# 14 WATER RESOURCES

## *Water and Grain Import Wars in the Middle East*

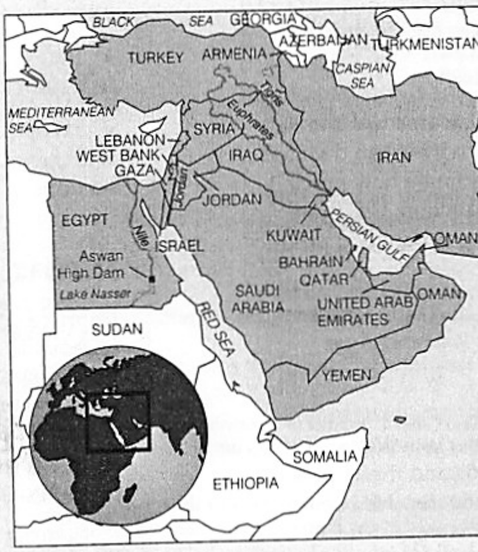



**Figure 14-1** The Middle East, whose countries have some of the highest population growth rates in the world. Because of the dry climate, food production depends heavily on irrigation. Existing conflicts between countries in this region over access to water may soon overshadow both long-standing religious and ethnic clashes and attempts to take over valuable oil supplies.

Future wars between countries in the Middle East could be fought over water. Most water in this dry region comes from three shared river basins: the Nile, Jordan, and Tigris-Euphrates (Figure 14-1).

Ten countries share water from the Nile River basin (Figure 14-1), but three countries—Egypt, Sudan, and Ethiopia—use most of the water. Egypt, where it rarely rains, is mostly desert and would not exist without irrigation water from the Nile.

Because of water scarcity, Egypt already has to import 40% of its grain to feed its current population of 71 million. Yet by 2050, its population is expected to increase to 115 million, greatly increasing its demand for already scarce water.

Most of the precipitation that feeds 85% of the Nile's flow falls in Ethiopia. With a total fertility rate of 5.9 children, its population is projected to increase from 68 million in 2002 to 173 million by 2050, roughly tripling its water needs. To meet these needs and help lift its people out of poverty, Ethiopia plans to divert more water from the Nile.

Sudan also plans to divert more of the Nile's water to help feed its population, which is expected to increase from 33 million to 64 million between 2002 and 2050. This will at least double its water needs.

Such upstream diversions by Ethiopia and Sudan would reduce the amount of water available to water-short Egypt. Its options are to **(1)** go to war with Sudan and Ethiopia to obtain more water, **(2)** cut population growth, **(3)** improve irrigation efficiency, **(4)** spend $2 billion to build the world's longest concrete canal and pump water out of Lake Nasser (the reservoir created from the Nile by the Aswan High Dam) to create more irrigated farmland in the middle of the desert, **(5)** import more grain to reduce the need for irrigation water, **(6)** work out water-sharing agreements with other countries, or **(7)** suffer the harsh human and economic consequences of extreme hydrological poverty.

The Jordan basin is by far the most water-short region, with fierce competition for its water among Jordan, Syria, Palestine (Gaza and the West Bank), and Israel (Figure 14-1). The combined populations of these already water-short countries are projected to more than double from 33 million to 69 million between 2002 and 2050. Some *good news* is that in 1994, Israel and Jordan signed a peace treaty that addressed their disputes over water from the Jordan River basin.

Syria plans to build dams and withdraw more water from the Jordan River, decreasing the downstream water supply for Jordan and Israel. Israel warns that it will consider destroying the largest dam that Syria plans to build.

Turkey, located at the headwaters of the Tigris and Euphrates Rivers, controls how much water flows downstream to Syria and Iraq before emptying into the Persian Gulf (Figure 14-1). Turkey is building 24 dams along the upper Tigris and Euphrates Rivers to **(1)** generate huge quantities of electricity, **(2)** irrigate a large area of land, and **(3)** generate several million jobs for its 67 million people.

If completed, these dams will reduce the flow of water downstream to Syria and Iraq by up to 35% in normal years and much more in dry years. Syria also plans to build a large dam along the Euphrates River to divert water arriving from Turkey. This will leave little water for Iraq and could lead to war between Syria and Iraq.

Resolving these water distribution problems will require a combination of **(1)** regional cooperation in allocating water supplies, **(2)** slowed population growth, **(3)** improved efficiency in water use, **(4)** increased water prices to encourage water conservation and improve irrigation efficiency, and **(5)** increased grain imports to reduce water needs.

Instead of water military wars we could have grain-import economic wars. Water-short countries able to pay for imported grain instead of those that are the strongest militarily may win the competition for scarce water and food.

Thus the availability of water and food in water-short countries is connected to the interlocking problems of **(1)** *population growth and control* and *water conservation* to reduce water needs and **(2)** *environmentally sustainable economic growth* to provide enough money to reduce water needs through grain imports.

*Our liquid planet glows like a soft blue sapphire in the hard-edged darkness of space. There is nothing else like it in the solar system. It is because of water.*

JOHN TODD

This chapter addresses the following questions:

- What are water's unique physical properties?
- How much fresh water is available to us, and how much of it are we using?
- What causes freshwater shortages, and what can be done about this problem?
- What are the pros and cons of using dams and reservoirs to supply more water?
- What are the pros and cons of transferring large amounts of water from one place to another?
- What are the pros and cons of withdrawing groundwater and converting salt water to fresh water?
- How can we waste less water?
- What are the causes of flooding, and what can be done to reduce the risk of flooding and flood damage?
- How can we use the earth's water more sustainably?

## 14-1 WATER'S IMPORTANCE AND UNIQUE PROPERTIES

**Why Is Water So Important?** We live on the water planet, with a precious film of water—most of it salt water—covering about 71% of the earth's surface (Figure 7-5, p. 147). All organisms are made up mostly of water; a tree is about 60% water by weight, and most animals are about 50–65% water.

Each of us needs only about a dozen cupfuls of water per day to survive, but huge amounts of water are needed to supply us with food, shelter, and our other needs and wants. Water also plays a key role in (1) sculpting the earth's surface, (2) moderating climate, and (3) diluting pollutants.

**What Are Some Important Properties of Water?** Water is a remarkable substance with a unique combination of properties:

- *There are strong forces of attraction (called hydrogen bonds,* Appendix 2, Figure 4) *between molecules of water.* These attractive forces are the major factor determining water's unique properties.
- *Water exists as a liquid over a wide temperature range because of the strong forces of attraction between water molecules.* Its high boiling point of 100°C (212°F) and low freezing point of 0°C (32°F) mean that water remains a liquid in most climates on the earth.
- *Liquid water changes temperature very slowly because it can store a large amount of heat without a large change in temperature.* This high heat capacity **(1)** helps protect living organisms from temperature fluctuations, **(2)** moderates the earth's climate, and **(3)** makes water an excellent coolant for car engines, power plants, and heat-producing industrial processes.
- *It takes a lot of heat to evaporate liquid water because of the strong forces of attraction between its molecules.* Water absorbs large amounts of heat as it changes into water vapor and releases this heat as the vapor condenses back to liquid water. This is a primary factor in distributing heat throughout the world (Figure 6-10, p. 117) and thus plays an important role in determining the climates of various areas. This property also makes water evaporation an effective cooling process, which is why you feel cooler when perspiration or bathwater evaporates from your skin.
- *Liquid water can dissolve a variety of compounds.* This enables it to **(1)** carry dissolved nutrients into the tissues of living organisms, **(2)** flush waste products out of those tissues, **(3)** serve as an all-purpose cleanser, and **(4)** help remove and dilute the water-soluble wastes of civilization. Water's superiority as a solvent also means that water-soluble wastes pollute it easily.
- *Water molecules can break down (ionize) into hydrogen ions ($H^+$) and hydroxide ions ($OH^-$), which help maintain a balance between acids and bases in cells, as measured by the pH of water solutions* (Figure 3-5, p. 49).
- *Water filters out wavelengths of ultraviolet radiation* (Figure 3-9, p. 52) *that would harm some aquatic organisms.*
- *The strong attractive forces between the molecules of liquid water cause its surface to contract (high surface tension) and to adhere to and coat a solid (high wetting ability).* These cohesive forces pull water molecules at the surface layer together so strongly that it can support small insects. The combination of high surface tension and wetting ability allow water to rise through a plant from the roots to the leaves (capillary action).
- *Unlike most liquids, water expands when it freezes.* This means that ice has a lower density (mass per unit of volume) than liquid water. Thus ice floats on water. Without this property, lakes and streams in cold climates would freeze solid and lose most of their current forms of aquatic life. Because water expands upon freezing, it can also **(1)** break pipes, **(2)** crack a car's engine block (which is why we use antifreeze), **(3)** break up streets, and **(4)** fracture rocks (thus forming soil).

Water is the lifeblood of the biosphere. It connects us to one another, to other forms of life, and to the entire planet. Despite its importance, water is one of our most

## 14-2 SUPPLY, RENEWAL, AND USE OF WATER RESOURCES

**How Much Fresh Water Is Available?** Only a tiny fraction of the planet's abundant water is available to us as fresh water (Figure 14-2). About 97.4 % by volume is found in the oceans and is too salty for drinking, irrigation, or industry (except as a coolant).

Most of the remaining 2.6% that is fresh water is **(1)** locked up in ice caps or glaciers or **(2)** in groundwater too deep or salty to be used (Figure 14-2).

Thus only about 0.014% of the earth's total volume of water is easily available to us as soil moisture, usable groundwater, water vapor, and lakes and streams (Figure 14-2). If the world's water supply were only 100 liters (26 gallons), our usable supply of fresh water would be only 0.014 liter (2.5 teaspoons).

Some *good news* is that the available fresh water amounts to a generous supply. Moreover, this water is continuously collected, purified, recycled, and distributed in the solar-powered *hydrologic cycle* (Figure 4-27, p. 83) as long as we do not **(1)** overload it with slowly degradable and nondegradable wastes or **(2)** withdraw it from underground supplies faster than it is replenished. The *bad news* is that in parts of the world we are doing both.

Differences in average annual precipitation divide the world's countries and people into water *haves* and *have-nots*. For example, Canada, with only 0.5% of the world's population, has 20% of the world's fresh water, whereas China, with 21% of the world's people, has only 7% of the supply.

As population, irrigation, and industrialization increase, water shortages in already water-short regions will intensify and heighten regional tensions

**(2)** shift precipitation patterns, and **(3)** disrupt wate supplies and thus food supplies. Some areas will ge more precipitation and some less. Some river flow will change.

**What Is Surface Water?** Precipitation that doe not infiltrate the ground or return to the atmospher by evaporation (including transpiration) is called **sur face runoff,** which flows into streams, lakes, wetlands and reservoirs.

About two-thirds of the world's annual runoff i lost by seasonal floods and is not available for huma use. The remaining one-third is **reliable runoff,** whic generally we can count on as a stable source of wate from year to year..

A **watershed,** also called a **drainage basin,** is region from which water drains into a stream, lake reservoir, wetland, or other body of water.

**What Is Groundwater?** Some precipitation infil trates the ground and percolates downward throug voids (pores, fractures, crevices, and other spaces) i soil and rock (Figure 14-3). The water in these voids i called **groundwater.**

Close to the surface, the voids have little moistur in them. However, below some depth, in the **zon of saturation,** the voids are completely filled wit water.

The **water table** is located at the top of the zone o saturation. It falls in dry weather and rises in we weather. An unsaturated zone, or **zone of aeratio** lies above the water table. In this zone, pores of roc and soil contain air and may be moist but not satu rated with water.

Porous, water-saturated layers of sand, gravel, o bedrock through which groundwater flows are calle **aquifers** (Figure 14-3). Aquifers are like large elo gated sponges through which groundwater seeps. An

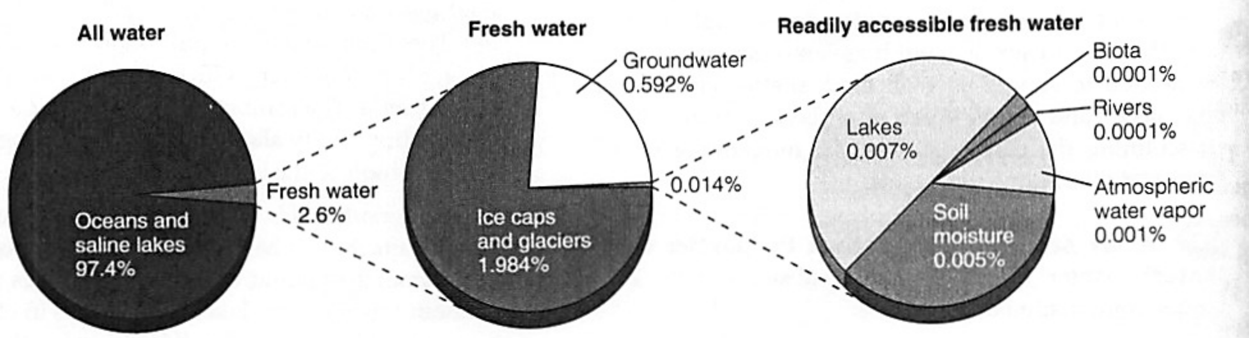



**Figure 14-2** The planet's water budget. Only a tiny fraction by volume of the world's water supply is fresh water available for human use.

