Define Infrastructure
2nd Part, The Water, Sanitary Sewer and Storm Drain Systems
Outside the United States
By Robert H. Lowdermilk
03/10/10

Where did the various parts of our infrastructure come from?

All parts of our infrastructure have come out of searches for solutions to major problems that confront all of us every day. Highways came from our need to gather resources and move them to where we need them. Water supply systems came from our daily need for water to live. Sanitary sewer systems came from the recognition that the accumulation of human waste and filth in cities and towns encouraged and multiplied the incidence of disease and plague in their populations. Storm drain systems and dams evolved from the need to prevent the periodic destructive surges of waters that ran through our settlements. Thirst, starvation, disease, pestilence or floods and the cold of winter drove our culture's infrastructure.

Once in place our infrastructure requires appropriate maintenance to keep it functioning efficiently. When our infrastructure is in an optimum condition it reduces the cost and increases the availability of everything associated with it. When it works well we forget it is even there. When it breaks down the consequences get sequentially worse, even catastrophic. Natural disasters like earthquakes, hurricanes and tsunamis demonstrate this. The critical problems that our infrastructure once corrected can come flooding back and re-assault us. Our infrastructure makes us members of the first world nations and our innovations lead many other nations in the world. When we realistically rank our most important needs, a safe, clean, healthy and happy living environment is our most important priority. Our infrastructure is like our blood vessels; it makes everything else possible.

Look at something as simple as having a drink of safe, healthy water on demand. Or how inconvenient, dangerous and disagreeable it would be to have the hundreds of thousands of people who live in the city of Denver trying to get rid of their own personal human waste. The stench, filth and disease would be incredible. How could our culture function without our water and sewer systems?

Right! In the past it must have been terrible. Is that an indication of what it was always like? She asked.

In mankind's distant history the number of humans were few and the distribution of their waste was as wide spread as with animals today. Acquisition of water from springs, rivers and lakes was a daily problem throughout all history, along with the acquisition of food and protection from the elements and enemies. Early man was an itinerant hunter-gatherer. Villages and cities emerged where water and other resources were available. But as humans gathered into larger and larger groups they generated new unrecognized problems. Each part of our infrastructure evolved to solve those problems.

When did they start using sewers? She asked.

We can't tell you exactly. The Minoan Kingdom on Crete in 1700 BC was using underground systems to transport waste and surface water away from palaces and homes. Archeologists found sinks, bathtubs and toilets that emptied into an underground sewer in the Minoan Palace at Knossos on the island of Crete. Some of the homes of ancient

Greeks used sewers. The Greek physician Hippocrates, who lived between 460 and 377 BC, suggested that there was a close connection between sanitation and health.

The Romans were especially adept at sanitary engineering. I have seen the remains of ancient Roman Aqueducts in several countries. The Aqueducts brought large volumes of water into their cities for drinking and bathing and what remained was used to flush out human and other waste products. In Ephesus Turkey, where Paul preached, we saw an almost complete sanitary facility. One central point of interest was a large public marble privy with approximately 20 side-by-side latrine holes lining two walls of a large building. Water had flowed under those privy holes from water storage cisterns that were supplied by multiple, side-by-side eight-inch diameter clay water lines that brought water from the aqueducts. Other culverts transported the waste in the flushing waters to the local river. In the river the waste products were diluted and eventually oxidized. That was the earliest water and sanitary system I have ever seen. Modern water and sanitary systems evolved out of that basic water carriage concept.

In Rome sewers were built around 800 BC and used to carry off surface water and refuse. Romans recognized that if the empire could be enriched by an adequate municipal infrastructure the citizenry would be healthier and more productive. After the Roman armies had conquered new lands Roman engineers built all weather roads and water and sewer systems in the major cities. Roman rule benefited many in their empire by providing a cleaner, healthier and safer environment with their infrastructure systems. This encouraged the allegiance of occupied peoples.

That sounds very simple. Didn't we just follow the Roman's lead? She asked.

No, Europe virtually forgot the Roman sanitary concepts for approximately 1,400 years. They didn't reappear until early in the nineteenth century. With the fall of the Western Roman Empire in 476 AD and the rise of the Dark Ages a brotherhood arose that was noted for their skill in combat. These men accepted the creed that un-cleanliness was next to godliness and their culture dominated Europe through the Medieval Period and beyond the Renaissance, until the early 19th century. Streams, towns and homes were filthy. Sanitation and the custom of bathing decreased. Diseases were commonplace. Epidemics decimated towns and villages. Twenty-five percent (or more) of the ancient European population died of disease (dysentery, typhoid fever, smallpox, malaria, plague, measles etc).

