Urban Wastewater Management in the United States: Past, Present, and Future

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SINCE 1800 there have been several urban wastewater management strategies and technologies implemented in the United States. The management strategies can be categorized as either centralized, where all the wastewater is collected and conveyed to a central location for treatment or disposal, or decentralized, where the wastewater is primarily treated or disposed of on-site or near the source. Historically, municipalities, consulting engineers, and individuals have had the option of centralized or decentralized wastewater management and could have chosen from a variety of collection and disposal technologies to implement the management strategy. Although these options were available, the majority of engineers, public health officials, policy makers, and members of the public typically preferred one management strategy and one technology to the others. The reasons for a particular preference were based on a combination of cost, urban development patterns, accepted scientific theories, tradition, religious attitudes, prevailing public opinion on sanitation, the contemporary political environment, and many other factors.

The development of urban wastewater management strategies and technologies from the early nineteenth century to the present

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exhibited a cyclical tendency. During the middle of the nineteenth century, the centralized water-carriage sewer system replaced the ailing decentralized privy vault-cesspool system. From the end of the nineteenth century to the present day, centralized management has remained the preferred urban wastewater management method, although the implemented technology has changed. During the past few decades, however, renewed interest in previously discarded decentralized management alternatives has been spurred by urban development patterns that have changed wastewater management needs.

The objectives of this paper are to (1) review the development of wastewater management strategies and technology choices in the United States since the early nineteenth century and (2) discuss how recent trends suggest potential future urban wastewater management directions. The first part of the paper reviews the primary factors that contributed to the paradigm shift from decentralized management in the early nineteenth century to centralized management in the late nineteenth century. The second part of the paper describes the late nineteenth-century debate between the advocates of the two basic centralized technologies: the combined-sewer system and the separate-sewer system. The third part of the paper touches on the changes in urban wastewater management caused by changing urban development patterns during the first half of the twentieth century. The final part identifies decentralized wastewater management, wastewater reuse, and wet-weather flow management as three key wastewater management issues today and discusses them in the context of future urban wastewater management in the United States.

Introduction of Centralized Wastewater Management

Residential wastewater management in seventeenth-century colonial America consisted primarily of a privy with the outlet constructed at ground level, usually discharging into the yard, street, gutter, or an open channel serving as a sewer. Because population densities were (Duffy) low, privies constructed in this way did not create sanitation problems or unbearable nuisances in colonial cities (e.g., New York City in the eighteenth century), but as populations increased, so did the sanitation problems and nuisances. The majority of residents accepted the sanitation problems and nuisance conditions as a necessary part of urban life, except during epidemics or following a disease outbreak when sanitation was given considerable attention. (Rosenberg) To alleviate the nuisance conditions caused by the discharge of privies into streets and gutters, residents would construct a vault or tub beneath the privy, or would discharge wastewater into a nearby cesspool. Privy vaults and cesspools were meant to store the wastewater until it either soaked into the ground or could be manually removed and disposed of away from the residence.

One alternative to the privy vaults and cesspools used in the United States was the dry sewage system. Dry sewage systems in the nineteenth century (e.g., pail systems) entailed placing containers beneath the seats of privies to collect human excrement. Once the containers were full, the homeowner or other responsible party would transport the excrement to a convenient disposal location near the residence. Compared to the privy vault, dry collection of human waste required a diligent effort on the part of the homeowner to maintain the system in a sanitary state. The prime advantages of the dry sewage system were the quick removal of wastes from the residence and the potential use of the waste as fertilizer on nearby farmland. Municipalities often contracted workers to remove the wastes from residences and deposit them in suitable disposal locations outside the city limits. But the crews hired to perform these duties did not perform adequately, leading to accumulated wastes, nuisances, and public health problems.

Folwell

"Report of Committee..."

Decentralized dry sewage systems were more common in Europe and Asia than in the United States because Europeans and Asians had more experience using human excrement as fertilizer and doing so cost effectively. In addition to the reluctance to effectively use human excrement in the United States, residents were not enthusiastic about maintaining or cleaning dry sewage systems. Despite the simplicity of the dry sewage systems, the prevailing opinion during the mid-nineteenth century in Europe and the United States was against their use in urban areas, as suggested by the following excerpt from an 1876 report by a committee appointed by the Local Government Board of England:

Armstrong
Folwell

> "…none of the so-called dry-earth or pail systems, or improved privies, can be approved, other than as palliations for cesspit middens, because the excreta is liable to be a nuisance during the period of its retention, and a cause of nuisance in its removal; and, moreover, when removed, leaves the crude sewage, unless otherwise dealt with by filtration through land, to pollute any watercourse or river into which such sewage may flow. We have no desire to condemn the dry-earth or pail system for detached houses, or for public institutions in the country, or for villages, provided the system adopted is carefully carried out."

As quoted in Philbrick

An early attempt at centralized wastewater management in the United States was the construction of public and private sewers to transport the cumulative wastes from a city block or from several city blocks to a nearby water body. There were fewer public sewers than private in the early nineteenth century, and most were constructed primarily for the purpose of removing storm water. Sewers were built both below ground as underground conduits and above ground as open channels. Typically, underground sewer conduits and open sewers ran along the center of a street or the sides of a street. Sewers constructed before the 1850s were not planned, designed, or constructed by trained engineers because sewers were not perceived as technically complex systems requiring the services of an engineer. Another shortcoming of the early sewers in the United States was caused by the contemporary urban decision mechanisms that forced sewer construction to proceed piecemeal. Consequently, few public or private sewers constructed in the early nineteenth century achieved the goal of ameliorating sanitation problems.

Report on the Social...

Goldman

Philbrick

Dry sewage systems and public and private sewers were commonly used in Europe and the United States, but the predominant wastewater management technology in the first half of the nineteenth century was the privy vault-cesspool system operated in a decentralized manner. Privy vaults and cesspools were basically holes in the ground, occasionally lined, constructed in cellars, beneath residences, or within close proximity to residences. They were designed to drain much of the wastewater into the surrounding soil, but they still required periodic cleaning. The unplanned and uncontrolled drainage of wastewater from privy vaults and cesspools contaminated soils and groundwater, and that occasionally led to contaminated drinking water and disease outbreaks. Benjamin Latrobe noted that Philadelphia's main water supply in 1798 was also its greatest source of disease due to groundwater contamination from increasing population and inadequate wastewater management. Another example is Baltimore, where the City Health Commissioner reported in 1879 that of the 71 wells and springs surveyed, 33 were filthy, 10 were bad, 22 were suspicious, and only six were good.

Armstrong

Cain

Metcalf and Eddy 1928

Privy vaults and cesspools were lined to prevent leaching of wastes into the soil, but lining increased the required frequency of cleaning. Similar to dry collection of wastes, the cleaning of privy vaults and cesspools was inconsistent and inadequate. Wastes accumulated till privies and cesspools overflowed and produced nuisance conditions and potential public health problems. In most cases, both lined and unlined privy vaults and cesspools proved unable to manage urban wastewater effectively during the mid-nineteenth century

Tarr et al. 1984

because the lined ones required too frequent cleaning to be cost effective over a long term, and the unlined ones contaminated groundwater and the surrounding soil.

None of the centralized or decentralized management technologies implemented during the early nineteenth century consistently prevented contamination of nearby surface water or groundwater. By the mid-nineteenth century, engineers, public health officials, and the general public were searching for alternative wastewater management options. One solution that was promoted in Europe and the United States was a centralized management strategy using water-carriage waste removal. The new concept of centralized water-carriage waste removal entailed planning a coordinated system of conduits and channels that used water to convey the wastes away from the sources to a central disposal location. The centralized water-carriage sewer system gained favor, especially in Europe, following the success of the first modern-day system constructed for Hamburg, Germany in 1843.