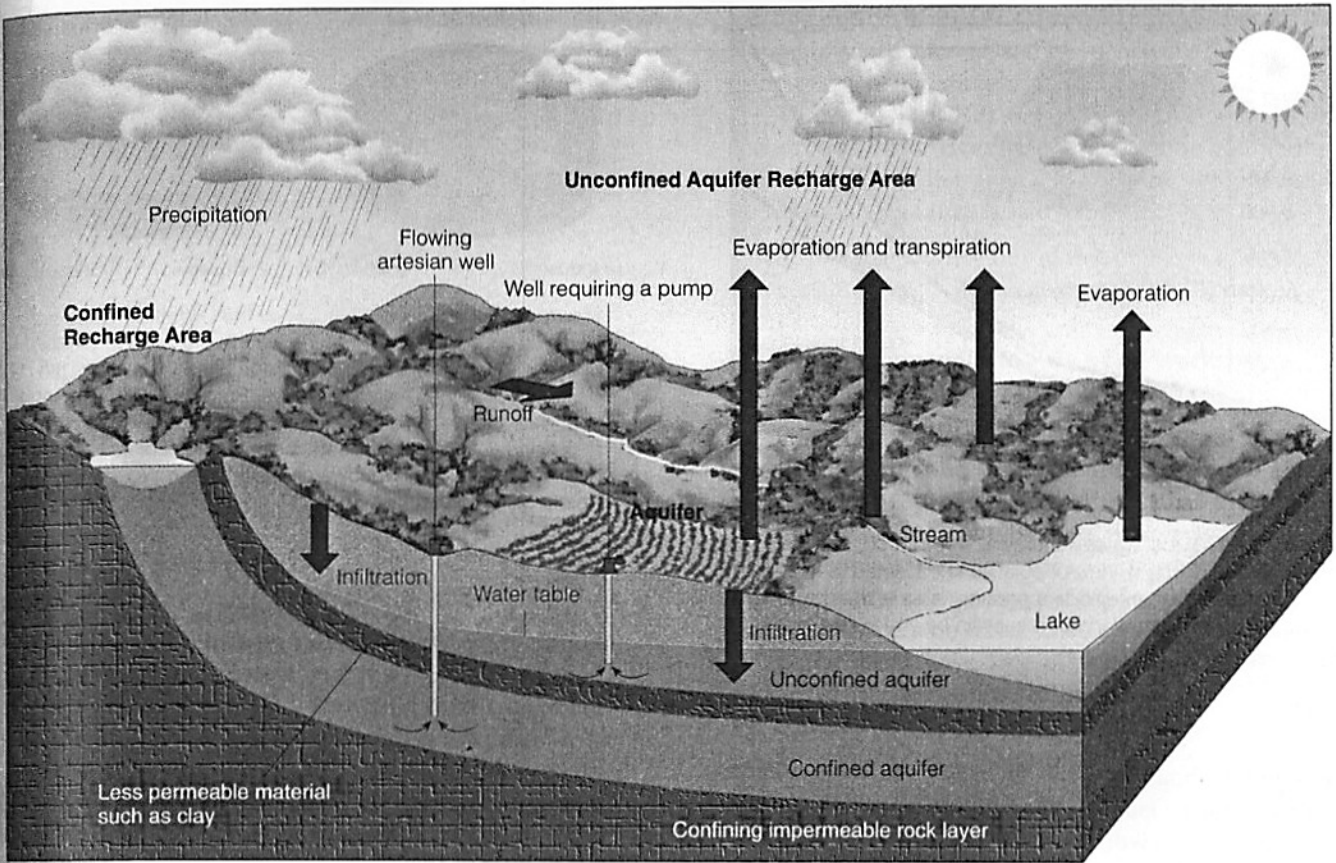



**Figure 14-3** The groundwater system. An *unconfined aquifer* is an aquifer with a water table. A *confined aquifer* is bounded above and below by less permeable beds of rock. Groundwater in this type of aquifer is confined under pressure.

area of land through which water passes downward or laterally into an aquifer is called a **recharge area.**

Aquifers are replenished naturally by precipitation that percolates downward through soil and rock in what is called **natural recharge,** but some are recharged from the side by *lateral recharge.* Groundwater moves from the *recharge area* through an aquifer and out to a *discharge area* (well, spring, lake, geyser, stream, or ocean) as part of the hydrologic cycle (Figure 4-27, p. 83). Groundwater normally moves from **(1)** points of high elevation and pressure to **(2)** points of lower elevation and pressure. This movement is quite slow, typically only a meter or so (about 3 feet) per year and rarely more than 0.3 meter (1 foot) per day.

Some aquifers get very little (if any) recharge and on a human time scale are nonrenewable resources. They are often found fairly deep underground and were formed tens of thousands of years ago. Withdrawals from such aquifers amount to *water mining* that, if kept up, will deplete these ancient deposits of water.

**How Much of the World's Reliable Water Supply Are We Withdrawing?** Since 1900, global water withdrawal has increased about ninefold and per capita withdrawal has quadrupled, with irrigation accounting for the largest increase in water withdrawal (Figure 14-4, p. 316). As a result, humans now withdraw about 35% of the world's reliable runoff. At least another 20% of this runoff is left in streams to **(1)** transport goods by boats, **(2)** dilute pollution, and **(3)** sustain fisheries and wildlife.

Thus we directly or indirectly withdraw more than half of the world's reliable runoff. Because of increased population growth and economic development, global withdrawal rates of surface water are projected to **(1)** at least double in the next two decades and **(2)** exceed the reliable surface runoff in a growing number of areas.

Nature's water delivery does not match up with the distribution of much of the world's population. For example, Asia, with 61% of the world's people, has only 36% of the earth's reliable annual runoff. In contrast, South America, with 26% of the earth's reliable runoff, has only 6% of the world's people.

**How Do We Use the World's Fresh Water?** Uses of withdrawn water vary from one region to another and from one country to another (Figure 14-5).

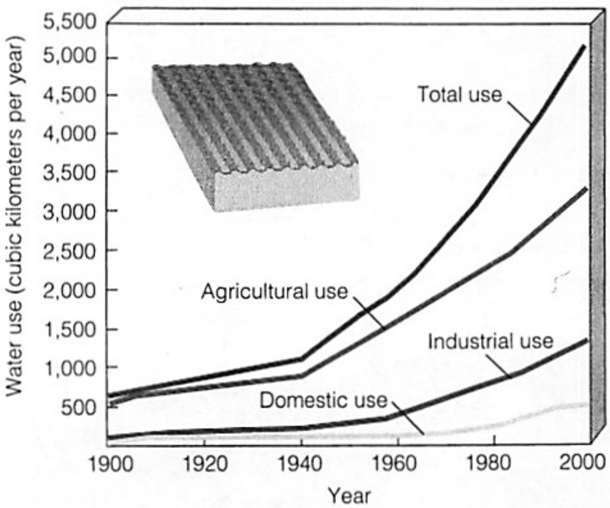



**Figure 14-4** Global water withdrawal, 1900–2000. Between 2000 and 2050, the world's population is expected to increase by about 3.3 billion people and greatly increase the demand for water. (Data from World Commission on Water Use in the 21st Century)

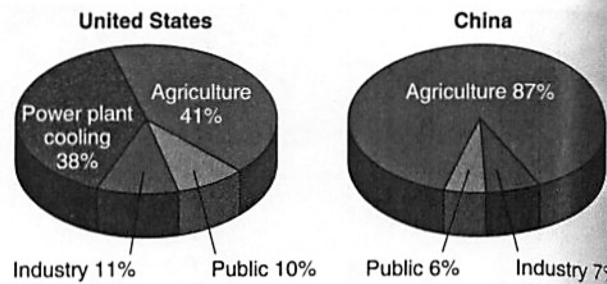



**Figure 14-5** Use of water withdrawn in the United States and China. The United States has the world's highest per capita use of water, amounting to an average of 4,800 liters (1,280 gallons) per person per day in 1999. Between 1980 and 1999, total water use in the United States decreased by 10% despite a 17% increase in population, mostly because of more efficient irrigation. (Data from Worldwatch Institute and World Resources Institute)

Worldwide, about 70% of all water withdrawn each year from rivers, lakes, and aquifers is used to **(1)** irrigate 18% of the world's cropland and **(2)** produce about 40% of the world's food.

Industry uses about 20% of the water withdrawn each year, and cities and residences use the remaining 10%. Agriculture and manufacturing use large amounts of water (Figure 14-6).

Some of the water withdrawn from a source may be returned to that source for reuse. *Consumptive water use* occurs when water withdrawn becomes unavailable for reuse in the basin from which it was removed—mostly because of losses such as evaporation or contamination.

**Case Study: Freshwater Resources in the United States** The United States has plenty of fresh water. However, much of it is **(1)** in the wrong place at the wrong time or **(2)** contaminated by agricultural and industrial practices. The eastern states usually have ample precipitation, whereas many western states have too little (Figure 14-7, top).

In the East, the largest uses for water are for energy production, cooling, and manufacturing. The largest use by far in the West is for irrigation (which accounts for about 85% of all water use).

In many parts of the eastern United States, the most serious water problems are **(1)** flooding, **(2)** occasional urban shortages, and **(3)** pollution. For example, the 3 million residents of Long Island, New York, get most of their water from an increasingly contaminated aquifer.

The major water problem in the arid and semiarid areas of the western half of the country is a shortage of runoff, caused by **(1)** low precipitation (Figure 14-7, top), **(2)** high evaporation, and **(3)** recurring prolonged drought. Water tables in many areas are dropping rapidly as farmers and cities deplete aquifers faster than they are recharged.

In the United States, many major urban centers (especially those in the West and Midwest) are located in areas that do not have enough water (Figure 14-7, bottom). Water experts project that conflicts over

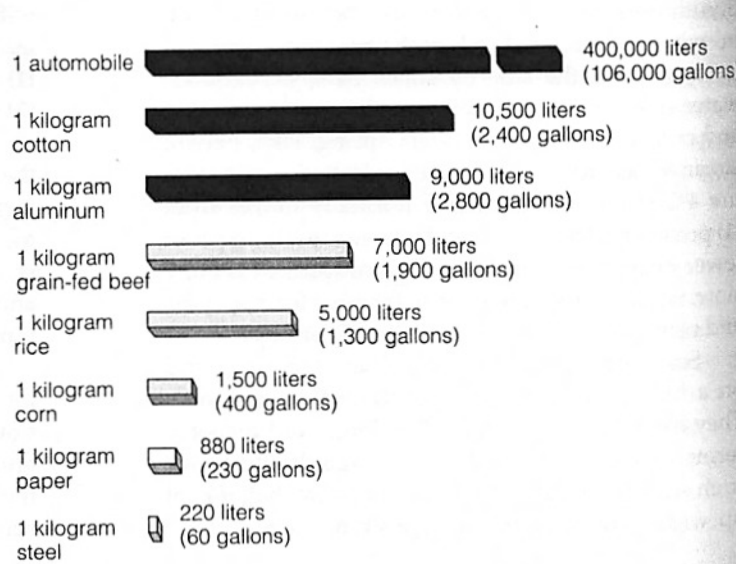



**Figure 14-6** Amount of water needed to produce some common agricultural and manufactured products. (Data from U.S. Geological Survey)

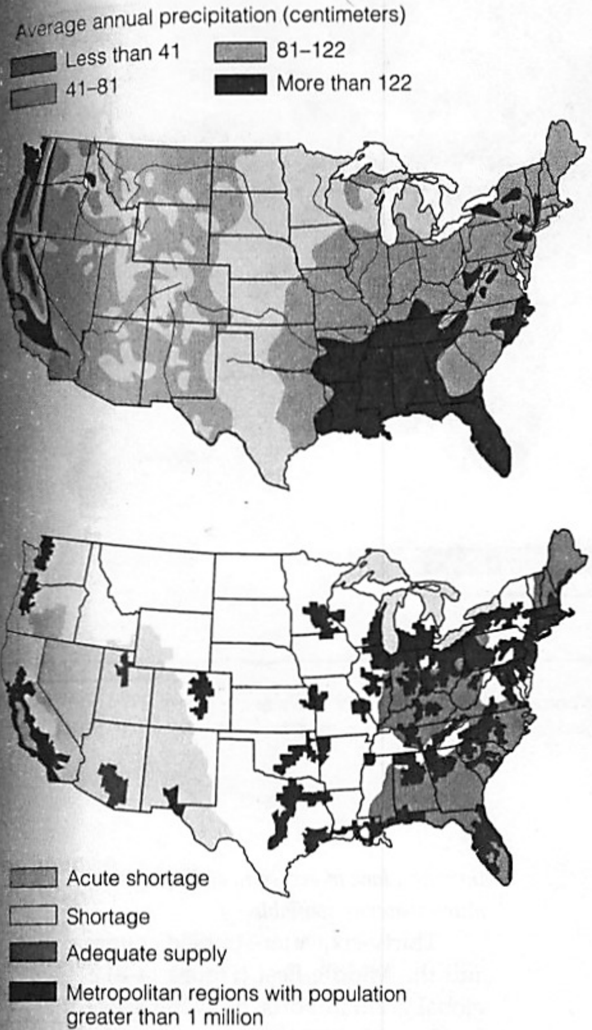



**Figure 14-7** Average annual precipitation and major rivers (top) and water-deficit regions in the continental United States and their proximity to metropolitan areas having populations greater than 1 million (bottom). (Data from U.S. Water Resources Council and U.S. Geological Survey)

water supplies within and between states will intensify as more industries and people migrate west and compete with farmers for scarce water.

## 14-3 TOO LITTLE WATER

**What Causes Freshwater Shortages?** According to water expert Malin Falkenmark, the four causes of water scarcity are **(1)** a *dry climate* (Figure 6-7, p. 116), **(2)** *drought* (a period of 21 days or longer in which precipitation is at least 70% lower and evaporation is higher than normal), **(3)** *desiccation* (drying of the soil because of such activities as deforestation and overgrazing by livestock), and **(4)** *water stress* (low per capita availability of water caused by increasing numbers of people relying on limited runoff levels).

Figure 14-8 (p. 318) shows the degree of stress on the world's major river systems, based on comparing the amount of water available with the amount used by humans. A country is said to be:

- *Water stressed* when the volume of its reliable runoff per person drops to below about 1,700 cubic meters (60,000 cubic feet) per year.
- Suffering from *water scarcity* when yearly per capita water availability falls below 1,000 cubic meters (35,000 cubic feet)

According to the United Nations, currently about 500 million people live in countries that are water-scarce or water-stressed. By 2025, there may be 2.4–3.4 billion people in such countries. Income level and location determine how many of these people have access to a reliable and safe water supply.

Some areas have lots of water, but the largest rivers (which carry most of the runoff) are far from agricultural and population centers. For example, South America has the largest annual water runoff of any continent, but 60% of the runoff flows through the Amazon River in remote areas where few people live.

In some areas, overall precipitation may be plentiful but **(1)** most arrives during short periods or **(2)** cannot be collected and stored because of a lack of water storage capacity. For example, only a few hours of rain provide over half of India's rainfall during a four-month monsoon season.

Even when a plentiful supply of water exists, most of the 1.2 billion poor people living on less than $1 a day cannot afford a safe supply of drinking water and live in hydrological poverty. Most are cut off from municipal water supplies and **(1)** must collect water from unsafe sources or **(2)** buy water (often coming from polluted rivers) from private vendors at high prices. In developing countries, people not connected to municipal water supplies on average pay 12 times more per liter of water than people connected to such systems, and in some areas they pay up to 100 times as much.

Since the 1970s, water scarcity intensified by prolonged drought has killed more than 24,000 people per year and created millions of environmental refugees. In water-short rural areas in developing countries, many women (Figure 12-27, p. 271) and children must walk long distances each day, carrying heavy jars or cans, to get a meager and sometimes contaminated supply of water.

