perhaps 20 inches of rain and snow a year. If you live in the Eastern half, your cup runneth over with perhaps 40 inches a year (figure 1.1). Life is not fair. Neither is the distribution of water. But we must deal with the world as nature provides it. How do Americans deal with it? The answer is "very wastefully." All of us contribute to the national hydrocide. Consider the following facts.

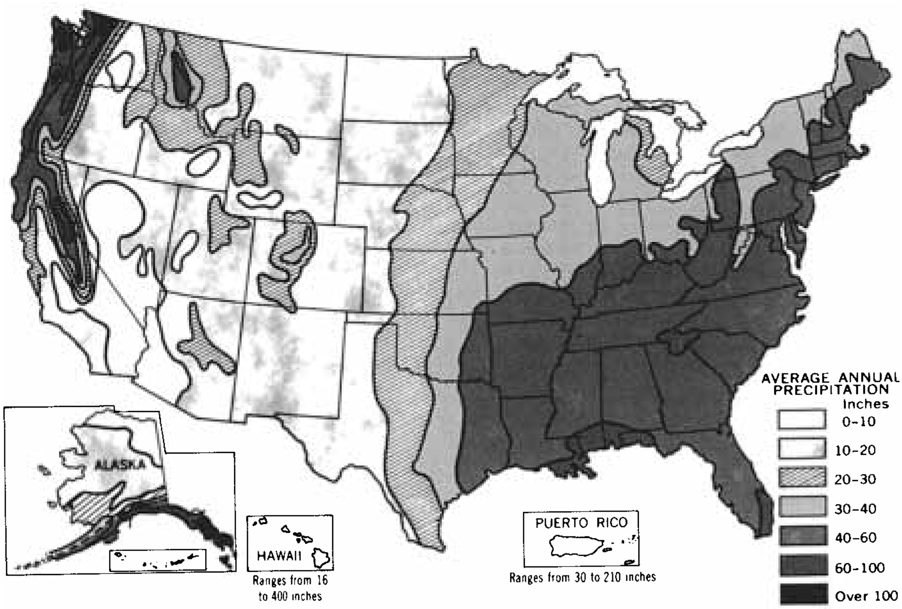

Figure 1.1
Average annual precipitation in the United States (U.S. Water Resources Council, 1968, *The Nation's Water Resources*).

• The channel of the formerly mighty Colorado River in the Western United States is dry when it reaches its outlet at the Gulf of California, the result of too much removal by users upstream.

• Water is being removed from underground reservoirs many times faster than it is naturally replenished. Most of the withdrawals from our underground water bank are for crop irrigation.

• Water usage in the United States has increased sixfold since 1900 although the population has increased less than fourfold.

• One in five Americans drinks water from a treatment plant that violates safety standards. Forty percent of these plants release water with dangerously high levels of disease-causing bacteria.

• According to the U.S. Geological Survey, the water in 47 percent of city wells contains toxic organic compounds. In rural areas, 14 percent of wells contain these chemicals. Over a person's lifetime, ingestion of these chemicals has adverse health effects such as cancer and reproductive problems.

Let's look at these factors in our national hydrocide to see why we have them and what we might do to remedy them.

The Colorado River

> The first thing they noticed was that the river was no longer there. Somebody had removed the Colorado River.
>
> —Edward Abbey, *The Monkey Wrench Gang*

The dry channel at the southern end of the Colorado River is perhaps the prime example of surface-water scarcity produced by human activities (figure 1.2). The river originates in western Colorado, then flows through southeastern Utah and along the boundary between California and Arizona before entering Mexico and spilling into the Gulf of California. Actually, the word *spilling* is inaccurate, because the river channel is dry at its contact with the Gulf. Humans are to blame. The Colorado River is among the most heavily plumbed rivers in the world, providing water for 30 million people, one-tenth of the American population.

The region through which the river flows is semiarid, with an annual precipitation of only 15 inches, and nearly 90 percent of this moisture evaporates before reaching the river channel. Even so, the average volume

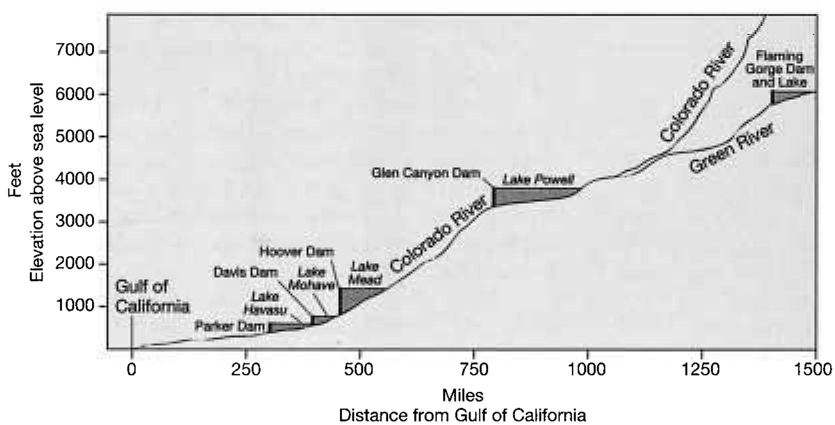

Figure 1.2
Drainage area served by the Colorado River and the dams constructed to minimize annual variations in rainfall.

of water carried by the river is more than 15 million acre-feet per year. (An acre-foot is an area of 1 acre covered with water to a depth of 1 foot; about 325,000 gallons of water, enough to supply the water needs of a family of 5 for 1 year.) You would think that 5 trillion gallons of water a year (15 million × 325,000) would be enough to keep people happy. And it was, until the increase in the number of people in southern California in the first half of the twentieth century and the growth of Las Vegas, Phoenix, and Tucson in the last half.

The influx of people to California and Arizona quickly generated water problems. Southern Californians wanted to transport Colorado River water westward to supplement the inadequate amount of precipitation that nature supplies to Los Angeles, about 15 inches per year. Phoenix, with only 8 inches of rainfall a year but with a climate that appeals to retirees from the frigid Northeast, also wanted Colorado River water. And there was a growing agricultural base in central Arizona that depended on water for irrigation. Also wanting more water after World War II was arid Las Vegas, with only 4 inches of rain per year. This city's heady mixture of gambling and prostitution stimulated its growth from a small community in 1950 to its position today as one of America's fastest-growing metropolitan areas, with a population of 1,500,000.

