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Flowing Through Time: A Brief History of Water Distribution Systems and their Influence on Development

Susan M. Limberg
Civil Engineering Department
Norwich University
Northfield, VT 05663 USA

Faculty Advisor: Tara Kulkarni

Abstract

In recent times water has taken up its place in the "sustainability spotlight" right alongside energy and rightly so. The World Health Organization (WHO) declared 2008 to be the International Year of Sanitation. The United Nations' Millennium Development Goal on Environmental Sustainability aims to halve by 2015 the proportion of population without sustainable access to safe drinking water and basic sanitation. The need for sufficient quantities of good quality water is at the heart of any progressive civilization and an engineer must ensure that the system is designed to treat, transport, and distribute water that is sustainable, accessible and affordable to all of the world's population. In this research an investigation was conducted on how water systems have evolved through the years by using three time periods starting in Ancient Rome, around 312 B.C., the 1800's, and present-day as the bases for comparison. Special attention was paid to aqueducts that have been used as a way to transport safe water to cities and villages for centuries. Peer reviewed and published literature from the era of Julius Sextus Frontinus, who in his reign as the Water Commissioner of Rome oversaw the construction of nine aqueducts to the present day 226 mile aqueduct systems of Los Angeles and the 336 mile Central Arizona Aqueduct project have been studied in great depth.

Keywords: Water, History, Development

"Water ... worth more than gold and more crucial for survival above all other resources on earth."
--- globalwater.org

1. Body of Paper

The common knowledge that the human body is composed of 80% water leads to the unsurprising conception that water is the most crucial resource to human existence. People should not be surprised that we need water in our bodies to function, water to drink, water to bathe, and water for crops and irrigation. Similarly, people should not be surprised that even though water is a survival necessity, millions right now do not have clean, efficient water systems for their daily needs. What is a water system? According to the United States Environmental Protection Agency (EPA), "Water distribution systems are large networks of storage tanks, valves, pumps, and pipes that transport finished water to consumers. Finished water is that which has gone through all the processes in a water treatment plant and is ready for delivery [4]." My research is based on the three eras of approximately 312 B.C. in Ancient Rome, the 1800's, and the present, subsequently finding what the most contemporary fluid system strategy was for the period.

The Early Romans are recognized as one of the first and most advanced people to engineer effective water systems. After their initial sources such as the Tiber River, local springs, and shallow wells became polluted and unable to support a growing population, the city turned to new technology famously known as the aqueduct. This water system is credited to Julius Sextus Frontinus, who in his reign as the Water Commissioner of Rome oversaw the construction of nine aqueducts that carried water from outlying sources such as fresh springs and streams into the city. During Frontinus's era, the aqueducts were solely gravity based which allowed for a gentle, steady flow.[8]

The popular but inaccurate image is that Roman aqueducts were elevated throughout their entire length creating miles of intricate arches. In truth, there were five main types of aqueducts that serviced Rome at this time. The first type was used when the natural slope of the land allowed for the water to flow into the cities. Roman engineers were very practical; whenever possible the aqueducts followed a steady downhill course at or below ground level [19]. Under this circumstance, covered trenches were built to prevent the water from being contaminated by dust, dirt, and other impurities as well as being heated by the sun. This type of aqueduct accounted for four out of every five miles of aqueducts built in Rome [17]. The second type of aqueduct was used when an obstacle, such as a mountain, was in the direct path of the desired flow. In this case, tunnels were made through the mountain. Shafts were also dug into the mountain to enable more workers to carve the tunnel at any one time and also to allow for cleaning of the tunnels later on. If the aqueduct was to go through a valley, watertight, pressurized, lead pipes were utilized to trail the water down one side of the valley where it would then be pushed up the other side due to the pressure from the downward sloping pipe. If the aqueduct needed to be elevated up to five feet, a wall was built for the water to travel across. Only under the circumstances that the aqueduct should need to be raised even higher, the most famous of the structures was built: the arcade. This is the aqueduct that creates a highly elevated bridge for the water to flow across by use of beautiful architectural pergolas.