A number of analysts believe that *access to water resources, already a key foreign policy and environmental and economic security issue for water-short countries*

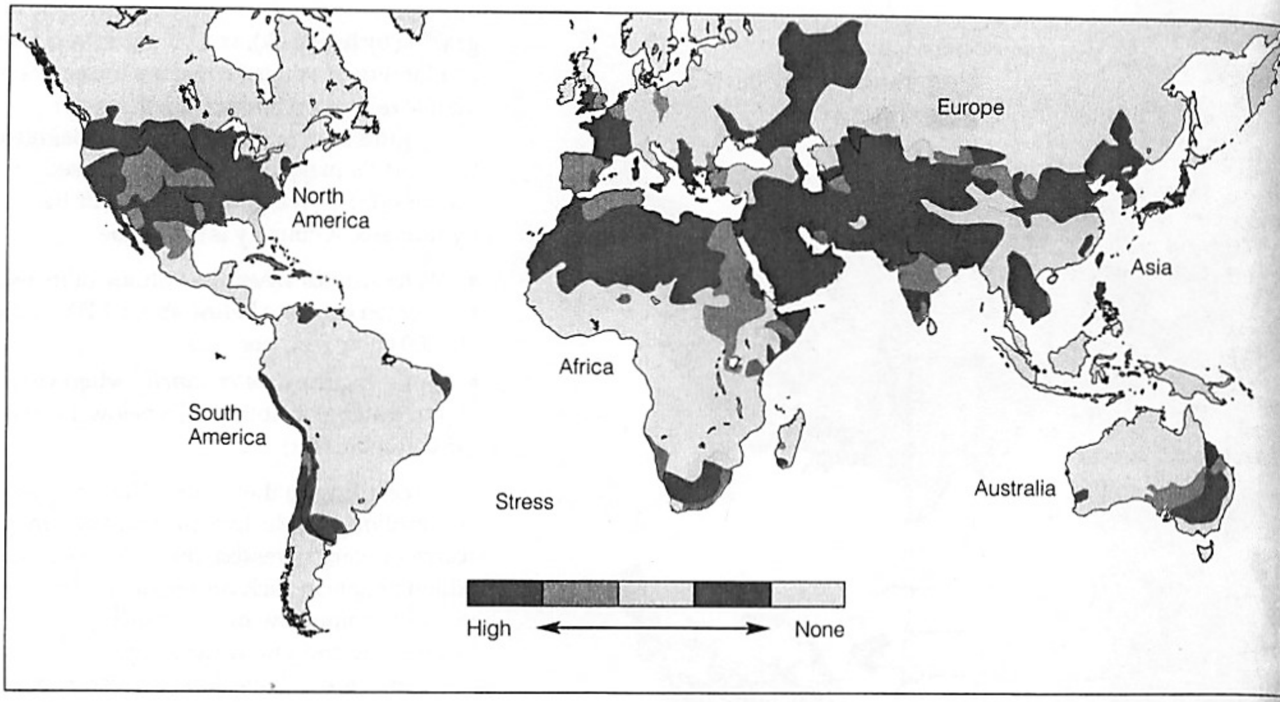



**Figure 14-8** Stress on the world's major river basins, based on a comparison of the amount of water available with the amount used by humans. (Data from World Commission on Water Use in the 21st Century)

(p. 312), *will become even more important over the next 10–25 years.*

**How Can We Increase Freshwater Supplies?** Six ways to increase the supply of fresh water in a particular area are to **(1)** build dams and reservoirs to store runoff, **(2)** bring in surface water from another area, **(3)** withdraw groundwater, **(4)** convert salt water to fresh water (desalination), **(5)** waste less water, and **(6)** import food to reduce water use.

In *developed countries,* people tend to live where the climate is favorable and then bring in water from another watershed. For example, since 1900 the United States has spent at least $400 billion—mostly as government subsidies—in building dams, reservoirs, aqueducts, pipelines, and flood control levees to manage and supply farmers and cities with low-cost water and hydroelectric power.

In *developing countries,* most people (especially the rural poor) must settle where the water is and try to capture the precipitation they need. Millions of the more than 820 million undernourished people live in poor farm families in Asia and Africa, where long dry seasons make crop production difficult or impossible without irrigation. But conventional irrigation techniques are too expensive for many of these rural poor people. *Poverty is the principal cause of hunger, malnutrition, and lack of access to sufficient water, regardless of how much water is available.*

Thirty-six water-stressed countries in Asia, Africa, and the Middle East (Figure 14-8) account for 26% of global grain imports. As water stress increases in coming decades, such imports are likely to rise.

## 14-4 USING DAMS AND RESERVOIRS TO SUPPLY MORE WATER

**What Are the Pros and Cons of Large Dams and Reservoirs?** Large dams and reservoirs have benefits and drawbacks (Figure 14-9 and Case Study, p. 321). The main purpose is to capture and store runoff and release it as needed for **(1)** controlling floods, **(2)** producing hydroelectric power, and **(3)** supplying water for irrigation and for towns and cities. Reservoirs also provide recreational activities such as swimming, fishing, and boating.

Between 1950 and 2000, the number of large dams (more than 15 meters or 49 feet high) has increased nearly sevenfold, from about 5,700 to more than 45,000. In the United States, more than 70,000 dams are capable of capturing and storing half of the country's entire river flow.

As a result, many rivers resemble an elaborate plumbing system, with multiple dams used to control

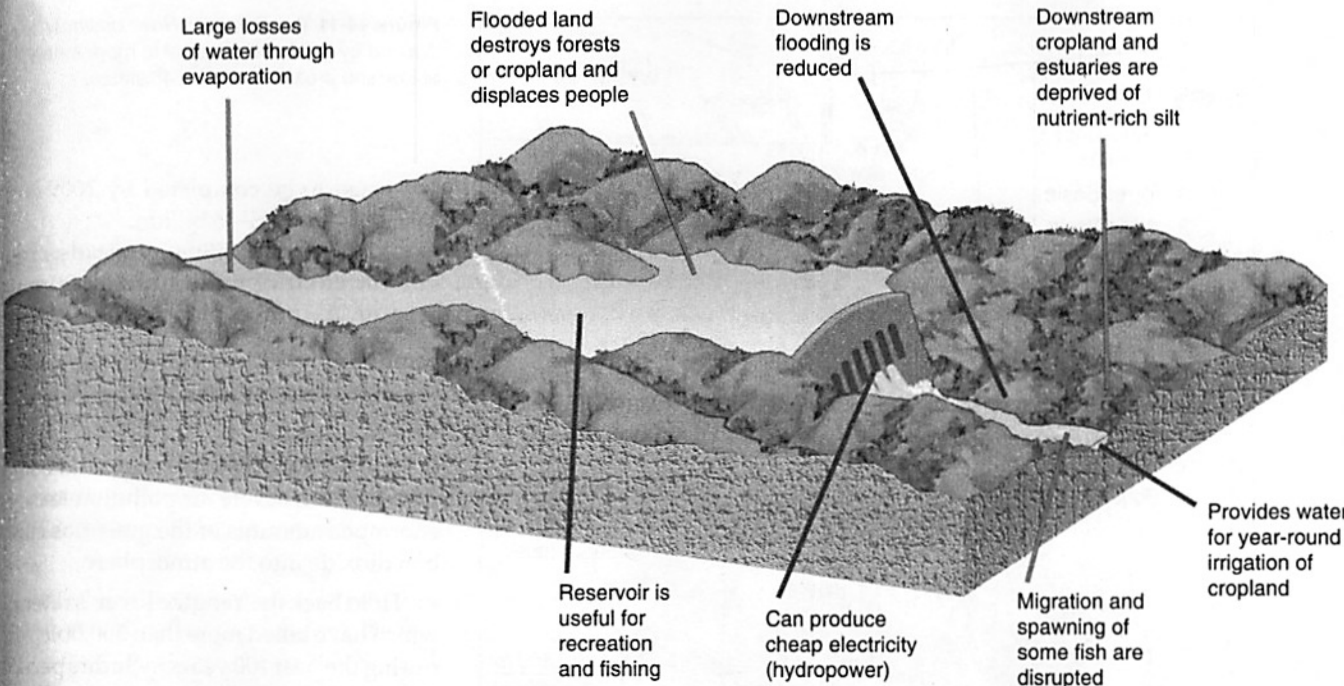



**Figure 14-9** Main advantages (green) and disadvantages (orange) of large dams and reservoirs. The world's 45,000 large dams now impound about 14% of the world's runoff.

the timing and flow of water, like water from a faucet. This engineering approach to river management often impairs the important ecological services that rivers provide (Figure 14-10). For example, according to water-resource expert Peter H. Gleck, more than 24% of the world's freshwater fish species are threatened or endangered, primarily because dams and water withdrawals have destroyed the free-flowing river ecosystems (Figure 7-23, p. 160) where they once thrived.

Some *good news* is that these dams have increased the annual runoff available for human use by nearly one-third. Some *bad news* is that a series of dams on a river, especially in arid areas, can reduce downstream flow to a trickle and prevent it from reaching the sea as a part of the hydrologic cycle. According to the World Commission on Water in the 21st Century, half of the world's major rivers either **(1)** run dry part of the year and fail to reach the ocean or **(2)** have little water left in them when they get to the sea. Causes include a combination of **(1)** prolonged drought in some areas, **(2)** dams, and **(3)** increased diversion of water for irrigation and for cities.

Major rivers that run dry and do not reach the sea anymore during the dry season include the **(1)** Colorado in the southwestern United States (Figure 14-11, p. 320 and Case Study, p. 322), **(2)** Rio Grande along the border between Texas and Mexico, **(3)** Yellow in northern China, **(4)** Nile in the Middle East (Figure 14-1), **(5)** Ganges and Indus in South Asia, and **(6)** Amu Darya and Syr Darya in five counties that once were part of the Soviet Union.

A small number of countries have taken some steps to remove the old, dangerous, or environmentally harmful dams. In 1998 and 1999, for example, two dams in France's Loire River basin were demolished to help restore the region's fisheries. In 1999, a dam on Maine's Kennebac River was dismantled to open up a 29-kilometer(18-mile) stretch of the river for fish spawning. It is one of 500 dams that have been removed from U.S. rivers in the past few years.

- **Deliver nutrients to the sea, which helps to sustain coastal fisheries**
- **Deposit silt that maintains deltas**
- **Purify water**
- **Renew and nourish wetlands**
- **Provide habitats for aquatic life**
- **Conserve species diversity**

**Figure 14-10** Some ecological services provided by rivers. Currently, the services are given little or no monetary value when the costs and benefits of dam and reservoir projects are assessed. According to environmental economists, attaching even crudely estimated monetary values to these ecosystem services would help sustain them.

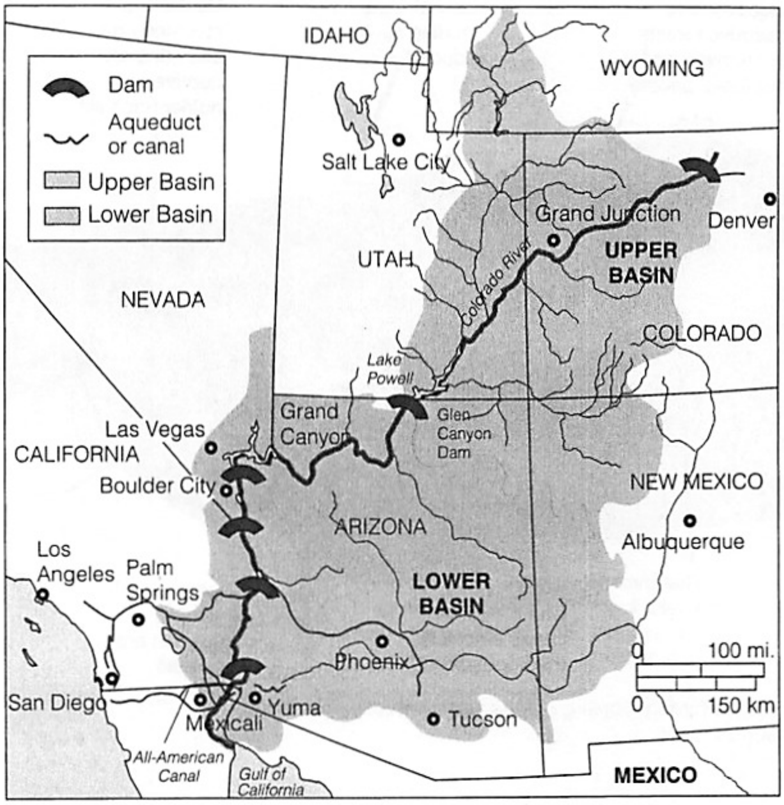



Figure 14-11 The *Colorado River basin.* The area drained by this basin is equal to more than one-twelfth of the land area of the lower 48 states.

**Case Study: China's Three Gorges Dam** When completed, China's Three Gorges project on the mountainous upper reaches of the Yangtze River (Figure 14-12) will be the world's largest hydroelectric dam and reservoir. This 2-kilometer-(1.2-mile-) long dam is supposed to be completed by 2009 at an estimated cost of $25–65 billion.

According to Chinese officials, this superdam, with the electric output of 20 large coal-burning or nuclear power plants, will

- Generate almost 10% of China's electricity for use by industries and about 150 million people.
- Help China reduce its dependence on coal, which causes severe air pollution and releases enormous amounts of the greenhouse gas carbon dioxide into the atmosphere.
- Hold back the Yangtze River's floodwaters, which have killed more than 500,000 people during the past 100 years including 4,000 people in 1998. According to Chinese officials, the 15 million people living in the Yangtze River Valley will benefit from such flood protection. This greatly exceeds the 1.9 million people who will be relocated from the area to be flooded to form a gigantic 600-kilometer-long (370-mile-long) reservoir behind the dam (Figure 14-12, right).
- Reduce flooding and silting of the river by eroded soil.