What should be done? Who owns the water, anyway? Legal battles over the ownership of Colorado River water brew continuously among the states that border the river and also between the United States and Mexico, because the water has been overappropriated. More water has been allocated to the states than the river can supply. Problems began in 1922 when an agreement called the Colorado River Compact divided the river into an upper and a lower part. Wyoming, Colorado, Utah, and New Mexico were to share the water of the upper part of the drainage area, and Nevada, Arizona, and California were to share the lower-basin water. The users of each part were allocated 7.5 million acre-feet per year, half the average yearly flow of 15 million acre-feet. In 1922 the yearly flow was higher than normal at about 20 million acre-feet, a heady surplus. This agreement among the states was followed in 1945 by a treaty with Mexico that allocated our southern neighbor a minimum of 1.5 million acre-feet per year. Hence, more water was allocated in these two agreements than the river contains in an average year.

As we know, an average is a central value around which there is variation. In rainy years river flow will exceed the 15 million acre-feet average; in dry years it will be less. Recall that the treaties allocated acre-feet of water to the contestants, not percentages; the allocation was 7.5 million acre-feet, not 50 percent of the annual flow. Since 1922 or 1945 there have been many years of less-than-average flow. In 1934 flow was less than 5 million acre-feet; in 1940 it was 7 million; and in 1963 and 1964 flow was a minuscule 3 million acre-feet. We have entered lawyers' heaven.

The method chosen to circumvent these unfortunate allocations was to build dams along the river, which would store water during wet years and release it during dry years. This would smooth out the yearly variations in river flow. There are now ten major dams along the Colorado River. Obviously, the dams could not change the predam average yearly flow of 15 million acre-feet. They could only make the yearly variations in rainfall less traumatic.

The phenomenal population growth in southern California, Arizona, and southern Nevada has drawn increasing attention to the inadequacy of the water supply in this region. Colorado River water provides for the households of tens of millions of people, fills swimming pools and sprinkles green lawns in Los Angeles, powers neon lights in Las Vegas casinos, and irrigates 2 million acres of farmland in southern California, southern Arizona, and northern Mexico. Turbines in the dams also generate nearly 12 billion kilowatt-hours of electricity annually. There is no long-term solution to the problem of inadequate surface water for the burgeoning population in this area of the United States.

Subsurface Water

> Humans build their societies around consumption of fossil water long buried in the earth, and these societies, being based on temporary resources, face the problem of being temporary themselves.
>
> —Charles Bowden

What about water located underground? More than half the U.S. population depends on subsurface water as their primary source of drinking water. It has been estimated that the amount of freshwater contained in rocks below the ground, estimated to be 33 quadrillion (33,000,000,000,000,000) gallons,[2] is about 100 times the amount held in freshwater lakes and rivers. Perhaps this is where we should look for additional water. Where do large supplies of subsurface water (called groundwater) occur and how do we tap into it? Nearly all groundwater suitable for drinking or irrigation occurs within 1,000 feet of the ground surface in tiny holes in rocks. Most of these holes are in rocks called sandstones and limestones. The holes are called pores and the percentage of pores in a rock is called its porosity. Typical porosities in water-bearing rocks are 10–20 percent. Although pores in rocks are unimaginably abundant, most pores are very small, with diameters between 1/500 and 1/25 of an inch. Few of them can be seen without using a microscope, so most people are unaware of their existence. Underground water is not generally located in large caverns similar to Carlsbad Cavern or Mammoth Cave but in microscopic cavities in rocks.

A layer of rock that yields water in amounts large enough to be useful is called an aquifer. Aquifers must not only contain lots of water-filled pores, but the pores must also be interconnected (the amount of interconnection is called the permeability) so the water in the rock can move toward the wells that have been drilled into it. How much water can we expect to get from a suitable rock? Nearly all aquifers are layered rocks that are tens to hundreds of feet thick. They are miles to tens or even hundreds of miles in length and width.

However, it is never possible to withdraw all the water. Perhaps 20 percent will remain unrecoverable in the aquifer. There are hundreds of aquifers of various sizes in the United States and they supply 25 percent of America's total water needs. Groundwater wells supply about 37 percent of all "city water," about 96 percent of rural domestic supplies, and 34 percent of the water used in agriculture. We withdraw 28 trillion gallons from aquifers each year. However, like surface-water supplies, groundwater reservoirs can be overtapped. One well-studied example of an overdrawn aquifer is the Ogallala Formation.

The Ogallala Aquifer

The body of sandstone rock called the Ogallala Formation is the largest and best-studied aquifer in the United States (figure 1.3). It has been a major supplier of water to the American midcontinent, from Nebraska southward

