Is Dilution The Solution To Pollution? Municipal Sewerage Systems In Late Nineteenth Century San Francisco And London

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Abstract

This article explores the historical development of wastewater management planning in two cities: San Francisco and London. Both cities constructed their municipal sewerage networks in the late 1800s, and both cities designed these networks as combined systems, which carry storm water and sewer water in the same pipes. Due to differences in political and public attitudes towards sewage management and to the relative status of engineers versus scientists, London and San Francisco followed different processes in the development of municipal sewer systems. While London entertained a science-based approach that yielded innovative ideas in biological sewage treatment, San Francisco retained a traditional engineering approach that favored sewage conveyance over treatment. Though both cities eventually adopted similar combined sewer systems that have left challenging urban infrastructure planning legacies, London's experimental methods a century ago provide a useful model for infrastructural problem-solving today, as planners attempt to accommodate growing urban populations with infrastructure solutions that achieve multiple public benefits. San Francisco and London are both ripe for new wastewater planning experiments that expand upon nineteenth century British notions of biological treatment, incorporating ecological, social, and economic benefits into municipal wastewater management.

Introduction

The planning concept of designing multi-purpose spaces to maximize public benefits is becoming both popular and practical. This practice has connections to a broader concept of ecological origin: closed-loop cycles. In nature, every element has multiple functions, both to promote redundancy as protection against system failure, and to optimize the use and re-use of finite resources. For example, wetland ecosystems filter pollutants from influent streams, provide nutrient-rich nursery spaces for terrestrial and marine life, and sequester carbon with their dense biomass. To create closed-loop systems seems the newest task of the modern planner, because these systems can combine multiple economic, environmental, and often social benefits. Such thoughtful planning arises from careful examination of all factors involved, after achieving a thorough understanding of the system to be modified.

Our built environment today, however, reflects relatively little closed-loop thought in its planning and design. A legacy of the Industrial Revolution and Modernist thought, many human systems, from transportation networks to suburban subdivisions to sewerage systems, have been constructed with a single beneficiary in mind. These single-purpose engineered solutions to complex urban issues have in recent years given rise to detrimental unintended consequences, due to a lack of forethought by the original designers about the interconnectedness of the urban fabric. This paper explores the development of one such engineered element in the American landscape: wastewater management.

Virtually since its inception in the United States, municipal wastewater planning has focused solely on the efficient quarantine, relocation, and sanitization of a city's sewage. Elsewhere in the world, sewage has been recognized as a biological resource with potential applications as fertilizer, a fuel source, or just another element in an ecological nutrient cycle, to be returned to a larger natural system for re-use (Doughty 1974). The development of combined sewer systems in two important nineteenth century cities, London and San Francisco, illustrate the influence of public ideologies and attitudes in shaping municipal infrastructure. Both cities in the late 1800s were responding to growing urban populations, and both embraced sanitary reform and Enlightenment principles of the Progressive Era. However, while San Francisco focused on expedited conveyance strategies and favored an engineered approach, London was willing to entertain scientific exploration of actual sewage treatment, beyond sheer conveyance. By focusing on the underlying design processes that led to the creation of these two famous sewer systems in the latter half of the 1800s, this paper lends insight into why these systems are so difficult to integrate into today's multipurpose urban fabric, and offers some interesting, if not new, directions for wastewater management.

Context and Impetus for Municipal Sewerage

Both San Francisco and London share a form of municipal sewerage known as a combined system, which is an increasingly rare artifact of nineteenth century wastewater planning. Its origins trace back to engineers in the mid-1800s who believed that combining storm water with sewer water would eliminate the worst of the city's sewerage problems, by removing sewage from streets and by minimizing odor through dilution. Both cities were faced with population increases and with prevailing attitudes toward sewerage technology, which emphasized conveyance of sewage out of the public realm at all costs, regardless of ramifications on the surroundings. By 1850, London was already the largest metropolitan area in Europe with a population of 2.3 million inhabitants, whereas San Francisco was still a small port city of 36,000 people. Over the next 50 years, however, both cities witnessed exponential growth: London tripled its population to 6 million and San Francisco grew by an order of magnitude to 340,000 (ONS 2004; CGSL 2007).

Existing wastewater management conditions in both San Francisco and London in the mid-nineteenth century highlighted a clear need for city-wide sewerage. As cities densified, increasing water demands led to problems with sewage disposal, from raw sewage overflows into city streets to contamination of the urban water table (Schultz and McShane 1978). Initial responses to these health risks and odor nuisance caused by street sewage actually compounded the problem, as individual property owners haphazardly constructed their own underground sewer pipes (SFPUC 2007). Without oversight by a city-wide agency or any sewerage guidelines, many sewers were ineffective, having been built on the uphill sides of streets or narrowest at the lower ends (Grunsky 1909).