Once in or near Rome, water from the aqueducts flowed into large, covered catch-basins. According to design, this was where the water was intended to deposit sediment. The water was then distributed by free-flowing canals and man-made pipes to storage reservoirs and into the community. The number of splits to private homes and businesses was limited; most Romans attained their supply of water for domestic use from the public fountains. Water was thought to have only been piped to private dwellings of those propitious enough to have official authorization. However, the technology of having running water was so desirable that persons were known to consistently bribe water officials to tap into an aqueduct and split the flow to assuage their personal needs. Frontinus described the situation of running secret pipes under the pavement all over the city as "puncturing." Large quantities of water that were supposed to furnish the city and public fountains were stolen though this epidemic.[19]

Under limited technology and knowledge of diseases, Roman water quality standards were primitive, taking into consideration only factors of the immediate senses such as taste, temperature, smell, and visual appearance. Since the quality of water from the nine aqueducts varied, the worst waters were used to supply man-made lakes and crop irrigation while the considered "best" was used for drinking.[9]

Even though the aqueduct is considered a piece of technology beyond the time period, it has been said that Roman sewers are overpraised. Despite their durability and longevity, the sewer system ignored very basic sanitary principles. For example, the system carried sewage, urban runoff, and drainage water all together. This was made possible by designing large openings along the city streets. However, these openings worked both ways: letting waste in but at the same time endangering the public to the effluvia of the sewers. To alleviate the threat that this posed to the public's health, the Romans had two protections. One was that the water from the aqueducts constantly flushed the sewers, and the second was that the natural hills of the city gave the drains a steep slope, allowing for a continuous flow. The Roman sewer system poured directly into the Tiber River, and consequently, the flow of the river was greatly affected by the discharge of the Roman sewers.[7]

Much like the pipes bringing water into the city, there were very few private branches of the sewer system. For the majority of the population, whom did not have private indoor lavatories, there were two feasible options. Citizens could enter one of the city's public latrines for a relatively small charge or they could use chamberpots. The Roman styled sumptuous latrines were not an option for destitute, indolent, and the convalescents of society. Those under this category were forced to use chamberpots. Chamber pots were emptied into large barrels under the stairwells of the apartment-like residences, or if these stations were not provided, chamberpots could be emptied into an opening into the central sewer system. However, there were many people who emptied chamberpots from their windows onto the streets below.[14]

It may be assumed that the barrels of collected waste would be dumped into the same sewer openings or even into the Tiber River itself, but this was not the case. The Emperor Vespasian decreed to have the contents of the city's latrines and chamberpot vats collected, decanted, and stored in large reservoirs. The waste was then taxed and sold to what we would consider the "dry cleaners" of Rome. The Romans discovered that the ammonia in urine had properties useful for cleaning and likewise became an economic gain for the city.[19]

Aside from the glitches, Rome's overall water system was an engineering achievement. Imperial Rome had a constant supply of quality water. Once the water arrived in Rome, conversely, the distribution system was limited. With both the drinking water and wastewater systems, access points were generally public and located outside the household. But it must be remembered that Rome's water and wastewater systems were the best in antiquity and that improvements to the designs were not made until modern times. It is also important to remember that there is a contrast in lifestyles when comparing the ancient Roman systems with our water distribution today. In modern America, life is centered around the household. This was not the case in early Rome. Romans lived to a large extent outside their homes. Thus, not having private running water and sanitary facilities was not as great of an inconvenience as it would be deemed today.

From the Early Roman era through the early 1800's, there was relatively little progress made in water purification techniques and the design of water systems. The developments that did occur during this time frame were not lead by the United States. Conversely, in the early and mid-1800's, water treatment studies were headed by England, France, and Scotland. It was not until after the Civil War that scientists in the United States largely began to take an interest in water system engineering, sanitation, and comprehensive public health initiatives. After this seemingly late start to caring about water standards, today, the people in the United States' water supply profession, in accordance with their government institutions, lead the world in drinking water regulation as well as technological water developments.[13]

Before improvements could be made to the ancient water systems, modern engineers first had to come to the realization that certain diseases were capable of being initiated and spread through drinking water. With this breakthrough, contemporary thinkers were able to devise improvements that would drive notable better health. Examples of such improvements include the introduction to sand filtration systems and disinfection of the water by using the chemical chlorine [13]. By the early 1800's, slow sand filtration was beginning to be used regularly in Europe [6].

Throughout the mid to late 1800's, scientists were able to gain a greater understanding of the sources and effects of drinking water contaminants. In this time frame, scientists were beginning to better understand those impurities that were not visible to the naked eye, and that before this time, were mostly undetected. In 1855, epidemiologist Dr. John Snow proved that cholera was a waterborne disease by linking an outbreak of illness in London to a public well that was contaminated by sewage. In the late 1880's, Louis Pasteur demonstrated the "germ theory" of disease, which explained how microscopic organisms could transmit disease through a media such as water. During the late nineteenth and early twentieth centuries, concerns regarding drinking water quality continued to focus mostly on pathogens in public water systems. Scientists discovered that turbidity was not only a visual problem, but that particles suspended in water, such as fecal matter, could harbor pathogens. As a result, the design of most drinking water treatment systems built in the United States during the early 1900's was driven by the need to reduce turbidity, thereby removing bacterial contaminants that were causing typhoid, dysentery, and cholera epidemics. This is when the United States began to use slow sand filtration.[6]