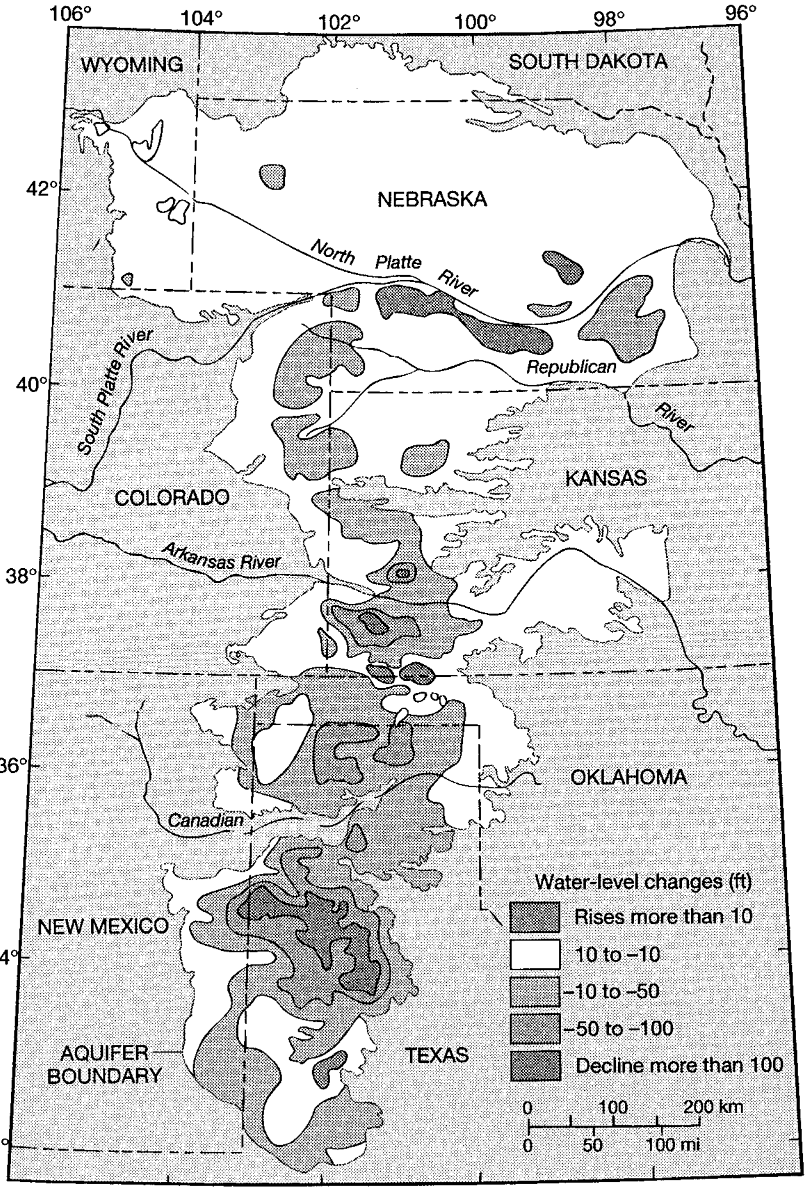

Figure 1.3
Changes in water level in the Ogallala aquifer between 1850 and 1980. The declines have continued to the present day (U.S. Geological Survey).

to Texas. Today, Ogallala water irrigates more than 14 million acres of farmland. It supplies water to 20 percent of all irrigated land in the United States. The aquifer extends over 225,000 square miles and holds more than 70 quadrillion gallons of water (70,000,000,000,000,000 gallons). It averages 200 feet thick but in some areas the thickness reaches 1,400 feet. This aquifer is truly a monster in size. Water in the Ogallala accumulated undisturbed from rainfall over millions of years, but for the past 80 years this water has been withdrawn at an ever-increasing rate. Without Ogallala water there would be little agriculture in this region because annual rainfall is only 16 to 20 inches, not enough to stimulate the agricultural abundance we have come to expect. Water from the Ogallala aquifer serves an area that produces about 25 percent of U.S. food-grain exports and 40 percent of wheat, flour, and cotton exports.

The aquifer can yield as much as 1,000 gallons per minute, 24 hours a day. But thousands of wells tap the Ogallala, so that the rate of withdrawal is currently eight times greater than the rate of replenishment by the low annual rainfall.[3] Without Ogallala water, agricultural production will drop to a third of its present volume. To date, only about 5 percent of the total groundwater resource has been used up, but water levels have declined 30 to 60 feet in large areas of Texas. Wells must be deepened and the energy cost to pump the water to the surface increases to the point where farming becomes uneconomical. In northeast Texas the area under irrigation dropped by one-third between 1974 and 1989 because irrigation from the Ogallala no longer is practical. If present usage continues, the Ogallala will be effectively dry within a few decades, with disastrous effects on the economy of a large area of the United States. Our present ability to irrigate at low cost is coming to an end, not only in the midcontinent but in other areas as well.

Water Use

To take anything for granted, is in a real sense, to neglect it and that is how most of us treat water.

—Robert Raikes, *Water, Weather, and Prehistory*

What part of the American economy is responsible for our dwindling water supply? Where can the biggest cuts be made? Is anyone trying to make these cuts? How can we help?

Agriculture

Probably the chief reason water usage grew three times faster than the growth in population since 1900 is the expansion of agriculture. Agriculture is by far the biggest consumptive water user in the United States, most of it groundwater (figure 1.4). Agriculture accounts for 43 percent of our water use. Surprisingly, the most productive croplands are located in areas with relatively low annual rainfall. The average yearly precipitation for the United States is 30 inches per year. The San Joaquin Valley of California yields 50 percent of the nation's fruit and vegetables but has only 8–12 inches of annual rainfall. The Midwest produces most of our grain but has 10–30 inches of precipitation, marginal for farming.

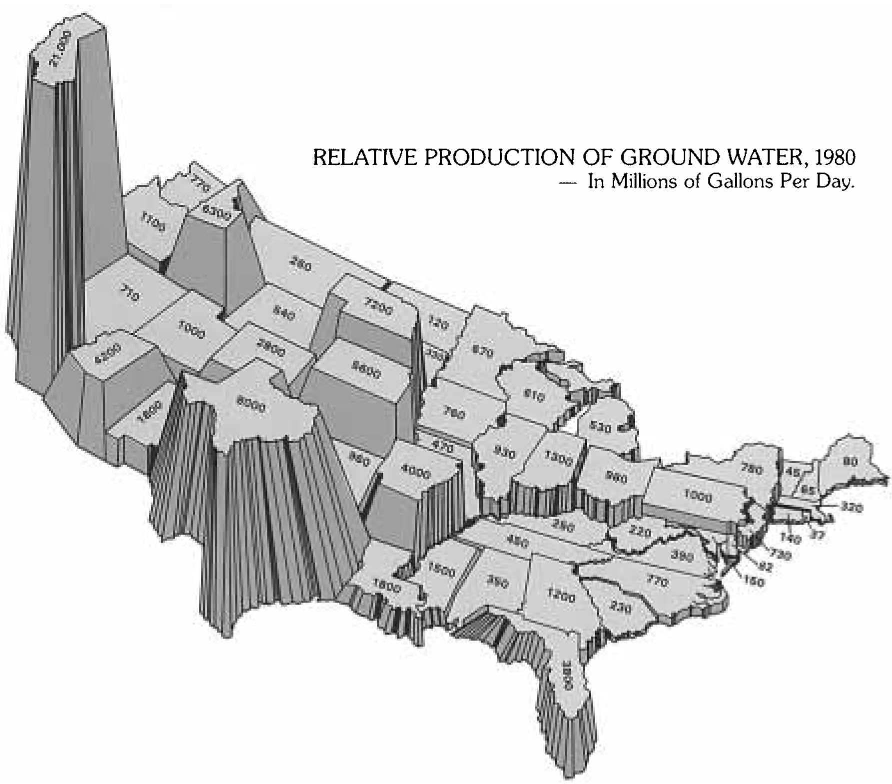

Figure 1.4
Where groundwater use is concentrated. The greatest use by far is in the major agricultural areas (U.S. Water Resources Council, 1980).

Our agricultural abundance in these water-deficient areas has been achieved in two ways. The first is the enormous government water subsidy to farmers. For example, in California's San Joaquin Valley farmers can buy a thousand cubic meters (264,200 gallons) of water from a federal project for $2.84, even though it cost the government $24.84 to deliver that water, nine times as much. In terms of the farmers' profit, the water is actually worth $80–$160. The second way farmers survive in the Valley is by supplementing inadequate rainfall with irrigation water, most of it from groundwater. Can we cut the amount of water used for irrigation without affecting the amount of food we produce? The answer is yes; water use can be reduced significantly. In many agricultural areas it has been and the result is that although population increased by 40 million since 1980, the nation used 10 percent less water in 1995 than in 1980.

