

HISTORICAL PERSPECTIVE OF WATER USE AND DEVELOPMENT

DRINKING WATER FOR EARLY CIVILIZATIONS

EARLY IRRIGATION AND FLOOD-CONTROL
PROJECTS

EARLY WATER TRANSPORTATION DEVELOPMENT

EARLY HYDROPOWER DEVELOPMENT

Life must be lived forward, but understood backward.

Søren Kierkegaard (1813–1855),
Danish philosopher

Throughout history, water development, management, and policy have evolved in a wide variety of ways. In the arid Middle East, for example, elaborate irrigation projects were constructed thousands of years ago to raise food for humans and domesticated animals, and fiber for clothing. The region between the Tigris and Euphrates rivers was known as the Fertile Crescent in large part because of the abundance provided by ancient irrigation projects. In China, several canals in use today were built during royal dynasties around 600 B.C. and earlier to transport people, cargo, and armies across that massive country. Later, Western Europeans developed similar construction techniques for elaborate water transportation networks. For centuries waterwheels were used to divert water for crops, to provide water for fountains in royal gardens, to grind grain, and to supply drinking water. The technology of waterwheels—developed in Greece and Rome approximately 2000 years ago—transformed the economy of Western Europe by A.D. 1100.

Much of our knowledge of ancient “hydraulic,” or water-based civilizations has been

obtained from ruins, artifacts, and artwork—the remains of a Roman aqueduct in Italy, for example, a bas-relief sculpture from Mesopotamia, or a temple in China. Ancient societies prospered when water supplies were properly managed; conversely, poor water management usually brought a decline in the health and well-being of citizens and, in extreme cases, even extinction to an entire civilization.

In this chapter, pay close attention to the historical context of the early hydraulic civilizations discussed. What similarities existed between irrigation in Egypt, Babylonia, Spain, and Mexico? What role did the *qanat* play in the settlement of desert regions around the world? How important were canals in the settlement and prosperity of China and Western Europe? We can learn important lessons from these ancient civilizations, and can gain insight into present-day issues and opportunities regarding water development, management, and policy.

Knowledge of the past helps to anticipate the future.

Thucydides (460–400 B.C.), Greek philosopher

DRINKING WATER FOR EARLY CIVILIZATIONS

Water is the basis of life on Earth and the foundation of all civilizations. The ancient Persians, for example, listed water as the first word in their dictionary, calling it *ab*, to show its importance in their culture. The Egyptian civilization used a

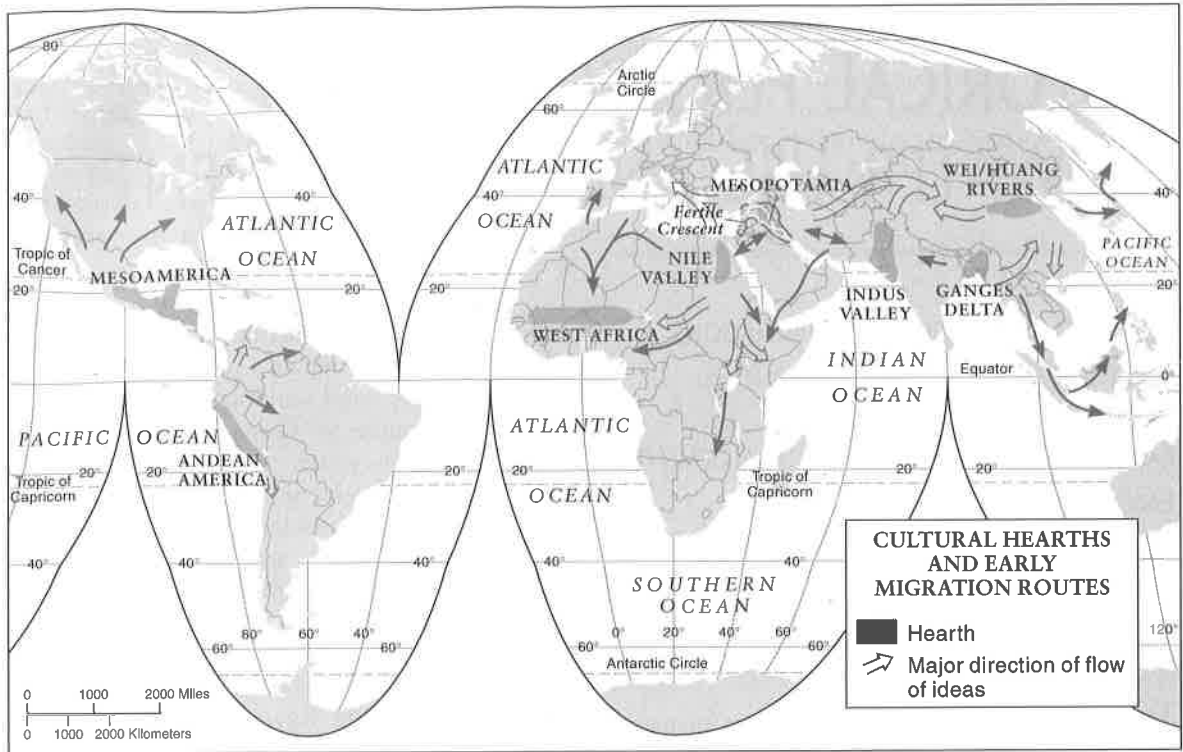


FIG. 1.1. Cultural hearths are centers of early civilization. Many of these regions were extremely dry, and water was a necessity to provide food and fiber for survival. *Geography: Realms, Regions, and Concepts*, 10th Edition, by Harm de Blij and Peter O. Muller. Copyright © 2002 H. J. de Blij and John Wiley & Sons, Inc. This map was originally produced in color. Adapted and reprinted by permission of John Wiley & Sons, Inc.

wavy line to represent the word *water*. This symbol later became the Hebrew letter *mem* (representing *mayim* or water) and eventually the Latin letter M.¹

Long before these early civilizations flourished, our Stone Age ancestors lived in caves and other camps that were close to sources of drinking water, such as springs and lakes. Wild game often congregated near these watering holes and provided a source of food, but also potential danger. The needs of early people were quite basic—food, water, and shelter. As time passed and human populations increased, prehistoric communities tended to form near lakes in central Africa and along rivers in the Middle East, northern China, and India (see Figure 1.1).

As human numbers increased, wild animals, disease, and dense vegetation that made it difficult to cultivate crops may have driven some settlements to relocate to drier climates. In other regions, variable precipitation forced humans to relocate to wetter areas that had more reliable food supplies. The early Somalians of eastern Africa were nomadic because of a constant search for water and grass for their cattle herds. Between periods of drought and continual rains, this nomadic culture traveled great distances across deserts to reach greener pastures. Whenever possible, the Somalians dug groundwater wells by hand, at regularly spaced intervals along their desert routes, to provide drinking water for caravans of nomads and cattle. Groundwater wells in the

desert provided a reliable source of drinking water for their own use and, later, served as the foundation for the development of small desert communities. Eventually, larger cities developed around these underground water sources in the African desert.

Why were ancient well diggers able to find groundwater in the middle of an African desert? The most probable answer is that during the Pleistocene epoch—when glaciers covered portions of North America and Europe—the climate of northern Africa and the Middle East was relatively wet. Modern satellite imagery of the region shows evidence of ancient riverbeds that have long since been covered by blowing desert sands. Ancient water from that geologic time remains underground even today.

