6

CONTROLLING WATER

Engineering is the art of directing the great sources of power in nature for the use and convenience of man.

—THOMAS TREDGOLD, PIONEERING ENGLISH CIVIL ENGINEER (1788–1829)

PERHAPS THE MOST CRITICAL CHARACTERISTIC FOR THE SURvival of our species has been the ability to manipulate the environment, including efforts to control the waters around us. It is almost instinctive. Put kids in a creek or a stream with a bunch of rocks and sticks, and there's a good chance they will start to build a dam. Suffer a devastating flood, and communities will start to build levees and dikes. Faced with a lack of rainfall, farmers will dig ditches to bring water to their field, drill wells, or build reservoirs to bank water for dry periods. It should be no surprise that epic tales of floods and droughts as well as the increasingly urgent need to provide food for growing populations helped inspire early humans to manipulate water to their advantage.

The evolution of modern humans involved more than the biological transition to *Homo sapiens*. It required creating communities, developing engineering and technological skills, and transforming cultures. As expanding populations led to larger organized communities, there were also social advances in the form of enhanced trade and economies, blossoming art and culture, and concentrated political power. The growth of towns and cities also drove the need to find larger and larger quantities of fresh water than ever before from greater and greater distances. Even with lower population densities than we find today, ancient cities outgrew their local water supplies, especially in regions where river flows were unreliable and where groundwater was hard to find and collect. These challenges led to the first efforts to build large-scale water infrastructure of the kinds we still rely on today: canals and aqueducts to move water from where nature provided it to where it was needed, dams and reservoirs to store water in wet periods for use in dry ones, and levees and diversions to reduce the destructive power of floods.

The ancient Sumerian city of Eridu was founded around 5200 BCE near the mouth of the Euphrates River and was the home of the Sumerian god of fresh water, Enki. Archaeological digs have revealed the extensive use of artificial irrigation in the form of a canal system to channel water from rivers and streams to the city and surrounding farms. An ancient document recovered from the ruins talks about the role of one of the earliest known government officials, the canal inspector. Indeed, Sargon the Great, who reigned from around 2334 to 2279 BCE and is known as the first ruler of the Akkadian Empire after conquering the Sumerian city-states, may have started his career as an irrigation official in the royal service of Sumeria, becoming the powerful administrator of the water system.[1]

When Hammurabi founded the kingdom of Babylon (ca. 1792–1750 BCE), he too understood the importance of reliable irrigation supplies for political power. Letters and documents recovered from the time describe the construction of a canal called "Hammurabi is abundance for the people," and this influential king is described in the Code of Hammurabi (uncovered on a giant stone stele in Sura in 1901) as "he who establishes abundant waters for its people."[2] Other early cultures also prized the ability to manage and manipulate water for social benefit.

A remarkable example of large-scale water management was discovered in marshlands along China's Yangtze River delta. The Liangzhu culture, dated to between 5,300 and 4,300 years ago, predated the historical Chinese dynasties and included a vast hydraulic system of large and small dams, cisterns, irrigation canals, and water temples built around 5,000 years ago in a region of early intensive rice farming. Archaeologists believe the construction of these projects at Liangzhu required thousands of people and that the control of water supported tens of thousands more for centuries before being abandoned around 4,200 to 4,300 years ago as the region became drier.[3]

The Chinese also have an ancient legend about the "Great Yu Who Controlled the Waters" (大禹治水), a king remembered for his efforts to control the floodwaters of the Yellow River more than 4,000 years ago. The first record of his exploits comes from inscriptions and pottery created more than a thousand years after his death. The legend tells of a figure who ate, slept, and worked with common workers to build diversions, canals, and levees that allowed the Chinese civilization to flourish alongside a river capable of devastating floods. Because of his efforts, Yu was so popular that he became the founding emperor of the Xia dynasty at the transition from the Stone Age to the Bronze Age. This dynasty is the first in Chinese history and considered by some to be the true beginning of Chinese civilization. Due to a lack of direct evidence of his existence, some historians speculate that Yu symbolically represents the efforts of the early communities struggling to tame devastating floods. However, the Great Yu is, even today, celebrated as a wise ruler who worked to help the common people by conquering floods thousands of years ago.[4]