How has the reduction in agricultural water use been accomplished? By improved irrigation methods, an improvement that greatly increases the amount of water available for other needs. A modest 15 percent efficiency gain in irrigation frees up double the amount of water used by humans for other purposes. About half of America's cropland is irrigated using large sprinklers that spray into the air about 10 feet above the ground. With the help of the wind, the water is distributed over a wide area. This method of irrigation is relatively inefficient because much of the water evaporates without hitting the ground. A newer sprinkler design delivers water closer to the crops by means of drip tubes extending vertically from the sprinkler arm. Efficiencies as high as 95 percent have been reported. Adapting an existing sprinkler for this system costs about $25–$65 per acre, and the water, energy, and crop-yield gains typically make it a cost-effective investment, recouped in 2 to 4 years. Improvements in efficiency such as the drip sprinklers have reduced depletion of the Ogallala aquifer in the Texas High Plains by 30 percent.[4]

Another very efficient method of getting needed water to crops and getting more crop per drop is drip irrigation, used on only 4 percent of our irrigated cropland. Almost all of the water reaches the plant; efficiencies with this method are more than 90 percent. Losses of water to evaporation and runoff are nearly eliminated. Water use is reduced by 30–70 percent and crop yields are increased by 20–90 percent over standard irrigation methods.

But a drip irrigation system is expensive to install. Miles of pipes and tubes must be laid on the rows of plants, and the holes in the pipe through which the water drips onto the roots of the plant should be as close to the plant as possible. Installation of a drip-irrigation system costs about $1,000 per acre. Perhaps the federal government could offer tax incentives to encourage large farms to switch to drip irrigation. Even without a tax incentive, increases in the irrigation efficiency of American agriculture will have to be made. The choice is "change or die." Groundwater reserves are being depleted almost everywhere.

Industry

Industry accounts for 38 percent of America's water use. The bulk of water used in manufacturing occurs in four industries: paper, chemicals, petroleum, and metals. One or more of these industries is involved in the production of most of the products we use every day, from clothes and computers to cars and plastics. All require large amounts of water to produce. According to the U.S. Geological Survey, producing 1 pound of paper uses about 100 gallons of water. Making a ton of steel requires 50,000 gallons; aluminum, 1,000,000 gallons.

However, in contrast to the water used in agriculture and in the home (see below), only 10 percent of industrial water is actually consumed. Nearly all of it is used for cooling, processing, and other activities that may heat or pollute the water but do not use it up. This creates the possibility of recycling water within a factory and many industrial operations take advantage of this opportunity. More than 95 percent of the water used for steel production and processing is recycled. Intensive recycling of water by American industry has reduced its water use by 36 percent since 1950, while industrial output has nearly quadrupled. Whereas our manufacturing operations were using each gallon of water supplied to them an average of 1.8 times in 1954, the recycling rate is now about 17.

In deciding how much to recycle, a manufacturing plant balances the cost of getting water and treating it before disposal against the cost of adding equipment to treat and reuse wastewater within the plant. In most industries, recycling partially offsets its costs by recovering valuable materials, such as nickel and chrome from plating operations, or fiber from the manufacture of paper. Studies have shown that industrial use of water per unit of production has steadily declined in recent decades. No doubt much of the decline has resulted from passage of the Clean Water Act in 1972, which restricts the discharge of untreated wastewater. As the cost of obtaining water and treating it after use continue to rise, recycling becomes increasingly more cost-effective.

Home Use

About 19 percent of the nation's water use is in the home, so that part of the reason for our diminishing water supply lies in increased cleanliness and the nearly universal access Americans have to modern plumbing. In 1900 less than one in five homes had running water; today nearly all homes do. Three-quarters of the water you use at home you use in the bathroom, mostly for showers and toilet flushing (figure 1.5).

Showers In 1900 Americans bathed or showered only once or twice a week (or less!). Most women washed their hair only once a month (and used borax or egg yolks for shampoo). Only 14 percent of our homes had bathtubs. As late as 1950 only 29 percent of Americans bathed daily in the winter; in 1999 it was 75 percent. In many parts of rural America, bathing in the early 1900s was often more a seasonal than a daily affair. The notion of being wet all over at once, indoors, was little short of revolutionary and

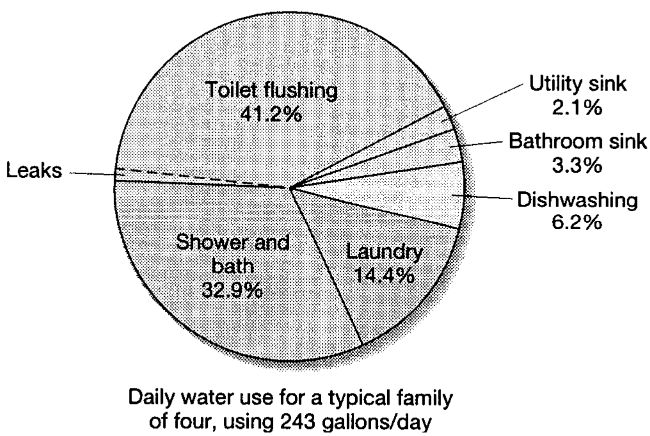

Figure 1.5
Use of water in an average American home (American Water Works Association).

workingmen might prefer to walk to a river for the privilege of cleanliness. Nowadays, most of us shower daily, a water drain of at least 5 gallons for every minute the water is running. The feel of a massaging hot shower for 10 minutes may be invigorating, but when 295 million people do it every day the water use is staggering.

No one expects Americans to stop showering, or even to shower less frequently. But our use of shower water can easily be reduced significantly. One way is to install a plastic or metal washer behind the showerhead to restrict the flow of water. Low-flow showerheads can also be purchased for a few dollars. They cut the showerhead volume by 50 percent, saving about 5,000 gallons of water per person over a year. Multiply by 295 million to see the nationwide annual saving. A cost-free way to cut use of shower water is to step into the shower, wet yourself, turn off the water, soap yourself, and then rinse the water-sweat-dirt mixture from your beautiful frame. Three minutes of running shower water are enough to accomplish the body-cleaning job, be your body large or small. Keep in mind that in addition to the greatly increased use of showers by Americans, there are a lot more of us taking showers. In 1900 there were only 76 million of us; today we are 295 million. And the amount of water that falls on the 50 states has increased only slightly (5–10 percent) during the last hundred years (a result of global warming).