While filtration was a reasonably effective treatment to reduce turbidity, it was the use of disinfectants, such as chlorine, that played the largest role in diminishing the number of waterborne disease outbreaks in the 1900's. In 1908, chlorine was used for the first time as a primary disinfectant of drinking water in Jersey City, New Jersey [2]. While the United States was just beginning to get their feet wet using chemical purifiers, the use of other disinfectants such as ozone was beginning in Europe around this time. In the 1970's and 1980's, improvements were made in membrane development for reverse osmosis filtration and other treatment techniques such as ozonation. Some treatment advancements were driven by the discovery of chlorine-resistant pathogens in drinking water that can cause illness. Other advancements resulted from the need to remove the increasing numbers of chemicals found in sources of drinking water. These other chemicals were not employed in the United States until several decades later.[6]

Another key to the advancement of water systems was the concept of pumps. Pumps proved to be fundamental in water system design. Wooden pumps were created and existed until the 1700's. These first water system pumps were formulated to empty the bilges of ships. They were made from delved logs with wooden pistons that produced suction. The more modern metal type piston pumps, driven by steam, were developed in the early and middle 1800's. However, it was not until the introduction of electrically powered pumps that water system expansion became feasible on a large scale.[13]

Water systems in the United States have come a long way since the first gravity flow aqueduct. In fact, Drinking water supplies in the United States are considered to be among the safest in the world [22]. By using the information that has been gathered and researched in the past, we are continuing to build on the technology we have so far including gravity, pumps, filtration, water standards, and sanitation issues [5]. Presently, research is seeking to recycle as much water as possible and to improve the previously made structures to keep them running in the most efficient and expedient manner possible by conducting research that focuses on increasing the life of drinking water and wastewater systems, determining the causes of system failures, and finding ways to prevent future problems.[4]

However, even in the United States, water sources can become contaminated, causing sickness and disease from waterborne germs, such as Cryptosporidium, E. coli, Hepatitis A, Giardia intestinalis, and other pathogens [22]. To help prevent sickness, drinking water sources require proper treatment to remove these disease-causing agents. For example, public drinking water systems use various methods of water treatment to provide safe and clean water for their communities.

The first step in common water treatment processes is coagulation and flocculation. This means that chemicals with a positive charge are added to the water. The positive charge of these chemicals neutralizes the negative charge of dirt and other dissolved particles present in the water. When this occurs, the particles attach to the chemicals and form larger particles. These large particles are referred to as floc. The second step is Sedimentation**.** Sedimentation is a settling process in which the floc sinks to the bottom of the water supply tank, due to its weight. Next, once the floc has settled, the clear water will flow over the settled flecks and pass through filters of varying compositions (sand, gravel, and charcoal) and pore sizes, in order to remove dissolved particles, such as dust, parasites, bacteria, viruses, and chemicals. This procedure is called filtration**.** After the water has been filtered, a disinfectant (for example, chlorine or chloramine) is then added in order to kill any remaining parasites, bacteria, and viruses. This is the disinfection part of the water treatment process.[22]

Water may be treated differently in different communities depending on the quality of the source water. Typically, surface water requires more treatment and filtration than ground water because lakes, rivers, and streams contain more sediment and pollutants, making the water more likely to be contaminated.[22]

Another important aspect of our current water systems is the concept of recycling and reusing water. “It's not **wastewater.** It's **resource water** [5].” Some examples of where we see or even use reprocessed water without even realizing it is in cooling systems, boiler feed water, industrial processes, irrigation, watering green spaces such as golf courses, ground water storage and recovery**,** and salt intrusion barriers in coastal communities. The Environmental Protection Agency (EPA) is also looking into green infrastructure that would reduce the amount of runoff that the sewer systems would have to handle. Some ideas that they have been investigating are porous pavements, rain gardens and swales, and green roofs.[4]

Beyond being able to reuse water, the new objective is to convert wastewater treatment plants into bio-refineries that not only reprocess water, but are also capable of producing energy and valuable by-products such as biopolymers. The long-term goal is to better the environment. By optimizing performance, extracting value, and generating energy from wastewater treatment plants, the aim is to help control costs and reduce the carbon footprint.[5]

“Water ... worth more than gold and more crucial for survival above all other resources on earth [20].” And yet, so many men, women, and children do not have enough safe water to drink and therefore can never live a healthy life. As for people in the United States, they are among the propitious; they have the technology that continues to develop and create safer communities for people to live in. The vast majority have clean, purified water to drink and bathe, and sewage systems to carry away waste. They are progressing and it is not a question of having safe water, but being able to reuse and recycle water to help the environment. This process has been and will continue to be a long journey that we conclude began back with the water engineers in ancient Rome.

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