Today, tens of thousands of dams—from tiny stone barriers to massive modern marvels of earth, concrete, and steel—store, modify, channel, and divert the waters of almost every major river. So much water has been stored behind the world's dams that it has measurably altered the very rotation of the planet.* The length of a day on Earth is a few microseconds shorter today because of the impoundment of thousands of cubic kilometers of water in artificial reservoirs in places water didn't use to be.[5]

While evidence of most ancient dams has long since been washed away by the erosive powers of water and time, archaeologists have found remains from thousands of years ago of some of the first efforts to control and manage the flow of rivers for human use. The earliest evidence for rudimentary dams is the remains of small stone structures used to capture

* Like a spinning skater who shifts her weight distribution by drawing her arms toward her body to speed up her spin.

rainfall and hold water on agricultural fields for longer periods of time and diversions to move water from a stream to a field or small reservoir. But archaeologists have also uncovered evidence of more ambitious efforts to control large flows in Mesopotamia and Egypt, including true dams in the sense of a physical, permanent structure built across a river to create a reservoir to store water, provide flood control, or divert water to an aqueduct for distant use.

In the 1920s and 1930s, Antoine Poidebard, a Jesuit missionary, former French spy, and aviator, adapted the use of aerial photography developed during the Great War to archaeological research. He flew his modified biplane over the Middle East, taking pictures that revealed traces of ancient civilizations buried under the sands. He published a series of photos and a detailed map in his 1934 book *La trace de Rome dans le désert de Syrie* that he believed proved the existence of early Roman towns in regions along the Euphrates and Tigris Rivers.[6] This work made him famous, in both archaeological circles and with the general public eager for information from the mysterious Levant.[7]

One of the sites revealed in his photos was Jawa, in the western part of the black basalt desert a hundred kilometers northeast of Amman, Jordan. It was not until the 1970s, however, that a team of archaeologists, led by Svend Helms of the London University Institute of Archaeology, began to excavate the remote site. What they found was not an old Roman town, but a far older Bronze Age settlement dated to around 5,600 years ago (around 3600 BCE) along the Wadi Rajil, a waterway that drains the southeastern part of the volcanic region of Jebel al-Druze.[8] Helms described Jawa as "the best preserved fourth-millennium town yet discovered . . . paradoxically built in a place—the Black Desert—where it could hardly exist today and probably hardly when it was built."[9] Even though it was founded when the climate would have been somewhat wetter, the community would have had to find ways to harness the irregular flows of the Wadi Rajil to survive.

During their exploration of Jawa, Helms and his team uncovered the remains of elaborate water-collection and -distribution canals and channels to collect rainwater to irrigate terraced gardens and fields. The channels were fed by three dams constructed between 3500 and 3400 BCE. Two smaller structures diverted water from the Wadi Rajil to the