Toilets Although the first flush toilet was developed more than 3,000 years ago, the concept seems to have been lost over the millennia, and human-waste disposal in 1900 was as primitive as it had been 2,000 years earlier. It consisted either of an outdoor privy (known in colonial times as a "necessary house") or a chamber pot, to be emptied into privy pits. Water closets, as they were named, began slowly appearing in America in the 1800s, imported from England. But adoption in this country was slow. In 1900 only 10 percent of American homes had a flush toilet. There were cultural concerns about performing indoors a process hitherto associated with nature. In addition, the cost of installation and the problem of disposal of the human waste kept them from the masses. The disposal problem was solved in the 1860s by Thomas Crapper (yes, that really is his name; his biography is titled *Flushed with Pride*), who commercialized the flush toilet. Today, 98 percent of American homes have at least one flush toilet, a facility each of us visits 2,500 times a year, about 6–8 times a day. And toilet enthusiasts have their own professional organization. The World Toilet Organization holds annual congresses highlighting toilet-related issues. Unbeknownst to most of us, there are toilet associations worldwide promoting toilet education and culture.

The toilet in use in most American homes until relatively recently used 5 gallons of water per flush. Sensing that too much water was going down the drain together with the other stuff, Congress in 1992 mandated that toilets sold in the United States use no more than 1.9 gallons per flush. The latest ultra low-flow models use only 1.6 gallons per flush, a water saving of 70 percent over the 5-gallon models. In 1988, Massachusetts became the first state to require that all new toilets installed use no more than 1.6 gallons. If we assume that an average person spending quality time in the bathroom makes five flushes per day, she or he will save 2,920 gallons of water in a year by using only 1.6 gallons per flush. Multiply by 295 million to see the nationwide saving. Many municipalities have started requiring low-flow toilets in new construction. And no wonder. American toilets flushed about 16.4 million times and used 48.5 million gallons of water *at halftime during the 1999 televised Thanksgiving Day football game.*[5] The mind swirls at the thought of flushes by the Super Bowl TV audience, estimated to have been 144 million in the United States for the 2004 event.

Ever count the number of flushes your family makes each day? Probably not. As an interesting experiment, put a notepad and pencil in each bathroom in your house and ask each person to keep track. Almost certainly the total will be higher than you think.

Even worse than the careless hand on the flush mechanism is the silent toilet-bowl leak, probably the single greatest water waster in most homes. It has been estimated that about 20 percent of all toilets leak. In 2002, water leaks accounted for 14 percent of home water use in the typical single-family home. In some areas of the country, such leaks cause about 95 percent of the complaints to city governments about excessive water bills. A leak of 1 gallon every 6 minutes—not an unusual amount—totals 10 gallons per hour or 240 gallons per day, almost equal to the average amount of water consumed each day in a single-family home. The leak nearly doubles total water consumption. To detect the silent leak in the toilet bowl, place a few drops of food coloring in the tank and wait 5–10 minutes; if the color shows up in the bowl, there's a leak.

Other Bathroom Uses Another way we waste water in the bathroom is during hand washing, brushing teeth, and shaving. One hand wash, one teeth cleaning, and one shave with the faucet running uses 20–25 gallons of water. All these standard procedures can be accomplished with a small amount of water in a stoppered basin, cutting water use by 90 percent.

Clothes Washing Few people had washing machines in 1900. Today Americans own 80 million of them. Eighty-one percent of American families have one. The average washing machine uses about 30 gallons of water to wash a full load and about 35 billion loads of wash are done in the U.S. each year. Fourteen percent of household water consumption is used in washing machines. Keeping us in clean clothes uses perhaps 1,000 billion gallons of water per year. However, newer washing machines use less water than older ones and new federal standards in 2002 for these gadgets ensure that this trend will continue. Obviously, Americans are not going to trash all their washing machines and use a less water-intensive method to clean dirty clothes, and no one is going to volunteer to wear smelly clothes to save water. So more efficient machines are the only realistic solution. However, we should recognize that the invention of the washing machine has greatly increased America's use of water since 1900.

Dish Washing An automatic dishwasher is present in 57 percent of American homes, using 5–11 gallons of water per run. When dish washing is done by hand, a savings of at least 50 percent can be made by filling the kitchen sink for the soapy part of the process and conserving additional water by not leaving the faucet running during rinsing. A running faucet during washing and rinsing can use thirty times more water than an electric dishwasher.

Car Washing Cars and trucks were rare sights in 1900. Today the average American adult owns *at least* one car and washes it with the hose running full blast for the 15–20 minutes it takes to sanitize our proudest possession. A ½-inch garden hose under normal water pressure pours out more than 10 gallons per minute; a ¾-inch hose delivers almost 32 gallons per minute. A better way to wash your car is to use a bucket with soapy water for the washing. Don't forget to turn off the hose when you finish rinsing. Should you or one of your children forgetfully leave the hose on overnight, you can easily waste twice as much water as your family uses in an entire month.

Leaky Water Pipes

Finally, there is a big water waster that we, as individuals, can do nothing about. Many of the 880,000 miles of water mains in American cities are old (a century is not unusual) and leaky.[6] Water mains break 237,600 times each year in the United States, 0.27 breaks per mile of pipe per year. (Water mains are the central conduits through which city water is piped; pipes from the street curb to the homeowner's water tap are called service lines.) In New York City about 600 aging water mains break each year and the city loses 15 percent of its municipally pumped water to leaks, which is about the national average. Buffalo loses 40 percent. St. Louis's water system predates the Civil War. According to the American Water Works Association, a "huge wave" of water-supply pipes laid 50–100 years ago are approaching the end of their useful lives, and "we can expect to see significant increases in break rates and therefore repair costs over the coming decades." The EPA estimates that replacing these old parts of our metropolitan infrastructure will cost at least $138 billion. Local governments and ratepayers currently provide 90 percent of costs to build, operate, and maintain public water and sewer systems. A major federal investment is needed to close a $23-billion-a-year gap between infrastructure needs and present funding in order to meet priorities in the federal Clean Water Act and the Safe Drinking Water Act. As noted by the Water Infrastructure Network, "If we do nothing, the nation can expect increased threats to public health, environmental degradation, and real economic losses. At times and in places, these threats will be small and barely noticeable, but over the next two decades, and even more quickly in some locations, losses will mount and solutions will be financially unmanageable."[7] Obviously, these repairs and replacements will have to be made eventually, if not by you then by your children or grandchildren. Given the current extent of America's water usage and pollution problems, the sooner we begin replacement of the water distribution system, the better.