Armstrong

Philbrick

Waring 1873

Metcalf and Eddy 1928

1984

Tarr et al., found a combination of demographic and technological factors to have caused the decentralized management options (e.g., privy vault-cesspool system, dry sewage system) to become overwhelmed in urban areas. In addition to the factors that contributed to the failing of decentralized management, several other factors aided in the gradual change to centralized management that occurred in the mid-nineteenth century. Building upon the thorough discussion by Tarr et al., we will now briefly describe six factors that contributed to the change from decentralized to centralized wastewater management: (1) failure to keep pace with population growth; (2) construction of public water supplies and water closets; (3) public health concerns; (4) limited technology transfer; (5) socioeconomic considerations; and (6) a lack of alternative solutions.

1984

Population Growth

During the nineteenth century, there was considerable urban population growth in the United States. In 1820, less than 5 percent of all Americans lived in urban areas (cities with a population larger than 8,000), but by 1860 the percentage increased to 16 percent and by 1880 had risen to 22.5 percent. From 1820 to 1880, most major cities in the United States experienced considerable growth. For example, during this time Boston's population increased eightfold, New York City's tenfold, Philadelphia's thirteen fold, and Washington, D.C.'s fivefold. As a result of this increased population density in urban areas, the decentralized privy vault-cesspool wastewater management systems became overtaxed. Mitigation measures included

U.S. Bureau of Census

increasing the cleaning frequency and constructing additional privy vaults and cesspools. The improvements, however, only slightly reduced the periodic overflows and development of nuisance conditions. The privy vault-cesspool system, as it existed then, was inadequate to handle the increased amount of wastewater. The centralized water-carriage sewer system, on the other hand, was being promoted as the management alternative for urban areas with increasing populations.

Tarr et al. 1984

Waring 1973

Public Water Supplies and Water Closets

Another major cause of the abandonment of the decentralized privy vault-cesspool system was the increased construction of piped-in water-supply systems. More and more during the middle of the nineteenth century, potable water supplies were being piped in because local water sources were contaminated, frequent disease outbreaks were occurring, and water quantities above what was available locally were needed for fire fighting and street flushing. Water-supply systems were constructed in most of the major U.S. cities in the early to mid-nineteenth century, and by 1860, the 16 largest cities in the nation had waterworks.

Armstrong
Dworsky and Berger
Fair and Geyer

Tarr et al. 1984

Piped-in water supplies influenced wastewater management in two ways. First, water-carriage waste removal required a copious supply of water, and the introduction of a piped-in water supply made water-carriage sewer systems viable. And second, the improved standard of living for urban dwellers in the nineteenth century coupled with the availability of water led to the implementation of modern plumbing fixtures and a concomitant increase in wastewater production. The water closet probably had the most significant effect on wastewater management compared to the other plumbing fixtures because it increased not only wastewater quantity, but also the quantity of fecal matter in discharges. The high level of fecal matter being discharged with the wastewater heightened the risk of disease transfer and outbreak, but this was not understood at the time.

The increased wastewater levels overwhelmed the privy vault-cesspool system, but few municipalities planned for, or constructed, additional wastewater management infrastructure. Residents had two ways of addressing the increased wastewater being produced: (1) continue to discharge to an existing privy vault or cesspool, or (2) create an illegal connection to a storm sewer or street gutter. Both choices were ineffective solutions because neither the privy vault-cesspool system nor the storm-sewer system were designed to accommodate the increased wastewater. Instead of addressing infrastructure needs, municipalities implemented ordinances to mitigate the problems created by the increased wastewater quantities. One such ordinance was instituted in Boston during 1844 that prohibited [Armstrong] the taking of baths without a doctor's order. Municipalities also tried to prohibit the discharge of fecal matter to the sewer system. Bans such as these were in effect in Boston until 1833, in Philadelphia until [Armstrong] 1850, and in New York until 1854, at which time sanitary connections [Goldman] to sewers became required. The enforcement of imposed wastewater discharge limits and the prevention of illegal sanitary connections to the storm-sewer system was difficult for a municipality. Privy vaults and cesspools continued to overflow, while the connections to the storm-sewer system also resulted in sanitation problems. In most cases, neither the privy vault-cesspool system nor the uncoordinated sewer system were able to handle the increased quantity of wastewa- [Goldman] ter. In many American cities (e.g., New York City), physicians, public health officials, and the general public demanded action to address the wastewater management problems created by the influx of piped-in water, and most supported the implementation of centralized water-carriage sewer systems.

Public Health

By the mid-nineteenth century, engineers, public health officials, and the general public were searching for alternative wastewater management options that would effectively implement principles being [Philbrick, Waring 1873] espoused by the growing sanitary reform movement. Sanitary reform during the nineteenth century was largely predicated upon the mias- [Duffy, Peterson] mic theory of disease etiology. The miasmic theory held that an invisible noxious gas emanating from putrefying organic material caused some diseases. Cleaning urban areas by removing human wastes expeditiously (commonly believed to be within two to three days) would, therefore, prevent the development and the transmission [Waring 1873] of disease. The contagionist theory of disease etiology differed from the miasmic, or anticontagionist, theory. The contagionists proposed that some diseases were transmitted by direct and indirect contact [Tarr et al. 1984, Waring 1873] with a diseased person or carrier through microscopic organisms. The supporters of the anticontagionist theory promoted street cleaning and the cleansing and ventilation of residences (especially tenements). The supporters of the contagionist theory viewed quarantine measures and the proper management of wastes from diseased individuals as the proper strategies to prevent disease transmission. Both theories contributed to a number of laws, regulations, and ordinances passed [Metcalf and Eddy 1928, Rosenberg] in response to disease outbreaks. Although contagionists and anticontagionists differed in their opinions of disease etiology, the majority of both eventually supported water-carriage removal of [Melosi 1996, Rosenberg] human wastes from urban areas.

London is an example of a European city that developed a water-carriage sewer system partly in response to disease outbreaks. A cholera epidemic struck London in 1848 causing 14,600 deaths by 1849. Cholera again erupted in 1854 causing 10,675 deaths. Many scientists and doctors studied these outbreaks to understand the cause and modes of transmission, but Dr. John Snow was the first to formulate a theory consistent with present-day scientific understanding and to verify it with evidence. Dr. Snow wrote a short pamphlet in 1849 titled *On the Mode of Communication of Cholera* in which he argued that cholera was a contagious disease caused by a poison reproducing itself in the bodies of its victims. The pamphlet did not convince many, but Snow was able to test his theory scientifically with the outbreak of cholera in 1854. Dr. Snow recorded the location of outbreaks during the epidemic and charted the drinking water source of infected individuals. He was able to show statistically that cholera victims drew their drinking water from a sewage-contaminated part of the River Thames, while those who remained healthy drew their water from an uncontaminated part. Besides this evidence, Snow also established a connection between cholera outbreaks and a contaminated water supply at the Broad Street public well. Prodded by public outcry, bacteriological discoveries by Pasteur and Koch, and by the findings of studies by Snow and Budd that linked sewage-polluted water with disease, Parliament passed an act in 1855 to improve the waste management of the metropolis. This act provided the foundation for the development of London's comprehensive water-carriage sewer system eventually designed by Joseph W. Bazalgette.

Viessman and Hammer
Metcalf and Eddy 1928

Rosenberg

Dworsky and Berger

Hey and Waggy

Metcalf and Eddy 1928

In the United States, repeated cholera epidemics and other disease outbreaks gradually influenced municipalities to improve sanitation practices. Between 1832 and 1873, numerous American cities were afflicted with major outbreaks of disease, including cholera in 1832, 1849, and 1866 and typhoid in 1848. The causes of the outbreaks were attributed to a variety of reasons including unsanitary conditions and punishment from God. The experience gained from the epidemics improved the understanding of cholera and other diseases and their corresponding etiology. A cholera outbreak, following the Civil War, provided a chance to practice some of the prevention techniques based on improving sanitary conditions and disinfecting the waste products of infected individuals. The relative success of those measures indicated that the effective management of human wastes was an important component in protecting public health. The search for an effective method of protecting public health by managing human wastes invariably encouraged the construction of water-carriage sewer systems.