S I D E B A R

Camels were the primary method of transportation across deserts because they could live without water for over a month. However, if a nomad miscalculated traveling distances—or if a desert groundwater well suddenly went dry—a caravan could quickly run out of drinking water. This created a deadly situation and left the traveler with few options for survival. At this point, nomads were forced to resort to the *uusmiirad*, a procedure that involved extracting water from the stomach and intestines of a slaughtered camel, and then drinking it to survive. It was the ultimate sacrifice for the animal but meant life for the nomad.²

Groundwater systems became more elaborate in many parts of the world with the development of *qanats* (underground water delivery systems, from a Semitic word meaning “to dig”). Since around 1000 B.C., *qanats* have been constructed in southwest Asia, North Africa, and the Middle East to tap into reliable sources of groundwater. A *qanat* consists of a mother well connected to long, underground delivery tunnels that stretch to nearby communities. A *qanat* mother well was dug by hand, generally near the foothills of a mountain range, to tap into plentiful sources of groundwater. A gently sloping tunnel was

constructed from the mother well to villages and fields at lower elevations. Gravity provides the means to move groundwater from the mother well along the sloped tunnel system. Vertical shafts were constructed along the sloping delivery tunnel to allow numerous access points. *Qanats* vary in length from 25 to 28 miles (40 to 45 km) and have depths up to 400 feet (122 m).³

In Afghanistan, Pakistan, and western China, a groundwater system with a mother well and sloped delivery tunnel is called a *karez*. The word *falaj* or “unfailing springs” is used in Oman, while in Morocco and Cyprus, this system is called a *fog-garas*. *Qanats*, probably one of the greatest hydrologic achievements of the ancient world, allowed communities to develop in locations without reliable water supplies. Today, most of the world’s *qanats* are found in Iran (Figure 1.2).⁴

Qanats are still the traditional source of water in the Middle East and parts of China. In northern Iraq, these ancient water delivery systems are still used today to provide water to some of the oldest cities of the world, including Sulaimaniya (population approximately 400,000). Iran has over 22,000 *qanats*, which supply 75 percent of all water currently used in that country. Early Spanish explorers transferred the technology to northern Chile, where five hand-dug groundwater tunnels are still used today in the nitrate-mining region of the Atacama Desert.⁵

Digging underground tunnels for a *qanat* was very dangerous work, and cave-ins were common. Generally, an underclass of the local population was forced to construct and maintain the water delivery system. Small boys were often used to dig in the cramped and more confined areas during construction, and the loss of life was shocking. On some construction projects, workers wore their funeral clothes as they dug in case the earth above the tunnel collapsed. This eliminated the need for coworkers to dig out a buried worker to provide a proper burial.⁶

The ancient Romans also developed extensive water delivery systems for their cities. Surface water and groundwater were stored in cisterns

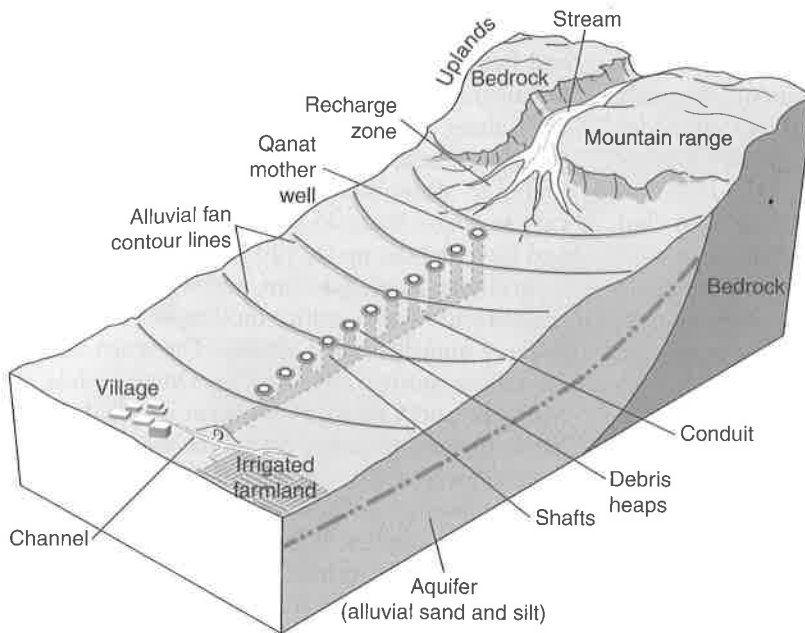


FIG. 1.2 A typical *qanat* system. These water harvesting tunnels conveyed water from aquifers in highlands to lower elevations for irrigation and household consumption. It's important to note that there are some 22,000 *qanat* systems in Iran, representing more than 170,000 miles (275,000 km) of underground tunnels. The Iranian *qanat* systems rival the great aqueducts of the Roman Empire.

(underground reservoirs lined with clay or dug in limestone formations) at higher elevations near a city. Water from these underground storage reservoirs was distributed by gravity through a network of pipes to public fountains and baths, as well as to a few private citizens. Distribution pipes were made of lead or baked clay. Wastewater from

the water system was generally returned to a nearby river through sewer pipes buried beneath city streets. The first Roman **aqueduct** (an elevated water delivery system made of stone) was built in 312 B.C., and by 300 B.C. there were 14 aqueducts in Rome (see Figure 1.3) delivering 40 million gallons (over 151 million l) of water daily to Roman

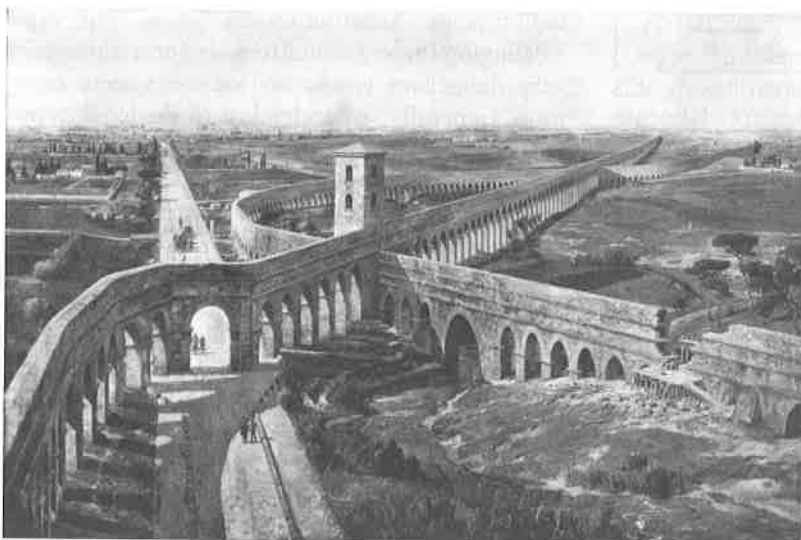


FIG. 1.3 Crossing of two Roman aqueducts in Via Latina southeast of Rome. These aqueducts were described as *Romanae providentiae magnitudinis que primitiae* ("the first fruits of Rome's foresight and greatness") by author Raffaele Fabretti in 1680. This painting, by Zeno Diemer, is on display at the Deutsches Museum, Munich, Germany.

citizens.⁷ Excess water from these delivery systems was used to power the city's fountains and flush sewage into the Tiber River.⁸

S I D E B A R

Sextus Julius Frontius (A.D. 30–104) was the first water commissioner of Rome. In A.D. 97, he wrote a two-volume work, *On Aqueducts*, in which he described advances in aqueduct construction since ancient times:

*Will anybody compare the idle Pyramids, or those other useless, though much renowned, works of the Greeks, with these aqueducts, with these many indispensable structures?*⁹

The construction of aqueducts and other water delivery structures allowed Roman cities to grow in size and population, and reduced the amount of time required for individuals (usually women) to obtain daily water supplies for the home. Water pipelines, aqueducts, and other delivery features became a symbol of a maturing civilization. Little or no concern was given to wastewater disposal as long as wastes were removed from homes, streets, and gutters. Natural cleaning processes in local rivers purified some human waste if the population density of an area was not too great.

