WATER TRANSPORT

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Summary
This paper and the articles that follow present both a general discussion of the subject, water transport, and some of the details of the various facilities required to accomplish that goal. The brief history given in this paper provides a perspective of water transport as practiced by the ancients from the dawn of civilization and changed but little until the industrial revolution made iron available in great quantity for pipe and machinery. The knowledge of the agents that cause disease, the means to eliminate those agents in public water supplies, the pumps and piping to bring fresh, pure water to every household, to carry wastewater away from every household, and the facilities to protect the environment from domestic and industrial wastes were all discovered or developed in the explosive half-century centered around 1885.

Canals are much the same today as in ancient Sumeria. Tunnels are now bored hundreds of times faster than in the days of the Caesars. Pipe, once made only of lead, clay, or bored logs, is now made from cast iron, steel, reinforced concrete, and plastic in
diameters from a few millimeters to several meters. Moreover, they now supply the humblest citizen whereas in olden times only the kings or the very wealthy could afford piped water.

Where our forebears were limited to water lifters, we now have a wide variety of pumps to suit every purpose from pumping from a well 300 m deep to pumping to a water tower 30 m high, or to pump wastewater to a treatment plant many kilometers distant. (There are even pumps that develop so much pressure that the water jet cuts thick steel.) Before the 18th century, water measurement was unknown, but now most households have water meters used for assessing cost, and there are accurate meters for every flow rate and size of conduit.

Beyond cisterns for storing rain or low dams for storing spring runoff, the ancients would probably have thought little about saving water. Today, there is a thriving effort to conserve precipitation and to reclaim wastewater for industrial purposes such as cooling towers, irrigating park lands, and even for direct reuse.

1. Introduction

Of all of the life support systems that exist, an adequate supply of safe, potable water and the safe collection, treatment, and return of wastes to the environment is the most—or certainly among the most—important to the well-being of a community. The transportation of water and wastes is an important aspect of keeping water supplies safe as well as sequestering wastes until treatment. Many kinds of facilities are required for water (and wastewater) transport. The objective in this topic is to provide a general overview of water transport systems with examples and limited references to some of the most appropriate literature.

Before the 1900s, a large percentage of the population was periodically devastated by salmonellosis, typhoid, and cholera. Scarcely a family existed that did not experience a death from a waterborne disease. More recently, E-coli outbreaks have occurred in California, Ontario, and Michigan. In modern times, carcinogens have appeared in some water supplies. Treatment of water, first by filtration, later by disinfection, and still later by sorption on activated carbon as well as other site-specific processes has, however, virtually eliminated water as a source of disease. The treatment of wastes and their safe return to rivers, lakes, and—to some degree oceans—has provided the planet with a healthy environment everywhere such practices are maintained.

2. A Glimpse into History

Our hunter-gatherer forbears had no need for water works. They simply camped beside their source of water. For most of our existence on earth, water has been delivered to the point of use in jars or bags of animal skins—a practice still followed by some peoples. As population increased, however, and people settled into communities, the need for public supplies and irrigation drove the inhabitants to construct canals, pipelines, and even dams and tunnels. Some of these works are surprisingly ancient.

2.1. Eastern Mediterranean
Minoan technologies (3000 to 1000 B.C.) were so advanced in construction and operation of water and wastewater facilities in Crete as to compare with Europe and North America in the 1850's. Water was transported in sophisticated hydraulic systems over long distances to cities and palaces equipped with bathrooms, bathubts, flush toilets, and carefully planned and executed sewer projects. The sewers were made of stone blocks and lined with cement. Toilet seats were carved in stone. The villa of Hagia Triadha, near the south coast of Crete, has an advanced system of sewers still functioning perfectly 4000 years after construction. Evidently, the Minoans were superb artisans, energetic, prosperous, and innovative. How many of the works built today will still be functioning in 4000 years? Minoan technologies were exported to Greece as early as the Mycenaean period (2800 to1100 B.C.)