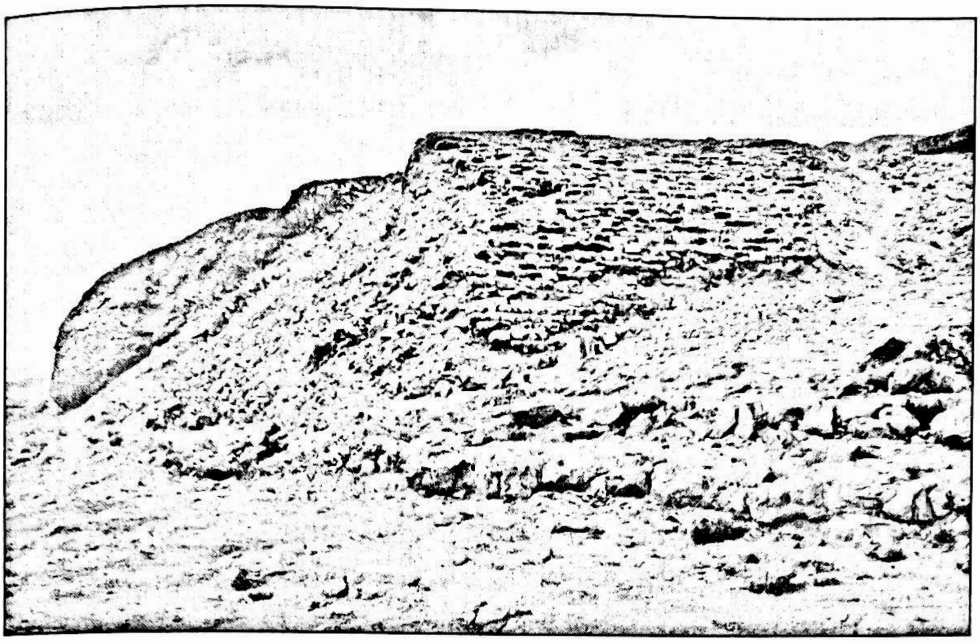

FIGURE 5. The remains of the Sadd el-Kafara Dam in Egypt. Photo by Jean-Luc Frérotte (2008) and used with permission.

cultivated fields, while the third, the Jawa Dam, is now considered the oldest known dam designed to block the entire flow of the river and store water for dry periods. Jawa Dam was about 50 meters long and 9 meters high, built from gravel reinforced with rock fill, with dry masonry walls surrounding an earthen core. The dam ultimately failed, washed away by a high flood characteristic of the region and climate.

The second-oldest large dam found by archaeologists is the Sadd el-Kafara in Egypt, built ca. 2700 to 2600 BCE, many centuries after the Jawa Dam. Located on the Wadi al-Garawi, a tributary to the Nile south of Cairo, the Sadd el-Kafara was a masonry-faced, rock- and earth-filled dam built to control flooding and perhaps provide more reliable local water supply (Figure 5). It was substantially larger and more sophisticated than the dam at Jawa, measuring over 110 meters (around 330 feet) long and 14 meters (over 40 feet) high. It is estimated that if it had been completed, it could have stored nearly a half-million cubic meters of water, or more than 120 million gallons. Archaeological evidence suggests it was under construction for more than a decade, but it was destroyed before completion, also overwhelmed by a major flood.[10] There is no sign that Egyptian engineers tried to build another dam for nearly a thousand years.[11]

The most successful ancient dam found to date is the Great Marib Dam near the city of the same name, along the river Dhana in Yemen. Marib was the capital of the Sabaean kingdom, thought to be Sheba mentioned in the Old Testament and the Holy Koran. The Sabaeans were a Semitic people who controlled trade in spice, silk, ivory, and other goods, including frankincense and myrrh, between the East and the West. The dam—an earth-filled and stone-fronted dam—was built by the Sabaeans around 800 to 700 BCE, though there is some tentative evidence that a smaller, earlier version may have been built around 1750 BCE.[12] The dam was more than 650 meters long and 14 meters high and provided water supply and irrigation water, storing around 400 million cubic meters of water. It lasted for more than a thousand years, with numerous breaches and repairs through the centuries. One stone inscription on the dam describes repairs requiring 20,000 workers and 14,000 camels.[13] The dam finally succumbed to a flood around AD 570 that breached the dam and destroyed its foundations.* This flood was so damaging, it receives a mention in the Holy Koran, written a half century later, which describes a flood sent by God as a punishment for the Sabaeans turning away from Islam, destroying the dam, laying the countryside and fields to waste, and leaving behind only wild growth and "bitter fruits." "But they [the Saba] turned away and so We let loose upon them a devastating flood that swept away the dams and replaced their gardens by two others bearing bitter fruits, tamarisks, and a few lote trees" (Koran 34:16; translation from the Islamic Foundation, United Kingdom).