Rosenberg

Armstrong

Duffy
Rosenberg

Tarr et al. "The Development and..."

Technology Transfer

The planning and design of wastewater management systems in European and American cities was usually based on the experience of the design engineers because the transfer of technology was slow, and standardized wastewater management procedures were not yet widely published. During the nineteenth century, junior engineers from most disciplines would learn engineering skills on the job from senior

Kirby and Laurson

engineers. The newness of wastewater management meant that there were few experienced engineers available in the United States. Consequently, the first coordinated U.S. wastewater management efforts followed practices established in Europe. European cities were constructing large-scale centralized water-carriage sewer sys-

Hering 1881
Philbrick

tems and proving them successful for removing wastewater from urban areas. U.S. engineers often consulted with the designers of the

Hering 1881

successful European systems when designing their own systems. Thus, through person-to-person technology transfer, European engineers promoted the use of centralized sewerage technology in the United States.

Socioeconomic Considerations

There are two basic socioeconomic reasons why the implementation of centralized water-carriage sewer systems was favored over decentralized privy vault-cesspool systems. First, water-carriage sewer systems were believed to be more cost effective over the long term than privy vaults and cesspools. Experience in England showed that the cost of a water supply and water-carriage sewer system, with interest, divided over a period of thirty years would be less than the

Waring 1873

cost of keeping privy vaults and cesspools clean. Similarly in the United States, centralized sewer system advocates pointed out that the capital and maintenance costs of sewer systems would represent a saving over the annual cost of collection and cleaning with the privy

Goldman
Tarr

vault-cesspool system. Based on this economic reasoning, city councils, sanitary engineers, and health groups almost unanimously agreed that water-carriage sewer systems provided the most benefits and the lowest long-term costs compared to other disposal options, as was the

Duffy
Goldman

case for New York City. The second socioeconomic reason was the public opinion in favor of sewer system implementation because of

Folwell

the potential advantages it offered, most notably, convenience. Water-carriage sewer systems eliminated most maintenance work by the homeowner and permitted wastes to be collected and disposed of in the least obtrusive and offensive manner. Public opinion could not directly secure funds for the construction of a centralized water-carriage sewer system, but its influence over elected officials could indirectly secure funds.

Lack of Alternatives

The final reason why the centralized water-carriage sewer system replaced the decentralized privy vault-cesspool system was because no alternatives were mentioned as replacements for, or improvements to, the decentralized privy vault-cesspool system. Society often supports ideas, technologies, or political candidates simply because they present a change from the status quo. In the case of urban wastewater management, nuisances and sanitary problems were obvious, change was desired, and the only alternative solution known to be available was the centralized water-carriage sewer system.

During the second half of the nineteenth century, there was growing public demand to replace decentralized privy vault-cesspool systems with centralized water-carriage sewer systems. Proponents of centralized sewer systems outlined three reasons for municipalities to construct sewers:

Melosi 1996

Tarr et al. 1984

1. The capital and maintenance costs would be lower than the annual costs associated with the collection from and cleaning of decentralized privy vault-cesspool systems.
2. The public's health would improve and result in lowered morbidity and mortality from infectious disease.
3. More people and industries would be attracted to these cleaner, healthier cities.

The opponents of centralized sewer systems argued that:

Tarr et al. 1984

1. Human waste that might be used for fertilizer would now be lost.
2. There would be an increased danger of contamination of the subsoil by leakage, pollution of the waterways with threats to drinking water supplies and shellfish, and the generation of disease-bearing sewer gas.
3. A heavy tax burden would be created on the current generation or, if financed with bonds, the burden would be placed on future generations.

The reasons offered by either side were difficult to substantiate except under the simplest conditions. And as the second point against water-carriage systems indicates, the reasons were sometimes based on inaccurate scientific information. Nevertheless, due primarily to the reasons already discussed, centralized management became the favored management option over the failing decentralized privy vault-cesspool system. The introduction of new technologies to implement water-carriage waste removal and the establishment of new municipal management mechanisms permitted the planning, design, and construction of coordinated networks of water-carriage sewer systems during the last half of the nineteenth century. The next section of this paper discusses the period in the development of wastewater management in the United States when the debate switched from centralized versus decentralized to combined- or separate-sewer systems.

Goldman

Combined- Versus Separate-Sewer System Technology

Combined-sewer systems (CSSs) by design use a single conduit to transport storm water and other household and industrial wastewater to a designated disposal location. Hamburg, Germany is often cited as the first city in the modern era to comprehensively plan, design, and construct a CSS. The evolution of the CSS in the United States from sanitary connections to storm sewers into a planned network of large-diameter sewers occurred during the late nineteenth century. The first combined systems followed the tradition of the first sewers and discharged their contents into the nearest waterway. The relatively high flow rate in the urban waterways compared to the wastewater discharges prevented, to some degree, the development of nuisance conditions until later when urban populations increased and the wastewater discharges became overwhelming.

Metcalf and Eddy 1928

The first comprehensively planned CSSs in the United States were constructed in Chicago and Brooklyn in the late 1850s. The designs of the Chicago system by E.S. Chesbrough and the Brooklyn system by J.W. Adams were both heavily influenced by European experiences. Chesbrough and Adams both reviewed the plans of several European cities, e.g., London and Paris, while formulating the plans for their respective cities. As the first CSSs were being constructed in Europe and the United States, several authorities on wastewater were advocating a separate-sewer system (SSS). The concept underlying the SSS was to manage storm water and sanitary wastewater separately. The first SSS design incorporated two conduits, one to convey the sanitary wastewater to a specified disposal location and another to transport the storm water to the nearest receiving body of water. Two originators and staunch supporters of the SSS concept were the Englishmen Edwin Chadwick and John Phillips. Chadwick was strongly in favor of sanitary reform practices, and he viewed water-carriage sewage removal as a necessary aspect of proper urban sanitary management. Phillips had similar views and had the foresight to propose a centralized SSS for London in 1849, but a few years later Joseph Bazalgette's interceptor concept for combined sewers was implemented.

Metcalf and Eddy 1928

Peterson

Metcalf and Eddy 1928

Despite having a choice between a combined or separate system in the late nineteenth century, most of the centralized systems constructed in the United States were combined because: (1) there was no European precedent for successful SSSs; (2) there was a belief that CSSs were cheaper to build than a complete separate system; and (3) engineers were not convinced that agricultural use of separate-sewer sanitary wastewater was viable. Of these three, the primary deterrent to the acceptance of a two-conduit separate system was cost. It was less expensive to remove storm water and sanitary wastewater in a single conduit than to plan and construct two separate conduits. SSSs later became economically attractive when a system design was introduced that omitted underground storm-water removal. Tarr

The first step in the acceptance of the SSS concept was the introduction of vitrified clay pipe. Clay pipes could be constructed with smaller diameters and in different shapes than traditional wood, brick, or stone sewers. Clay pipes had economic advantages over traditional brick pipes because their smaller size reduced material costs and their ability to be delivered precast reduced labor costs. Clay pipes also had sanitary and performance advantages over the larger combined-sewer conduits. Clay pipes were much more impervious than brick pipes, retarding the leakage of sewage into the surrounding soil. The improved performance of clay pipes was due to the much smoother interior of the clay versus the brick and mortar interiors of most combined sewers. The cost advantage of CSSs over SSSs diminished with the development of smaller diameter clay pipes. Rawlinson Waring 1873