One of the oldest works (ca 2800 B.C.) was the pipelines in ancient Sumeria, the stone collars of which still exist. Egyptians built the first known dam of masonry 15 m (meters) high on the Nile River to supply water to the capitol at Memphis in 2900 B.C. Assyrians, Babylonians and Persians built dams from 700 to 250 B.C. for public water supply and irrigation. Many earthen dams were built in the 5th century B.C. in Ceylon. A large stone crib dam, constructed about 240 B.C. in China, was 30 m high and 300 m long.

The great Assyrian aqueduct, built under Sennacherib about 690 B.C., brought water from the Greater Zab River to the ancient city of Nineveh in northern Iraq, 80 km (kilometers) distant. A limestone bridge 300 m long and 10 m high carried a canal 15 m wide over a stream and valley to supply both domestic and irrigation water. More than two million heavy blocks of limestone were used in the bridge.

2.2. Rome

The aqueducts of Rome are especially remarkable. For over 400 years after the founding of Rome, water from the Tiber River supplied the city. The first aqueduct was built in 312 B.C. Two were begun in Caligula's reign and finished in Claudius' reign. By the time Frontinus became water commissioner of Rome in 97 A.D., there were eight main aqueducts bringing waters of high quality from springs and rivers to the fastidious Romans. Another aqueduct from a lake brought unpalatable water. These aqueducts were partly below ground (with some tunneling), partly on substructures, and partly on arches. Lead pipes delivered water to the public and to the wealthy. The Romans even constructed some inverted siphons (a pressure pipe dipping into a swale or valley and discharging at nearly the same elevation as the entrance) made of lead pipe several cm (centimeters) thick. Greeks, however, probably invented the siphon. A large Greek siphon was constructed at Pergamon about 180 B.C.

The Romans used a practical method for determining whether a potential water source was safe. If the nearby inhabitants who used the water stayed healthy, the Romans appropriated it.

Romans also built aqueducts in many other places. One of the most spectacular leaps the Gard River near Nimes, France in three graceful tiers of carefully fitted cut stone arches without joint mortar. The total length of the arched structure is nearly 275 m and the
entire aqueduct was 48 km long. Another, built in 100 to 110 A.D., consists of two tiers of arches with a maximum height of 36 m and a length of 823 m. It still supplies water to Segovia, Spain.

Many ancient cities relied on water supplied by rainwater from roofs and stored in cisterns. Fortresses like Megiddo, Israel, are one example. Constantinople with huge cisterns under the city is another.

### 2.3. London

The oldest water supply system (with a well-known history of progress) in Europe is that for London. The remains of three giant water-lifting systems dated in the first century were found near the heart of Londinium, the Roman name for London. They could have raised 140 cubic meters per day by using a chain to pull buckets up from a deep well. Romans imported a culture of bathhouses and high standards for clean water, and probably local waters, including the Thames, were so polluted that the water-lifting systems were an important source of fresh water.

Work commenced in 1235 on a water system about 5.5 km long from a lead-lined cistern to London was finished 50 years later. A 150 mm lead pipe system from Tybourne (a brook) was begun in 1236. Other sources from brooks and springs were introduced from time to time. There were, however, no pipes to individual houses. House supply was water in buckets carried by porters, until in 1582 water was conveyed in lead pipes from a "forcier" at London Bridge. The "forcier" consisted of a water wheel about six meters in diameter supplying power to 16 pumps made of pistons 175 mm diameter in cylinders nearly 1.5 m long. The whole machine was mounted between piers of the bridge on a wooden frame that rose and fell with the tide. At low tide, the water flowing past the water wheel was swift, and the pumps could force a stream of water over a church steeple. Eventually, there were three such machines operated by the family of the builder until 1701.