Water Prices

There are more than 200,000 public water systems in the United States, and Americans greatly underpay in all of them for the water they use. The unrealistically low cost of public water supplies is a serious impediment to water conservation. An average urban family uses about 12,000 gallons per month, costing only about $25. At this ridiculously low price we can refill an 8-ounce glass of water with tap water 2,500 times for less than the cost of a can of soda. At such a low price for municipal water there is no financial incentive to conserve. If state utility commissions allowed utilities to double or triple their charges to reflect national water scarcity, conservation might become more popular. Researchers have found that domestic water use drops by from 3 to 7 percent when prices increase 10 percent.[8] Given human nature, conservation will not become more widespread until water shortages become more widely understood and felt in the wallet. An increase in price doesn't make me any happier than it does you. But there is no realistic alternative. Cheap water is not a birthright.

Fifty years of studies have shown that water demand is responsive to price changes, both in the short term, as individuals and companies respond by making do with less, and in the long term, as they turn to more efficient devices in the home and workplace. For example, when Boulder, Colorado, moved from unmetered to metered systems, water use per person dropped by 40 percent and stayed there.

Water is not only underpriced; it's also inappropriately priced.[9] Most of the 60,000 water systems in the United States charge uniform rates, meaning that consumers pay the same rate per gallon no matter how much they use each month. One-third of municipalities use an even worse pricing method. They offer volume discounts; the more water you use the less you pay. Only 22 percent of utilities charge higher rates for those who use more. And less than 2 percent of water companies charge more during summer, when demand is greater. To avoid hurting the poor, water utilities can follow the example of electric utilities that subsidize the first kilowatt-hours of electricity use with very low "lifeline rates." At some point we will have to change the extravagant way we use water. The patient is sick and getting worse. It is time to do something.

An innovative approach to conserving the nation's water and homeowners' money has recently been introduced in Brazil: digital water.[10] Brazilian engineers have come up with an electronic device known as a water manager. With this device customers draw water on a strictly pay-as-you-go basis. The water user buys a smart card at a local convenience store that, like a long-distance telephone card, is programmed for a certain number of credits. At home, the purchaser punches the card's code into a small keyboard and pushes the LOAD key. The water manager automatically sends a signal to the water company to supply you with water. When the user runs out of credits, just push the LOAN key and the water authority will pump you a bridge loan to carry you until you can run out and purchase another card. According to Brazilian officials, water managers save water, electrical power, and money. They discovered that households using the water manager saved 40 percent on their water bills. Becoming increasingly conscious of what something costs gets people to use less.

Recycling Wastewater

> The bad news is that if the drought keeps up, within a few years we'll all be drinking reclaimed sewer water. The good news is that there won't be enough to go around.
>
> —Bill Miller

Although recycled wastewater still totals less than 1 percent of America's water use, the amount is increasing rapidly. Hundreds of American cities are using recycled water for nondrinking purposes such as crop irrigation and landscaping. California and Florida, our major fruit and vegetable producers, have wholeheartedly embraced the practice of irrigating crops and public areas with treated municipal wastewater.

Other nonpotable applications include cooling water for power plants and oil refineries, industrial-process water for such facilities as paper mills, toilet flushing, dust control, construction activities, concrete mixing, wetland enhancement, and artificial lakes.

Many communities are studying the safety, economics, and feasibility of directing treated sewer water into the ground to replenish dwindling aquifers, even those tapped for public drinking water. This practice is not federally regulated, but all water used for drinking or crop irrigation must meet EPA purity standards. In other words, you can inject what you want but when you draw it back up to use it again it must meet safety standards. The nation of Israel is a leader in the use of purified recycled wastewater. The government projects that one-third of its water needs in 2010 will be met by reclaimed and recycled sewage water.

Water Pollution

Water, water, everywhere, nor any drop to drink.
—Samuel Coleridge

Americans are making a two-pronged attack on their water supply. Not only do we use it extravagantly but we pour harmful chemicals in it as well. In his research for a PBS documentary report, Bill Moyers found out that his blood contains 84 synthetic chemicals. He is in relatively good shape. The bodies of most people on earth contain traces of some 500 synthetic chemicals that didn't exist before the 1920s.[11] How many of these are harmful and in what amounts is largely unknown. Basic toxicity data are not publicly available for nearly 75 percent of the 3,000 chemicals produced in the highest volume each year, excluding pesticides.[12] Are we crazy? Who is pouring poisons in our water and why?

Scary Indicators

A nationwide reconnaissance of pharmaceuticals, hormones, and other organic wastewater contaminants in 139 U.S. streams in 30 states was conducted by the U.S. Geological Survey in 2001.[13] They searched for 95 chemicals and found one or more of them in all 139 streams sampled. A mixture of 7 or more were found in half the streams. Most of the contaminants were present in concentrations that did not exceed current drinking-water guidelines, but recent studies indicate that mixtures of certain chemicals may produce greater than anticipated effects—that is, more severe symptoms, unpredicted effects on organs not known to be affected by the individual components, and effects at concentrations much lower than those known to be harmful for the individual components.[14] Therefore, concentrations of individual chemicals in a mixture to which a person is exposed are not necessarily indicative of the ultimate effects.

Late in 2002 the H. John Heinz III Center for Science, Economics, and the Environment released the results of a 5-year study of the nation's streams and groundwater.[15] It revealed that 13 percent of the streams were seriously polluted, as were 26 percent of the groundwater samples.

As of 2003, 270,000 miles of rivers and streams are too polluted for fishing and swimming.[16] In 1975 a health advisory was issued (still in place in 2003) that children and women of childbearing age should not eat fish from the 315-mile-long Hudson River in New York because of pollution by a cancer-causing chemical. In 1984, 193 miles of the river was declared a Superfund site. Cleanup is expected to take about 6 years. The Environmental Protection Agency reported in 1998 that 40 percent of America's rivers, lakes, and estuaries were no longer suitable for fishing and swimming, largely due to runoff of polluted water from agricultural and urban areas.[17] Forty-one states now advise anglers to limit wild-fish consumption because of contamination by mercury. Bass are particularly adept at accumulating mercury in their tissues. All eight states bordering the Great Lakes restrict consumption of fish from the lakes because of the high concentrations of mercury, pesticides, and more exotic chemicals such as dioxins and PCBs in the fish tissues. Children, whose bodies are growing rapidly, are particularly sensitive to these pollutants. The list of diseases caused by high levels of these pollutants reads like a medical dictionary.