George E. Waring, Jr. furthered the acceptance of the SSS in the United States during the late nineteenth century. Waring was outspoken about the economic advantages of his version of the SSS, which incorporated smaller diameter clay pipes and did not include a conduit for storm-water removal. Those characteristics made it much less expensive compared to the traditional combined system. Waring also argued persuasively in favor of his separate system in terms of the sanitary advantage it provided compared with the combined system. He subscribed to the anticontagionist theory and believed the rapid removal of wastes was imperative to prevent the creation of disease-bearing gases in the sewer system. Waring's separate system removed wastes rapidly compared to the traditional CSS that often needed the aid of a rainstorm to flush the system. Waring 1875 Waring 1873 Waring 1873

Waring constructed his first separate system in the United States in 1875 for the small Massachusetts community of Lenox. He went on to design many other systems, but the system he constructed in Memphis, Tennessee in 1880 is probably the best known. In the late 1870s, Memphis experienced several outbreaks of yellow fever. Not Tarr Odell yet aware of the connection of mosquitoes to that disease, officials were desperate to improve sanitary conditions. Waring's proposed separate system was by far the least expensive of the several sewerage systems proposed. After the system was completed, sanitary conditions improved noticeably, and, coincidentally, the incidence of yellow fever decreased. The apparent success of this system further promoted the SSS concept. Waring experienced early success, but other engineers were critical of his SSS design and the methods he used to promote his product and company. It took several years, but eventually evidence was gathered that suggested the Waring system Hering 1887 had significant shortcomings, even the system constructed in Memphis.

With the success of the Waring SSS design, two centralized water-carriage technologies (combined and separate) were firmly established in the late nineteenth century, but there was little guidance to help select the proper technology for a particular city. In an attempt to remedy this situation, the U.S. National Board of Health sent Rudolph Hering, an American engineer, to Europe in 1880 to investigate European sewerage practices. In his report, he suggested a model for the choice between centralized combined- and separate- Hering 1881 sewer systems. Hering's model recommended using CSSs in extensive and closely built-up districts (generally large or rapidly growing cities), while using SSSs for areas where rainwater did not need to be removed underground. Ultimately, Hering concluded that the final decision should hinge on local conditions and financial considerations because neither system had a significant sanitary advantage.

During the late nineteenth century, engineers had identified the basic information needed to successfully plan and design centralized sewer systems: (1) surface topography, (2) average and extreme rainfall, (3) the physical characteristics of the soil and the character of the surface, (4) population density and its future prospects of growth, (5) the disposal of rainfall, and how much, if any, should be taken into Philbrick sewers, and (6) the ultimate disposal of the sewage itself. However, no standardized set of procedures existed for planning and designing the system and the newness of the technology prevented the development of a standardized decision process to choose between a combined- or separate-sewer system. Joel A. Tarr argues that a simple design choice between two clearly defined technologies (e.g., combined- or separate-sewer system) should be made based on a rational Tarr model of engineering choice (e.g., cost-benefit calculations). The lack of standardization in the decision mechanism and design procedures, however, prevented a rational model from being developed.

The debate over sewerage technology choice continued during the 1880s despite Hering's report and the acceptance of its recommendations by many engineers, public health officials, and sanitarians. By the 1890s, most engineers had accepted Hering's recommendations for sewer technology choice. The general thought prevailed that neither the combined- or separate-sewer system had significant sanitary advantages. The choice for implementation was instead based upon local needs and system costs. In dense urban areas, storm water had to be considered in the wastewater management plans. CSSs required only one conduit and were thus less costly than a full separate system that required two conduits, one for the removal of household wastewater and another for storm water. Therefore, the perceived cost benefits of CSSs made them the primary system constructed in urban areas in the 1890s. Before the end of the century, however, many began to reevaluate the SSS because it was more compatible with the growing trend of wastewater treatment implementation. This idea is discussed in the next section.

White

Tarr

Philbrick

Shift to Centralized Separate-Sewer System Technology

At the end of the nineteenth century, the basic techniques of urban wastewater collection were established, the sewer technologies were mostly developed, and the necessary construction materials and equipment were available. By that time, most major U.S. cities had also constructed some form of a sewer system. In 1909, cities with populations over 30,000 had approximately 24,972 miles of sewers, of which 18,361 miles were combined sewers, 5,258 miles were separate sanitary sewers, and 1,352 miles were storm sewers. In larger cities (populations over 100,000), there were 17,068 miles of sewers, of which 14,240 miles were combined sewers, 2,194 miles were separate sanitary sewers, and 634 miles were storm sewers. The CSS was clearly the predominant wastewater management choice over the SSS in urban areas, especially the larger cities. But, gradually, a shift from the CSS to the SSS as the centralized technology of choice occurred in the early twentieth century. Several factors contributed to the shift, but three stand out as vital: (1) the growing urban population and shifting development patterns, (2) the changing characteristics of wastewater quantity and quality, and (3) the eventual requirement of wastewater treatment.

U.S. Bureau of the Census 1913

During the early twentieth century, the increasing population in urban areas was creating increased wastewater discharges to receiving waters. The population in the United States surged over fourfold from 1850 to 1920. This population increase was accompanied by an increase in the number of cities with populations greater than 50,000

Melosi 1980

(from 392 to 2,722). During the same time period, the percent of total U.S. population in urban areas increased from 12.5 percent to 51 percent. Sewer systems constructed in the late nineteenth century were not planned for this magnitude of population increase and the corresponding increase in wastewater discharged. The rapid industrialization of American cities further changed the characteristics of wastewater being discharged by introducing a variety of new contaminants into the waste stream. In addition, industries typically selected an area to open operations that was close to a cheap labor force, a transportation corridor, and a waste disposal site. This pattern of industrial development helped to increase the population density in urban areas and the amount of wastes discharged to urban waterways.

A centralized CSS discharging to nearby waterways without wastewater treatment was unable to adjust to the augmented wastewater characteristics in the early twentieth century. Combined-sewers merely were transferring the nuisances and public health risks from the urban area to adjacent waterways and to downstream riparian residents. The water quality issue that attracted the most attention in the late nineteenth and early twentieth centuries was the concern for protecting drinking water supplies from sewage contamination. The relationship between sewage-polluted waterways and
Armstrong
disease transmission had been clearly defined. The need for wastewater treatment and water treatment to protect public health was being
Hazen
discussed. The construction of both wastewater and water treatment facilities, however, was a heavy financial burden and few municipalities could afford to construct the infrastructure for water and wastewater treatment. A debate evolved between those who thought it was in the best interest of public health to construct both wastewater and water treatment facilities and those who believed providing only water treatment was more cost effective and provided comparable protection of public health.

Both wastewater and water treatment were limited at the turn of the century. The four most common wastewater treatment technologies were dilution, land application and irrigation of farmlands (wastewater farming), filtration, and chemical precipitation, and they were all more conducive to treating the smaller and more easily
Whipple et al.
controlled separate wastewater flows. Combined wastewater treatment methods targeted dry-weather flow (DWF). An intercepting sewer would be constructed to transport approximately twice the
Whipple et al.
mean daily DWF to a treatment facility or suitable disposal location. Economic limitations constrained the size of the sewers and wastewater treatment facilities to below the size needed to manage the potential high flow rates during wet weather. Storm overflow devices

had to be constructed to provide relief when flows exceeded capacity, which resulted in periodic overflows of diluted raw sewage directly to the receiving water. Few wastewater treatment facilities were constructed in the late nineteenth century to treat combined wastewater because of the associated difficulties. For example, of 27 U.S. cities with wastewater treatment works by 1892, 26 had SSSs (21 used land application methods and six used chemical precipitation). Tarr

Water treatment facilities were not built for combined-sewer systems because those facilities limited capacity to treat combined wastewater during wet weather and because many felt that the diluted combined wastewater was not harmful to receiving waters, believing that the natural dilution and self-purifying capacity of the receiving-water body would be sufficient to treat combined wastewater. Scientific studies indicated that chemical and biological resources of a water body could stabilize wastes through natural purification, and the assimilative capacity of the water body could minimize degradation. Both combined- and separate-sewer systems were planned and designed to discharge the maximum amount that the receiving water could dilute (e.g., an average of 6 ft^3/s of stream flow per 1,000 persons). As cities grew and more cities started discharging wastes to rivers and streams, however, the dilution capacities were being exceeded and the need for wastewater treatment became more apparent.