The Romans also altered natural water features by digging canals to drain lakes and marshes. In A.D. 52, the Roman emperor Claudius constructed a canal to Lake Fucinus, a naturally formed lake near Rome. His plan was to grow crops on the fertile soil left behind in the dried lake bed. The canal included a tunnel 3 miles (5 km) long and 7 feet (2 m) in diameter, dug by hand through a mountain. In Damascus, the capital of present-day Syria, Roman workers constructed six canals to divert water from the Barada River for use in the city. A dividing point of all six canals, called “the parting of the streams,” was a popular recreation spot for Roman citizens.¹⁰

The Roman Empire also developed extensive water delivery systems in France, Italy, the Netherlands, and Great Britain. In A.D. 1236, a system of pipelines was constructed in London to carry water from the Thames River and nearby springs to residents in the city. In 1619, the New River Company (a privately owned company) delivered

water throughout London, making it the first time that every home in a city received water through a network of pipes. By the end of the 1800s, most towns and cities in Great Britain had municipal water systems.¹¹ Some English communities privatized their public water systems (which were developed through the payment of taxes) by selling stock to fund the development of private water companies. In other locations, carts went door to door to deliver water to English homes—for a fee.

A CLOSER LOOK

The search for water dominated the activities of early civilizations. Ancient inhabitants of central Africa, northern China, and India lived in regions where drinking-water supplies were generally adequate for small numbers of people. However, as populations increased, human settlements relocated to areas that received less (or erratic amounts) of precipitation. This placed greater pressure on communities to develop more reliable sources of drinking water.

The Romans created the most extensive water delivery systems of the ancient era with the construction of aqueducts, although the *qanat* system in the Middle East was also quite elaborate. Why did ancient civilizations alter the natural environment in search of water supplies? What role did climate and geography play in decisions to dig wells, to construct elaborate aqueducts, or to drain lakes and marshes to create additional cropland? Did other alternatives exist during ancient times to meet the water demands created by population growth and limited water supplies?

Today, drinking-water sources vary greatly around the world. For example, cities such as New Orleans, Louisiana, and Izmit, Turkey, use rivers as their drinking-water sources. Paris, France, uses a combination of water from rivers and groundwater. Chicago, Illinois, obtains water from Lake Michigan, while Reykjavik, Iceland, uses groundwater that does not require any treatment because of its high quality.

Major drinking-water issues today often revolve around water quality concerns. Unfortunately, much of the Earth's freshwater resources found in lakes, rivers, and groundwater have been contaminated to some degree—either naturally or by humans—and this water is not safe to drink without treatment. We'll discuss these issues in detail in Chapter 5 and Chapter 11.

EARLY IRRIGATION AND FLOOD-CONTROL PROJECTS

Irrigation projects are found throughout the world today but were also prevalent thousands of years ago along major rivers of the world, such as the Nile, Indus, and Yangtze. Without irrigation, food was scarce during dry periods, and civilizations could not survive.

EGYPT

When the Nile inundates the land, all of Egypt becomes a sea, and only the towns remain above water, looking rather like the islands of the Aegean.

King Herodotus, Egypt, 500 B.C.

Irrigation was vital for the permanent settlement of extreme northeastern Africa, since the region receives only about 1 inch (25 mm) of precipitation annually. The ancient Egyptians relied on monsoonal rains in the mountains of Ethiopia to the south to bring floodwaters and fertile sediments to the Nile River Valley of Egypt. During seasonal floods, water spilled over the banks of the swollen Nile and naturally irrigated adjacent valley lands. These floods were sometimes so extensive that ships didn't bother to follow the natural course of the river, but instead floated across the countryside as if on an ocean.

As the Egyptian population increased and more food was required, dikes and irrigation canals were constructed to spread floodwaters across more land in the Nile Valley. King Scorpion (circa 3200 B.C.) called the initial cutting of ground for a new canal the "Day of Breaking the River" (Figure 1.4). The development of each new irrigation canal signified the growing power and wealth of the Egyptian civilization through increased food production, the payment of additional taxes to the king or queen of Egypt, and a general improvement in economic prosperity.

To supplement the floodwaters of the Nile River, Egyptians used lifting devices (probably imported



FIG. 1.4 This earthen jug depicts King Scorpion cutting the first sod of an irrigation canal, a ceremony that continued into the 19th century in Egypt (now on display in the Ashmolean Museum, Oxford, England).

from Mesopotamia) to withdraw groundwater to irrigate crops. These ancient tools included the **shadouf**, a lever system with a bucket attached to a long pole on a pivot; the **tambour**, an auger-type device attributed to Archimedes and sometimes called the "Archimedes screw"; and the **saqia** waterwheel, an elaborate animal-powered waterwheel (probably introduced from Persia) with multiple buckets to lift water (see Figure 1.5). These were the earliest irrigation "pumps" invented and are still in use today in the Middle East.¹²

CHINA

In China, the Huang He River (also called the Yellow River) was the cradle of Chinese civilization. The Huang He has a long history of devastating floods and repeated attempts by Chinese dynasties to control, or conquer, the "raging beast." Precipitation in the Huang He River Basin ranges between 8 and 24 inches (200 and 600 mm) per year. This wide variation in precipitation leads to variable water supplies throughout the country. In some locations, the diversion of water for irrigation is a major concern, while flood control is a greater need in other areas. Flooding has been a major problem along the Huang He for centuries; thousands of lives were sometimes lost during single flood events.

Levees (earthen and rock dikes) were constructed over 2500 years ago along smaller branches of the Huang He River to control floods.

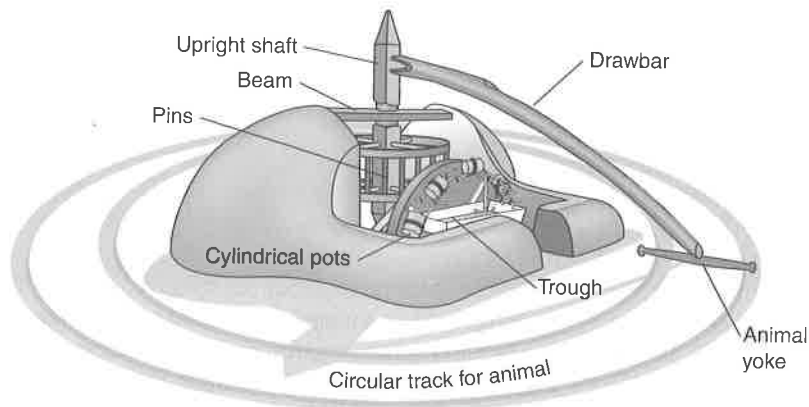


FIG. 1.5 Ancient water-lifting devices. Top left and top center: *Shadouf*; Top right: *Tambour* (Archimedes screw); Bottom: *Saqia*.

However, larger flood-control projects were rarely attempted on the main river channel, because water flows were too great to control with the primitive dam construction technology of the time.

Yu the Great was the first manager of Chinese waters and later became emperor of China (Figure 1.6). Around 2280 B.C., Emperor Yao asked Yu to construct dams, dikes, and other waterworks along the Huang He River to protect and enhance life for his citizens. Yu the Great was so successful in reclaiming land and controlling floods that, after the death of Emperor Shun (Yao's successor), Yu became the new emperor of China. Later, Emperor Yu also became head of all water engineers in his country. Emperor Yu the Great is still honored in China today.

In addition to floods, food shortages were common in ancient China, so government-sponsored irrigation projects were developed to feed the growing population. Around 560 B.C., the Cheng State Irrigation Canal was completed for use in the north-central region of modern Henan. Around 300 B.C.



FIG. 1.6 This temple to Yu the Great is located at the foot of Kuaiji Mountain in Shaoxing City, Zhejiang Province, China. The three characters, from top to bottom on the temple, read *Da Yu Ling*—*Da* meaning “big,” “great,” or “majesty;” *Yu* for Emperor Yu’s name; and *Ling* meaning “mausoleum.” The three Chinese characters together mean “The Majesty Yu’s Mausoleum.” Emperor Yu led the fight against floods throughout China and gained eternal respect from the people of his country.

the Changshui and Cheng Kuo canals were completed to irrigate extensive areas around Henan and Shensi.¹³

During the Chai Dynasty in about 300 B.C., the Ministry of Public Works for the Chinese government was responsible for water management, repair of levees, cleaning of irrigation ditches, drainage of floodwaters, and storage of water in reservoirs. Chinese dynasties were considered “good” or “bad” based on the maintenance and improvements they made to the country’s irrigation systems.¹⁴

During the Ming Dynasty (A.D. 1368–1644), the chief water administrator in China advocated building huge stone levees along the Huang He River to channelize floodwaters. He theorized that confining the flow of water within the river channel would increase the velocity of floodwater and scour the riverbed to a greater depth. It was hoped that this greater river channel capacity would ultimately reduce flooding. Today, the same theory is being debated along the Platte River of central Nebraska.

