Collection Systems Past and Present

A Historical Perspective of Design, Operation, and Maintenance

Were the skills of ancient sanitary engineers woefully inadequate by today's standards? Don't count on it. Many writings and projects completed by ancient engineers remain intact today, and they may challenge us to question the real nature of scientific progress. Vitruvius, an engineer who designed military works for the Roman government, wrote about water supply engineering sometime around 25 B.C.

Sanitary engineering didn't begin with the Roman Empire, however. Explorations have revealed arched sewers in Nineveh and Babylon dating from the seventh century B.C. In certain civilizations circa 2500 B.C., drainage and sewer systems commonly ran from individual homes. It can be argued, in fact, that sanitary engineering declined from this point until the mid-1800s.

The Romans built aqueduct and sewer systems on a grand scale, but there were few house connections. Rome's famous Cloaca Maxima (or main drain) was primarily a conduit for removal of stormwater and underground water. There was little recognition of public health needs, and compulsory sanitation would have been considered an invasion of individual rights.

As civilization progressed through the Middle Ages and into the renaissance period, it could hardly be described as having benefited from sanitation practice. In fact, the lack of effective sanitation directly contributed to enormous suffering through the Black Death, Bubonic Plague, and other afflictions. In most respects, sanitation practice went backward.

Not until the mid-1800s did science and engineering practices emerge to meet public health needs and modern practices in wastewater conveyance and management begin to take hold. But the jury is still out on the systems that modern society has developed. Today's utility managers can only dream of developing, maintaining, and operating systems that compare in longevity to those systems built in ancient times, many of which are still in service.

Ancient Sanitary Systems: 3400 to 1200 B.C.

The Indus civilization of circa 2550 B.C. and the Aegean civilization of circa 3400 to 1200 B.C. are prime examples of how early enlightened people handled municipal sewerage needs.

The Indus people (located in mod-
Since the 1800s, several epidemics had taken their toll on U.S. cities. As a result, they began constructing sewer works, such as this brick arch that conveyed sanitary sewage and sometimes storm water over brooks, streams, and treatment works.
ern-day Pakistan) had well-built houses and baths, with burned brick drainage systems. At the Mohenjodaro site, about 130 miles north of modern Hyderabad, practically every house had a bathroom. The bathroom was always placed on the street side of the building for convenient wastewater disposal into the street drains. Latrines in houses were placed on the street wall for the same reason. Washing places were adjacent to the latrines, thus conforming to modern sanitary standards. Baths and latrines located on upper floors were usually drained by vertical pipes, with closely fitted spigot joints, set in the building wall. These pipes, still sound after 5000 years, are the precursor to clay spigot-and-socket sewer pipe, and a testament to the material’s durability.

Bath, kitchen, and latrine waters, as well as stormwater runoff from the roof, entered the street through pipes that drained to brick-lined pits, which had outlets to street drains about three-fourths the distance above the bottom of the pits. These pits were cleaned occasionally, as were the settling basins or soakage pits located along the street drains. These pits may be regarded as the precursors of septic tanks and grit chambers. Their maintenance presumably implies the need for the first sanitation maintenance workers.

Each street had one or two drainage channels, with brick and stone covers that could be lifted to remove obstructions. The drains were set 18 to 24 in. below the street level, and varied from 12-in. deep and 9-in. wide to 24-in. deep and 18-in. wide. Many houses had individual wells located, in most cases, adequate distances from the drains to prevent water supply contamination.

**Minoan Civilization: 3000 to 1000 B.C.**

While the Mohenjo-daro ruins present a picture of personal and community cleanliness, other early civilizations reached similar heights. The Minoan civilization, which flourished around the Aegean Sea about 3000 to 1000 B.C., developed a considerable knowledge of hydraulics, as demonstrated by the Palace of Minos, near Knossus on Crete.

The Minoans built fountains, so they knew how to transport water in pipes under pressure. Drinking water was obtained in part from wells, many of which had hard liners. Their bathtubs were remarkably similar to modern ones.

From 1900 to 1700 B.C., they constructed elaborate and well-built stone drain systems. These systems carried wastewater, roof water, and general drainage a considerable distance beyond the palace.

Each section of the palace had a subsidiary drainage system connected to the main drain. These systems had vertical shafts that acted both as roof drains and ventilation ducts. Such...
sanitary arrangements seem to have been part of all Cretan building.

Latreines within the palace were directly connected to vertical chutes or horizontal drains and flushed by emptying a large jar of water into the latrine. The seat was the edge of a wood plank, set vertically into recessed slots in the side walls.

Considered as a whole, these sites represent a people who lived comfortably and hygienically years ago.

**Clay Pipes**

Excavations have unearthed clay objects that trace humankind’s advancements in arts and crafts, and chronicle its constant struggle to improve living conditions. One important step in this progress was the manufacturing of clay pipe for drainage.