What caused the fall of the Roman Empire and what caused the Dark Ages?

Many books have been written trying to answer those questions. I will tell you what I suspect. These are selected quotes from an archeological report about a late Roman city. "In the Roman excavations there were pots and stone buildings and columns. But then suddenly you get a layer of nothing but dark, humus-looking soil." This layer is called "dark earth." Only 5 years ago archeologists explained the "dark earth" layer in old Roman cities by assuming that the people living in the city before the Roman Empire declined had left the city and turned it into a "garden." Now it appears that the "people shifted" away from their traditional Roman brick and stone structures "to organic building materials. They had thatched roofs and wooden houses," (and because) "they didn't have Roman garbage removal," … "they just dumped the ashes and charcoal from their hearths out in the road" … (where it was) … "compacted."

It took over 100 years for the Western Roman Empire to weaken and die. On September 4, 467 a German chieftain deposed the last Emperor of the Western Roman Empire and we generally mark this date as the end.

I believe that as Roman rule declined a less technically capable Germanic culture took over. With no Roman law, the Germanic tribes looted and pillaged and armed gang law ruled. As a result the infrastructure, the cities and the cleanliness of the past disappeared. I suspect that the "dark earth" of the Roman settlements is a record of a more barbarous culture replacing a technical culture,

So that is how values changed so drastically away from sanitation. How bad did it get?

Near the end of the Dark Ages, around 1350 AD Europe was struck by the Black Death plague, one of the deadliest pandemics in human history. Over half of the population in European may have died from it. Rat populations thrived in the mess and stench that was commonplace in medieval times. Rats spread the plague by transporting bacteria carrying fleas. The bacteria were communicated to humans who were bit by the fleas. The Black Death plague traveled around the world and for hundreds of years returned repeatedly to Europe. The virility and recurrences of the Black Death plagues are good indicators of the unsanitary environments of humans in Europe and around the world. Europe's sanitation practices remained terrible for centuries.

What other evidence do you have that tells us that they lived like that?

We have archeological evidence, but surviving writings clearly describe how they lived. I'll give you three examples that infer the dreadful filth and stench that was rampant in the larger cities in England and Europe. An Etiquette Book written by Erasmus in 1530 stated: "It is impolite to greet someone who is urinating or defecating." A British royal court posted a warning in 1589 that said: "Let no one, who ever, he may be, before, at, or after meals, Early or late, foul the staircases, corridors; or closets with Urine or other filth." The effort to change this cultural habit was evidently not successful for in another etiquette book, The Gallant Ethic, written in 1700, it was suggested: "If you see someone relieving themselves, you should act as if you had not seen them!" It is recorded in Danish history "Hangmen also cleaned latrines." The author who reported this record wondered if this was a form of "Job diversification?!"

That is funny! She laughed. But, with such terrible conditions throughout England and Europe, where did the solution to this unsanitary problem start?

It started in London, but in order to understand the conditions, technology and concepts of the time let me give you a little more history. Lets look at London's evolution toward sanitation.

The Industrial Revolution started in England. Her governmental policy of leaving business alone encouraged inventiveness, creativity and the growth of wealth. The Industrial Revolution evolved from the liberation of individual thought and action. It brought forth new concepts that led to the invention of more efficient mechanization processes and better industrial organizations reducing unit costs and multiplying production. With lower delivered unit costs and better quality, English industry captured much of the world's markets.

London was the capital of a massive empire and one of England's major industrial centers. It was a magnet that encouraged major population movements from both England's rural areas and her empire, just like the United States in the last century, and

London's population multiplied. In 1800 London was a city of approximately one million people. That was a 40% increase over 50 years earlier. By 1850 London's population had expanded to 2.4 million, putting incredible pressure on London's water infrastructure. London's privy facilities also proved to be insufficient and were unable to accommodate her exponential growth.

I understand how an exponential increase in population without a concurrent increase in refuse handling capability can produce unsanitary conditions, but how did they start cleaning up the problems they had?