Remarkably, some of the oldest dams are still in use, repaired, updated, and modified over the centuries. The Kallanai or Grand Anicut Dam was built on the Kaveri River in Tamil Nadu, India, sometime between 100 BCE and AD 100 during the reign of King Karikalan. It was somewhat modernized in the nineteenth century by the British and still provides irrigation water. The Kaerumataike Dam was built in AD 162 on the Yodo

* The Great Marib Dam is considered one of the great feats of ancient engineering, but it recently suffered extensive damage from multiple air strikes by Saudi Arabian military actions in Yemen. G. Carvajal, "The Great Marib Dam, One of the Engineering Wonders of Antiquity," *LBV Magazine*, June 29, 2020; "UNESCO Director-General Condemns Airstrikes on Yemen's Cultural Heritage," UNESCO, June 2, 2015.

River below Lake Biwa, Japan's largest freshwater lake. Many dams built by the Roman Empire are still in operation, including the Proserpina and Cornalvo Dams near Merida, Spain, built between the late first and early second century AD. They were built originally as earthen dams but have been refurbished and reinforced with concrete in recent years, and both still provide local water supply. The Quatinah Barrage (or Lake Homs Dam) in Syria on the Orontes River was built for irrigation purposes around AD 284 by the Roman emperor Diocletian. At that time, it was almost certainly the largest dam ever built, extending two kilometers long with a concrete core buttressed by basalt blocks. A more modern and larger version was built between 1934 and 1938 and still supplies water for the city of Homs.

During the First Age of Water, the energy needed to move water long distances or pump it from wells could come from only three places: human muscle, animal power, or gravity. Yet the importance of water and the need for large quantities of it for growing cities and irrigated agriculture spurred technological innovation. By around 3000 BCE, irrigation canals had been dug throughout Mesopotamia to divert water from the Tigris or Euphrates River to nearby fields for agriculture. The shadoof—a rudimentary crane with a long pole and bucket and a counterweight—was invented, permitting a worker to efficiently lift water out of a river to an irrigation channel or village water supply (Figure 6). By 2000 BCE,

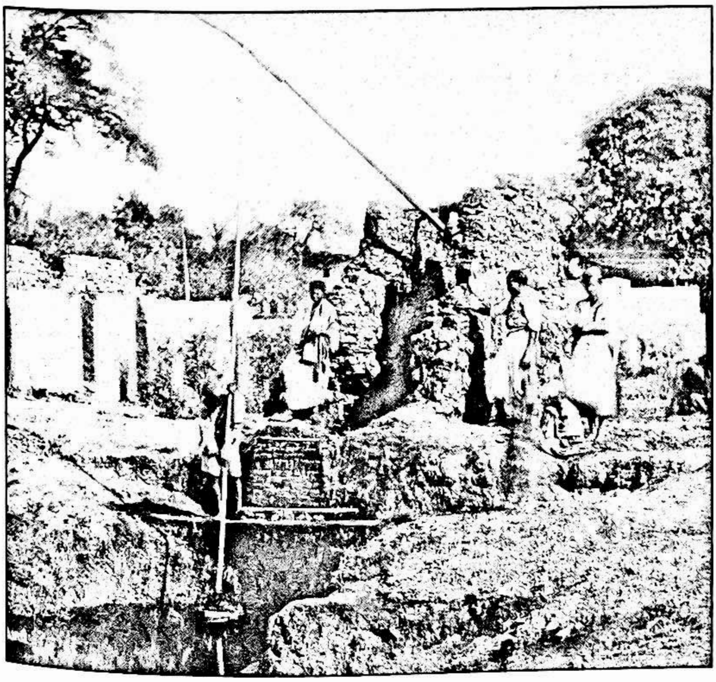

FIGURE 6. A shadoof, or water crane, North Africa: men are shown operating the water-raising machine. Photograph, 1870/1886? Public domain. https://wellcomecollection.org/works/s7dvjsfw.

the shadoof was in use in ancient Egypt, and versions have been seen in many other early cultures.