In London as well, unsuccessful attempts to manage municipal sewage spurred a concerted professional effort to devise a better system. Unlike San Francisco, however, London's sewage problems arose from the problematic schemes of a royally-appointed engineer rather than uncoordinated citizen efforts. Joseph Bazalgette, the chief engineer of the London Metropolitan Board of Works in the 1850s, devised and implemented the original plan for London's combined sewer system. This scheme piped wastewater underground through the city into the River Thames Estuary via innovative cement pipes that leaked far less than conventional brick or clay pipes. Bazalgette's system, however, became somewhat unpopular by the 1880s when sewage releases ceased to correspond with an *outgoing* tide. A famous incident called The Great Stink occurred during the summer of 1858 when stagnant Thames sewage became so noxious that Parliament suspended its session and convened city-wide hearings to devise a solution (Halliday 1999).

The Rise of Professional Sanitary Engineering

Over the course of the nineteenth century, health experts, engineers, and the public drew attention to deleterious impacts of existing wastewater disposal practices and criticized such practices in both San Francisco and London. Foremost in planning literature is Edwin Chadwick, who is largely credited as the founder of the 1840s sanitary movement in London that arose after a series of cholera epidemics, which fueled the development of the modern public health and planning professions. Similarly, as was the case with numerous urban reform issues during the Progressive Era, San Francisco's municipal sewerage construction was pre-dated by a flurry of literature bemoaning the public health risks of sewage in the city. Pamphlets such as, "Hygiene: as regards the sewerage of San Francisco" (Stout 1868), "Report on a System of Sewerage" (Humphreys 1876) and "The Problem of the Sewerage of San Francisco: A Polyclinic Lecture" (Stallard and London 1892) chorused that defective sewerage was a driving factor in regular disease outbreaks that often claimed lives (Manson 1893).

The response to these calls for action in cities like San Francisco and London eventually led to the creation of a professional wastewater management field. British civil engineer Baldwin Latham first coined the term "sanitary engineering" in 1873, at first as a loose collection of professionals that included plumbers along with engineers (Tarr 1984). In 1848, a London Metropolitan Commission of Sewers was established, and was later dissolved into the Metropolitan Board of Works in 1855. This group recruited scientists and engineers to design a solution to the city's municipal sewerage problems. In 1882, a Royal Commission on Metropolitan Sewage Discharge held hearings to examine water quality in the lower Thames River, to solicit advice and new ideas from the city's scientific and urban communities (Hamlin 1988).

In San Francisco, the development of a municipal sewerage system first began in August 1892 with the creation of a Board of Engineers. One Board member, Carl Grunsky, was largely responsible for the city's sewer system design in 1899, and eventually became the City Engineer from 1900 to 1904. According to Grunsky (1909), the purpose of creating a sewerage system in San Francisco was "to better the primitive conditions which have been maintained there too long, and to call attention to a novel solution of the storm-water flow problem which is an outgrowth of the study of San Francisco conditions." Combining the pressure by health and engineering professionals with the results of their own field studies of existing sanitary conditions in San Francisco, the Board of Engineers in 1893 announced a plan for an interconnected municipal sewerage system.

Both San Francisco and London, however, experienced high turnover of their municipal engineers, perhaps because the task was too challenging or simply undesirable. Between 1848 and 1855 in London, no less than six sewer commissions struggled with developing a unified municipal system, and one commission apparently wrestled with 137 different schemes for handling London's wastewater (Halliday 2004). Similarly in San Francisco, only four months after its creation, the Board of Engineers was dismissed in January 1893 by San Francisco's Board of Supervisors, because the Engineers had been attempting too much scientific analysis and not enough prescriptive engineering, in the minds of the Supervisors (Manson 1893). The Board of Supervisors then renamed two of the same people from the Board of Engineers as "Engineers in Charge," who were again instructed to design and build a city-wide wastewater management system. The work of these two engineers, Carl Grunsky and Marsden Manson, has become the foundation for most of San Francisco's sewerage since that time (Grunsky 1909). Despite their accomplishments, the Engineers in Charge were again dismissed in 1893 and for the next six years virtually no planning occurred on the sewage management front. Not until 1899, when the first San Francisco Waste Water Master Plan was released, did wastewater planning re-emerge, driven by public concern over pollution overflows onto the city's beaches.