Cleanup usually starts with water. I found one report from 1833 that claimed that the South London Waterworks Company was supplying each of the 12,046 homes in their area with one gallon of water per day. This doesn't seem like much by our standards now, especially when compared with Thames Water, currently supplying London and its environs with its water. That company now supplies each of the13.6 million customers it serves (one quarter of England and Wales's population) with approximately 360 gallons of pure clean water each day. The source of the water is still the Thames River and its tributaries. Thames Water's present facilities and organization is phenomenal. My, how much we improved! Let me give you a sense of proportion by describing some of London's earlier water supplying companies and the tribulations they went through.

London is situated on the Thames River. It flows into the North Sea. This large and navigable river has always been London's most important water source. The wells, streams or springs that augmented London's water supply also flowed into the Thames. In the past everything in that drainage flowed into the Thames, including London's effluent and storm water. Dilution was the only agent available to reduce the virulence of microbes attacking anyone who drank its waters. The incidence of water borne disease increased as the population within the drainage of the Thames increased.

Some London residents collected water from the Thames' shore and records of frequent drowning testify that many poorer citizens sought cleaner water by wading into the deeper flows. Private water companies supplied most of London's water until well past the mid1800s. They fetched water from the Thames River, public fountains or wells and sold it by the tankard.

The evolution of London's larger water companies is a record of the technology and depth of sanitation knowledge at that time. In 1247 work began on the Great Conduit. This was a long lead pipe that was designed to conduct clean water from a spring to a large cistern. Brewers, cooks, wealthy Londoners and fishmongers purchased this water. In 1582 the first pumped water system, powered by water wheels, was installed. In 1613 a 40-mile supply channel was completed from Hertfordshire to north London. In 1666 the Great Fire of London destroyed most of the lead and wood water-supplying infrastructure and new systems had to be reestablished.

In the 18th century at least 4 private enterprises attempted to satisfy London's water demands. One was the Chelsea Waterworks Company. It was established in 1723. It initially took its water from the tidal Thames. In 1752 it used two one-atmosphere Newcomen beam steam engines to deliver water to its reservoirs at Green Park and Hyde Park. The Newcomen, the second steam engine ever invented, was patented in 1716. In 1829 Chelsea became the first company to install a slow sand filtration system to purify its water. The Metropolis Water Act of 1852 required that any

company wishing to supply household water must move their water intake above the Thames polluted tidewater zone. Chelsea was the last company to accomplish this in 1856 and because of the poor choice for the new location it was forced to move its water intake again in 1875.

For over two centuries at least 15 private water supply companies struggled to satisfy London's water demand. The water companies installed cast iron pipe, moved their intakes, built and operated additional reservoirs and installed new steam powered pumps, water towers and water filtering reservoirs to improve the clarity, taste and quality of their water to satisfy ever more stringent government requirements.

Some succeeded and others didn't. In 1850 the Southwark and Vauxhall Waterworks company had their company's water described, by a water reformer who was studying London's water quality, physician and microscopist Arthur Hall Hassall, as "the most disgusting which I have ever examined".

Sounds pretty damning doesn't it? I asked. **It sure does! She answered.** You need a little perspective. 1850 it was just about the time that Louis Pasteur, in France, was making the discovery that germs cause disease. His discoveries had not even been communicated outside his lab. The owners and managers of the water companies really didn't know what to do to respond to Arthur Hassall's criticism. But in 1852 the Metropolis Water Act was enacted and the water companies were told that their water was to be "effectively filtered."

Water filtration was made compulsory. This may have improved the appearance of the water but it didn't remove all the disease causing microbes. Water from the Thames could not be considered sanitary until the early years of the 20th century, when continuous chlorination of drinking water began in England.

It appears that private water companies tried to respond, but that didn't satisfy the government and in 1902 all 9 private water companies were nationalized. The Metropolitan Water Board then operated London's water supply system until 2006 when the system was re-privatized as Thames Water, a state-regulated private company.

Many of London's water lines are cast iron pipes, date back to the nineteenth century and are in great need of replacement or repair. There is widespread criticism about the amount of water that is lost through leaks in London's water distribution system.