Archaeologists have also uncovered evidence that by around 700 BCE, mechanical screw pumps were being used, lifting water inside a cylinder. An Akkadian clay tablet recovered from the ruins of Nineveh describes in detail bronze machines in the form of a water screw for raising water to palace gardens. Archimedes (287–212 BCE) later described this technology—and its invention is sometimes mistakenly attributed to him—and similar devices are described in writings of the Greek author Strabo (ca. 64 BCE to AD 24) (Figure 7).[14]

Both the shadoof and the more efficient water screws still require huge amounts of human or animal energy to operate over long periods and, even so, deliver only modest amounts of water for gardens or personal use or for irrigating small agricultural fields. Far better for moving large quantities of water is to take advantage of gravity: find a water source uphill of your demand and engineer a gently sloping channel that brings water downhill to you. Such aqueducts required a great deal of planning and careful construction. Even today, when massive mechanical pumps powered by modern sources of energy are available to lift water over mountains, engineers design aqueducts to take as much advantage of gravity as possible. For these early cultures, there was no other option.

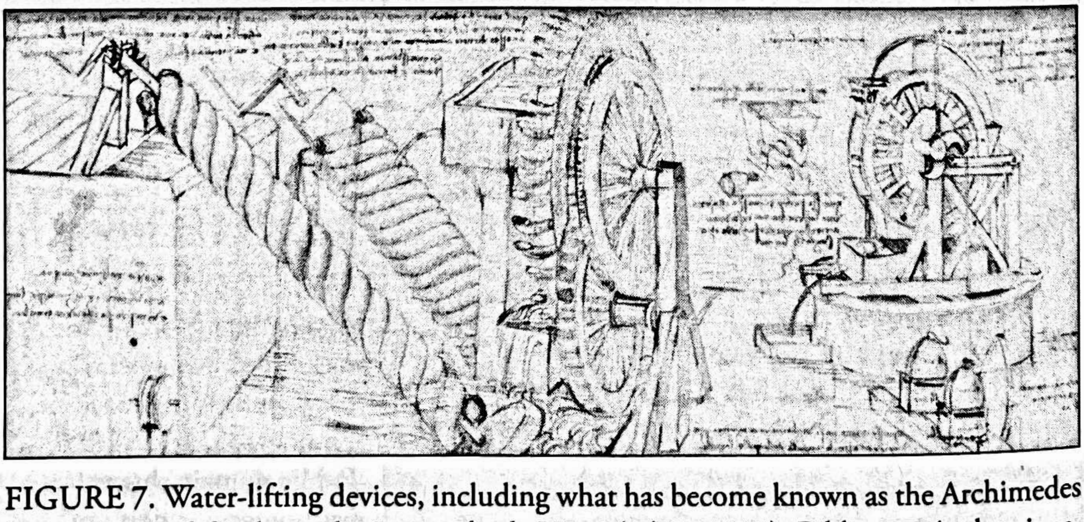

FIGURE 7. Water-lifting devices, including what has become known as the Archimedes Screw (*on the left*), drawn by Leonardo da Vinci (1452–1519). Biblioteca Ambrosiana, Milan, Italy, 1480. Atlantic Codex (Codex Atlanticus), f. 26 verso. Public domain.

Three to four thousand years ago, ancient builders began digging through rock and soil to create underground channels to bring water from mountain aquifers to the arid and semiarid villages of what are today Iran and the Arabian Peninsula. Over time, they dug thousands of these subsurface canals, called *qanats* in Iran and *karez* in Afghanistan and China, and even today qanats provide substantial amounts of water for some communities. A survey by the Iranian government in 2014 identified 37,000 active qanats delivering more than 10 percent of the country's groundwater supply.[15] Until the 1960s and the construction of the Karaj Dam and other water systems, Iran's capital city, Tehran, depended on an ancient qanat system bringing water more than twenty kilometers from the Elburz Mountains.