Hey and Waggy

Fair and Geyer

The state of water treatment in the late nineteenth century was slightly better than the state of wastewater treatment. Filtration was the first water treatment process effectively employed in England and elsewhere in Europe prior to 1829, but was not used in the United States until 1871 following the 1869 publication of James Kirkwood's *Report on the Filtration of Waters*. Research conducted at the Lawrence Experiment Station in Massachusetts produced scientific evidence demonstrating the effectiveness of water filtration to remove germs (e.g., typhoid) from water supplies. The results instilled confidence in filtration technology, justifying the relatively high cost of constructing water treatment facilities. During the 1890s, approximately 20 U.S. municipalities constructed water filtration facilities. The introduction of disinfection technologies was the next significant advance in water treatment. In the early twentieth century, chlorine compounds and eventually chlorine itself were introduced to water supplies to kill disease-causing bacteria. Disinfection was simple, cost effective, and successful in preventing disease transmission via drinking water. Prior to the widespread use of disinfection, municipalities would either install wastewater treatment facilities, drinking water filtration facilities, or a combination of the two to protect their drinking water.

Armstrong
Hey and Waggy

Armstrong

Armstrong
Tarr et al. 1984

Fair and Geyer

The arguments for wastewater treatment included the need to improve or maintain the aesthetic appearance of water bodies, to prevent the exposure of the public to disease-carrying sewage, and to improve the efficiency of water treatment facilities by having a cleaner source of water. The argument against the need for wastewater treatment when drinking water supplies were treated were twofold. First, the need for wastewater treatment to prevent disease outbreaks was in question if filtration and disinfection were used to treat drinking water prior to distribution. And second, the development of nuisance conditions could be eliminated with prudent planning that prevented receiving waters from becoming overwhelmed with wastewater. The argument over the need for wastewater treatment in addition to water treatment usually pitted state and local boards of health, often composed mostly of physicians, against municipalities and their consulting engineers. The boards of health were generally in favor of both wastewater and water treatment for sanitary reasons, while consulting engineers and municipalities generally favored the implementation of only water treatment for economic reasons. The prevailing opinion of noted engineers (e.g., Allen Hazen) during the early twentieth century was against the need for wastewater treatment. This opinion was displayed in an editorial published in a 1903 issue of *Engineering Record*:

Fair and Geyer

Tarr et al. 1984
Tarr and McMichael

Hazen

> "… it is often more equitable to all concerned for an upper riparian city to discharge its sewage into a stream and a lower riparian city to filter the water of the same stream for a domestic supply, than for the former city to be forced to put in wastewater treatment works."

Quoted in Tarr et al. 1984

The arguments against wastewater treatment were successful in the early twentieth century. By 1905, more than 95 percent of the urban population discharged their wastewater untreated to waterways. Little changed over the first quarter of the twentieth century, and in 1924 more than 88 percent of the population in cities of over 100,000 continued to dispose of their wastewater directly to waterways.

Metcalf and Eddy 1928

In the early twentieth century, several factors brought the use of wastewater treatment into favor. First, there was a growing sense of the desirability of resource conservation. The Progressive Movement in the United States from 1900-1914 was advocating the protection of natural resources and was decidedly in favor of protecting water quality. Second, laws and regulations were being passed at local and state levels with the goal of protecting water quality from developing nuisance conditions. The new set of laws and regulations in the early

Schultz and McShane
Tarr et al. 1980

twentieth century provided more power to protect water quality than the laws enacted in the late nineteenth century. Third, following the passage of the more protective legislation, the attitude of the state courts evolved to favor stricter enforcement. Several cases were ruled in favor of downstream municipalities if the discharge of wastewater by upstream municipalities had caused a nuisance condition or property damage. In these cases, the downstream municipality was often awarded compensatory damages, but damages were often not awarded in cases involving the identification of sources of waterborne disease because of the relatively poor understanding of the science behind disease transmission. Occasionally, the fines levied against a municipality encouraged the construction of wastewater treatment facilities. Fourth, opinions expressed by business groups, public health groups, and media representatives were in favor of wastewater treatment facility construction.

Tarr et al. 1980

Tarr et al. 1980

"Sewage Purification..."

Tarr et al. 1980

As the requirement for wastewater treatment was being defined in the early twentieth century by legislation and public opinion, wastewater treatment technology was also improving. The U.S. Public Health Service, its predecessor organizations, and related organizations (e.g., Lawrence Experiment Station) studied stream pollution, water treatment, and wastewater treatment extensively. In the 1890s, studies increased the understanding of the cause-effect relationship between wastewater discharges and disease transmission (e.g., sewage-polluted waterways and typhoid fever). These findings supported the implementation of wastewater treatment to prevent stream pollution. In the twentieth century, the research focused on cost-effective methods to treat wastewater and drinking water. Probably the most influential wastewater treatment development was the demonstration of the cost-effective use of the activated sludge process to treat large quantities of wastewater.

Armstrong

The availability of cost-effective treatment techniques, coupled with the growing requirement for wastewater treatment, eventually led to wider implementation of wastewater treatment in the middle of the twentieth century. The consequence of increased wastewater treatment was the need for a more consistent and manageable wastewater flow. The SSS provided a much more constant and treatable flow compared to the CSS. For this reason, SSSs were favored for newly urbanizing areas where wastewater treatment was needed or would possibly be needed in the future. SSSs also became favored in areas not requiring wastewater treatment because of perceived sanitary and cost advantages compared to CSSs.

Hey and Waggy
Holden

By the end of the 1930s, support for SSSs had gathered enough strength so that municipalities were augmenting CSSs to function as separate or partially separate systems or were completely replacing them with new separate systems. CSSs, however, were still required under specific circumstances, and the decision of which centralized technology to implement was based on several factors including:

Holden

Henderson

- Was there an existing sewer system serving the population in the area; and if so, was it a separate, combined, or partially separate system?
- Was there a waterway nearby and what was the capacity of that waterway to dilute wastewater?
- Was pumping a possible requirement?

In some cities, conditions dictated a mixture of combined and separate sewer conduits. This could result from extending a combined system into a newly urbanizing area by constructing a separate system or replacing a combined system with a separate system by using the previously combined conduit as the storm-water conduit and constructing a new sanitary wastewater conduit. The use of both combined and separate technology in a single city was termed "compound system." Compound systems were usually difficult to manage and often evolved into combined systems.

Folwell

Continued Changes in Urban Wastewater Management

A review of the first half of the twentieth century suggests that progress in collection systems consisted more of new construction and the extension or improvement of old systems than in the development of new techniques. Progress in wastewater treatment technologies, on the other hand, involved the introduction and demonstration of many new techniques, most notably the construction of large-scale activated sludge treatment facilities. In the middle of the twentieth century, suburban migration, increased industrialization, prosperity, and economic expansion continued to create new problems for traditional urban wastewater management efforts in the United States. In the nineteenth century, urban areas contained an integrated mixture of residential, commercial, and industrial land uses with high building density. Rural development, conversely, consisted primarily of farmsteads and low-density residential land use. Wastewater management requirements (e.g., storm-water management) were clearly defined for urban development and rural development. Throughout the nineteenth century, but intensifying in the first half of the twentieth century, migration to the suburbs clouded the differences between urban and rural development.

Bruce

Armstrong

Jackson

During the beginning and middle of the twentieth century, suburban migration continued to change the methods of urban wastewater management. Increased mobility provided by the automobile, efficient roadway systems, and improved public transportation enabled people to live further from their place of employment. Suburban areas could spread further out into rural regions, which forced the extension of municipal services designed for high-density urban centers out into low-density suburban areas. Furthermore, mixed urban development waned in favor of the isolated suburban neighborhood with nearby commercial and industrial districts. The urban sprawl pattern of development required an adjustment to wastewater management methods that had been developed in a different era.