Thames Water is upgrading the old lines with modern plastic piping. Completed in 1994 the Ring Main, a new "backbone network" of water mains, circles London in a 50 mile long tunnel. These water lines average more than eight feet in diameter. This transportation and reservoir system is even now being extended to further increase its capacity, connecting all of Thames Water's waterworks, water treatment plants, storage and pumping stations and transferring water virtually anywhere in the system if there is a break in any line. London's water system has now evolved into a gigantic totally modern system.

London's early water systems were terrible. Evidently the drinking water system they are now installing is world quality. But what did they do to get rid of their human waste?

If you think the story of getting access to clean water was bad, the history of how they handled their human waste problem is even worse. By the early 1700s virtually every London residence had a cesspool in its basement to handle its "night soil." Many of the

homeowners sold the accumulated "night soil" for crop fertilization. Children were often employed to help harvest this material. This was the norm in even the best of homes. Stench permeated even the most elegant parlors. These odors were ignored as much as possible. During the Gregorian and Victorian periods ladies in England carried Tussy Mussies. These were small silver cone-like containers, which contained bouquets of fragrant herbs or flowers used to fend off the vile and noxious odors.

The air London residents most feared was the "night air." This was the sulfurous industrial fog that was most noticeable at night. As a result Londoners sealed the doors and windows of homes and factories at sunset to protect those inside from the "night air." Whole families and crews of workers died mysteriously at night. Most of these deaths probably resulted from hydrogen sulfide or oxygen deficiency asphyxiation. Explosions also occurred. Both the asphyxiations and the explosions were probably the result of the anaerobic generation and accumulation of hydrogen sulfide, ammonia, methane and other toxic gasses from the "night soil" in cesspools.

When basement cesspools overflowed or soaked into walls or foundations they caused structural problems or contaminated wells. Cholera came out of India in 1816 and a series of Cholera epidemics spread around the world in the early 1800s. In1847 it was proved that lethal communication between cesspools and public water wells occurred when a well at 40 Broad Street was removed from service. The Cholera epidemic that had killed hundreds in just a few days was stopped. It was recorded that a cholera-infected baby diaper, thrown away in a nearby privy was the culprit.

Sewer means "seaward" in Old English. London's earliest sewers originally had been natural watercourses that lead to the Thames River. As the city grew these waterways were encapsulated and covered to accommodate London's traffic. They were initially designed to remove storm water from street surfaces. Prior to1815 it was illegal to introduce fecal matter into these sewers possibly because the exit points of London's storm drain sewers were located near the low tide level of the Thames. Rainwater posed no problem when the water gathered by these early storm-drain-sewers mixed imperceptibly with the waters of the Thames.

In 1847, this policy was changed making it mandatory to use the sewers as the vehicle to evacuate human waste from the city. The consequence of this decision was catastrophic. The 30-foot tide and the tidal reach of the Thames River became a filth laden hydraulic flow returning fecal matter to poor neighborhoods and driving filth-laden effluent back up the Thames. This is how it worked. The Thames empties into the ocean and is subject to the ocean's tide. When the tide came in, the Thames raised as much as 30 feet and a large part of the fecal matter and refuse of London's 2.5 million residents stopped with that rising tide, then reversed, and flowed back up the river. Many of the poor neighborhoods were lower than the 30-foot high tide level of the Thames. As the tide raised the river higher, the storm sewers filled up and returned the feces, back to the poor neighborhoods.

It has been estimated that in the distant past 50% of the population felt ill. Now do you wonder why?

You know the old saying, she asked: If you don't have profound knowledge, you are only tinkering.

Very insightful! I said.

How did the decision makers finally begin to understand how bad things were getting? She asked.

A series of reports on the consequences of unsanitary conditions, many written by Sir Edwin Chadwick, were presented to members of the House of Commons. Let me quote part of a public record written at that time: "The Commission also received reports from fifty of England's largest towns, containing between them a sixth of the entire population. Of these there was hardly one in which the drainage was good, and only six where the water supply was good; in thirteen the water was indifferent, in the seven the drainage. In forty-two the drainage, and in thirty-one the water supply was supremely bad. The proportion of privies to houses was appalling. There were parts of Manchester where thirty-three privies had to supply 7,095 persons - a proportion of one privy to every 215 persons. Such a state of affairs was cited not as an isolated instance, but as exemplifying a general deficiency. At Bristol, while Dr. Playfair was examining overflowing privies, Sir Henry De la Beche was obliged to stand at the end of the alley and vomit."