Recent proponents of the concept argue that increased flows in the Platte will accelerate scouring of the river channel. This, in turn, will enhance habitat for the endangered whooping cranes that stop to rest along the Platte River Valley during their annual migration between the Gulf Coast of Texas and Canada. Opponents have argued that the scouring concept is simply an attempt to claim additional water supplies from the neighboring upstream states of Wyoming and Colorado. (This controversy will be discussed further in Chapter 12.)

For centuries, many water managers along the Huang He River in China tried to alleviate flooding by using nature to control nature. Some believed that natural river processes—such as erosion, flooding, and silt deposition—should be allowed to occur without human interference. It was argued that only small-scale levee projects should be used to control natural flooding events. Chinese water managers who followed this philosophy constructed small flood-control projects, such as long, low levees that used natural sediment

deposits (including silt, gravel, sand, and other earthen materials) found within the river channel. The use of natural materials to hold a river within its channel was thought to be a wise practice, since it didn’t greatly interfere with nature.

In contrast, others tried to control or “conquer” nature and used larger, more restrictive construction techniques. In the 20th century, for example, the government of the former Soviet Union waged “a war against nature” to control the floods of the Huang He River. The communist philosophy was to force the river to serve useful purposes for Chinese residents. Soviet planners, civil engineers, and hydrologists (those who apply scientific and mathematical principles to solve a water-related problem) devised elaborate flood-control and irrigation projects throughout the country. These contrasting water management philosophies created conflict and debate regarding proper water management methods, and these continue today in China and around the world. These issues are discussed further in Chapter 7 in a guest essay regarding construction of China’s Three Gorges Dam.

S I D E B A R

Levees were used in China not only for flood protection, but also as instruments of war between feudal states. Between 404 and 221 B.C., dikes were sometimes used to divert floodwaters onto an opponent’s fields and villages. Loss of life was extensive, and eventually treaties were signed to ban this brutal practice of hydraulic warfare.

THE MIDDLE EAST

The ancient Sumerian culture had two very unpredictable rivers: the Tigris and Euphrates (located in present-day Turkey, Syria, and Iraq). Numerous irrigation projects were constructed, and the science of flood protection was well developed by Sumerian rulers. Taxes were collected from irrigators, and extensive laws were adopted to properly operate and maintain their irrigation systems.

The Assyrians, located in portions of modern-day Turkey, Iran, Iraq, and Syria in approximately



FIG. 1.7 The ancient Inca ruins at Machu Picchu in Peru still contain remnants of an expansive drainage network. It is located on a high Andes Mountain ridge at an elevation of 7,999 feet (2,438 m). Machu Picchu had a permanent population of about 300 but was abandoned around A.D. 1540. See <http://www.waterhistory.org/histories/machu> for an excellent overview of water supply and drainage at Machu Picchu.

2400 B.C., also created extensive irrigation laws. Various rules were developed for use of water obtained from precipitation, groundwater, and water stored in underground cisterns. All irrigators had to share in the work of removing sand and gravel deposited in irrigation canals by slow-moving water. In addition, irrigators had to minimize water contamination, assist with canal repairs after floods, and ensure that other water users at the end of the ditch received their fair share of water. Irrigators unwilling to cooperate with these rules were either beheaded or stoned to death.¹⁵

Around 500 B.C., rainfall harvesting was developed in the Middle East to channel surface water runoff for irrigation of crops. Stone walls were constructed to divert precious precipitation directly to crops or into underground cisterns for drinking water. These methods are still used today in the Judean Desert of Israel.

INDIA, SPAIN, PORTUGAL, AND SOUTH AMERICA

A water-harvesting system—similar to the methods used today in Israel—was developed in the Thar Desert of western India. Stone walls, cisterns, dams, water holes, and tanks captured

enough storm water to allow thousands of people to live in the desert environment. Roman and Moorish invaders of Spain and Portugal brought irrigation techniques to the Iberian Peninsula around A.D. 800. **Acequias**, or irrigation ditches, were developed, as well as **acenas** (water mills) and **charcas** (reservoirs). In South America, stone-walled terraces have been found that were drained with elaborate ditch systems on steep hillsides of the Andes Mountains. In Peru, the lost city of Machu Picchu (see Figure 1.7) stands as a monument to the hydraulic engineering skills of the ancient Incas. Similar technology was used in Bolivia, Ecuador, Colombia, and Suriname.

NORTH AMERICA

Large-scale irrigation began in the present United States with the efforts of the **Hohokam Indians** in approximately A.D. 800. Canals 30 to 60 feet (9 to 18 m) wide diverted water from the Salt River and irrigated land near the present site of Phoenix, Arizona. Almost 300 miles (483 km) of canals irrigated 250,000 acres (101,175 ha) of desert land and provided food for 200,000 people over 1200 years ago.¹⁶

About 150 years later—around A.D. 950—the **Anasazi Indians** developed community irrigation projects in the desert lands of southwest Colorado. Small reservoirs were used to collect surface water runoff during rainstorms. Upstream water channels were lined with rocks, soil, and brush to divert precious water supplies into reservoirs for drinking water or onto fields for crop irrigation. Other crude water management methods used small rows of strategically placed rock dams (today called check dams) to flood small fields of vegetables, beans, and corn.¹⁷

In the 15th century, Spanish settlers migrated north from Mexico to modern-day California, Arizona, and New Mexico. Spanish missionaries typically constructed many small irrigation canals to raise crops near their churches. Some of this irrigation technology was obtained from the ancient Aztecs of Mexico, while other techniques were replicated from irrigated farms in Spain and Portugal. The Aztec civilization had an impressive system of aqueducts that delivered irrigation and drinking water to its communities, including the Aztec capital of Tenochtitlán, at the present site of Mexico City. The Aztecs used rock and mortar for these aqueducts, and even designed dual water delivery systems so that one could be cleaned while the other provided an uninterrupted water supply to residents.

Another major irrigation effort began in North America in 1847, when **Brigham Young** (1801–1877) and 1500 Mormon followers settled in the Salt Lake Valley of Utah Territory, a dry region that receives only 15 inches (380 mm) of average annual precipitation. Fortunately, over 40 inches (1020 mm) of water falls as snow during the winter months in the nearby Wasatch Mountains. Mormon settlers constructed diversion dams across river channels to divert runoff from melting snow into irrigation canals (see Figure 1.8). These early dams were not elaborate and were typically made of logs, rocks, and brush (sticks and weeds), using methods similar to those of the Anasazi Indians centuries earlier. Irrigation canals were constructed with the use of horses pulling plows



FIG. 1.8 This map, made for a 1903 U.S. Department of Agriculture report, shows the primary irrigation ditches in the Salt Lake City, Utah area. The Mormon leader, Brigham Young, was largely responsible for the development of these water delivery systems throughout the Salt Lake Valley during the 1800s.

followed by workers with picks, shovels, and their bare hands.¹⁸

Construction of an irrigation canal was not a simple task. A canal with too steep a slope allowed water to move too fast. This often led to erosion problems that washed out the side of an earthen canal. If the canal was too flat, irrigation water would flow too slowly or would pool and not move at all in low spots. Canals were usually constructed with a fall (slope) of about 2 feet per mile (less than 1 m/km). Some early settlers in the Salt Lake Valley used the water surface in a teacup as a level to guide canal diggers.¹⁹

During the initial years of settlement, competition for irrigation water in the Salt Lake Valley was limited because the Mormon settlers were part of a patriarchal society. That is, the welfare of the community generally came before the needs of the individual, and that philosophy was enforced by their leader, Brigham Young. (It was also quite clear to these early settlers that survival depended on cooperation to grow food in the arid valley.) Water resources were treated in the same manner and were shared during times of scarcity. In later years, this concept of equal rights for water use was replaced throughout much of the West with a rigid water

allocation system based on a strict priority system of water use (see Chapter 8).