The post-World War II industrial and economic expansion presented additional problems for traditional urban wastewater management methods. Industrial discharges were composed of myriad toxic chemicals, complex organic compounds, and other substances that were previously not considered in wastewater treatment. These complex mixtures presented acute human health risks also previously not considered. The post-war economic expansion created a prosperous society, and the increase in the standard of living increased the consumption of water and the production of wastewater. Recall that a similar increase in prosperity during the middle of the nineteenth century also increased the volume and complexity of wastewater flows, which contributed to the shift from the decentralized privy vault-cesspool system to the centralized sewer systems. The new plumbing fixtures introduced in the middle of the nineteenth century included the water closet, while the new plumbing fixtures introduced in the middle of the twentieth century included showers, dishwashers, clothes washing machines, and food-waste disposal units. The new fixtures again increased the volume of wastewater discharged to sewer systems and changed the composition of wastewater. The augmented wastewater characteristics required changes in wastewater collection and treatment.

Even though suburbanization, industrialization, and the economic expansion in the United States were clearly augmenting wastewater management needs, the traditional methods of wastewater management were not significantly changing in response. Centralized separate-sewer systems remained the technology of choice, but the use of decentralized septic systems in newly urbanizing areas with lower-density population was increasing. Decentralized septic systems were attractive because they eliminated capital expenditures for sewer systems and had fewer operation and maintenance costs compared to treatment facilities.

The response of the federal government to the developing urban wastewater management issue was to enact the Water Pollution Control Act of 1948. The legislation provided for comprehensive planning, technical services, research, financial assistance, and enforcement. The Water Pollution Control Act was extended in 1952 and became permanent legislation in 1956. The 1965 amendments to the Water Pollution Control Act were the first federal legislation to strongly address the issue of protecting water quality. One goal of the 1965 act was to enhance the quality and value of the water resources of the United States. The legislation established a uniform set of water-quality standards. A shift of the fundamental goal of water pollution control occurred with the passage of the 1965 amendments. The traditional goal of protecting public health was still foremost, but now preserving the aesthetics of water resources and protecting aquatic life became additional stated goals.

Despite the series of Water Pollution Control Acts, water quality was still deteriorating in the late 1960s. The federal government made a bold move with the passage of the 1972 Water Pollution Control Act. Earlier acts had set goals for the protection of water quality and had made funds available to help develop and construct wastewater collection and treatment facilities. But the 1972 Act set the unprecedented goal of eliminating all water pollution by 1985 and authorized

expenditures of $24.6 billion in research and construction grants. New regulations were also established for industrial and agricultural polluters. The availability of massive federal funding for constructing new or improving existing wastewater collection and treatment infrastructure lessened the need to search for the most cost-effective solution. Centralized SSSs and treatment facilities had been the most commonly implemented wastewater management infrastructure for newly urbanizing areas prior to the passage of the 1972 Water Pollution Control Act. The newly available federal construction grants further solidified this standing for the next few decades.

Urban Wastewater Management: The Outlook for the Future

Urban wastewater management is at a critical juncture in the United States and elsewhere. Methods must again change in response to urban development, population growth, and diminishing natural resources. Based on information in recent literature, current research focuses, and trends in the engineering and regulatory community, three aspects of wastewater management are becoming increasingly important now and will continue to be important in the foreseeable future development of wastewater management. The three aspects are decentralized wastewater management (DWM), wastewater reclamation and reuse, and heightened attention to wet-weather flow (WWF) management. Currently, consideration of these three aspects in wastewater management planning is improving the functionality of wastewater systems and creating sustainable alternatives to the traditional centralized SSSs.

The reduction in recent years of federal grant money for the construction of wastewater collection and treatment systems required municipalities to search for cost-effective wastewater management alternatives. In addition, federal legislation (e.g., the 1977 amendments to the Clean Water Act) required communities to consider alternatives to the conventional centralized sewer system, and financial assistance was made available. The requirement that municipal and industrial discharges identify cost-effective wastewater management solutions has curtailed the sometimes blind selection of centralized SSSs for newly urbanizing areas. And as stated earlier, since World War II newly urbanizing areas have been constructed with lower density than the historical urban areas for which centralized sewer systems were originally designed. The applicability of centralized management concepts in these less-densely populated urbanizing areas is questionable. The factors of cost-effectiveness and appropriateness have contributed to the development of alternative wastewater management methods including DWM technologies.

U.S. EPA 1997

Jackson

Decentralized wastewater management (DWM) is defined as the collection, treatment, and reuse of wastewater at or near its source of generation. A significant improvement in the newer decentralized technologies compared to the decentralized privy vault-cesspool system of the nineteenth century is the ability to integrate seamlessly and effectively with water-carriage waste removal. From the public's perspective, the primary deterrent to implementation of alternative wastewater management technologies has been the fear of a life-style change. Most individuals desire wastewater management to be unobtrusive, convenient, and not to require significant maintenance efforts on their part. The newer decentralized technologies have been developed to integrate easily with traditional plumbing fixtures and do not require a significant life-style adjustment. Essentially, the core components of DWM are the same as centralized collection and treatment systems, but the applied technologies are different. Water-carriage is still prevalent, but the wastewater is treated on site or near the site and not transported to a central treatment facility.

Crites and Tchobanoglous

Decentralized systems currently serve approximately 25 percent of the U.S. population, and approximately 37 percent of new development. DWM systems have been shown to save money, to promote better watershed management, and to be suitable for a variety of site conditions. Research has improved the operation and management of septic tanks and developed innovative and improved on-site treatment technologies, e.g., intermittent and recirculating packed-bed filtration. The result has been the increased implementation of DWM in developing urban fringe areas, the same areas where centralized SSSs would likely have been implemented two decades earlier if federal funding could have been easily secured.

U.S. EPA 1997

From the policy making and regulatory perspective, the most prominent concern about DWM is the lack of a body of authority with the appropriate powers to operate, manage, and regulate the system in the same manner as a centralized system. Creating such a managing body would require changing the status quo that has existed for many years, something many think is not possible. The primary difficulty in the near future for DWM is anticipated to be overcoming the years of institutional inertia built up in favor of centralized SSSs. One additional issue hindering the implementation of DWM technologies is the limited basic design requirements available. Because of the newness of the current decentralized technologies, engineering textbooks and manuals do not yet have adequate coverage of the concepts. A period of several years is needed until the necessary information is widely available and the ideas become incorporated into standard engineering practice.

U.S. EPA 1997

The second wastewater management concept that will be important in the future is wastewater reuse. Wastewater reuse generally occurs on site or at the end of a centralized collection and treatment operation. The development of local and on-site wastewater reuse technologies will further encourage the use of DWM technologies. DWM, coupled with wastewater reuse, has the potential to be a highly cost-effective wastewater management method in less densely populated urbanizing areas. Increased reuse of wastewater at the end of a centralized collection and treatment operation will reduce the demand for water resources, but will not, in general, promote the use of alternative wastewater management options. Difficulties with wastewater reuse include public perception of selected uses for the reclaimed wastewater and the need to find economic uses of reclaimed wastewater and waste products. Currently, reuse is more attractive economically in the industrial setting than in the residential setting. But with growing populations and the future demands on potable water in residential areas, wastewater reuse will likely become more economical in residential areas.