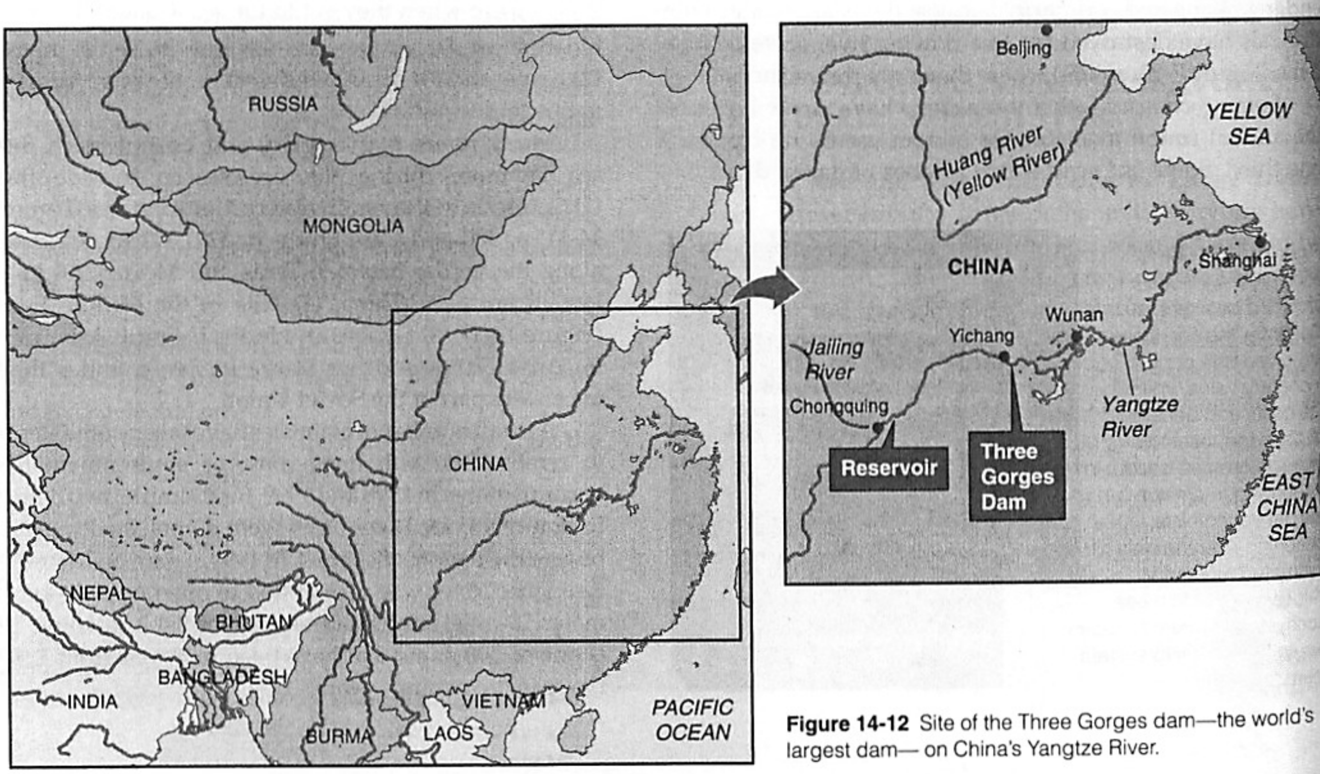



Figure 14-12 Site of the Three Gorges dam—the world's largest dam— on China's Yangtze River.

## Egypt's Aswan High Dam: Blessing or Disaster?

CASE STUDY

The Aswan High Dam on the Nile River in Egypt and its Lake Nasser reservoir (Figure 14-1) were built in the 1960s and demonstrate the mix of advantages and disadvantages of such projects.

The project's major benefits include the following:

- Supplying about one-half of Egypt's electrical power and reducing electricity prices.
- Storing and releasing water for irrigation, which is used to grow all of Egypt's food. This saved Egypt's rice and cotton crops during severe droughts in the 1970s and 1980s and helped avert massive famines. To many Egyptians, this more than paid for the cost of the dam.
- Increasing food production by allowing year-round irrigation of land in the lower Nile basin. Since 1970, this has helped increase Egypt's agricultural income by about 200%.
- Improving navigation along the river.
- Providing flood control for the lower Nile basin.

However, the project has also produced the following harmful ecological and economic effects:

- Ending the yearly flooding that for thousands of years had fertilized the Nile's floodplain with silt, most of it washed down from the Ethiopian highlands. Now the river's silt accumulates behind the dam, filling Lake Nasser and eventually will make the dam useless.
- Necessitating the use of commercial fertilizer on cropland in the Nile Delta basin at an annual cost of more than $100 million to make up for plant nutrients once available at no cost. The country's new fertilizer plants use up much of the electrical power produced by the dam.
- Increasing salinization (Figure 10-22, p. 221) because there is no natural annual flooding to flush salts from the irrigated soil. This has offset about three-fourths of the gain in food production from new land irrigated by water from the reservoir.
- Eliminating 94% of Nile water that once reached the Mediterranean Sea each year and upsetting the ecology of waters near the mouth of the Nile.
- Eliminating the annual sediment discharge where the Nile reaches the sea. This has **(1)** caused the coastal delta to erode and advance inland and **(2)** reduced productivity on large areas of agricultural land.
- Eradicating most of Egypt's sardine, mackerel, shrimp, and lobster fishing industries because nutrient-rich silt no longer reaches the river's mouth. This has led to losses of **(1)** approximately 30,000 jobs, **(2)** millions of dollars annually, and **(3)** an important source of protein for Egyptians. However, a new fishing industry taking bass, catfish, and carp from Lake Nasser has offset some of these losses.
- Uprooting 125,000 people when land was flooded to create Lake Nasser and changing nomadic grazing patterns.

In 1997, the Egyptian government **(1)** opened a new canal to transfer Nile water under the Suez Canal to irrigate land in the Sinai desert and **(2)** began a 20-year project to divert Nile water upstream from Lake Nasser and transport it hundreds of kilometers to irrigate land in Egypt's southwestern desert. This will open up land for human settlement to relieve population pressures in the crowded Nile valley.

These plans are threatened because about 80% of the water flowing into Lake Nasser comes from Ethiopia (Figure 14-1), which plans to build dams for irrigation and hydropower projects. This may not leave enough water in the Nile to support Egypt's plans for increased irrigation and could increase tension between the two countries.

Some analysts believe the Aswan dam's benefits outweigh its economic and ecological costs. Other analysts consider it an economic and ecological disaster. Time will tell who is right.

### Critical Thinking

**1.** Do you believe the benefits of the Aswan High Dam outweigh its drawbacks? Explain.

**2.** List two principles for designing and building large dams based on lessons from the Aswan High Dam.

Critics point to a number of drawbacks of the Yangtze dam and reservoir project:

- Forming the huge reservoir will **(1)** flood large areas of productive farmland and forests and **(2)** displace about 1.9 million people from their homes.
- The region's entire ecosystem will be radically changed.
- Water pollution will increase because of the river's reduced water flow.
- If the reservoir fills up with sediment and overflows (especially if the reservoir is kept filled at a high level, as planned, to provide maximum hydroelectric power), half a million people will be exposed to severe flooding.
- Annual deposits of nutrient-rich sediments below the dam will be reduced.
- The reduced downstream water flow will promote saltwater intrusion into drinking water supplies near the mouth of the river.

## The Colorado River Basin

CASE STUDY

The Colorado River flows 2,300 kilometers (1,400 miles) from the mountains of central Colorado to the Mexican border and eventually to the Gulf of California (Figure 14-11, p. 320). During the past 50 years, this once free-flowing river has been tamed by a gigantic plumbing system consisting of **(1)** 14 major dams and reservoirs (Figure 14-11), **(2)** hundreds of smaller dams, and **(3)** a network of aqueducts and canals that supply water to farmers, ranchers, and cities.

Today, this domesticated river provides **(1)** electricity (from hydroelectric plants at major dams), **(2)** water for more than 25 million people in seven states, **(3)** water used to produce about 15% of the nation's produce and livestock, and **(4)** a multibillion-dollar recreation industry of whitewater rafting, boating, fishing, camping, and hiking enjoyed by more than 15 million people a year.

Take away this tamed river and **(1)** Las Vegas, Nevada, would be a mostly uninhabited desert area, **(2)** San Diego, California (which gets 70% of its water from the Colorado), could not support its present population, and **(3)** California's Imperial Valley (which grows a major portion of the nation's vegetables) would consist mostly of cactus and mesquite plants.

However, three major problems are associated with use of this river's water:

- The Colorado River basin includes some of the driest lands in the United States and Mexico (Figure 14-7).
- Legal pacts in 1922 and 1944 allocated more water to the states in the river's *upper basin* (Wyoming, Utah, Colorado, and New Mexico) and *lower basin* (Arizona, Nevada, and California; Figure 14-11) and to Mexico than now flows through the river, even in years without a drought.
- Because of so many withdrawals, the river rarely makes it to the Gulf of California. Instead, it fizzles into a trickle that disappears into the Mexican desert or (in drought years) the Arizona desert. This **(1)** threatens the survival of species that spawn in the river, **(2)** destroys estuaries that serve as breeding grounds for numerous aquatic species, and **(3)** increases saltwater contamination of aquifers near coasts.

Legal battles are increasing over how much of the river's limited water can be withdrawn and used by **(1)** cities, **(2)** farmers, **(3)** ranchers, and **(4)** Native Americans (who as senior owners of water rights dating back to the mid-1880s have the law on their side and have been winning legal battles to withdraw more water).

Environmentalists have initiated mostly unsuccessful attempts to keep more of the river wild by **(1)** not building so many large dams and **(2)** removing some of the existing dams to help protect the river's ecological services (Figure 14-10).

Traditionally, about 80% of the water withdrawn from the Colorado has been used to irrigate crops and raise cattle because ranchers and farmers (after Native Americans) got there first and established legal rights to use a certain amount of water each year. This large-scale use of water for agriculture was made possible because the government **(1)** paid for the dams and reservoirs and **(2)** under long-term contracts has supplied many of the farmers and ranchers with water at a very low price. This has led to inefficient use of irrigation water and growing crops such as rice, cotton, and alfalfa (for cattle feed) that need a lot of water.

Some cities (such as Tucson, Arizona, and Colorado Springs, Colorado) have been buying up the legal water rights of nearby farmers and ranchers. Others are paying farmers to install less wasteful irrigation systems (Figure 14-18, p. 330) so more water will be available to support urban areas. It is estimated that improving overall irrigation efficiency by about 10–15% would provide enough water to support projected urban growth in the areas served by the river to 2020.

These controversies illustrate the problems that governments and people in semiarid regions with shared river systems face as population and economic growth place increasing demands on limited supplies of surface water.

### Critical Thinking

**1.** What are the pros and cons of reducing or eliminating government subsidies that provide U. S. farmers, ranchers, and cities with cheap water from the Colorado River?

**2.** If the legal system allowed it, put the following users in order of how much water you would allocate to them from the Colorado River: farmers, ranchers, cities, Native Americans, and Mexico. Explain your choices.

## 14-5 TRANSFERRING WATER FROM ONE PLACE TO ANOTHER

**What Are the Pros and Cons of Large-Scale Water Transfers?** Tunnels, aqueducts, and underground pipes can transfer stream runoff collected by dams and reservoirs from water-rich areas to water poor areas. Although such transfers have benefits they also create environmental problems (Case Study p. 324). Indeed, most of the world's dam projects an large-scale water transfers illustrate the important ecc logical principle that *you cannot do just one thing.*


**Figure 14-13** The California Water Project and the Central Arizona Project involve large-scale water transfers from one watershed to another. Arrows show the general direction of water flow.

One of the world's largest watershed transfer projects is the *California Water Project.* In California, the basic water problem is that 75% of the population lives south of Sacramento, but 75% of the state's rain occurs north of Sacramento.

The California Water Project uses a maze of giant dams, pumps, and aqueducts to transport water from water-rich northern California to heavily populated areas and to arid and semiarid agricultural regions, mostly in southern California (Figure 14-13).

For decades, northern and southern Californians have been feuding over how the state's water should be allocated under this project. Southern Californians say they need more water from the north to support Los Angeles, San Diego, and other growing urban areas and to grow more crops. Agriculture uses 74% of the water withdrawn in California, much of it for water-thirsty crops. For example, alfalfa, one of the most water-intensive crops, is grown in the southern California desert. It uses about one-fourth of California's irrigation water but makes up only 0.1% of the state's economy.

Opponents in the north say that sending more water south would **(1)** degrade the Sacramento River, **(2)** threaten fisheries, and **(3)** reduce the flushing action that helps clean San Francisco Bay of pollutants. They also argue that **(1)** much of the water sent south is wasted unnecessarily and **(2)** making irrigation just 10% more efficient would provide enough water for domestic and industrial uses in southern California. However, if water supplies in northern California and in the Colorado River basin (Figure 14-11) drop sharply because of global warming, the amount of water delivered by the huge distribution system will plummet.

Pumping out more groundwater is not the answer because groundwater is already being withdrawn faster than it is replenished throughout much of California. To most analysts, quicker and cheaper solutions are **(1)** improving irrigation efficiency and **(2)** allowing farmers to sell their legal rights to withdraw certain amounts of water from rivers.

**Case Study: The James Bay Watershed Transfer Project** Another major watershed transfer project is Canada's James Bay project. It is a $60-billion 50-year scheme to harness the wild rivers that flow into Quebec's James and Hudson Bays to produce electric power for Canadian and U.S. consumers (Figure 14-14).

If completed, this megaproject would **(1)** construct 600 dams and dikes that will reverse or alter the flow of 19 giant rivers covering a watershed three times the size of New York State, **(2)** flood an area of boreal forest and tundra equal in area to Washington State or Germany, and **(3)** displace thousands of indigenous Cree and Inuit, who for 5,000 years have lived off James Bay by subsistence hunting, fishing, and trapping.

After 20 years, the $16-billion phase I has been completed. The second and much larger phase was


**Figure 14-14** If completed, the James Bay project in northern Quebec will alter or reverse the flow of 19 major rivers and flood an area the size of the state of Washington to produce hydropower for consumers in Quebec and the United States, especially in New York State. Phase I of this 50-year project is completed.

## The Aral Sea Water Transfer Disaster

CASE STUDY

The shrinking of the Aral Sea (see figure) is a result of a large-scale water transfer project in an area of the former Soviet Union with the driest climate in central Asia. Since 1960, enormous amounts of irrigation water have been diverted from the inland Aral Sea and its two feeder rivers to create one of the world's largest irrigated areas. The irrigation canal, the world's longest, stretches over 1,300 kilometers (800 miles).