In 1862, the U.S. Congress passed the **Homestead Act**, a landmark piece of federal legislation that opened the floodgates of development in the West. This law allowed anyone over the age of 21 to acquire ownership of 160 acres (65 ha) of land if he lived on it for a period of five years and made improvements, such as constructing a house or barn, cultivating crops, or planting trees. The cost of the land was only \$1.25 per acre (\$3.09 per ha, or roughly \$25/acre in today's dollars). As more people moved to the arid West, water for irrigation became a critical issue. Settlers constructed irrigation canals in areas with flowing rivers to grow food for growing communities. In other locations, groundwater wells were dug by hand, and windmills were used to pump it up to the land surface.

A CLOSER LOOK

Obtaining water loomed as the settlers' first and most pressing problem. Before the 1880s, no one attempted to farm any distance from a stream. But the great majority of newcomers staked claims wherever they could, relying on nature and neighboring wells until the time came when they could dig their own. Lacking special drills and often the horsepower to run machines, settlers dug into the ground with tools as basic as picks and shovels. It was not unusual for a settler to dig 40 feet (12 m) or more to reach groundwater. In the meantime, settlers hauled drinking water from some distant source, usually a well located in town or on a neighbor's claim. In the absence of windmills, pioneers pumped or raised water by hand—a time-consuming and strenuous task.

From hard experience, high plains farmers soon learned to appreciate a dependable water supply. With a well and a windmill, they could keep stock; and stock raising proved a crucial hedge against failure. By combining crop culture with keeping small numbers of horses and cattle, a cow for milk and butter, and a few pigs and chickens, a family had a better chance of hanging onto their land through the droughts that lay ahead.²⁰

Katherine Harris, *Long Vistas—Women and Families on Colorado Homesteads*. Reprinted with permission of the University Press of Colorado, Niwot, Colorado

S I D E B A R

The Chicago-based Sears, Roebuck & Company had an extensive line of windmills in the late 1800s to pump groundwater. Their design was fairly simple: Wind turned the rotor blades and rotated a gear-driven shaft that pumped a sucker rod. The up-and-down movement of the rod forced groundwater up to the land surface. Windmills offered in the Sears catalog ranged from the "direct-stroke" wooden model to the "high-g geared" steel line. Most models had 8-foot (2 m) rotors on top of towers that were 30 to 40 feet (9 to 12 m) high.

Around 1870 **Horace Greeley**, an editor for the *New York Tribune*, promoted the phrase "Go West, Young Man," to encourage settlement in the western United States. Through newspaper editorials and speeches around the country, Greeley expressed his strong belief that the United States needed to settle the vast regions west of the Mississippi River. The timing for his promotion was ripe: the Civil War had recently ended in 1865, and construction of the transcontinental railroad between Sacramento, California, and Omaha, Nebraska, had been celebrated in 1869. Greeley organized a group of settlers and investors from the East and encouraged them to settle at the confluence (junction) of the South Platte and Cache la Poudre rivers in northern Colorado. In many ways, Greeley's group hoped to replicate the success of Brigham Young and his followers who had settled in the Salt Lake Valley 23 years earlier. The geography of Horace Greeley's settlement (today called Greeley, Colorado) was in many ways similar to the site selected by Brigham Young: irrigation water was required to grow crops in the arid climate; adjacent streams had ample water supplies when snow melted from nearby mountains; and fertile valley land was available for crop production if adequate irrigation water was applied.

Construction of an irrigation canal (also called an irrigation ditch) began immediately as Horace Greeley's settlers arrived at their new community. (Greeley stayed in New York City to attend to newspaper duties.) Horses and mules pulled



FIG. 1.9 This old photo shows Robert Atchison's construction outfit digging the Bijou Ditch near the South Platte River in Colorado, circa 1870. Notice the metal "slips," or "scrapers," pulled by the horses. Thousands of miles of irrigation canals were constructed in this manner in the western U.S. during the second half of the 1800s.

metal scrapers called *slips* (see Figure 1.9) to construct the 15-mile-long (24 km) Greeley Irrigation Company Ditch. At the time, this effort was the largest community irrigation project in the United States. Over the next 20 years, scores of irrigation ditches were constructed in the South Platte River Basin of Colorado, and the area prospered, becoming one of the top agricultural producing regions in the country.

In later years, and into the 20th century, irrigation projects expanded across the United States. Settlers in arid regions relied on irrigation water to produce crops such as corn, wheat, oats, sugar beets, alfalfa, and vegetables. Some crops—including corn, oats, and alfalfa—were fed to livestock on farms to be used for food or to sell to buyers for cash. Sugar beets were produced for sale to local sugar factories for refining, while vegetables were grown for sale to local urban markets. Settlers in the West who didn't have adequate irrigation water were forced to move back to more humid regions (areas of greater precipitation) east of the Mississippi River, or they moved into town to work in other professions. Entire farming communities were abandoned in later years, when crops died as a result of inadequate water supplies. Drought during the 1930s drove thousands of settlers from

dust bowl farms and ranches in Nebraska, Kansas, and Oklahoma to seek new opportunities in California, Oregon, and Washington. Local economies of the abandoned areas were devastated, and many lives were financially ruined.

Irrigation continues to be extensively used around the world today. Between 1970 and 2000, the Earth's population increased by 2.3 billion people. This growing demand for food and fiber places great stress on food production and delivery systems around the world. Conflicts are increasing over water supply needs between irrigators and urban centers, over the use of fertilizer and other chemicals to enhance crop production and the need to avoid polluting rivers, lakes, or groundwater, and over the high production costs of irrigated farms. These issues will be discussed further in Chapter 5, Chapter 6, and Chapter 14.

P O L I C Y I S S U E

Ancient civilizations developed irrigation water projects to provide food for growing communities. Common crops were grains such as wheat and corn, vegetables, and hay for livestock, such as horses and cattle. Without supplemental water supplies, crops withered

and died from lack of moisture during the growing season. Irrigation meant food and life.

As technology improved, mechanical devices were invented to irrigate lands that were formerly at too high an elevation or were too far from a stream to receive water. The *shadouf*, *tambour*, and *saqia* were early methods used to lift water to fields that were higher than nearby water supplies. Dams and other methods of water diversion were later constructed to change the course of streams to deliver irrigation water to additional lands.

Irrigation has its drawbacks. Land irrigated year after year can become unproductive through a buildup of salts naturally found in the soil. Sediments (silt, gravel, and other earthen materials) can accumulate behind dams and can eventually make these structures unusable. Centuries of irrigation can destroy the ability of soils to produce adequate crops. When this loss of productive land occurs, an entire civilization may collapse, as has happened over the ages. Could early inhabitants in dry climates have developed alternatives to irrigation, or is it inevitable that humans will alter the natural environment by developing irrigation projects when food is needed?

EARLY WATER TRANSPORTATION DEVELOPMENT

EGYPT AND GREECE

Inland waterways, such as rivers and canals, have been used around the world for centuries to transport people and goods. In ancient Egypt, the movement of commerce relied on navigation of the Nile River, its tributaries, and artificial canals, since few roads existed in that desert region. Approximately 80 canals were constructed in the Nile River Valley by various dynasties for navigation and irrigation. Sometimes canal construction projects are controversial. In Greece, for example, a canal was

constructed in 1893 for navigation across the Isthmus of Corinth to connect the Aegean and Ionian seas. However, opposition by Greek merchants along the longer, more circuitous water route nearly stopped the project before it was completed. The merchants were afraid that business would suffer because customers would start bypassing their establishments. They were right.