More than 3000 years ago, city builders were using clay bricks to line subsurface drains. In ancient Babylon, the first cylindrical clay pipe was fashioned with the help of a potter’s wheel. Though primarily used for drainage, some of this pipe was used in house sewers as well. At the palace near Knossus, stone shafts, ducts, and clay pipe led stormwater to drains in the outer wall. Each pipe was tapered to fit into the next with a collar joint.

Early Roman engineers made extensive use of clay. Clay pipe was used as part of the radiant heating system in the Baths of Caracalla. The baths and rooms of this Roman structure were warmed by hot air that passed through socket-jointed, 12-inch diameter clay pipe flues. All four walls of the room were lined with these flues when exceptional heat was required.

**The Romans**

Among the great works of the Roman Empire still standing is the water supply system. References are often made to the design and operation of this highly developed system, and the Romans’ design and maintenance practices are recognized today.

Ancient water supply and distribution systems also included reservoirs, clarifiers, and settling basins. Vitruvius specified arched covers for open channels to shield the water from direct sunlight and prevent algae growth. Design standards for the aqueducts included tunnels and buried pipes for traversing valleys and hills.

Venting specifications were similar to today’s standards. The Romans relied on gravity flow, and indicated requirements for adequate vents and vacuum breakers to ensure that the line could be filled. Water flowed without pumps or other mechanical systems, and this imposed restrictions on elevations and on distances water could be moved. Without chlorination facilities to prevent the water from becoming septic, it was especially important to keep it moving.

By spacing reservoirs every few miles along a pipeline, the Romans avoided draining the entire system to make repairs. They also had design standards for reinforced pipe elbows with thrust blocks of stone—a practice that is used in modified form today.

As developed as the water supply system was, the wastewater systems of the Roman Empire were much less sophisticated, though still remarkable, achievements. Notably, the Roman goddess of beauty and health also bore the name Venus Cloacina, or Venus of the Sewers. The base of her statue stills stands in the Roman forum. The Romans appreciated the significance of systems that conveyed wastewater from population centers.

Although the great underground drains of Rome have been described many times, it is worth noting that these channels and conduits generally
nural irrigation outside Rome. This pilfering would occasionally leave insufficient water for cleaning the streets.

Even without water thievery, engineering safe and reliable water supply and disposal in ancient times required solutions to many of the same challenges engineers face today. Maintaining pressure, venting the piping systems, preventing water hammer, and eliminating leaks have been concerns common to both eras.

**Medieval Times**

When the Roman Empire fell, engineering and construction seem to have died with the ancient city. A virtual stoppage of sanitation advancement followed. In Berlin, refuse heaps piled up in front of St. Peter's Church until a 1671 law required every peasant who came to town to remove a load of filth when returning home.

The few records available on the use of clay pipe during the Dark Ages reveal that it was used mostly for drainage in and around the castles of local nobility and large landowners.

It was apparently common to construct such buildings with masonry cesspools below the living quarters. In 1183, during a meeting called by the emperor of the Holy Roman Empire, the floor of the main hall broke. The lords and knights fell into the cesspool below, where many perished. The emperor himself barely escaped death. The corrosive atmosphere of the cesspool had apparently deteriorated the floor.

Obviously, concern for maintenance had not yet developed; neither had concerns for hygiene, and catastrophic plagues took their place in history. Gross violations of sanitation affected even the highest classes. On August 8, 1606, an order prohibited any resident of the Palace of Saint Germain from indiscriminately “committing a nuisance” in the palace.

**Birth of Modern Systems**

In the mid-1800s, Louis Pasteur revealed conclusive proof that diseases are caused by germs. The importance of sanitation took on new life. Sanitary engineering entered a new age, and cities gradually undertook extensive sewer construction projects.

Modern sewerage practice was initiated in Hamburg, Germany, in 1843 and in London in 1847, when an act made it compulsory to connect houses with sewers. Even then, London simply removed its excrement from in and about its houses and transferred the entire mess to the Thames River. Nothing was done about it until 1855, when a cholera epidemic prompted passage of the Nuisance Removal Act, prohibiting gross river pollution.

Progress was slow, however, and London suffered two more cholera epidemics in 1866 and 1872. England

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The Mill Creek Sewer in St. Louis was designed to alleviate frequent flooding that occurred along Mill Creek. After construction in 1864, several rain events resulted in flooding, although the sewer had performed adequately at its design storm capacity of 1 in./hr. New segments were constructed in 1915.
was no slower or less intelligent, however, than the inhabitants of other European countries. Similar conditions could be described throughout Europe and America.

Another example of the slow progress of sanitary engineering rests in Sir John Harrington's flush toilet, invented in 1596. It was not generally used until almost 300 years later, when Thomas Crapper "perfected the flusher" with his "valveless water waste preventer."

Today's sanitary engineering practices developed firm roots in the mid-1800s. Glimpses of system maintenance practices began to emerge in the writings of the day's engineers.