This water diversion project (coupled with droughts) and high evaporation rates in this hot, dry climate has caused a regional ecological, economic, and health disaster. Problems caused by this massive water-diversion project include:

- Tripling of the sea's salinity.
- Decreasing the sea's surface area by 54% (see figure) and its volume by 75%.
- Reducing the sea's two supply rivers to mere trickles.
- Converting about 36,000 square kilometers (14,000 square miles) of former lake bottom to a human-made desert covered with glistening white salt.
- Causing the presumed extinction of 20 of the area's 24 native fish species as the salt concentrations in the sea's water have increased. This has devastated the area's fishing industry, which once provided work for more than 60,000 people. Fishing villages and boats once on the sea's coastline now are in the middle of a salt desert and have been abandoned.
- Eliminating 85% of the area's wetlands, which along with increased pollution has greatly reduced waterfowl populations.
- Disappearance of roughly half the area's bird and mammal species.
- Causing one of the world's worst salinization problems. Winds pick up the salty dust that encrusts the lake's now-exposed bed and blow it onto fields as far as 300 kilometers (190 miles) away. As the salt spreads, it kills wildlife, crops, and other vegetation and pollutes water. Aral Sea dust settling on glaciers in the Himalayas is causing them to melt at a faster than normal rate.
- Increasing groundwater and surface water pollution. To raise yields, farmers have increased inputs of herbicides, insecticides, fertilizers, and irrigation water on some crops. Many of these chemicals have percolated downward and accumulated to dangerous levels in the groundwater, from which most of the region's drinking water comes. The lower river flows have also concentrated salts, pesticides, and other toxic chemicals, making surface water supplies hazardous to drink.
- Alteration of the area's climate. The once-huge sea acted as a thermal buffer that moderated the heat of summer and the extreme cold of winter. Now **(1)** there is less rain, **(2)** summers are hotter and drier, **(3)** winters are colder, and **(4)** the growing season is shorter.
- Reduction of crop yields by 20–50% from a combination of climate change and severe salinization of almost a

postponed indefinitely in 1994 because of **(1)** an excess of power generated, **(2)** opposition by the Cree (whose ancestral hunting grounds would have been flooded) and Canadian and U.S. environmentalists, and **(3)** New York State's cancellation of two contracts to buy electricity produced by phase II.

## 14-6 TAPPING GROUNDWATER, CONVERTING SALT WATER TO FRESH WATER, SEEDING CLOUDS, AND TOWING ICEBERGS

**What Are the Advantages of Withdrawing Groundwater?** Pumping groundwater from aquifers has several advantages over tapping more erratic flows from streams. Groundwater **(1)** can be removed as needed year round, **(2)** is not lost by evaporation, and **(3)** usually is less expensive to develop than surface water systems.

Aquifers provide drinking water for almost one-third of the world's people. In Asia alone, more than 1 billion people depend on groundwater for drinking. In the United States, water pumped from aquifers supplies about **(1)** 51% of the drinking water (96% in rural areas and 20% in urban areas) and **(2)** 43% of irrigation water.

**What Are the Disadvantages of Withdrawing Groundwater?** Withdrawing groundwater from aquifers faster than it is replenished can cause or intensify several problems: **(1)** *water table lowering* (Figure 14-15, p. 326), **(2)** *aquifer depletion* (Figure 14-16, top, p. 326), **(3)** *aquifer subsidence* (sinking of land when groundwater is withdrawn, Figure 14-16, bottom),


Once the world's fourth largest freshwater lake, the Aral Sea has been shrinking and getting saltier since 1960 because most of the water from the rivers that replenish it has been diverted to grow cotton and food crops. As the lake shrinks, it leaves behind a salty desert, economic ruin, increasing health problems, and severe ecological disruption.

third of the area's cropland. More water could be withdrawn to flush out and lessen the area's acute salt problem. But Russian scientists estimate that freeing up this much water would mean retiring about half of the area's irrigated cropland, an unthinkable solution considering the region's already dire economic conditions.

- Greatly increased health problems from a combination of toxic dust, salt, and contaminated water for a growing number of the 58 million people living in the Aral Sea's watershed. Such problems include abnormally high rates of **(1)** infant mortality, **(2)** tuberculosis, **(3)** anemia, **(4)** respiratory illness (one of the world's highest), **(5)** eye diseases (from salt dust), **(6)** throat cancer, **(7)** kidney and liver diseases (especially cancers), **(8)** arthritic diseases, **(9)** typhoid fever, and **(10)** hepatitis.

Can the Aral Sea be saved, and can the area's serious ecological and human health problems be reduced? Since 1999, the United Nations and the World Bank have spent about $600 million to **(1)** purify drinking water, **(2)** upgrade irrigation and drainage systems to improve irrigation efficiency, flush salts from croplands, and boost crop productivity, and **(3)** construct wetlands and artificial lakes to help restore aquatic vegetation, wildlife, and fisheries. However, this process will take decades and will not prevent the shrinkage of the Aral Sea into a few brine lakes.

### Critical Thinking

What ecological and economic lessons can we learn from the Aral Sea tragedy?

**(4)** *intrusion of salt water into aquifers,* **(5)** *drawing of chemical contamination in groundwater toward wells,* and **(6)** *reduced stream flow* because of diminished flows of groundwater into streams. Also, industrial and agricultural activities, septic tanks, and other sources can contaminate groundwater.

According to Earth Policy Institute and the World Resources Institute, water tables are falling in many areas as the rate of water pumping exceeds the rate of recharge from precipitation. Such unsustainable *water mining* from overpumping aquifers produces about 8% of the world's current grain harvest. This is causing water tables to fall in

- The North China Plain, which produces more than half of China's wheat and a third of its corn. A 2001 survey found that the aquifer under North China's plain is falling faster than previously thought.
- Agricultural areas in **(1)** parts of the southern Great Plains of the United States, which are served by the gigantic but essentially nonrenewable Ogallala aquifer (Case Study, p. 327) and **(2)** in parts of the arid southwestern United States (Figure 14-7, top), especially California's Central Valley, which supplies about half the country's vegetables and fruits.
- Much of India, especially the Punjab. This jeopardizes as much as one-fourth of India's grain production.
- Parts of **(1)** Saudi Arabia, **(2)** northern Africa (especially Libya and Tunisia), **(3)** southern Europe, **(4)** the Middle East, and **(5)** Mexico, Thailand, and Pakistan.

According to water resource expert Sandra Postel, about 480 million of the world's 6.2 million people are being fed with grain produced with eventually unsustainable water mining from aquifers. This example of

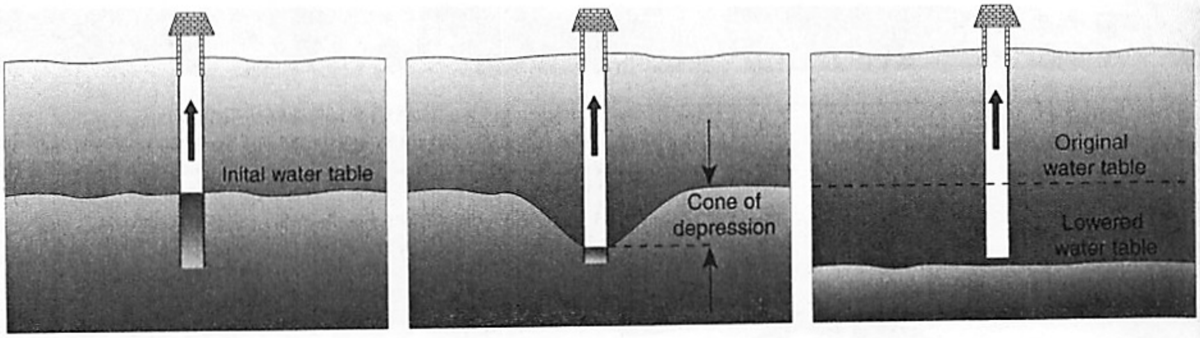



**Figure 14-15** Lowering of the water table when a well is drilled into an aquifer (left). A cone of depression (middle) in the water table forms if groundwater is pumped to the surface faster than it can flow through the aquifer to the well. If this excessive water removal continues, the water table falls (right).

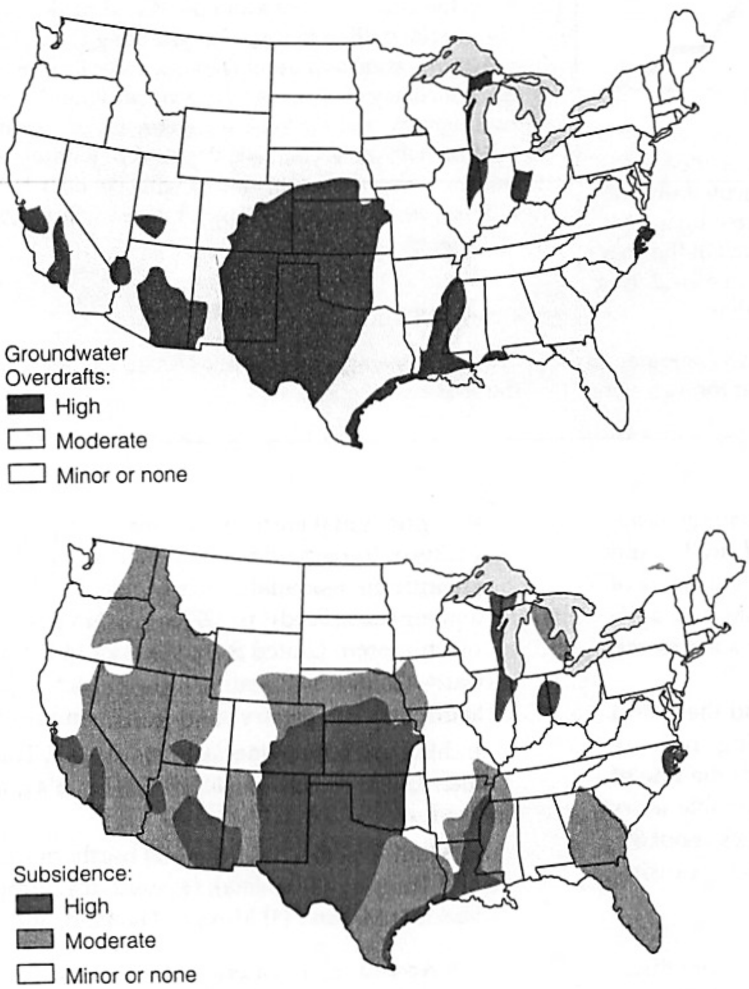



**Figure 14-16** Areas of greatest aquifer depletion from groundwater overdraft (top) and ground subsidence (bottom) in the continental United States. Aquifer depletion is also high in Hawaii and Puerto Rico (not shown on map). (Data from U.S. Water Resources Council and U.S. Geological Survey)

the tragedy of the commons (Connections, p. 11) is expected to increase as irrigated areas are expanded to help feed the 3.1 billion more people projected to join the ranks of humanity between 2002 and 2050.

Overpumping is a new phenomenon that has largely occurred since 1950 because of the development of increasingly powerful electric and diesel pumps that can remove water from an aquifer faster than it is renewed by precipitation. With water worth up to 70 times more in industry and cities as in agriculture, farmers almost always lose in the competition for scarce water.

In addition to limiting future food production, overpumping aquifers is increasing the gap between the rich and poor in some areas. As water tables drop, farmers must **(1)** drill deeper wells, **(2)** buy larger pumps to bring the water to the surface, and **(3)** use more electricity to run the pumps. Poor farmers cannot afford to do this and end up losing their land and either working for richer farmers or hoping to survive by migrating to cities.

When fresh water from an aquifer near a coast is withdrawn faster than it is recharged, salt water intrudes into the aquifer (Figure 14-17, p. 328). Such intrusion can contaminate drinking water supplies of many towns and cities along coastal areas.

Ways to prevent or slow groundwater depletion include **(1)** controlling population growth, **(2)** not planting water-intensive crops such as cotton and sugarcane in dry areas, **(3)** shifting to crops that need less water in dry areas, **(4)** developing crop strains that need less water and are more resistant to heat stress, **(5)** wasting less irriga-

## Mining Groundwater: The Shrinking Ogallala Aquifer

CASE STUDY

Large amounts of water have been pumped from the Ogallala, the world's largest known aquifer (see figure). This has helped transform vast areas of arid high plains prairie land into one of the largest and most productive agricultural regions in the United States.

Mostly because of irrigated farming, this region produces 20% of U.S. agricultural output (including 40% of its feedlot beef), valued at $32 billion per year. This has brought prosperity to many farmers and merchants in this region. But the largely hidden environmental and economic cost has been increasing aquifer depletion in some areas.

Although this aquifer is gigantic, it is essentially nonrenewable (stored during the retreat of the last ice age about 15,000–30,000 years ago) with an extremely slow recharge rate. In some areas, water is being pumped out of the aquifer 8–10 times faster than the aquifer's natural recharge rate.

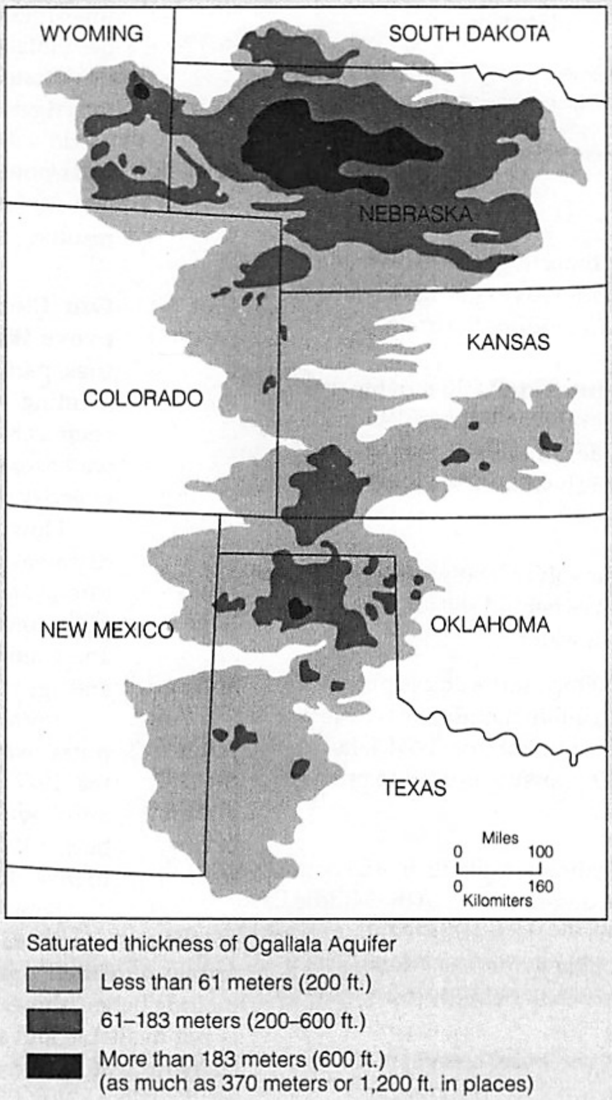
The northernmost states (Wyoming, North Dakota, South Dakota, and parts of Colorado) still have ample supplies. However, supplies in parts of the southern states, where the aquifer is thinner (see figure), are being depleted rapidly, with about two-thirds of the aquifer's depletion taking place in the Texas high plains.

Water experts project that at the current rate of withdrawal, one-fourth of the aquifer's original supply will be depleted by 2020 and much sooner in areas where it is shallow. It will take thousands of years to replenish the aquifer.