CHINA

Chinese commerce relied primarily on river transportation along the Huang He and Yangtze rivers. Combined, these two massive inland waterways allowed navigation on over 5000 miles (8000 km) of mainland China. Since these rivers flow west to east, a north-south "Grand Canal," the Da Yunhe, was constructed to allow the transport of freight, grain, and military troops between river valleys of the Wei, Yangtze, Hai, and Huang He.

The Da Yunhe extends nearly 1000 miles (1600 km) between Beijing to the north and Hangzhou in the southern part of the country (Figure 1.10). The canal maintains a depth of approximately 10 feet (3 m) and has an elevation change of only 138 feet (42 m) over its entire course. However, boats must contend with steep gradients of 20 to 30 feet (6 to 9 m) in a few locations. Inclined planes (ramps) were constructed in ancient times out of stone, and boats were dragged up or down these steep sections by horses and gangs of men. The ramp had a relatively smooth surface that extended the length of the unnavigable reach (section) of the canal. In other locations, water from rivers and lakes was released into the canal, and sluice gates (wooden barriers) were used to maintain adequate water levels for navigation.

In some areas, it was impossible to dig the Da Yunhe to the depth necessary to maintain a gradual elevation change. As technology improved, crude locks were constructed to replace inclined planes at some locations. **Locks** are basically a series of steps, or step chambers, that can be filled or emptied with water. Once a vessel enters a lock, watertight doors are closed, and sluices (wooden doors) are opened to release water into or out of the lock.



FIG. 1.10 The Grand Canal (in Chinese, Da Yunhe, or “great transport river”) is the world’s longest artificial canal and was constructed during the fourth and fifth centuries B.C. Peasants did most of the work, and nearly half of the six million men who worked on the canal died during construction. Today, the Da Yunhe connects the major Chinese cities of Beijing in the north and Hangzhou to the south.

Filling a lock with water elevates a boat to a higher elevation; releasing water from the lock lowers the elevation of the vessel. When the desired height is reached, lock doors are opened, and a boat continues on its journey. Occasionally, flash locks were used to provide a quick release, or flash, of water. This temporary discharge of water increased the amount of water in a section of a canal or small stream, raised the elevation of the water surface, and allowed a vessel to pass to a higher elevation along the Da Yunhe.

A section of the Da Yunhe was extended to Beijing around A.D. 600 to supply northern armies with food and other supplies. This helped improve China’s defenses and also increased trade between the northern and southern regions of the country. The Chinese economy relied heavily on canal navigation because it allowed

more grain to reach urban markets. Increased grain sales also meant more taxes paid to the Chinese government.²¹ The Da Yunhe is still the longest artificial waterway in the world and represents an engineering feat comparable to the Great Wall of China.

EUROPE

Numerous canals were built throughout Western Europe. The construction of the first navigation canal in France, the Canal de Briare, was completed around 1610 to link the Loire and Seine rivers. It was approximately 27 miles (43 km) in length. The Canal du Midi, completed in 1681 during the reign of Louis XIV, was the largest construction project in Europe up to that time. France developed approximately 3000 miles (4800 km) of artificial canals that interconnected

with 4600 miles (7400 km) of navigable rivers. On the Thames River in England, sluice gates were often used to maintain adequate water levels for navigation. These gates channeled water to one side of a river to increase depths for navigation.²²

Freight transportation along waterways was extensive in the region known today as the Czech Republic. As early as the 6th and 7th centuries, corn was transported on rivers from Bohemia to be traded with the Saxons for weapons and cloth. In the 11th century, landowners along the Czech waterways revolted when excessive tolls were charged for the transport of beer and field machinery (cutting sickles). All barge traffic was stopped along the route until the ruler of Bohemia, Charles of Luxemburg, ordered the opening of Bohemian waterways to free passage.²³

A CLOSER LOOK

Leonardo da Vinci (1452–1519) was a great water engineer and military planner. Around 1500, he developed plans to improve navigation and irrigation in Italy in the Arno River Valley around Milan and Florence. A by-product of this scheme was the drying up of the river at Pisa to destroy the city's water supply, thereby winning a war that had been going on for 10 years. Da Vinci designed canals, sluice gates, locks, and diversion dams to implement his plan for war and peace (Figure 1.11).

Niccolo Machiavelli, a government official in Florence (who would become famous for the Machiavellian method of politics of corruption and ruthlessness), was da Vinci's cohort in the water scheme. If successful, the Florentine economy would have flourished, da Vinci would have become rich, and Machiavelli would have been a political heavyweight in Italy. However, the plan did not succeed for a variety of reasons. Da Vinci went on to other interests, and Machiavelli was ousted from public office.²⁴

UNITED STATES

George Washington (1732–1799) was a strong proponent of canal construction in the original colonies of the United States. Through his travels,

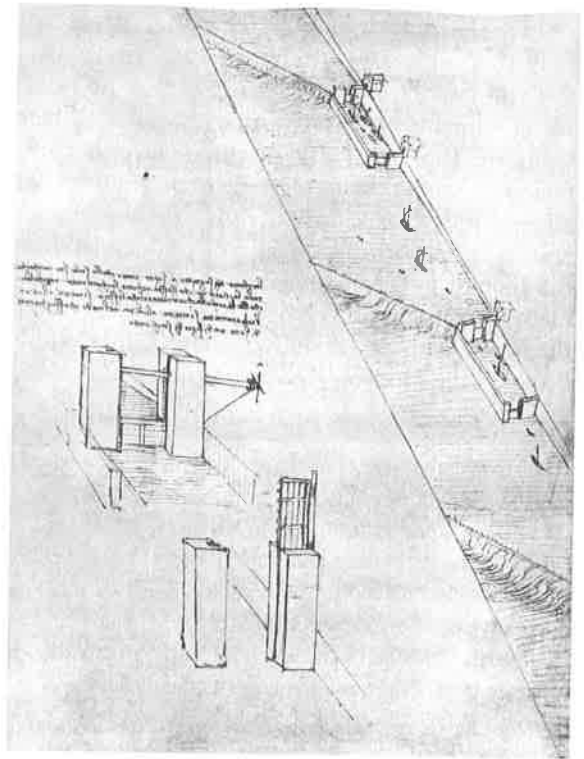


FIG. 1.11 These sketches are based on Leonardo da Vinci's studies of navigation on rivers with irregular flow rates. The left side of the drawing shows two sketches of drop-down sluice gates designed to allow boats to go either upstream or downstream. The annotation explains how the gates are operated by means of a winch. The drawing is from *Il Codice Atlantico di Leonardo da Vinci nella biblioteca Ambrosiana di Milano*, Editore Milano Hoepli, 1894–1904. The original is at the Biblioteca Ambrosiana in Milan, Italy.

Washington saw extensive inland waterways in England and France, and knew the great benefits they would provide to the economy of the young nation. At the end of the Revolutionary War, he took a six-week trip across the Allegheny Mountains to develop recommendations for a canal from the Ohio River to the Potomac. Washington later organized a company to build the Chesapeake and Ohio Canal, but it was only partially completed. Portions of the canal can still be seen in Washington, D.C., as part of the National Capital Parks System.

In the early 19th century, the United States had only 100 miles (160 km) of canals. However, the **Gallatin Report**, presented to Congress in 1808, fueled dreams of westward expansion. Albert Gallatin, U.S. Secretary of the Treasury, completed a comprehensive review and survey of all existing transportation routes in the United States. His report to Congress recommended that the federal government make a strong commitment to construction of new roads and canals to the West, with an emphasis on a canal/river link between the Hudson River and the Great Lakes.

S I D E B A R

De Witt Clinton, mayor of New York City and later governor of the State of New York, was a strong proponent of the Erie Canal, a project that began in 1817 and was completed by 1825. It was 363 miles (584 km) in length and connected Lake Erie near Buffalo to the Hudson River at Albany. However, not everyone was in favor of the \$7 million canal. Although “Clinton’s Ditch” was ridiculed as a potential money loser, freight and passenger traffic repaid the project in only 10 years. Today only pleasure craft use the Erie Canal, and tolls paid by travelers on the New York Thruway (I-90) underwrite the operation and maintenance of the State Canal System.