In 1832, Paris suffered the ravages of cholera, and authorities began to recognize the relationship between public health and the city's unsanitary conditions. New sewers built in Paris were designed and constructed with some recognition of maintenance needs. Sewers were built 6 or more feet deep whenever possible with the belief that workers would carry out their cleaning duties more efficiently if they could work without having to take unnatural positions. As noble as this might seem, it must also be recognized that these same sewers were used to route water mains, telegraph lines, pneumatic mail tubes, and gas mains, all of which required space for access and maintenance. These sewers also conveyed street refuse, not just wastewater and stormwater.

Cleaning the Paris sewer was accomplished using "bateaux vannes," or wagon vanes. These were cars or boats with wings reaching nearly to the sewer walls. The wings would partially dam the sewage, which would flow past the wings at a higher velocity than the ordinary current, scouring debris in the sewer and washing it downstream ahead of the cleaning device.

In England and the U.S. (which tended to follow English principle in the design of sanitary sewer systems), great uncertainty existed over design standards that are accepted without question today. In the nineteenth century, sewers were often laid at flat grade and occasionally at reverse slope. The relationship between size and velocity was not necessarily recognized, which contributed to the need for regular system maintenance to control odors. Large-diameter sewers often discharged to sewers of smaller diameter. Despite the uncertainties of the fledgling sanitary engineering practice, public health emergencies forced the development of sewer systems.

In 1879, Baltimore, Md., had 80,000 cesspools in use. Many had overflow pipes discharging into storm sewers, despite laws banning the practice. The City Health Commission reported that of 71 samples of pump and spring water taken in the city, 33 were filthy, 10 were bad, and 22 were suspicious—only 6 were good.

While Baltimore was the last major U.S. city to ban the use of cesspools, Boston, Mass., was the first to undertake construction of an intercepting sewerage system, an action authorized in 1876.

In 1873, a yellow fever epidemic in Memphis, Tenn., claimed 2000 lives. Five years later, another 5150 people died in the same city of the same cause. In 1880, construction of

Collection system construction in the 1940s and 50s was aided not only by more current construction techniques, but also by safety precautions such as hardhats and trench boxes.
a separate wastewater sewer system began, heralding the large-scale introduction of the concept of separate sewers to the U.S.

Separate Sanitary Sewers

The first application of a sewer system to remove house wastewater separately is not known. The principle was strongly advocated as early as 1842 by Edwin Chadwick, called the "father of sanitation" in England. Because of his imagination and tendency to not be constrained by technical knowledge, Chadwick was publicly branded a charlatan. His principles were later refined by, among other engineers, Sir Robert Rowlinson, whose "Suggestions as to Plans for Main Sewerage, Drainage, and Water Supply" was published by the local government board. This treatise contributed to the design of properly sized and aligned sewers, with adequate facilities for cleaning and maintenance.

Unfortunately, Colonel George Waring designed the Memphis system without regard to English experience with separate systems. The design of the Memphis system primarily used 6-in. lateral sewers, with a 112-gal flush tank at the head of each that discharged once every 24 hours. No manholes were provided initially, and the manholes provided for inspection failed because of the weight of the vertical risers crushing the small-diameter pipe. Ultimately, Waring's system was recognized as a failure in design. The Rowlinson type of separate system, with larger pipe laid without vertical or horizontal bends between successive manholes, became the norm.

Maintenance Practices

Much of the existing literature, ancient and otherwise, offers little information regarding collection systems maintenance practices. Only occasional and vague reference is made to the maintenance worker. In sixteenth-century Denmark, the cleaning of latrines was the job of the hangman. Other references indicate that system maintenance most often fell to the peasant class. While the apparent disdain for system maintenance is archaic by today's standards, it helps to remember that today's systems have yet to stand in service for 2500 years with little or no maintenance. One must wonder whether future engineers will be able to point to such achievements from the present era.

By 1938, maintenance of sanitary sewers had become a topic of recognized publications, as evidenced by M.W. Loving's "Concrete Pipe in American Sewerage Practice," published by the American Concrete Pipe Association. In this bulletin, reference is made to the April 1938 issue of Water Works and Sewage, in which George E. Finch, then engineer for the Bureau of Sewers in Baltimore, and A.M. Rawn, assistant chief engineer for the Los Angeles County Sanitation District, present insights to then-modern maintenance practices.

According to the article, Baltimore had a staff with clearly defined maintenance duties scheduled, including record-keeping requirements. Rawn noted that the crew used beach balls to clean debris and sand from newly constructed lines. Great detail is provided regarding the merits of the common beach ball and how to properly modify it for use in cleaning sewers. For pipe larger than 30 inches in diameter, the use of a "sewer hoe" is recommended. Clearly, this 1938 publication recognized the importance of maintenance as coequal to good design.

Evolving Sanitation

Engineers can take considerable pride in sanitary engineering achievements of the last 150 years. They have finally caught—and perhaps even surpassed—the Indus' standards of 2500 B.C. Let's hope that in this enlightened age, our utility systems experience the necessary combination of planning, design, construction, operation, and maintenance to place them among those great works recognized as having served humankind well throughout the years.

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