This account is an exact quote from their official records in the middle 1800s?

Yes, and I quoted it exactly as it was written. Now do you understand how bad it was? London was not that unusual. Similar conditions existed in cities all around Europe and the world.

Why would anyone move to these cities? Why wouldn't they just stay in the rural areas away from this mess?

Cities offered more advantages than did the rural areas. England was the heartland of the Industrial Revolution. London was its capital and the center of the British Empire. Employment opportunities abounded. London offered many things, employment, more safety and an improved ability to feed yourself and your family. It was an improvement over what they left behind and their choice was cities like London.

But, it sounds like London's sewage problem was getting worse and worse as the population increased. When did they finally start coming up with a real solution? She asked.

London's sewer problem was so immense and obvious that the smell it imparted to the Thames periodically drove some members of Parliament away from their Parliamentary sessions. In 1855 the Metropolitan Board of Works was formed. 1858 was the "Year of the Great Stink." There was an extremely hot summer and the heat accelerated the decay of an already fetid Thames and multiplied its odors. That year Parliament passed an Act that gave The Metropolitan Board of Works the authority to solve London's sewage problem. Upon the passage of the Act, Benjamin Disraeli, England's Prime Minister, met with Joseph Bazalgette, the board's Chief Engineer, and told him to deal with the stink before Londoners were asphyxiated and the problem became political.

Bazalgette built a very large integrated system that included two large dimensioned main line sewer systems that were constructed of brick. Combined they totaled 83 miles in length, one servicing the north side of the Thames River and the other the south. These interceptor sewer mains gathered the effluent of 1,100 miles of transmission sewers and 13,000 miles of small local sewers and conveyed the sewage, partly by gravity and partly by pumping, to temporary storage reservoirs and discharge

points on each side of the Thames River, fourteen miles below London Bridge. By 1866 most of London was connected to Bazalgette's sewer network. London's sewage disposal and supporting river embankment reclamation projects along the river were completed in 1874. Bazalgette was knighted in 1875.

Sir Bazalgette was very competent and recognized that simply building a sewer system wouldn't solve London's problem. The sewage had to be released well below London, at the proper time, so that it would flow out to sea and not accumulate in the Thames River. To handle this problem, and utilize the twice-daily outgoing tides, pumping stations and 27 million gallon sewage reservoirs were constructed on either side of the Thames. These reservoirs retained sewage for 6 hours until the appropriate release time. The contained sewage was discharged twice each day, immediately after high tide so it could flow out on the ebb, toward the sea.

In 1885 chemical and bacterial treatments were included to improve the process. The chemical treatment, the removal of the resulting sludge and its transportation to the ocean cost London about seven hundred and fifty thousand dollars per year. The new system was worth its price, because it reduced the incidence of disease and flooding in London's low-lying neighborhoods. London's sewer solutions became a model for other systems being built in Europe and the United States. London uses virtually all of Sir Bazalgette's original sewer system to this day.

London went from being a terrible example to being a good one. But what happened to encourage the sanitary concepts we now have?

It took many discoveries to create the scientific basis for the concept of sanitation. In 1774 Carl Wilhelm Scheele, a Swedish chemist isolated chlorine. In 1810 Sir Humphry Davy proved it was an element. In 1854 Dr. John Snow made the connection in London between human wastes and water supplies and used chlorine to try to purify a Cholera contaminated well. Chlorine is a tool that still plays a major roll in sanitation.

From the mid to the late1800s additional scientific discoveries made major advances in overcoming widely held inaccurate theories about medicine and sanitation. Louis Pasteur proved that germs could cause disease. Joseph Lister fathered antiseptic techniques. Robert Koch developed groundbreaking microbiological research techniques and opened the door to the science of disease germ identification. Their discoveries made the rapid expansion of biomedical knowledge possible.

After Pasteur, Lister and Koch's scientific discoveries, sanitation took a massive leap forward. Newspapers, the newly established worldwide telegraph system and the words of respected men spread support for sanitation's life saving capabilities. With this base of support, scientific knowledge about sanitation and engineering inventiveness then improved everything from the design and construction of water and sanitary sewer treatment plants to home cleanliness.

Now cleanliness is thought of as being next to Godliness. This maxim is now so widely accepted that it is a basic cultural concept and God only knows the countless lives it has saved.