Shortly after the Gallatin Report was presented to Congress, the country went “canal crazy.” The state governments of Virginia, Pennsylvania, Maryland, New York, Ohio, New Jersey, Indiana, and Illinois entered the canal-building business and developed waterways such as the Erie, Pennsylvania Main Line, and the Chesapeake and Ohio canals. These new transportation routes helped open markets to farmers and ended the isolation of “western” areas of the United States. Small towns grew as emigrants streamed west of the Allegheny Mountains, employment increased, and the nation’s economy strengthened. The Erie Canal cut travel time between New York City and Buffalo, New York, from 20 days to 6 and reduced the cost of moving freight from \$100 to \$5 per ton.²⁵ By the end of the 1800s, the United States had over 4000 miles (6400 km) of navigable canals.

The Mississippi River also played a major role in the history of navigation in the United States. In the 1700s, keelboats and flatboats were the typical mode of transportation on the Mississippi until the introduction of steamboats in the 1800s. The first steamboat to travel on the Mississippi River was probably the *New Orleans*, built by Robert Fulton and Robert Livingston in 1810 in Pittsburgh.²⁶

Obstacles and other natural barriers were common along the Mississippi River during the 1800s. Floods, erosion, and variations in stream flow all combined to make navigation on the river quite dangerous (see Figure 1.12). Hidden sandbars and deadly “snags” (a Scandinavian word meaning “sharp”) were dangerous obstacles and led to a refinement of terms to describe different types of snags in the Mississippi:

- Planter* A tree trunk buried in the sand on one end but floating free at the other end.
- Raft* A snag that almost completely blocked a channel.
- Sleeper* A water-logged tree floating just beneath the surface of the water.
- Sawyer* A snag balanced so delicately that a breeze caused it to bob up and down.

(Sawyer was an appropriate name for author Mark Twain to give to the main character of his novel *The Adventures of Tom Sawyer*, written in 1876. Twain’s own pen name was also derived from a Mississippi River term; it referred to the depth of water in the Mississippi River. “Mark Twain” signified the second mark on the line that measured river depth: 2 fathoms—12 feet, or almost 4 m—safe clearance depth for a steamship. Twain, whose real name was Samuel Clemens, was a “cub” steamboat captain at age 21, and rafts, planters, sleepers, and sawyers were constant worries for steamboat operators of that era. The Civil War ended his career on the river, since all riverboat traffic was halted. Twain turned to writing.)²⁷



FIG. 1.12 River obstructions have plagued navigation on the Ohio, Missouri, and Mississippi rivers and their tributaries since the 1800s. Due to the economic depression of 1838, no federal snag removal efforts were made between 1839 and 1842. During that time, hundreds of steamboats sank and caused enormous problems for the transportation of people and materials. This photo is of the U.S. Army Corps of Engineers snagboat *R.E. DeRussy*, which was built in Albany, New York, in 1867. The vessel had two hulls and a windlass for hoisting snags and wrecks from the Ohio River and its tributaries. Note the workers with axes standing in the pile of trees in the foreground. Snag removal was very labor intensive.

S I D E B A R

A new obstacle to navigation came along in 1856, when a railroad bridge was constructed across the Mississippi River between Davenport, Iowa, and Rock Island, Illinois. Shortly after completion, the steamer *S.S. Effie Afton* rammed a bridge pier (foundation) and severely damaged the structure.

Immediately, the steamer company sued the Chicago & Rock Island Railroad Company for obstructing navigation on the river. The local court agreed and called the bridge a public nuisance. The railroad company appealed the ruling and took the case all the way to the U.S. Supreme Court, where the decision was reversed. The Court issued a landmark ruling in favor of the railroad company after listening to the compelling arguments of its attorney from Illinois, Abraham Lincoln.

Steamboats of the 1800s could travel along the Mississippi River from New Orleans north to St. Louis and beyond on the main stem of the Mississippi, to the northeast on the Ohio River, or northwest along the Missouri River into

Montana. Navigation provided a critical supply of materials to western cities and outposts until the construction of railroads took business away from the riverboats. Powerful railroad executives and politicians helped secure favorable government contracts for the construction of railroads around the country. This provided direct competition to navigation interests for the transportation of materials and led to a steady decline in the number of riverboats operating along the Mississippi River and its tributaries.

Even now in the 21st century, water transportation on rivers and lakes continues to be a very important mode of transportation around the world. Grains, textiles, cotton, lumber, fuel, and innumerable other commodities are shipped daily on intricate networks of rivers and lakes in many parts of the world. Unfortunately, conflicts over water flows and the needs of other water users and the natural environment are becoming more frequent. See Chapter 7 for more information on present-day water transportation issues.

EARLY HYDROPOWER DEVELOPMENT

The energy contained in moving water has been used to power some of the earliest machines made by humans. The first waterwheels were developed to grind grains such as corn and wheat for human consumption. Later, improved waterwheel technology was utilized to power factories that produced textiles, wood products, and metal machines. More recently, modern versions of the waterwheel have generated electricity when constructed within the hydropower facilities of a dam.

In Mesopotamia and ancient Egypt, the *norria*, or Egyptian waterwheel, was used to divert water from a stream or groundwater well for irrigation. This waterwheel had a chain connected to a series of earthen pots rotated by a wheel. Water was lifted by the pots and then spilled into an irrigation channel. If the flow of the stream increased, more jars were added to the waterwheel. If water flow decreased, jars were removed to allow the *norria* to rotate more efficiently.

Waterwheels were used in Greece as early as 100 B.C. to grind grain. Water from a stream flowed into a horizontal paddle wheel that contained numerous buckets mounted on a vertical shaft. The weight of water in the buckets caused the waterwheel to rotate. This turned a shaft attached to a millstone that ground corn or wheat for bread or other food items. This simple technology, called *milling*, spread quickly and was used in China by A.D. 100.²⁸

The city of Hama in present-day Syria received its water from the River Orontes. River water was lifted by huge waterwheels and then emptied into enormous stone aqueducts. The aqueducts were waterproofed with a 1-foot-thick (30 cm) layer of primitive concrete made from lime, sand, and broken limestone. Millions of limestone blocks formed the archways across valleys.

Around A.D. 300, the Romans improved waterwheel design by using a horizontal drive shaft attached to a vertical wheel. This new shape allowed the buckets to be placed just

below the surface of a flowing stream. Again, the weight of the water in the buckets turned the waterwheel.

By 1086, there were 5000 mills operated by water power in England. By 1800, the number had grown to over 500,000 mills throughout Europe. Many included a **mill raceway**, or canal, that diverted water from a river to provide an efficient and steady flow of water for a waterwheel. Mills powered by waterwheels ground corn and wheat, powered bellows and hammers to make iron, ground ingredients to make paper, cut wood, crushed olives for oil, drilled gun barrels, and powered textile factories.²⁹

Conflicts over waterwheel diversions and river navigation occurred as early as A.D. 1000. In England, waterways were under the jurisdiction of the Lord High Admiral. Since most watermills required the construction of a dam across a river to supply water to a raceway, conflicts with navigation traffic would inevitably occur. The dam at Chester was installed to power mills in the city, but the dam had to be constructed across the River Dee. When royal command ordered it removed to restore navigation, the business community in the city objected. The Lord High Admiral agreed with the merchants and refused the order. The dam at Chester still stands today.³⁰

The mills on the Blackstone River in Rhode Island and Massachusetts are excellent examples of U.S. watermills (see Figure 1.13). The Blackstone has a drop in elevation of over 400 feet (122 m) between Worcester, Massachusetts, and Providence, Rhode Island, and a massive 31-foot (9 m) drop at Woonsocket, Rhode Island. This reach of the Blackstone River became a hotbed for waterwheel development, and Woonsocket became one of the largest textile-manufacturing centers in the United States in the 1800s.