In the Everglades, a sign posted by the National Park Service reads:

> WARNING. HEALTH HAZARD
> Do not eat more than one bass per week per adult due to high mercury content.
> Children and pregnant women should not eat bass.

In July 2001 Massachusetts public health officials warned young women and children under 12 to stop eating most fish caught in state rivers and lakes because of mercury poisoning, and to avoid some other seafood. According to the Centers for Disease Control and Prevention in 2001, one of ten American women of childbearing age is at risk for having a baby born with neurological problems due to in utero mercury exposure. That's 375,000 babies at risk every year. Most of the mercury comes from America's coal-fired power plants.

The Mississippi River is the most polluted river in the United States.[18] The river's banks are lined with city-sized chemical plants, which dump more than 50 million pounds of toxins annually. The 150-mile stretch from Baton Rouge to New Orleans is known to water-pollution specialists as the "Cancer Corridor." This section of America's largest waterway contains 500 hazardous-waste sites and the highest concentration of manufacturers, users, and disposers of toxic chemicals in the United States. Most of the 100–150 industrial sites that line the river's banks are petrochemical plants that manufacture products from petroleum, such as organic chemicals, pesticides, gasoline, plastics, and synthetic fibers. The 13 Louisana parishes (counties) that depend on the Mississippi for drinking water have among the highest U.S. mortality rates for several forms of cancer—including rectal cancer, a disease often linked to drinking water. Among the 13 parishes, rectal cancer rates are highest among those living downstream from or within the Cancer Corridor.

Millions of pounds of unidentified chemicals buried near the plant sites threaten both surface and groundwater supplies. Nearly half of the buried drums leak. However, we need not wait for the storage drums to rust and leak. Hazardous waste can be legally injected into the ground, with the obvious potential to pollute aquifers. Although there is some regulation of these injections it is not adequate to protect our aquifers. According to the Legal Environmental Assistance Foundation, at least 25 states have documented evidence of problems caused by underground injection of hazardous waste.

Groundwater pollution is essentially permanent, because groundwater recycles slowly, remaining in aquifers for an average of 1,400 years compared to 16 days for river water. Roughly 64 percent of America's liquid hazardous waste is directly injected into the ground.[19] Nearly three times more liquid waste is injected into the ground than is poured into our rivers. Texas (oil refineries) generates one-third of America's hazardous waste; Texas and Louisiana do more than two-thirds of the injecting. In southern Louisiana, chemicals discharged by the petrochemical plants and other industrial sites are regularly found in public drinking water. Cancer rates are abnormally high within the corridor.

There are signs along many of America's rivers warning of pollution by mines, sewage, pesticide runoff from farms, or other sources. Runoff of pesticides and fertilizer from America's farms is one of the country's most vexing and unsolved pollution problems. Runoff from farms along the Mississippi River has so polluted the nearshore waters of the Gulf of Mexico that a "dead zone" has formed around the mouth of the river.[20]

Major Sources of Pollution

Listing in rank order the major pollution producers can generate controversy. But it is generally agreed that the number one polluter in the United States is the American military. It is responsible each year for the generation of more than one-third of the nation's toxic waste[21] (Army, 37 percent; Air Force, 26 percent; Navy, 16 percent; inactive military sites, 20 percent), an amount greater than the five largest international chemical companies combined. Our domestic military installations contain more than 20,000 toxic sites and just under 10 percent of all bases are on the federal Superfund list.[22] These defense sites have contaminated an area larger than Florida. But the American public can do nothing about this appalling situation. The EPA is forbidden to investigate or sue the military. The Defense Department spends a minuscule 1.5 percent of its budget on environmental concerns, and there has been a steady decline in environmental funding in recent years.[23]

Second on the list of major polluters is the chemical industry. They produce most of the tens of thousands of organic compounds used in manufacturing and agriculture. These compounds are part of the technological society that provides our high living standard. We cannot stop using them unless we return to technologically simpler lives. The problem lies in disposal of the chemicals after use. They are legally dumped into our groundwater, our lakes and our rivers. The amount of industrial pollution dumped into our rivers, streams, and lakes rose 26 percent between 1995 and 1999.[24] The U.S. Public Interest Research Group (PIRG) released a report in 2003 reviewing state-by-state releases of toxic chemicals into our water and air in 2000, according to EPA data (table 1.2). Sort of quenches your thirst, doesn't it?

Compounding the problem is illegal dumping. An EPA report in June 2003 revealed that one-fourth of industrial facilities are not complying with their Clean Water Act discharge permits and that only one in seven of these noncomplying firms are fined for their infractions. Those who are

Table 1.2
Releases of toxic chemicals into the environment in 2000 and the medical problems the chemicals are known to cause

Amount of chemicals (pounds)	Malady caused
>100 million	cancer
>138 million	birth defects, learning disabilities
50 million	reproductive disorders
>1 billion	neurological problems
>1.7 billion	respiratory diseases
1.6 million of lead and its compounds	neurological problems, learning disabilities, behavioral problems
166,000 of mercury and its compounds	neurological problems

Source: U.S. Public Interest Research Group, http://uspirg.org/uspirg.asp?id2=8822&id3=USPIRG&.

fined pay an average of only $5,000 per incident, hardly burdensome to a major chemical company.[25]

The problem with changing industrial practices is that although injecting pollutants deep underground commonly poisons our aquifers, it is an inexpensive way to get rid of unwanted chemicals. The politically powerful chemical industry does not want to repeal federal laws that permit underground waste disposal. A better and potentially safer method of disposal is incineration, which can convert poisonous chemicals into harmless compounds. But it is very expensive. Changing from underground waste disposal to incineration will increase the cost of many products. Are we willing to pay for this?

Nearly all of America's produce is grown with massive help from pesticides, our third most serious source of pollution. These chemicals are washed by rainfall off the cropland into surface waterways and large quantities of the pesticides drain downward into our groundwater supplies. Are congressional representatives from farm states likely to vote for laws that restrict pesticide use or that require crops to be grown organically, without the use of pesticides (chapter 4)? Not likely.

A rapidly growing source of water pollution is animal excrement from the increasing number of factory farms in the United States. Americans eat a lot of meat, one million animals per hour,[26] and live animals produce a lot of urine and feces (figure 1.6). In 2000, 2.7 trillion (2,700,000,000,000) pounds of animal waste was produced by cattle (82.1 percent), hogs (12.1 percent), poultry (5.5 percent), and sheep (0.3 percent). For each pound of steak, a cow produces 53 pounds of feces and urine. Animal farms produce 86,600 pounds of excrement *every second,* more than 130 times the amount of waste that people do.[27] Texas produced twice the amount of animal excrement as the next leading state and twenty-eight times the waste of New York City's human population. Talk about being "full of it"!