Thus, it was in response to public opinion, not experimental science that in May 1899, the San Francisco Board of Supervisors decided once again to continue Grunsky and Manson's engineering work. However, it was not until September that funds were definitively earmarked for developing this citywide system. Although both San Francisco and London were strongly influenced by public opinion in developing wastewater management, London's government took quick action, whereas San Francisco seemed reluctant about actually funding municipal wastewater treatment planning.

Contrasting Paradigms: Biological Innovation versus Conventional Engineering

Interestingly, in mid-nineteenth century London, the experiments and surveys of individual scientists and planners, not engineers, proved the most influential in driving the development of London sewerage technology. London in the mid-1800s was a hotbed of experimentation, in terms of both technological advances and institutional structures, to explore new municipal sewerage designs. In 1876 alone, 476 patents were approved for precipitation processes to remove solids from wastewater, and the idea of sewage farms was also proposed as a way to handle sewage sludge (Hamlin 1988). In addition to Edwin Chadwick, other pioneers like Joseph Bazalgette, William Dibdin, and August Dupre deserve attention for their contributions to the development of contemporary wastewater treatment practices. Much of the legacy of these individuals in London sanitary planning history stems from the dual support from government and public sentiment for scientific experimentation in pursuit of a sewerage solution.

On the other hand, San Francisco city officials discouraged scientific innovation in favor of safer, conventional engineered approaches to sewerage design. Several contemporaneous ideological and political trends may help account for these differences between San Francisco and London wastewater policies. First, in contrast to Britain, American engineers trumped scientists as technological innovators. In the mid-nineteenth century, the scientific community held much less sway over sanitation theory than did engineers, for "a politics of anarchistic growth and individualism largely marginalized scientists and doctors in the formation of policy" (Platt 2004, 152). Platt further asserts that scientists simply could not compete with "the nearly sacred space reserved for engineers in planning large-scale infrastructure projects to improve the quality of urban life." This sentiment is reflected in the fact that in San Francisco, a Board of Engineers with only two members - rather than a committee of scientists - was appointed to design the sewage system, and these two men were promptly fired after only four months for their extensive surveys of hydrologic, topographic, and tidal regimes in the San Francisco area (Grunsky 1909).

Secondly, active local enterprise in the United States seemed, at the time, to obviate the need for centralized government control over the development of public works and urban infrastructure. Sam Bass Warner has labeled this concept "privatism," meaning individual-oriented pursuit of wealth. Sanitary engineers sought recognition of their budding profession from local public and private sectors, which discouraged them from trying experimental or untested technologies. Thus, as they struggled to gain status in the field, engineers often avoided experimental solutions involving risk in order to maintain professional prominence (Tarr 1984). Additionally, since engineers were wedded to local power brokers, the "engineers were able to retain their privileged positions by proposing ever-bigger technological fixes that generated more and more jobs and contracts for the politicians to dole out" (Platt 2004, 159). Fueling the engineers' confident claims was the federalist American public, who, because of their traditional mistrust of centralized government, often looked to local politicians or private interest groups for essential services like water and sanitation (Schultz and McShane 1978).

As a result, American engineers acquired a powerful voice at the urban design table, and city officials most often agreed with the advice of these strategic elite. At the urging of engineers in the 1870s and 1880s, many cities adopted expensive sewer building programs that paved over massive portions of the city to improve drainage and to hide this new wastewater infrastructure (Schultz and McShane 1978). As Konvitz (1985) asserts, the construction of urban water and sewerage systems led to a rapid and drastic change in the American city's form, and in particular its hydrologic regime. By the time San Francisco began to seek engineers to design its system in the 1880s, London had moved beyond initial design into treatment, soliciting scientists to explore ways to reduce odors and break down municipal sewage.

Municipal Sewerage Goals: Conveyance versus Treatment

The different sectors of expertise upon which San Francisco and London relied seem to correlate with differences in the cities' overall goals of wastewater management. While San Francisco was consumed with finding a conveyance solution to street sewage issues, London had already experienced the drawbacks of conveyance to local receiving waters, and was beginning to explore actual treatment technologies. Though causality is unclear, it is interesting to note that in San Francisco where engineers predominated, a single-purpose conveyance system arose, whereas in London where scientists were encouraged to devise solutions through experimentation, new innovative treatment technologies emerged beyond simple conveyance strategies.

At the outset, both San Francisco and London recognized the paramount need for a new system that could convey sewage away from the public realm. The intent behind Bazalgette's original 1859 conveyance scheme was affirmed and emulated several decades later by American engineers; U.S. Engineer General Alexander offered the following advice to Mayor Selby of San Francisco in 1870: "The true purpose of the sewer is the instant removal from the vicinity of the dwellings of all refuse matter liable to decomposition and which is capable of being conveyed by water" (Alexander 1870).