Conflict between navigation and watermills in the United States was common. If a miller needed to divert water for a watermill at the same time a boat needed to pass by, water in a river had to be shared. In addition, the miller was also required



FIG. 1.13 Slater Mill and Dam are located on the Blackstone River in Pawtucket, Rhode Island, at the head of Narragansett Bay. This early mill was constructed by Samuel Slater in 1793 and was the first cotton mill in the United States to use mechanical spinning machines. By 1800, the town of Pawtucket had 29 cotton mills, and by

1830, a dam was located every mile along the Blackstone River and its tributaries. Today, the Slater Mill Historic Site is a popular tourist attraction as the birthplace of the Industrial Age in America.

to pay the navigator for lost water, or “flash,” since navigation was slowed down, or “injured.” The law recognized that river navigation existed long before the miller arrived. It was commonly agreed that the earlier (or “prior”) water use for navigation had a priority over water needs at a watermill.

The first recorded industrial use of the Niagara River, a boundary between Ontario and New York State, was in 1759. A small canal was dug to power a waterwheel for a sawmill. In 1875, the Niagara Falls Hydraulic Power & Manufacturing Company built a canal 35 feet (11 m) wide and 8 feet (2 m) deep to divert water from the Niagara River, above the falls, to sawmill sites below. The 150-foot (46 m) drop in elevation provided massive amounts of water energy to turn the waterwheels. A few years later, those same wheels generated electricity.³¹

Thomas Edison’s development of the incandescent light bulb created demand for cheap, plentiful power sources to turn electrical generators. The

first hydropower station for Edison’s electric system was a waterwheel constructed on the Fox River in Wisconsin in 1882. In 1896, the Westinghouse Company installed the first electric generators in the vicinity of Niagara Falls near Buffalo, New York, and later at other locations around the United States and Canada. By the early 1900s, hydropower provided over 40 percent of all electricity used in the United States, and by 1945, it supplied 75 percent of the electrical needs for the Pacific Northwest. Today in Canada, 60 percent of all electricity is generated with hydropower, while worldwide the figure is approximately 15 percent.³² See Chapter 7 to learn more about modern power production at Hoover and Grand Coulee dams in the western United States.

One of the boldest engineering and commercial feats of the past century, the successful development of the water-power of Niagara Falls, was the signal for the utilization of water powers all over the world. This masterpiece of nature remains to-day with its beauty and grandeur unmarred, its 8,000,000 horse-power inappreciably affected by the petty thefts of man, and its usefulness enhanced a thousand-fold.

William Andrews, “How Niagara Has Been Harnessed,”
American Monthly Review of Reviews, June 1901

P O L I C Y I S S U E

The invention of the waterwheel was an extremely important event in history. One of its earliest uses was to divert water from a river or a groundwater well for irrigation. By 100 B.C., waterwheels were used to grind grain, and the technique quickly spread to other civilizations. Centuries later, the waterwheel was redesigned to operate mills around the world. Significant events related to the development of waterwheels are included in Table 1.1.

Why was there such a tremendous application of hydropower technology? What role did population growth play in this transfer of technology?

TABLE 1.1 Selected Water Development Events, 3200 B.C.—A.D. 2004

Year ^a	Event	Present Location
B.C.		
3200	King Scorpion proclaims “Day of Breaking the River”	Egypt
2280	Yu the Great constructs various waterworks	China
1000	<i>Qanats</i> constructed	Middle East
560	Cheng State Irrigation Canal completed	China
500	Water harvesting developed	Middle East
500	Dikes and levees constructed for flood control	China
312	First Roman aqueduct built	Italy
100	Waterwheels used to grind grain	Greece
A.D.		
100	Waterwheels used to grind grain	China
300	Romans improve design of waterwheels	Italy
800	Hohokam Indians develop irrigation	Arizona
800	Irrigation introduced by Romans and Moors	Spain
950	Anasazi Indians use irrigation	Colorado
1000	Conflict between boats and waterwheel in Chester	England
1086	5000 mills operated by waterwheels	England
1400	Spanish settlers migrate north to California, Arizona, and New Mexico	United States
1500	Leonardo da Vinci proposes irrigation/navigation system at Milan	Italy
1610	Canal de Briare completed	France
1619	Network of pipes deliver water to every home in London	England
1800	Waterwheel development rapidly increases	Rhode Island
1808	Gallatin Report presented to Congress	Washington, DC
1810	Steamboat <i>New Orleans</i> constructed in Pittsburgh	Pennsylvania
1825	Erie Canal completed	New York
1847	Mormons develop irrigation in the Salt Lake Valley	Utah
1856	Abraham Lincoln argues Mississippi River navigation case	Washington, DC
1862	U.S. Congress passes Homestead Act	Washington, DC
1870	Horace Greeley promotes irrigation in Greeley	Colorado
1882	Hydropower plant developed for Edison electrical system	Wisconsin
1945	Hydropower provides 75 percent of electrical needs in Pacific Northwest	United States
2004	Hydropower provides 60 percent of all electricity supplies	Canada

^aSome dates are approximate.

Was it inevitable that navigation would come into conflict with this new “use” of water from rivers? What if the navigation industry had been highly organized prior to the construction of waterwheels in England? What could the navigation industry have done to prevent infringement on their water needs? Would this have been a proper protection of a prior (or “senior”) water user, or should the new milling technology

have been given unrestricted use of water as long as society benefited from this new water use? What rights should an existing industry have over a new water use from a river?

Finally, how should the environment be protected within this debate? These issues will be explored in Chapter 8 and Chapter 12.

CHAPTER SUMMARY

Water use has evolved over thousands of years from basic human needs to complex technological innovations. Early civilizations focused on the need for food, shelter, and drinking water. Later, as populations multiplied and food demands increased, irrigation was developed. Improved food supplies led to larger urban population centers that required greater supplies of water for drinking needs and sanitation requirements. The Romans were one of the earliest civilizations to construct extensive aqueducts and other urban water delivery systems. Navigation flourished along natural and artificial waterways to transport goods,

soldiers, and other material. Hydropower was widely used to grind grain and later for other manufacturing purposes. Conflict between navigation and milling industries occurred frequently in some locations.

As the population of the world expanded, irrigation, navigation, and milling industries expanded. In the United States, canal construction for navigation was extensive in eastern regions of the country, while irrigation was generally confined to the western territories. Why? Chapter 2 will attempt to answer that question.

QUESTIONS FOR DISCUSSION

1. Describe the earliest water uses by humans.
2. Discuss the development of *qanats*.
3. Explain why groundwater exists today in desert regions of the Middle East.
4. Why did early civilizations develop irrigation projects?
5. Discuss the development of navigation in the United States.
6. Discuss the allocation of water between mill owners and navigators. Within this context, do you agree that the prior (or "senior") user of water (navigation) should obtain priority over the "junior" water user (mill owners who diverted water from a stream and may have constructed a dam across a river)?
7. Abraham Lincoln was a staunch supporter of construction of the transcontinental railroad. Almost a century earlier, George Washington had lobbied heavily for the construction of canals to improve the economy of the country. What recent U.S. presidents have used water to promote (or discourage) economic development? In what ways have they done so?
8. Are you aware of any ongoing conflicts between navigation and other water uses in your community or region? If so, what are the issues?
9. Discuss the evolution of waterwheels. What types of products were produced with this technology?
10. Are irrigation, navigation, or hydropower generation controversial topics in your area? If so, what are some of the issues under debate? What water resources agencies are involved?

KEY WORDS TO REMEMBER

<i>acenas</i> p. 9	<i>charcas</i> p. 9	locks p. 13	<i>shadouf</i> p. 6
<i>acequias</i> p. 9	Gallatin Report p. 16	mill raceway p. 18	<i>tambour</i> (Archimedes screw) p. 6
Anasazi Indians p. 10	Hohokam Indians p. 9	<i>noria</i> p. 18	
aqueduct p. 4	Homestead Act p. 11	<i>qanats</i> p. 3	
Brigham Young p. 10	Horace Greeley p. 11	<i>saqia</i> p. 6	

SUGGESTED RESOURCES FOR FURTHER STUDY

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