Farm-animal production increased by 25 percent between 1980 and 1997. Most of this growth has occurred in large operations called *factory farms* that gain efficiency by raising animals in controlled indoor environments; manure is pumped into huge open air pits. From there it is sprayed onto agricultural fields. But the amount of waste applied often exceeds what the crops can absorb, leaving the rest to evaporate or run off into surface waters. In addition to this runoff, waste pits have cracked or leaked, killing hundreds of thousands of fish and seriously contaminating drinking water and soil. According to the Sierra Club, concentrated animal feeding operations have polluted 35,000 miles of rivers.

Figure 1.6
Feedlot for cattle showing normal concentrations of wastewater, feces, and urine (photo courtesy Soil Conservation Service).

Cures

In principle the cure for most water pollution is simple. Stop pouring noxious chemicals into our waterways and stop injecting them below ground. Ending these activities will not end all water pollution because some pollution results from other sources, such as water drainage through waste piles at abandoned mines, farm-animal waste, leakage into aquifers from landfills (chapter 3), and other sources. But ending conscious and deliberate pollution will certainly bring an end to the worst offenses.

In practice the cure for most water pollution is fraught with political difficulties, which is the reason the cure has not been accomplished. Perhaps most difficult to deal with is the military. A claim of "national security" always trumps public concerns about the environment. But surely it is possible to establish a congressional committee whose members have security clearances and who could investigate pollution by the military without compromising national security.

As we will see throughout this book, the ways to end or seriously curtail environmental pollution are known. Scientists know how to solve most problems of environmental pollution or degradation. The problems are political. Are Americans concerned enough to stop pollution if it increases their cost of living? Will they vote for politicians who promise to be hard-nosed on this issue? Sooner or later they will have to. There is no other choice.

The Quest For Perfection

Filthy water cannot be washed.
—West African proverb

For practical, political, and economic reasons, it is impossible to eliminate all forms of pollution from the environment. In the long run, it may turn out that humans are the most lethal and infectious virus on earth, able to infect and destroy all other living forms. With regard to the purity of water and air, the goal of zero contaminants, as desirable as it may be, is usually unattainable. Furthermore, even when it is obtainable using available technology, the cost of removing the last few remaining units of a noxious substance from the water or air can be astronomical. Removing the first

75 percent may be easy and cheap, but removing the next 20 percent can cost twice the amount of the initial 75 percent. The next 4 percent may cost five times as much, and the last 1 percent may require an extremely costly herculean effort. The technology may be there but at what cost-benefit ratio?

Therefore, an acceptable level of contamination needs to be determined in relation to the possible risk to human health and life. Suppose an organic contaminant in the water has been found in the laboratory to be carcinogenic when fed in measured amounts to rats, mice, or bunny rabbits. How do we assess the risk to humans of small amounts of the substance? Data from experiments on humans are lacking (no volunteers) and the experts disagree on what constitutes a safe level of exposure. Science cannot give a certain answer. Hence, economics and politics dictate what will be considered an acceptable level. In the area of water pollution, a good example is arsenic, long known to be harmful in "large" amounts. The acceptable amount was set at 50 parts per billion parts of water by the U.S. Public Health Service in 1942, which the EPA estimated in 1988 would result in a skin-cancer risk of 1 in 400 and estimated in 1992 would cause an internal cancer risk of 1.3 per 100 people. In 2002 the EPA lowered the acceptable limit to 10 ppb.[28] Other examples of limits established by other than purely scientific means include the dangers of inhaling ultrafine particles in the air and establishing a safe limit for radon exposure (chapter 7). In many cases we simply do not know what is safe (your body can deal with it without harm) and what is not.

The Value of Human Life

But sweet, sweet is this human life,
So sweet, I fain would breathe it still.
—William Cory, *Mimnermus in Church*

How much is a human life worth? How far should the government go to save lives by reducing everyday hazards? Life is priceless, of course, especially when it is yours or a loved one's. Yet governments have budgets and must try to weigh costs and benefits. Unpleasant as it is to face the question of what someone's life is worth, the realities of the world we live in require an answer. Surely, a human life is worth at least a few hundred dollars. But is it worth a few billion?

Kip Viscusi of the Harvard Law School has researched this question.[29] What are people willing to pay to reduce the risk of death at their place of work, and how much money will they accept as compensation for an increased risk of dying on the job? The answer he determined, based on many surveys, is around $7 million. On this basis, many federal regulations fail a basic cost-benefit test (table 1.3). Only about half the regulations he studied were "cost-effective" as defined by saving a life at the cost of less than $7 million.

According to John Morrall, an official at the Office of Management and Budget twenty years ago, environmental regulations such as restrictions on different kinds of pollution generally cost over $1 billion for every life saved, and often much more. The cost of these regulations is far higher than the results seem to justify, based on what Americans believe is the value of a single life.

Conclusion

There are many reasons to be concerned about the future adequacy of America's water supplies. Current uses are depleting or contaminating

Table 1.3
The cost of selected federal regulations

Regulation (year issued)	Cost per life saved
Child-proof lighters (1993)	$100,000
Respiratory protection (1998)	100,000
Logging safety rules (1998)	100,000
Electrical safety rules (1990)	100,000
Steering-column standards (1967)	200,000
Hazardous-waste disposal (1998)	1.1 billion
Hazardous-waste disposal (1994)	2.6 billion
Drinking-water quality (1992)	19 billion
Formaldehyde exposure (1987)	78 billion
Landfill restrictions (1991)	100 billion

Source: The Economist, January 24, 2004, p. 9.

many of our most important supplies, and once supplies are depleted or contaminated it may be impossible to replace or cleanse them. Even when cleansing is possible it is always very costly. As with many things in life, an ounce of prevention is worth a pound of cure.

We have made impressive gains over the past few decades in restoring and protecting our water resources, but much more remains to be done. The chief reason for the gains has been federal legislation such as the Clean Water Act. Resistance is growing, however, to the enormous investments that continually must be made in treating municipal and industrial wastes. But there is no alternative. If the way we protect our military establishment, operate our industries, and run our farms results in the pollution of our water we have no choice but to either change the way we live or treat the problem we have created.

We are often told that the two certainties in life are death and taxes. To that we can add a third: the cost of water is going to increase, most probably by a significant amount. But it is so cheap now that Americans can handle it. We will grumble and recall “the good old days” of cheap water, but we will survive. After all, if we are not willing to pay for guaranteed supplies of fresh, clean water, what are we willing to pay for?