Government subsidies designed to increase crop production also increase depletion of the Ogallala by **(1)** encouraging farmers to grow water-thirsty cotton in the lower basin, **(2)** providing crop-disaster payments, and **(3)** providing tax breaks in the form of groundwater depletion allowances, with larger breaks for heavier groundwater use.

Depletion of this essentially nonrenewable water resource can be delayed if farmers **(1)** use more efficient forms of irrigation (Figure 14-18, p. 330), **(2)** switch to crops that need less water, or **(3)** irrigate less land.

Cities using this groundwater can also implement policies and technologies to reduce their water use and waste. People enjoying the benefits of this aquifer can help by **(1)** installing water-saving toilets and showerheads and **(2)** converting their lawns to plants that can survive in an arid climate with little watering (Figure 14-21, p. 332).




The Ogallala is the world's largest known aquifer. If the water in this aquifer were above ground, it could cover all 50 states with 0.5 meter (1.5 feet) of water. Water withdrawn from this aquifer is used to grow crops, raise cattle, and provide cities and industries with water. As a result, this aquifer, which is renewed very slowly, is being depleted (especially at its thin southern end in parts of Texas, New Mexico, Oklahoma, and Kansas). (Data from U.S. Geological Survey)

### Critical Thinking

**1.** What are the pros and cons of giving government subsidies to farmers and ranchers using water withdrawn from the Ogallala to grow crops and raise livestock that need large amounts of irrigation water? How do you benefit from such subsidies?

**2.** Should these government subsidies be reduced or eliminated and replaced with subsidies that encourage farmers to use more efficient forms of irrigation and switch to crops that need less water? Explain.

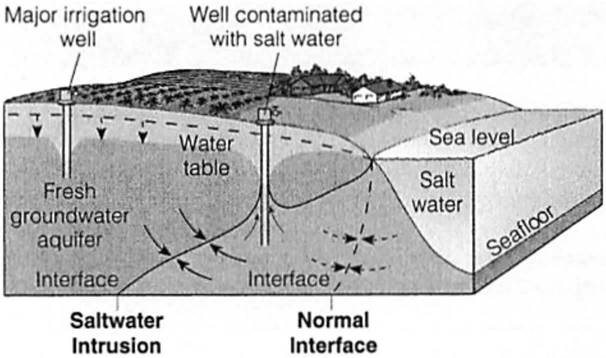



**Figure 14-17** Saltwater intrusion along a coastal region. When the water table is lowered, the normal interface (dashed line) between fresh and saline groundwater moves inland (solid line), making groundwater drinking supplies unusable.

tion water, and **(6)** importing grain, with each imported metric ton of grain saving roughly 1,000 metric tons of water needed to produce the grain.

**How Useful Is Desalination?** Removing dissolved salts from ocean water or from brackish (slightly salty) groundwater, called **desalination,** is another way to increase supplies of fresh water. The two most widely used methods are:

- *Distillation,* which involves heating salt water until it evaporates (and leaves behind salts in solid form) and condenses as fresh water.
- *Reverse osmosis,* in which salt water is pumped at high pressure through a thin membrane whose pores allow water molecules, but not dissolved salts, to pass through. In effect, high pressure is used to push freshwater out of salt water.

About 13,300 desalination plants in 120 countries (especially in the arid, desert nations in the Middle East, North Africa, the Caribbean, and the Mediterranean) meet less than 0.2% of the world's water needs. Desalination would have to increase 25-fold just to supply 5% of current world water use.

This is unlikely because desalination has two major disadvantages:

- *It is expensive because it takes large amounts of energy.* Desalinating water costs 2–3 times as much as the conventional purification of fresh water.
- *It produces large quantities of wastewater (brine) containing high levels of salt and other minerals.* Dumping the concentrated brine into the ocean near the plants increases the local salt concentration and threatens food resources in estuary waters, and dumping it on land could contaminate groundwater and surface water.

Desalination can provide fresh water for coastal cities in arid countries (such as sparsely populated Saudi Arabia and Israel), where the cost of getting fresh water by any method is high. In the United States, desalination plants are used to meet some of the water needs along coastal areas of Florida, southern California, Virginia, North Carolina, and Texas.

Scientists are working to develop new membranes for reverse osmosis that can separate water from salt more efficiently and under less pressure. If successful, this strategy could help bring down the cost of using desalinization to produce drinking water. However, desalinated water probably will not be cheap enough to irrigate conventional crops or meet much of the world's demand for fresh water unless **(1)** affordable solar-powered distillation plants can be developed, and **(2)** someone can figure out what to do with the resulting mountains of salt.

**Can Cloud Seeding and Towing Icebergs Improve Water Supplies?** For decades, several countries, particularly the United States, have been experimenting with seeding clouds with tiny particles of chemicals (such as silver iodide). The particles form water condensation nuclei and thus produce more rain over dry regions and more snow over mountains.

However, cloud seeding **(1)** is not useful in very dry areas, where it is most needed, because rain clouds rarely are available there and **(2)** would introduce large amounts of the cloud-seeding chemicals into soil and water systems, possibly harming people, wildlife, and agricultural productivity.

Another obstacle to cloud seeding is legal disputes over the ownership of water in clouds. During the 1977 drought in the western United States, the attorney general of Idaho accused officials in neighboring Washington of "cloud rustling" and threatened to file suit in federal court.

Some have proposed towing huge icebergs to arid coastal areas (such as Saudi Arabia and southern California) and then pumping the fresh water from the melting bergs ashore. But the technology for doing this is not available and the costs may be too high, especially for water-short developing countries.

## 14-7 USING WATER MORE EFFICIENTLY

**What Are the Benefits of Reducing Water Waste?** Mohamed El-Ashry of the World Resources Institute estimates that *65–70% of the water people use throughout the world is lost through evaporation, leaks, and other losses.* The United States, the world's largest user of water, does slightly better but still loses about 50% of

## Water Rights in the United States

SPOTLIGHT

Laws regulating access to and use of surface water differ in the eastern and western parts of the United States. In most of the East, water use is based on the *doctrine of riparian rights.*

Basically, this system of water law gives anyone whose land adjoins a flowing stream the right to use water from the stream as long as some is left for downstream landowners. However, as population and water-intensive land uses grow, there is often too little water to meet the needs of all the people along a stream.

In the arid and semiarid West, the riparian system does not work because large amounts of water are needed in areas far from major surface water sources. In most of this region, the *principle of prior appropriation* regulates water use.

In this first-come, first-served approach, the first user of water from a stream establishes a legal right for continued use of the amount originally withdrawn. If a shortage occurs, later users are cut off in order until enough water is available to satisfy the demands of the earlier users. Some states have a combination of riparian and prior appropriation water rights.

Most groundwater use in the United States is based on *common law,* which holds that subsurface water belongs to whoever owns the land above such water. This allows landowners to withdraw as much groundwater as they want. Because the largest users have little incentive to conserve, this can deplete the aquifer for everyone and create a tragedy of the commons (Connections, p. 11).

A system of legally protected water rights allows individuals owning rights to **(1)** sell, trade, or lease them to make money, **(2)** ease water shortages, or **(3)** protect the ecosystem services of rivers (Figure 14-10). For example, some water-short cities in the western United States are paying nearby farmers to install more efficient irrigation methods in exchange for the water the farmers save.

Private organizations and government agencies are also buying up water rights and using them to help restore aquatic environments by returning the water to rivers and wetlands. However, water markets must be regulated to avoid excessive water prices (especially for the poor) and inequalities in water distribution.

### Critical Thinking

What are the advantages and disadvantages of **(a)** the principles of riparian rights and prior appropriation for access to surface water and **(b)** the common law approach to groundwater use in the United States? If you disagree with these approaches, how would you divide up water rights?

the water it withdraws. El-Ashry believes it is economically and technically feasible to reduce such water losses to 15%, thereby meeting most of the world's water needs for the foreseeable future.

Accomplishing this will require greatly increased use of water-saving technologies and practices. It will **(1)** decrease the burden on wastewater plants, **(2)** reduce the need for expensive dams and water transfer projects that destroy wildlife habitats and displace people, **(3)** slow depletion of groundwater aquifers, and **(4)** save energy and money.

**Why Do We Waste So Much Water?** According to water resource experts, there are three major causes of water waste. One is *water subsidy policies.* Governments and international lending agencies often provide subsidies for development of water supply projects such as dams and large-scale water transfer schemes. This creates artificially low water prices that help water users but discourage improvements in water efficiency. Similar subsidies for improving water efficiency are rare. According to water resource expert Sandra Postel, "By heavily subsidizing water, governments give out the false message that it is abundant and can afford to be wasted—even as rivers are drying up, aquifers are being depleted, fisheries are collapsing, and species are going extinct."

Government-subsidized irrigation water in the western United States costs U.S. taxpayers an estimated $2–2.5 billion per year. However, farmers, industries, and others benefiting from government water subsidies argue that they **(1)** promote settlement and agricultural production in arid and semiarid areas, **(2)** stimulate local economies, and **(3)** help lower prices of food, manufactured goods, and electricity for consumers.

Water prices may rise as water supplies are being rapidly privatized worldwide. Transnational corporations are buying large supplies of water in dozens of water-short countries for resale at huge profit. Two byproducts of this lucrative business are **(1)** decreased ability of poor farmers and city dwellers to buy enough water to meet their needs and **(2)** political control by such large corporations over any country that imports privately owned water from outside its borders.

A second cause of water waste is *water laws* that determine the legal rights of water users in countries such as the United States (Spotlight, above).

Water is also wasted because of *fragmented watershed management.* The Chicago, Illinois, metropolitan area, for example, has 349 water supply systems divided among some 2,000 local units of government over a six-county area. Water saved by government planning and regulations in one area of a watershed can be offset by lack of such policies in other areas.

**Solutions: How Can We Waste Less Water in Irrigation?** About 57% of the irrigation water applied throughout the world does not reach the targeted crops. Most irrigation systems distribute water from a groundwater well or a surface water source and allow it to flow by gravity through unlined ditches in crop fields so the water can be absorbed by crops (Figure 14-18, left). This *flood irrigation* method **(1)** delivers far more water than needed for crop growth and **(2)** typically allows only 60% of the water to reach crops because of evaporation, seepage, and runoff.

Some *good news* is that more efficient and environmentally sound irrigation technologies exist that could reduce water demands and waste on farms by up to 50%. Here are some examples:

- *Center-pivot low-pressure sprinklers* (Figure 14-18, right), which typically allow 80% of the water input to reach crops and reduce water use over conventional gravity flow systems by 20–25%.
- *Low-energy precision application (LEPA) sprinklers.* This form of center-pivot irrigation allows 90–95% of the water input to reach crops by spraying it closer to the ground and in larger droplets than the center-pivot low-pressure system. LEPA sprinklers use 20–30% less energy than low-pressure sprinklers an[d] typically use 37% less water than conventional gravi[ty] flow systems.
- *Using surge or time-controlled valves on conventional gravity flow irrigation systems* (Figure 14-18, left). The[se] valves send water down irrigation ditches in pulses instead of in a continuous stream, which can raise ir[ri]gation efficiency to 80% and reduce water use by 25[%].
- *Using soil moisture detectors to water crops only whe[n] they need it.* For example, some farmers in Texas bur[y a] $1 cube of gypsum, the size of a lump of sugar, at th[e] root zone of crops. Wires embedded in the gypsum are run back to a small portable meter that indicates soil moisture. Farmers using this technique can use 33–66% less irrigation water.
- *Drip irrigation systems* (Figure 14-18, center, and Solutions, p. 333)

Other ways to reduce water waste in irrigati[ng] crops are listed in Figure 14-19. Since 1950, water-sh[ort] Israel has used many of these techniques to slash irrig[a]tion water waste by about 84% while irrigating 44[%] more land. Israel now treats and reuses 30% of [its] municipal sewage water for crop production and pla[ns] to increase this to 80% by 2025. The government al[so] **(1)** gradually removed most government water sub[si]dies to raise the price of irrigation water to one of t[he] highest in the world, **(2)** imports most of its wat[er-]intensive wheat and meat, and **(3)** concentrates [on] growing fruits, vegetables, and flowers that need le[ss]

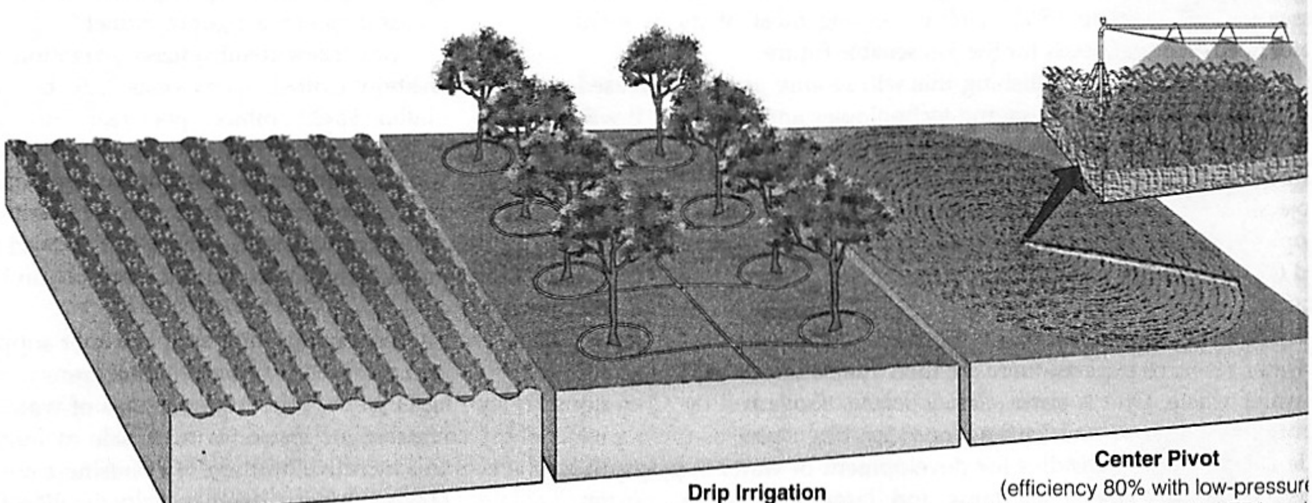



**Figure 14-18** Major irrigation systems. Because of high initial costs, center-pivot irrigation and drip irrigation are used on only about 1% of the world's irrigated cropland each. However, this may change because of the development of new low-cost drip irrigation systems (Solutions, p. 333).