Qanats are gravity-fed underground stone pipelines or aqueducts. They are often kilometers long, with access points at regular intervals where local workers can remove sand, silt, and debris and ensure continued flow of water. Dating of the remains of an ancient qanat at Miam in northeastern Iran suggests that it could have been built 3,500 to 4,200 years ago (2200 to 1500 BCE), but the exact dates for the earliest construction of qanats are probably lost.[16] The Ghasabe qanat in Gonabad, northeastern Iran, was built between 700 and 500 BCE by the Achaemenid Empire, runs more than thirty-three kilometers, and still carries water today. Water for the cities of Hagmatana, established around 620 BCE, and Persepolis, founded in 520 BCE, was supplied by qanats.[17] Between 560 and 330 BCE, the Persian/Achaemenid Empire expanded to Egypt and as far away as India, introducing qanats to cultures far from the Middle East.[18]

The earliest written record of qanats comes from fragments of a cuneiform tablet describing the eighth military campaign of the Assyrian king Sargon II in Persia in 714 BCE. Sargon II ruled Assyria from around 722 BCE until his death in battle in 705 in a reign marked by endless military campaigns against the kingdoms of Carchemish and Urartu in the north and west, Babylon in the south, Samaria and the Kingdom of Israel in the south and west, and Persia in the east.* Translations of the

* Sargon II adopted the name of Sargon the Great, who founded the Akkadian Empire 1,700 years earlier.

tablet describing Sargon's Persian campaign show that he found surprising "secret" subterranean canals providing water to the city of Ulhu and destroyed them to force the city to surrender. "I blocked the outlet of the canal [qanat], the stream (which was) his reservoir, and turned the fresh waters into mud. . . . With the widespreading armies of Assyria I overwhelmed all of their cities, like locusts."[19]

The lessons Sargon learned about water supply were passed on to his son Sennacherib. Sennacherib ascended to the throne in 705 BCE and ruled until he died in 681 BCE, murdered by two of his own sons attempting to take the throne. Of all the ancient rulers of Mesopotamia, from the earliest Sumerians to the Assyrians, Babylonians, Persians, and all the later empires, Sennacherib was the most committed to building, expanding, and maintaining a complex hydraulic society. Details of his reign are described in the Old Testament and in tens of thousands of cuneiform tablets recovered from the ruins scattered throughout the region. He is known for his attack on Jerusalem and King Hezekiah, his capture and destruction of the city of Babylon in 689 BCE, and his construction and expansion of the city of Nineveh as the capital of Assyria on the eastern banks of the Tigris River. At the peak of his power, Sennacherib ruled over lands from southern Turkey to Egypt.

Throughout his empire, Sennacherib applied and expanded on the lessons learned from his father about water. Around 700 BCE his workers built a twenty-kilometer qanat to provide water to the city of Erbil from the Wadi Bastura.[20] He massively expanded Assyria's use of sophisticated canals and built mechanical hand-powered pumps, artificial wetlands, and, ultimately, the massive Jerwan Aqueduct project, part of a remarkable succession of water engineering projects that succeeded in transforming the long-neglected city of Nineveh into a garden that some argue may have been the model for, or even the actual location of, what has come to be known as the famous Hanging Gardens of Babylon.[21]

In April 1932, Thorkild Jacobsen, a renowned Danish historian and archaeologist and later professor of Assyriology at Harvard University, heard rumors of ancient ruins in the foothills of Iraq while working to excavate the remains of Sargon II's capital city, Dur-Sharrukin.* He set out to explore the site, known as Jerwan, north of the present-day city of Mosul, and realized the significance of the ruins after coming upon cuneiform inscriptions and evidence of a colossal structure long buried in silt and dirt.

Earlier archaeologists had noted ruins, cut stone, and inscriptions in the area. In the 1840s and 1850s, English archaeologist and historian Sir Austen Henry Layard, known for his work uncovering the ruins of Nineveh and Nimrud and discovering the Library of Ashurbanipal, visited the village and noted the remains of a "well-built raised causeway of stone." Other archaeologists passing through the area around the turn of the century noted evidence of what they thought was a roadway or bridge, but it was Jacobsen who literally and figuratively put all the pieces together. He realized that the ruins were the remains of a large water aqueduct more than a quarter of a kilometer in length and fifteen meters wide, built with millions of stones carefully cut and assembled with waterproof cement, designed to carry water from the mountains across the Khenis River gorge to the Atrush canal and then another fifty kilometers to the Khosr River and Sennacherib's capital, Nineveh. This aqueduct, dated from around 700 BCE, is now considered to be the oldest known, predating Roman aqueducts by five centuries.