Crook et al.
Hey and Waggy

Crook et al.
Metcalf & Eddy, Inc. 1991

Managing the quantity and quality of wet-weather flow (WWF) is the final issue expected to significantly influence the development of wastewater management in the future. In the nineteenth and early twentieth centuries, WWF was viewed as a mechanism to cleanse the urban area of built-up filth on roadways and in the sewers. WWF gradually became viewed as wastewater when centralized SSSs developed into the wastewater management technology of choice in the early twentieth century. Separate storm-water discharges were observed to pollute waterways and create nuisance conditions. Even with some early recognition, it has taken the better part of the twentieth century for the importance of WWF in water quality degradation to become thoroughly documented. Currently, all wet-weather induced discharges (e.g., combined-sewer overflow (CSO), sanitary-sewer overflow (SSO), and separate storm-water discharges) are known to have detrimental effects on receiving water.

Ellis
Heaney and Huber
House et al.

U.S. EPA 1998
U.S. EPA 1996

In the late 1960s and throughout the 1970s, regulations were enacted in response to the documented effects of WWF on water quality degradation. The initial step was the 1972 passage of the Federal Water Pollution Control Act Amendments, which established policies for controlling wastewater discharges in an effort to protect water quality and acknowledged storm water as significant. The extension of the National Pollution Discharge Elimination System (NPDES) to include municipal separate storm-water discharges in the 1990s is having a significant effect on urban wastewater management. The requirement of municipal and industrial storm-water control and the current direction of combined-sewer overflow (CSO) and sanitary-sewer overflow (SSO) policies suggest the need to reconsider past wastewater management methods and technologies that were developed before storm-water discharges, CSO, and SSO were water quality concerns.

Dodson
Moffa

Dodson

Due to the widespread problems of CSO, there has been a massive effort to control or eliminate CSOs at the municipal, state, and federal level. The improved understanding of combined-sewer systems (CSS) has renewed the interest in the use of centralized CSSs in the United States and elsewhere under specific conditions. Lessons learned from past combined system problems have enlightened current engineers and improved the operation of existing systems. For example, CSSs can be planned for newly urbanizing areas of the appropriate density to take advantage of new construction to provide adequate inline and offline storage and increased capacity at the wastewater treatment facility. In addition, new construction of wastewater treatment facilities could be coordinated with the new CSSs to accommodate the increased sludge-handling capacity required. The improved storage capacity coupled with improved storm-water management would theoretically reduce CSO frequency.

The SSO problem has also come under scrutiny over the past decade. Most SSOs are a result of excessive groundwater infiltration and storm-water inflow (I/I) causing the sewer system to be overwhelmed. Overflow structures provide the necessary relief to protect the integrity of the collection and treatment system, but have an adverse effect on the receiving water. During wet weather, a sanitary-sewer conduit taking on excessive I/I essentially operates as a combined sewer. Millions of dollars in fines against a municipality can accumulate for SSO violations. Investigations into the causes of the SSO and the implementation of corrective actions could also cost millions of dollars. The level of funds required to address and correct SSO problems suggests the need to reduce wet-weather induced I/I in future wastewater management methods.

Wade

Studies in the past have compared the performance of centralized combined- versus separate-sewer systems. The results from the studies have shown combined and separate systems to discharge similar quantities of pollutants over the long term, suggesting that neither has environmental advantages. This is similar to the conclusions of Rudolph Hering's report to the National Board of Health in 1880. The need for a careful economic comparison between combined and separate systems is vital now that sanitary advantages are not as apparent. An unbiased comparison of combined and separate systems has renewed the interest in CSSs. Heaney et al., for example, reported that CSSs may discharge a smaller pollutant load to the receiving water than separate systems in cases where the storm water is discharged untreated and the sanitary wastewater is treated effectively. They presented an example in southern Germany where CSSs were being designed with extensive infiltration components to reduce the inflow of storm water to the drainage systems, reducing the frequency and magnitude of CSO events. CSSs are also used in Switzerland and Japan with similar results. In the United States, similar micro-management techniques are being used to improve the performance of CSSs. Proper planning of micro-management concepts, especially localized storm-water detention, will improve the performance of new CSSs, making them more attractive in the future.

Carleton
DeFilippi and Shih
Kaufman and Lai

Heaney et al.

Carr et al.

Summary

In summary, the history of urban wastewater management in the United States has an apparently circular tendency. Decentralized waste management (DWM) concepts (e.g., privy vaults, cesspools, dry sewage collection) were predominantly used in urban and rural areas up to the middle of the nineteenth century. During the middle of the nineteenth century, the decentralized privy vault-cesspool system became inadequate and was gradually replaced with centralized water-carriage sewer systems for several reasons, which we grouped into six categories in the first part of the paper. The use of centralized water-carriage has been the preferred wastewater management strategy in the United States up to the present. The centralized technology of choice, however, has changed since the late nineteenth century. CSSs were the original technology of choice until the early twentieth century when the wastewater management paradigm shifted to include wastewater treatment. SSSs then replaced combined systems as the technology of choice.

Centralized SSSs remain the preferred wastewater management option in newly urbanizing areas today. However, due to less dense urban development patterns, DWM technologies have resurfaced as viable alternatives. A better understanding of the fundamental treatment processes has resulted in the development of innovative decentralized technologies. Furthermore, technologies from the nineteenth century have been improved through the application of new equipment, e.g., intermittent sand filtration. Overall, there have been improvements in the planning, design, operation, and maintenance of DWM technologies compared to the privy vault and cesspool technologies of the nineteenth century, resulting in improved performance. In addition to the resurgence in DWM, two other important parts of future urban wastewater management discussed in the paper are wastewater reuse and wet-weather flow (WWF) management. Based on the history of wastewater management and especially recent trends, future urban wastewater management options will need to be an integrated combination of centralized and decentralized management technologies with emphasis on reuse and WWF management. Urban wastewater management will also have to continue to adjust to population growth and distribution trends, changing development patterns, technological innovations, and many of the other societal factors that have influenced wastewater management in the past, that are influencing it today, and that will continue to influence it in the future.

Bibliography

E.L. Armstrong, ed., *History of Public Works in the United States: 1776-1976* (Chicago: American Public Works Association, 1976).

F.E. Bruce, "Water Supply and Waste Disposal," in T.I. Williams, ed., *A History of Technology*, Volume II: *The Twentieth Century* c. 1900 to c.1950 Part II (Oxford: Clarendon Press, 1982).

L.P. Cain, "Raising and Watering a City: Ellis Sylvester Chesbrough and Chicago's First Sanitation System," *Technology and Culture* 13 (July 1972) 353-372.

M.G. Carleton, "Comparison of Overflows from Separate and Combined Sewers: Quantity and Quality," *Water Science and Technology* 22 (October 1990) 31-38.

R.W. Carr, S.G. Walesh, and D. York, "Micromanagement of Stormwater for Wet Weather Control," *Watershed & Wet Weather Technical Bulletin* 5 (January 2000).

R. Crites and G. Tchobanoglous, *Small and Decentralized Wastewater Management Systems* (New York: McGraw-Hill Companies, Inc., 1998).

J. Crook, D.K. Ammerman, D.A. Okun, and R.L. Matthews, "Guidelines for Water Reuse," *EPA-625/R-92-004* (Washington, D.C.: U.S. Environmental Protection Agency, 1992).

S.A. DeFilippi and C.S. Shih, "Characteristics of Separated Storm and Combined Sewer Flows," *Journal of the Water Pollution Control Federation* 43 (October 1971) 2033-2058.

R.D. Dodson, *Storm Water Pollution Control: Industry & Construction NPDES Compliance* (New York: McGraw-Hill, Inc., 1995).

J. Duffy, *A History of Public Health in New York City 1625-1866* (New York: Russell Sage Foundation, 1968).

L.B. Dworsky and B.B. Berger, "Water Resources Planning and Public Health: 1776-1976," *ASCE Journal of the Water Resources Planning and Management Division* 105 (March 1979) 133-149.

J.B. Ellis, ed., *Urban Discharges and Receiving Water Quality Impacts* (New York: Pergamon Press, 1989).