Over the objections and interferences of the land owners, a canal called the New River 5.5 m wide was begun in 1609 from Chadwell Spring to London, a straight line distance of about 30 km but a winding route of 60 km. King James I furnished some funds for completion in return for half the profits. (Later, the king's horse threw him into the New River and he nearly drowned.) The water level of the full reservoir at the end of New River was 25 m above high water in the Thames, so water could be delivered to cisterns in lower stories by gravity. As demand for water in upper stories increased, a 45-kilowatt steam engine was purchased in 1787 to provide a high-pressure supply. Wooden pipe mains were used until 1810, when wood began to be replaced with iron that could withstand 90 m of water pressure—a great convenience.

Water from the Thames was so turbid that a filter plant was installed in 1829. It consisted of ponds to allow coarse sediment to settle followed by a filter consisting of rows of parallel channels covered with bricks, then gravel, then coarse sand to form a bed for fine sand. Each of the three layers was 0.6 m thick, so the water had to pass downward through 3.6 m of sand and gravel to reach the drainage channels. When the sediment on the fine sand became too dense to allow satisfactory percolation, the top
was scraped off and fresh sand added. The filter was so successful that laws were passed in 1855 compelling filtration of all river water used in London. Another fifteen years were to pass before the beneficial action of bacteria and other microorganisms in the filter beds would be understood.

A major contribution to the conservation of water was the flush toilet perfected by Thomas Crapper by 1884. From Minoan times until about 1880, wastes were flushed away by lifting a plug in the water supply. In London, the plugs leaked and some users were too lazy to reinsert the plug. The useless waste of water appalled the Board of Trade which sought means to conserve it. With Crapper's Valveless Water Waste Preventer, leakage was prevented by breaking the siphon action in the storage tank.

3. Tunneling

For our purpose herein, tunneling is the drilling or excavation of a nearly horizontal aqueduct through a hill or mountain to avoid a route over or around the obstruction. Tunneling used to be an inordinately slow process. Although Chinese made black powder by 80 A.D., it was for many centuries unknown to Mediterranean people who either chiseled their way through rock or heated the face of the tunnel and flaked the rock with cold water. Tunnels were dug from both sides of a mountain, sometimes scarcely meeting. At one project, the tunnels passed each other in four years of digging. (The hydraulic engineer, who had been absent during this time, solved the problem by a survey for a short connecting tunnel. One of the best-known tunnel aqueducts was built under King Hezekiah about 700 B.C. to bring water to Jerusalem through solid rock. The tunnel was two m high by 530 m long.

Tunneling in rock became easier and faster with the advent of black powder first used in Europe for the Midi canal in France in the 17th century. Nobel's discovery of dynamite in 1866 revolutionized rock excavation. Tunnel progress in hard rock increased from less than a meter per week in the 17th century, to 30 m at the end of the 19th century, and to 250 m per week with full-face boring machines. Tunneling has become so effective that many large cities with no surface space for storm water storage are building tunnels 30 m below ground level for storing the peaks of storm water runoff.

Bibliography


Biographical Sketch

Robert L. Sanks, Consulting Engineer
Education: BS/1940/Civil Engineering
MS/1949/Structural Engineering
PhD/1965/Sanitary Engineering
Registration: 1966. Professional Engineer, Montana 2704PE. Previously registered in California, Utah.

Relevant Experience and Qualifications:

Environmental

Innovations
Invention of ramp in trench-type wet wells to make cleaning easy and quick. Introduced trench-type wet wells to Hydraulic Institute and to the profession. Research to improve performance in normal operations. 1990-present.

Responsible for the first use of these technologies in Montana: (1) Land disposal of sewage (by spray irrigation at Rocky Boy), (2) direct filtration (of Yellowstone river water for Colstrip), (3) secondary sewage treatment by biodisc (at Livingston), (4) use of onsite pilot plant tests for design of sewage treatment (at Livingston), (5) use of onsite pilot plant tests for design of water treatment facilities (at Colstrip)—all successful projects. (For several years, the Livingston plant produced the most highly treated wastewater in Montana.) 1970-1981
Pumping stations


PUBLICATIONS


HONORS AND AWARDS