Jacobsen translated inscriptions found at the site, including one carved into the foundation of the aqueduct that reads: "Sennacherib king of the world, king of Assyria. Over a great distance I had a watercourse directed to the environs of Nineveh, joining together the waters. . . . Over steep-sided valleys I spanned an aqueduct of white limestone blocks, I made those waters flow over it."[22]

The Jerwan Aqueduct was one piece of a larger set of hydraulic systems that Sennacherib built in his lifetime. After expanding the canal system to provide water for his new capital of Nineveh, he developed flood-protection systems in the form of wetlands and marshes to absorb high winter flows and irrigation systems to provide water in the summers

* Dur-Sharrukin is the present-day city of Khorsabad, Iraq.

for the agricultural fields of his expanding empire. As was true of kings and emperors throughout Mesopotamian history, he was not shy about boasting about his accomplishments, carving them into stone and baking them into clay tablets that today provide a historical record.

> I saw streams and enlarged their narrow sources and turned them into rivers. To give these waters a course through the steep mountains I cut through the difficult places with pickaxes and directed their outflow on to the plains of Nineveh. I strengthened their channels, heaping up (their banks) mountain high, and secured those waters within them. . . . I added them to the Khosr's waters forever. I had all of the orchards watered in the hot season. In winter, a thousand fields of alluvium above and below the city I had them water every year. To arrest the flow of these waters, I made a swamp and set out a canebrake within it.

Sennacherib continued to build water systems throughout his reign. In tablets recovered from the ruins of Nineveh dated between 694 and 690 BCE, he boasted,

> I greatly enlarged the site of Nineveh. Its wall and outer wall thereof, which had not existed before, I built anew and raised mountain high. Its fields, which through lack of water had fallen into neglect and . . . while its people, ignorant of artificial irrigation, turned their eyes heavenward for showers of rain—those fields I watered. . . . Eighteen canals I dug and directed their course into the Khosr River. From the border of the town of Kisiri to the midst of Nineveh I dug a canal . . . Sennacherib's Channel I called its name. . . . I, Sennacherib, king of Assyria, first among all princes, who marched safely from the rising sun to the setting sun, by means of the waters from the canals which I had caused to be dug . . . I irrigated annually to cultivate grain and sesame.[23]

Ironically, and perhaps unintentionally, Sennacherib inspired another major early feat of water engineering. The first known water tunnel dug from two ends simultaneously was carved from the rocks during the reign of King Hezekiah of Judah beneath the City of David in Jerusalem to protect the city's water source from an impending siege by Sennacherib and to deny water to the besieging Assyrian armies.[24] This underground aqueduct—now known as Hezekiah's Tunnel—runs a half kilometer and diverts the waters from the Gihon spring to the Pool of Siloam within Jerusalem's ancient walls. This tunnel corresponds to the waterworks mentioned in the Old Testament: "And the rest of the events of Hezekiah and all his mighty deeds, and how he made the conduit and the pool, and he brought the water into the city, they are written in the book of the chronicles of the kings of Judah" (2 Kings 20:20).[25]

By the time of his death, Sennacherib had built more than 150 kilometers of canals and channels, together with tunnels, dams, reservoirs, and extensive gardens, permitting irrigation of lands well beyond the borders of Nineveh.[26]

Thus began the era of large-scale water engineering, with succeeding empires learning from and advancing the practice of moving, storing, and manipulating the hydrologic cycle. The Romans improved and expanded on these concepts, building extensive and complex water networks across the vast territories they controlled to bring fresh water to Roman cities. As water flowed into Roman cities, it was used for drinking and irrigation and to supply hundreds of public fountains and baths, many of which still function today. Early Rome alone had eleven aqueduct systems supplying fresh water from sources as far as 92 kilometers away supporting what might have been a million people. The Aqua Virgo, an aqueduct constructed by Agrippa in 19 BCE during Augustus's reign, still supplies water to Rome's famous Trevi Fountain in the heart of the city.