- Lining canals bringing water to irrigation ditches
- Leveling fields with lasers
- Irrigating at night to reduce evaporation
- Using soil and satellite sensors and computer systems to monitor soil moisture and add water only when necessary
- Polyculture
- Organic farming
- Growing water efficient crops using drought-resistant and salt-tolerant crop varieties
- Irrigating with treated urban waste water
- Importing water intensive crops and meat

**Figure 14-19** Methods for reducing water waste in irrigation.

water. In 2001, China announced a policy to raise water prices gradually over a 5-year period to cut down water waste and help prevent a looming water shortage crisis.

Some *bad news* is that more efficient sprinklers are used on only 10% and drip irrigation on just over 1% of the world's irrigated cropfields. This could change with **(1)** development of cheaper sprinkler and drip irrigation technologies (Solutions, p. 333) and **(2)** increased government subsidies for farmers using more efficient irrigation methods.

Many of the world's poor farmers cannot afford to use most of the modern technological methods for increasing irrigation and irrigation efficiency. These farmers increase irrigation by using small-scale and low-cost traditional technologies such as **(1)** pedal-powered treadle pumps to move water through irrigation ditches (widely used in Bangladesh), **(2)** animal-powered irrigation pumps, **(3)** buckets with holes for drip irrigation, **(4)** small dams, ponds, and tanks to collect rainwater for irrigation, **(5)** terracing (Figure 10-26a, p. 224) to reduce water loss on crops grown on steep terrain, and **(6)** cultivating seasonally waterlogged wetlands, delta lands, and valley bottoms.

Paul Polak, a pioneer in low-cost irrigation technologies and president of International Development Enterprises, believes that a realistic goal for the next 15 years is to reduce hunger and poverty for 150 million of the world's poorest rural people by spreading the use of these and other low-cost irrigation techniques for small farms.

**Solutions: How Can We Waste Less Water in Industry, Homes, and Businesses?** Figure 14-20 lists ways to use water more efficiently in industries, homes, and businesses. Many homeowners and businesses in water-short areas are replacing green lawns in arid and semiarid regions with vegetation adapted to a dry climate (Figure 14-21, p. 332). This form of landscaping, called *xeriscaping* (pronounced "ZER-i-scaping"), reduces water use by 30–85% and sharply reduces inputs of labor, fertilizer, and fuel and the production of polluted runoff, air pollution, and yard wastes.

In Boulder, Colorado, introducing water meters reduced water use by more than one-third. About one-fifth of all U.S. public water systems do not have water meters and charge a single low rate for almost unlimited use of high-quality water. Many apartment dwellers have little incentive to conserve water because their water use is included in their rent.

Because of laws requiring water conservation, the desert city of Tucson, Arizona, consumes half as much water per person as Las Vegas, a desert city with even less rainfall and less emphasis on water conservation (Spotlight, p. 334).

About 50–75% of the water from bathtubs, showers, bathroom sinks, and clothes washers in a typical house could be stored and reused as *gray water* for irrigating lawns and nonedible plants. In the United States, California has become the first state to legalize reuse of gray water to irrigate landscapes. About 65% of the wastewater in Israel is reused in this way. See the website for this chapter for ways you can reduce your personal water use and waste.

- Redesign manufacturing processes
- Landscape yards with plants that require little water
- Use drip irrigation
- Fix water leaks
- Use water meters and charge for all municipal water use
- Raise water prices
- Require water conservation in water-short cities
- Use water-saving toilets, showerheads, and front-loading clothes washers
- Collect and reuse household water to irrigate lawns and nonedible plants
- Purify and reuse water for houses, apartments, and office buildings

**Figure 14-20** Methods of reducing water waste in industries, homes, and businesses.

**Figure 14-21** *Xeriscaping.* This technique can reduce water use by as much as 85% by landscaping with rocks and plants that need little water and are adapted to the growing conditions in arid and semiarid areas. The term Xeriscape® was first used 1978 in Denver, Colorado, and means "water conservation through creative landscaping."

## 14-8 TOO MUCH WATER

**What Are the Causes and Effects of Flooding?** Heavy rain or rapid melting of snow is the major cause of natural flooding by streams. This causes water in a stream to overflow its normal channel and flood the adjacent area, called a **floodplain** (Figure 14-22). Floodplains, which include highly productive wetlands (Figure 7-25, p. 162), provide important ecological and economic services by helping to **(1)** provide natural flood and erosion control, **(2)** maintain high water quality, and **(3)** recharge groundwater.

People have settled on floodplains since the beginnings of agriculture. They have many advantages, including **(1)** fertile soil, **(2)** ample water for irrigation, **(3)** flat land suitable for crops, buildings, highways, and railroads, and **(4)** availability of nearby rivers for transportation and recreation. In the United States, 10 million households and businesses with property valued at $1 trillion are located in flood-prone areas.

Floods are a natural phenomenon and have several benefits. They **(1)** provide the world's most productive farmland because they are regularly covered with nutrient-rich silt left after floodwaters recede, **(2)** recharge groundwater, and **(3)** refill wetlands.

Floods, like droughts, usually are considered natural disasters, but since the 1960s human activities have contributed to the sharp rise in flood deaths and damages. Three ways humans increase the severity of flood damage are by **(1)** removing water-absorbing vegetation, especially on hillsides (Figure 14-23), **(2)** draining wetlands that absorb floodwaters and reduce the severity of flooding, and **(3)** living on floodplains (Connections, p. 335). Urbanization also increases flooding by replacing water-absorbing vegetation, soil, and wetlands with highways, parking lots, and buildings that cannot absorb rainwater.

In developed countries, people deliberately settle on floodplains and then expect dams, levees, and other devices to protect them from floodwaters. However,

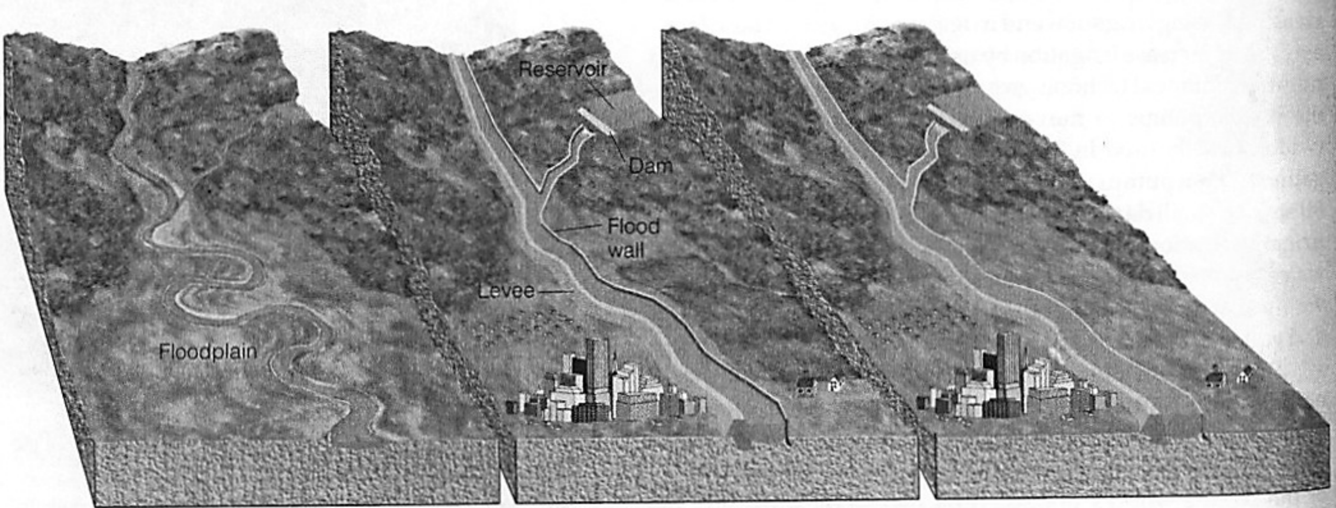



**Figure 14-22** Land in a natural floodplain (left) often is flooded after prolonged rains. When the floodwaters recede, deposits of silt are left behind, creating a nutrient-rich soil. To reduce the threat of flooding (and thus allow people to live in floodplains), rivers have been **(1)** dammed to create reservoirs that store and release water as needed, **(2)** narrowed and straightened (channelization), and **(3)** equipped with protective levees and walls (middle). These alterations can give a false sense of security to floodplain dwellers living in high-risk areas. In the long run, such measures can greatly increase flood damage because they can be overwhelmed by prolonged rains (right), as happened along the Mississippi River in the midwestern United States during the summer of 1993.

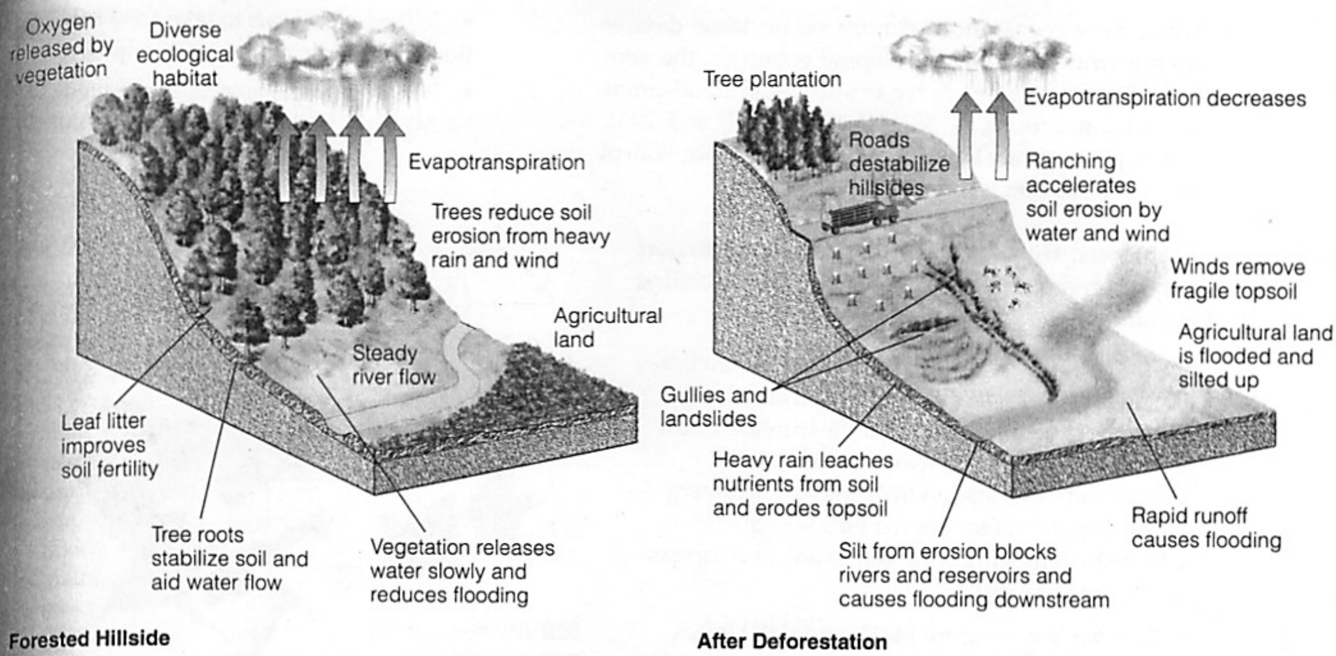



**Figure 14-23** A hillside before and after deforestation. Once a hillside has been deforested for timber and fuelwood, livestock grazing, or unsustainable farming, water from precipitation **(1)** rushes down the denuded slopes, **(2)** erodes precious topsoil, and **(3)** floods downstream areas. A 3,000-year-old Chinese proverb says, "To protect your rivers, protect your mountains."

## The Promise of Drip Irrigation

SOLUTIONS

The development of inexpensive, weather-resistant, and flexible plastic tubing after World War II paved the way for a new form of micro-irrigation called *drip irrigation* (Figure 14-18, middle, p. 330). It consists of a network of perforated plastic tubing, installed at or below the ground surface. The small holes or emitters in the tubing deliver drops of water at a slow and steady rate close to plant roots.

This technique, developed in Israel in the 1960s and now used by half of the country's farmers, has a number of advantages, including the following:

- *Adaptability.* The tubing system can easily be fitted to match the patterns of crops in a field and left in place or moved to different locations.
- *Efficiency,* with 90–95% of the water input reaching crops.
- *Lower operating costs* because 37–70% less energy is needed to pump this water at low pressure, and less labor is needed to move sprinkler systems.
- *Ability to apply fertilizer solutions in precise amounts,* which reduces **(1)** fertilizer use and waste, **(2)** salinization, and **(3)** water pollution from fertilizer runoff.
- *An increase in crop yields of 20–90% by getting more crop growth per drop of water.*
- *Healthier plants and higher yields* because plants are neither underwatered nor overwatered.

Despite these advantages, drip irrigation is used on less than 1% of the world's irrigated area. The capital cost of conventional drip irrigation systems is too high for most poor farmers and for use on low-value row crops. However, drip irrigation is economically feasible for high-profit fruit, vegetable, and orchard crops and for home gardens.

Some *good news* is that the capital cost of a new drip irrigation system is one-tenth as much per hectare as conventional drip systems. Another innovation is DRiWATER®, called "drip irrigation in a box." It consists of 1-liter (1.1-quart) packages of gel-encased water that is released slowly into the soil after being buried near plant roots. It wastes almost no water and lasts about 3 months. Egypt is using it to help grow 17 million trees in a desert community.

These and other low-cost drip irrigation systems could bring about a revolution in more sustainable irrigated agriculture that would **(1)** increase food yields, **(2)** reduce water use and waste, and **(3)** lessen some of the environmental problems associated with agriculture (Figure 13-13, p. 288).

### Critical Thinking

Should governments provide subsidies to farmers who use drip irrigation based on how much water they save? Explain.

when heavier-than-normal rains occur, these devices do not work. In many developing countries, the poor have little choice but to try to survive in flood-prone areas (Connections, p. 335). Between 1985 and 2001, floods prematurely killed about 300,000 people, 96% of them in developing countries.