G. Fair and J.C. Geyer, *Water Supply and Waste-Water Disposal* (New York: John Wiley & Sons, Inc., 1954).

A.P. Folwell, *Sewerage: The Designing, Construction, and Maintenance of Sewerage Systems*, seventh edition (New York: John Wiley & Sons, Inc., 1916).

J.A. Goldman, *Building New York's Sewers* (West Lafayette, Indiana: Purdue University Press, 1997).

A. Hazen, *Clean Water and How To Get It* (New York: McGraw-Hill Book Company, Inc., 1907).

J.P. Heaney and W.C. Huber, “Nationwide Assessment of Urban Runoff Impact on Receiving Water Quality,” *Water Resources Bulletin* 20 (February 1984) 35-42.

J.P. Heaney, L. Wright, D. Sample, R. Pitt, R. Field, and C.-Y. Fan, “Innovative Wet-Weather Flow Collection/Control/Treatment Systems for Newly Urbanizing Areas in the 21st Century,” in A.C. Rowney, P. Stahre, and L.A. Roesner, eds., *Sustaining Urban Water Resources in the 21st Century, Proceedings of an Engineering Foundation Conference* (New York: ASCE, 1999).

J.W. Henderson, “Drainage Considerations in the Development of a New Town,” *The Surveyor* 110 (March 9, 1951) 145-147.

R. Hering, “Sewerage Systems,” *Transactions of the American Society of Civil Engineers* 10 (1881) 361-386.

R. Hering, “Six Year’s Experience with the Memphis Sewers,” *Engineering & Building Record and the Sanitary Engineer* 16 (November 26, 1887) 738-739.

D.L. Hey and W.H. Waggy, “Planning for Water Quality: 1776 to 1976,” *ASCE Journal of the Water Resources Planning and Management Division* 105 (March 1979) 121-131.

G. Holden, “Storm-Water Overflow Chambers,” *The Surveyor* 92 (December 24, 1937) 797-799.

M.A. House, J.B. Ellis, E.E. Herricks, T. Hvitved-Jacobsen, J. Seager, L. Lijklema, H. Aalderink, and I.T. Clifforde, “Urban Drainage: Impacts on Receiving Water Quality,” *Water Science and Technology* 27 (December 1993) 117-158.

K.T. Jackson, *Crabgrass Frontier* (New York: Oxford University Press, 1985).

H.L. Kaufman and F.-H. Lai, “Conventional and Advanced Sewer Design Concepts,” *EPA-600/8-78-090* (Cincinnati: U.S. Environmental Protection Agency, 1978).
R.S. Kirby and P.G.Laurson, *The Early Years of Modern Civil Engineering* (New Haven: Yale University Press, 1932).

M.V. Melosi, “Environmental Crisis in the City: The Relationship Between Industrialization and Urban Pollution,” in M.V. Melosi, ed., *Pollution and Reform in American Cities, 1870-1930* (Austin: University of Texas Press, 1980).

M.V. Melosi, “Sanitary Engineers in American Cities: Changing Roles from the Age of Miasmas to the Age of Ecology,” in *Civil Engineering History: Engineers Make History, Proceedings of the First National Symposium on Civil Engineering History* (New York: ASCE, 1996).

L. Metcalf and H.P. Eddy, *American Sewerage Practice: Volume I, Design of Sewers* (New York: McGraw-Hill Book Company, Inc., 1928).

Metcalf & Eddy, Inc., *Wastewater Engineering: Treatment, Disposal, and Reuse*, third edition (New York: McGraw-Hill, Inc., 1991).

P.E. Moffa, ed., *Control and Treatment of Combined Sewer Overflows* (New York: Van Nostrand Reinhold, 1997).

F.S. Odell, “The Sewerage of Memphis,” *Transactions of the American Society of Civil Engineers* 10 (1881).

J.A. Peterson, “The Impact of Sanitary Reform Upon American Urban Planning, 1840-1890,” *Journal of Social History* 70 (1980) 23-52.

E.S. Philbrick, *American Sanitary Engineering* (New York: The Sanitary Engineer, 1881).

R. Rawlinson, “On the Drainage of Towns,” *Minutes of the Proceedings of the Institution of Civil Engineers* XII (Session 1852-1853, 1852).

Report on the Social Statistics of Cities, Vol. 18 and Vol. 19 of *The Tenth United States Census*, compiled by G.E. Waring (Washington, D.C.: GPO, 1887).

“Report of Committee on Disposal of Waste and Garbage,” *Papers and Reports of the American Public Health Association* 17 (1891).

C.E. Rosenberg, *The Cholera Years* (Chicago: The University of Chicago Press, 1962).

S.K. Schultz and C. McShane, “To Engineer the Metropolis: Sewers, Sanitation, and City Planning in Late-Nineteenth-Century America,” *The Journal of American History* 65 (1977) 389-411.

“Sewage Purification and Water Pollution in the United States,” *Engineering News* 49 (April 3, 1902).

J.A. Tarr, “The Separate vs. Combined Sewer Problem: A Case Study in Urban Technology Design Choice,” *Journal of Urban History* 5 (May 1979) 308-339.

J.A. Tarr, J. McCurley, F.C. McMichael, and T. Yosie, “Water and Wastes: A Retrospective Assessment of Wastewater Technology in the United States, 1800-1932,” *Technology and Culture* 25 (February 1984) 226-263.

J.A. Tarr, J. McCurley, and T.F. Yosie, “The Development and Impact of Urban Wastewater Technology: Changing Concepts of Water Quality Control, 1850-1930,” in M.V. Melosi ed., *Pollution and Reform in American Cities, 1870-1930* (Austin: The University of Texas Press, 1980).

J.A. Tarr and F.C. McMichael, “Historic Turning Points in Municipal Water Supply and Wastewater Disposal, 1850-1932,” *ASCE Civil Engineering* 47 (October 1977) 82-86.

J.A. Tarr, T. Yosie, and J. McCurley, “Disputes Over Water Quality Policy: Professional Cultures in Conflict, 1900-1917” *American Journal of Public Health* 70 (April 1980) 427-435.

United States Bureau of Census, *Compendium of the Tenth United States Census, Part I* (Washington, D.C.: GPO, 1883), Table V.

United States Bureau of Census, *General Statistics of Cities: 1909* (Washington, DC:, GPO, 1913).

United States Environmental Protection Agency, "National Water Quality Inventory," 1996 Report to Congress, *EPA-841/R-97-008* (Washington, D.C.: U.S. Environmental Protection Agency, 1998).

United States Environmental Protection Agency, "Response to Congress on Use of Decentralized Wastewater Treatment Systems," *EPA-832-R-97-001b* (Washington, D.C.: U.S. Environmental Protection Agency, 1997).

United States Environmental Protection Agency, "Seminar Publication—National Conference on Sanitary Sewer Overflows," *EPA-625/R-96-007* (Washington, D.C.: U.S. Environmental Protection Agency, 1996).

W. Viessman and M.J. Hammer, *Water Supply and Pollution Control,* sixth edition (Menlo Park: Addison-Wesley, 1998).

M.G. Wade, "Sealing Springfield," *ASCE Civil Engineering* 70 (May 2000) 52-55.

G.E. Waring, *Draining for Profit, and Draining for Health* (New York: Orange Judd & Company, 1873).

G.E. Waring, "The Sanitary Drainage of Houses and Towns," *Atlantic Monthly* 36 (November 1875) 535-553.

G.C. Whipple, E. Kuichling, G.W. Rafter, W.S. Johnson, J.P.A. Maignen, C. Potts, R.W. Pratt, J.W. Alvord, J.H. Gregory, and C.-E.A. Winslow, "Discussion on the Advances in Sewage Disposal," *Transactions of the American Society of Civil Engineers* 57 (1906) 91-140.

W.H. White, "European Sewage and Garbage Removal," *Transactions of the American Society of Civil Engineers* 15 (1886) 849-872.