The most recognizable feature of Roman aqueducts may be those modeled after the Jerwan Aqueduct, the bridges constructed using rounded stone arches, carrying water in channels at the top, crossing rivers and valleys along the hundreds of kilometers of aqueducts throughout the empire. In 2018 my wife and I explored the massive Pont du Gard, a remarkably well-preserved ancient Roman aqueduct bridge built in the first century AD across the Gardon River in southern France (Figure 8), and evidence of Roman aqueducts built between 310 BCE and AD 225 can still be found in France, Spain, Greece, North Africa, the United Kingdom, and Turkey. The engineering and construction skills needed to

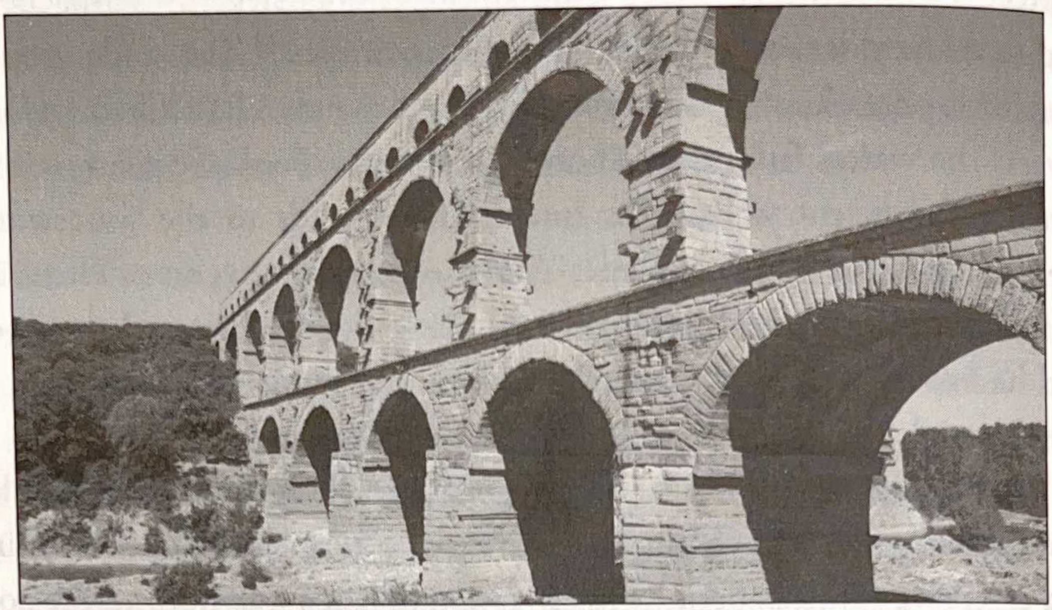

FIGURE 8. The Pont du Gard, built in the first century AD across the Gardon River in southern France. Water was carried in the aqueduct at the top of the bridge. Photo by Peter Gleick, 2018.

build and maintain these structures presaged the advances that occurred worldwide in the Second Age of Water.

The ability to manipulate and control water resources was recognized by even the earliest empires as crucial for political and economic power, as the efforts of Sargon the Great, Hammurabi, and Sennacherib attest. In the early twentieth century, Gertrude Bell,* a tremendously influential British political adviser, historian, and part-time archaeologist in the Middle East, said of Iraq that "he who holds the irrigation canals, holds the country."[27] It should therefore be no surprise that the First Age of Water also brought violent conflict directly associated with the control of vital water resources—the first water war, 4,500 years ago.

* When Bell died, King Faisal of Iraq wrote, "Gertrude Bell is a name that is written indelibly on Arab history—a name which is spoken with awe. . . . One might say she was the greatest woman of her time." K. E. Meyer and S. B. Brysac, *Kingmakers: The Invention of the Modern Middle East* (New York: W. W. Norton, 2008). Werner Herzog's movie *Queen of the Desert* (starring Nicole Kidman as Bell) chronicles her life.