### Solutions: How Can We Reduce Flood Risks?

Ways humans can reduce the risk from flooding include

- *Straightening and deepening streams* (channelization, Figure 14-22, middle). Channelization can reduce upstream flooding, but the increased flow of water can also **(1)** increase upstream bank erosion and downstream flooding and sediment deposition and **(2)** reduce habitats for aquatic wildlife by removing bank vegetation and increasing stream velocity.
- *Building levees* (Figure 14-22, middle). Levees contain and speed up stream flow but **(1)** increase the water's capacity for doing damage downstream and **(2)** do not protect against unusually high and powerful floodwaters, as occurred in 1993 when two-thirds of the levees built along the Mississippi River were damaged or destroyed.
- *Building dams.* A flood control dam built across a stream can reduce flooding by storing water in a reservoir and releasing it gradually. Dams have a number of advantages and disadvantages (Figure 14-9).
- *Restoring wetlands* to take advantage of the natural flood control provided by floodplains.
- *Identifying and managing flood-prone areas* (Figure 14-24). Such actions include **(1)** prohibiting certain

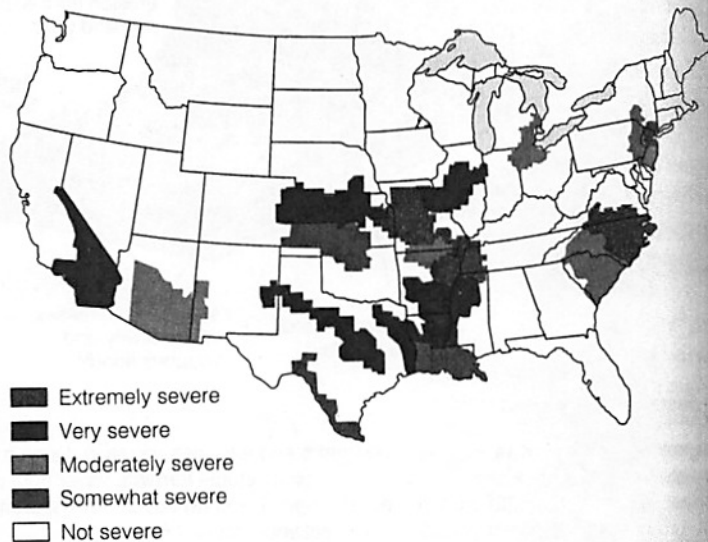



**Figure 14-24** Generalized map of *flood-prone areas* in the United States. State boundaries are shown in black. More detailed state and local maps are used to show the likelihood and severity of floods within these general areas. Flood frequency data and maps of flood-prone areas do not tell us when floods will occur, but they give a general idea of how often and where floods might occur, based on an area's history. (Data from U.S. Geological Survey)

## Running Short of Water in Las Vegas, Nevada

SPOTLIGHT

Las Vegas, Nevada, located in the Mojave Desert, is an artificial aquatic wonderland of large trees, green lawns and golf courses, waterfalls, and swimming pools. The city is also one of the fastest growing cities in the United States, with its population more than doubling from 550,000 in 1985 to 1.4 million in 2001. It is estimated that the city uses more water per person than any other city in the world.

Tucson, Arizona, in the Sonora Desert, gets only 30 centimeters (12 inches) of rainfall a year, and Las Vegas averages only 10 centimeters (4 inches). Tucson, now a model of water conservation, began a strict water conservation program in 1976, including raising water rates 500% for some residents.

In contrast, Las Vegas only recently started to encourage water conservation by **(1)** raising water rates sharply (but they are still less than half those in Tucson) and **(2)** encouraging replacement of lawns with rocks and native plants that survive on little water (Figure 14-21, p. 332).

Water experts project that even if these recent water conservation efforts are successful, Las Vegas should begin running short of water by 2007.

### Critical Thinking

**1.** If you were an elected official in charge of Las Vegas, what three actions would you take to improve water conservation? What might be the political implications of instituting such a program?

**2.** If water shortages by 2007 limit the growth of the population of Las Vegas, would you consider this outcome good or bad? Explain.

## Living Dangerously on Floodplains in Bangladesh

CONNECTIONS

Bangladesh (Figure 12-7, p. 257) is one of the world's **(1)** most densely populated countries, with 134 million people packed into an area roughly the size of Wisconsin, and **(2)** poorest countries, with an average per capita GNI PPP of about $1,590, or $4.36 per day.

The people of Bangladesh depend on moderate annual flooding during the summer monsoon season. They need these seasonal floodwaters to grow rice and help maintain soil fertility in the delta basin by receiving an annual deposit of eroded Himalayan soil.

However, excessive flooding can be disastrous. In the past, great floods occurred every 50 years or so, but since the 1970s they have come about every 4 years.

Bangladesh's increased flood problems begin in the Himalayan watershed. A combination of rapid population growth, deforestation, overgrazing, and unsustainable farming on steep, easily erodible mountain slopes has greatly diminished the soil's ability to absorb water. Instead of being absorbed and released slowly, water from the monsoon rains runs off the denuded Himalayan foothills, carrying vital topsoil with it (Figure 14-23, p. 333).

This runoff, combined with heavier-than-normal monsoon rains, has increased the severity of flooding along Himalayan rivers and downstream in Bangladesh. For example, a disastrous flood in 1998 **(1)** covered two-thirds of Bangladesh's land area for 9 months, **(2)** leveled 2 million homes, **(3)** drowned at least 2,000 people, **(4)** left 30 million people homeless, **(5)** destroyed more than one-fourth of the country's crops, which caused thousands of people to die of starvation, and **(6)** caused at least $3.4 billion in damages.

Living on Bangladesh's coastal floodplain also carries dangers from storm surges and cyclones. Since 1961, 17 devastating cyclones have slammed into Bangladesh. In 1970, as many as 1 million people drowned in one storm, and another surge killed an estimated 139,000 people in 1991.

In their struggle to survive, the poor in Bangladesh have cleared many of the country's coastal mangrove forests (Figures 7-2, p. 145, and 7-9, p. 149) for fuelwood, farming, and aquaculture ponds for raising shrimp. This has led to more severe flooding because these coastal wetlands shelter Bangladesh's low-lying coastal areas from storm surges and cyclones. Damages and deaths from cyclones in areas of Bangladesh still protected by mangrove forests have been much lower than in areas where the forests have been cleared.

### Critical Thinking

**1.** Bangladesh's population is growing rapidly and expected to increase from 134 million to 178 million between 2002 and 2025. How could slowing its rate of population growth help reduce poverty and the harmful impacts of excessive flooding?

**2.** How could reforestation in the upstream countries of Bhutan, China, India, and Nepal reduce flooding in those countries and in Bangladesh?

types of buildings or activities in high-risk flood zones, **(2)** elevating or otherwise floodproofing buildings that are allowed on legally defined floodplains, and **(3)** constructing a floodway that allows floodwater to flow through the community with minimal damage. This *prevention*, or *precautionary*, approach to reducing flood damage is based on thousands of years of experience that can be summed up in one idea: *Sooner or later the river (or the ocean) always wins.*

## 14-9 SOLUTIONS: ACHIEVING A MORE SUSTAINABLE WATER FUTURE

Sustainable water use is based on the commonsense principle stated in an old Inca proverb: "The frog does not drink up the pond in which it lives." Figure 14-25 (p. 336) lists ways to implement this principle.

The challenge in developing such a *blue revolution* is to implement a mix of strategies built around **(1)** irrigating crops more efficiently, **(2)** using water-saving technologies in industries and homes, and **(3)** improving and integrating management of water basins and groundwater supplies.

Accomplishing such a revolution in water use and management will be difficult and controversial. However, water experts contend that not developing such strategies will eventually lead to **(1)** economic and health problems, **(2)** increased environmental degradation and loss of biodiversity, **(3)** heightened tensions and perhaps armed conflicts or economic competition over water supplies and food imports (p. 312), and **(4)** larger numbers of environmental refugees from water-scarce areas.

*It is not until the well runs dry that we know the worth of water.*

BENJAMIN FRANKLIN

- Not depleting aquifers
- Preserving ecological health of aquatic systems

- Preserving water quality
- Integrated watershed management
- Agreements among regions and countries sharing surface water resources
- Outside party mediation of water disputes between nations

- Marketing of water rights
- Wasting less water
- Decreasing government subsides for supplying water
- Increasing government subsides for reducing water waste

- Slowing population growth

**Figure 14-25** Methods for achieving more sustainable use of the earth's water resources.

## REVIEW QUESTIONS

1. Define the boldfaced terms in this chapter.

2. Explain why there is a danger of water wars or economic competition between countries for food imports in the Middle East.

3. List nine unique properties of water and explain the importance of each property.

4. What percentage of the earth's total volume of water is available for use by us? How might global warming alter the hydrologic cycle?

5. Distinguish among *surface runoff, reliable runoff, watershed, groundwater, zone of saturation, water table, aquifer, recharge area,* and *natural recharge.* Explain how the water in some aquifers can be depleted.

6. Since 1900, how much has the total use and per capita use of water by humans increased? About what percentage of the world's reliable surface runoff is used by humanity?

7. About what percentage of the water we withdraw each year is used for **(a)** irrigation, **(b)** industry, and **(c)** residences and cities?

8. What are the major water uses and problems of **(a)** the eastern United States and **(b)** the western United States?

9. List four causes of water scarcity. What is *water stress?* How can growth in the number of water-stressed countries affect **(a)** global grain exports and prices, **(b)** hunger and malnutrition in developing countries, **(c)** the number of environmental refugees, and **(d)** the daily workload of many poor women and children?

10. List six ways to increase the supply of fresh water in a particular area.

11. List six ecological services that rivers provide.

12. List the major pros and cons of building large dams and reservoirs to supply fresh water. List the pros and cons of **(a)** Egypt's Aswan High Dam project, **(b)** building numerous dams along the Colorado River basin, and **(c)** China's Three Gorges dam project.

13. List the major pros and cons of supplying water by transferring it from one watershed to another. List the pros and cons of **(a)** the California Water Project, **(b)** the James Bay project in Canada, and **(c)** the Aral Sea water transfer project in central Asia.

14. List the pros and cons of supplying more water by withdrawing groundwater. Explain why excessive groundwater withdrawal can be viewed as an example of the tragedy of the commons and how it can increase the gap between the world's rich and poor. Summarize the problems of withdrawing groundwater from the Ogallala Aquifer in the United States. List five ways to prevent or slow groundwater depletion.

15. List the pros and cons of increasing supplies of fresh water by **(a)** desalination of salt water, **(b)** cloud seeding, and **(c)** towing icebergs to water-short areas.

16. What percentage of the water used by people throughout the world is wasted? List four benefits of conserving water. List three major causes of water waste.

17. Define and give the pros and cons of **(a)** the *doctrine of riparian rights,* **(b)** the *principle of prior appropriation* used to govern legal rights to surface water, and **(c)** the *common law* approach used to govern legal rights to groundwater in the United States. How can such rights promote **(a)** water waste and **(b)** water conservation?

18. List ways to reduce water waste in **(a)** irrigation and **(b)** industry, homes, and businesses. List six advantages of *drip irrigation,* and explain how it could help bring about a revolution in improving water efficiency.

19. What is a *floodplain?* What three major ecological and economic services does it provide? List four reasons why so many people live on floodplains. List the major benefits and disadvantages of floods. List three ways in which humans increase the damages from floods. Describe the nature and causes of the flooding problems in Bangladesh.

20. List the pros and cons of trying to reduce flood risks by **(a)** stream channelization, **(b)** building levees, **(c)** building dams, and **(d)** managing floodplains.

21. List 11 ways to use the world's water more sustainably and 4 disadvantages of not implementing such strategies.

## CRITICAL THINKING

1. What would happen to your body if suddenly your water molecules no longer formed hydrogen bonds with one another (Appendix 2, Figure 4)?

2. How do human activities increase the harmful effects of prolonged drought? How can we reduce these effects?

3. Explain how dams and reservoirs can cause more flood damage than they prevent. Should all proposed large dam and reservoir projects be scrapped? Explain.

4. Do you believe the projected benefits of China's Three Gorges dam and reservoir project on the Yangtze River will outweigh its potential drawbacks? Explain. What are the alternatives?

5. What role does population growth play in water supply problems?

6. Explain why you are for or against **(a)** gradually phasing out government subsidies of irrigation projects in the western United States (or in the country where you live) to raise the price of water and promote using water more efficiently and **(b)** providing government subsidies to farmers for improving irrigation efficiency.

7. Should the prices of water for all uses be raised sharply to include more of its environmental costs and to encourage water conservation? Explain. What harmful and beneficial effects might this have on **(a)** business and jobs, **(b)** your lifestyle and the lifestyles of any children or grandchildren you might have, **(c)** the poor, and **(d)** the environment?

8. Should we use up slowly renewable underground water supplies such as the Ogallala aquifer (Case Study, p. 327) or save them for future generations? Explain.

9. Calculate how many liters and gallons of water are wasted in 1 month by a toilet that leaks 2 drops of water per second (1 liter of water equals about 3,500 drops and 1 liter equals 0.265 gallon).

10. List five major ways to conserve water for personal use (see website material for this chapter). Which, if any, of these practices do you now use or intend to use?

11. How do human activities contribute to flooding and flood damage? How can these effects be reduced?

12. Congratulations! You are in charge of managing the world's water resources. What are the three most important things you would do?

## PROJECTS

1. In your community,
   a. What are the major sources of the water supply?
   b. How is water use divided among agricultural, industrial, power plant cooling, and public uses?
   c. Who are the biggest consumers of water?
   d. What has happened to water prices (adjusted for inflation) during the past 20 years? Are they too low to encourage water conservation and reuse?
   e. What water supply problems are projected?
   f. How is water being wasted?

2. Use the library or the Internet to discover **(a)** which industries in the country where you live use the most water and **(b)** which industries have done the most to improve water-use efficiency in the last 20 years.

3. Develop a water conservation plan for your school and submit it to school officials.

4. Consult with local officials to identify any floodplain areas in your community. Develop a map showing these areas and the types of activities (such as housing, manufacturing, roads, and recreational use) found on these lands.

5. Use the library or the Internet to find bibliographic information about *John Todd* and *Benjamin Franklin*, whose quotes appear at the beginning and end of this chapter.

6. Make a concept map of this chapter's major ideas, using the section heads and subheads and the key terms (in boldface type). See material on the website for this book about how to prepare concept maps.

## INTERNET STUDY RESOURCES AND RESOURCES FOR FURTHER READING AND RESEARCH

The website for this book contains helpful study aids and many ideas for further reading and research. Log on to

**www.info.brookscole.com/miller13**

and click on the Chapter-by-Chapter area. Choose Chapter 14 and select a resource:

- Flash Cards allows you to test your mastery of the Terms and Concepts to Remember for this chapter.
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1. University of California at Irvine. 2002. Satellite data on underground aquifer levels can be vital to water resource management, UC Irvine hydrologist finds; Use of NASA technology seen as breakthrough to understanding water availability, movement. *Ascribe Higher Education News Service* (June 10). *Keywords:* "satellite," "aquifer," and "levels." A new satellite now allows hydrologists to asses more accurately the condition of the world's aquifers. This has important implications for water management.

2. Postel, S. 1999. When the world's wells run dry. *World Watch* 12: 30. Keywords: "aquifer" and "depletion." This article represents a good summary of groundwater-use issues, including sustainability, conservation, and government policy.

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