This system of water-carriage sewerage spread across the United States between 1850 and 1870. In Chicago, the chief engineer for the first sewerage commission, Ellis Chesbrough, built over 54 miles of sewers during the mid-1850s. In response to public demand for municipal sewerage and water supplies, other cities began to create special districts and commissions that could initiate and fund urban wastewater planning

(Tarr 1984). By 1907, nearly every city in the nation had sewers, primarily due to public acceptance and demand for large-scale infrastructural solutions to wastewater issues (Schultz and McShane 1978). Interestingly, San Francisco's public provided the strongest push for wastewater management solutions, whereas in London it was the government that spurred action.

Unlike San Francisco, late nineteenth century London began to move beyond simple conveyance by experimenting with sewage treatment technologies. In response to the shortcomings of Bazalgette's system, Edwin Chadwick devised his own plan called the "arterial-venous" system, in which potable water would be brought into the city, and wastewater exported to agricultural areas as fertilizer. Chadwick borrowed technology from engineer John Roe and proposed egg-shaped sewer pipes that could self-clean (Peterson 1979).

Even more radically, William Joseph Dibdin, August Dupre, and their colleagues pioneered the concept of sewage as an ecosystem amenity that can be biologically treated. Interestingly, as the practice of dumping raw sewage into local water bodies increased, these scientists claimed that rivers were beneficial not for their dilution of raw sewage, but for their capacity to filter and uptake wastewater nutrients. In particular, Dibdin and Dupre championed the concept of biological treatment of wastewater, which actually became widely accepted across Britain at the time

Dibdin was chief chemist for various London agencies in the 1890s and was responsible for monitoring water quality in the Thames estuary, the main outfall of Bazalgette's municipal sewerage system. Contrary to prevalent notions at the time, he proposed that Thames estuary microorganisms could potentially purify London's sewage. This hypothesis grew out of a series of scientific experiments and hypotheses about sewage treatment during that time. In examining Thames mud, scientist Henry Clifton Sory was the first to assert that "an enormous quantity of this sewage is consumed by minute organisms … which feed upon it, so that it is their meat, and it ceases to be sewage" (Hamlin 1988, 201).

Meanwhile, toxicologist August Dupre first proposed that sewage could be oxidized by aerobic bacteria. He wrote to Dibdin in 1885 that:

> the destruction of organic matter discharged into the river in the sewage is, practically, wholly accomplished by minute organisms. These organisms, however, can only do their work in the presence of oxygen, and the more of that you supply the more rapid the destruction" (Hamlin 1988, 202).

In 1888, Dupre formally presented the biological treatment argument to the London Sanitary Institute, saying "our [sewage] treatment should be such as to avoid the killing of these organisms or even hampering them in their actions, but rather to do everything to favour them in their beneficial work" (Hamlin 1988, 203).

Inspired by these and other discoveries, Dibdin invented the contact filter bed in the early 1890s, hailed as one of the first instances of using "biological" technologies in sewage treatment (Hamlin 1988). It represented a change in sewage treatment philosophy, from one concerned with preventing decomposition by any means necessary, to one that aimed to speed the biological processes that break down sewage naturally (Hamlin 1988). Based on a series of experiments in 1894 that ran sewage through a filter that attracted bacteria, Dibdin proved that given the correct balance of oxygen and nutrients to the organisms such a contact filter could, and eventually *did*, purify seven million gallons of effluent per week. Dibdin's contact filter was perhaps a derivative of the slow sand filter purification system for drinking water, first developed in 1804 by John Gibb and later applied to London's drinking supply by James Simpson in 1829. Simpson's system became known as the "English system" and was readily accepted globally for drinking water pre-treatment (Melosi 2000).

By 1897, Dibdin had become a professional sewage treatment consultant, helping several towns outside London install contact filters in their treatment facilities over the next decade. The technology was celebrated as being "cheap, automatic, and simple"; newspaper editorials "expressed satisfaction with the bountiful world that it both illustrated and utilized, and expressed astonishment that it had taken so long to recognize so obvious and simple an answer" (Hamlin 1988, 215). Manchester city solicitor M.P. Balfour Browne neatly summarized this new direction in British sanitary engineering trends:

> sewage disposal at one time was simply a matter of engineering … and it is only recently that this matter has passed out of the hands of the chemist and passed into the hands of the biologist, who will tell us … that the method, and the only method, of disposing of sewage is by the bacterial method (Platt 2004, 157).

Biological treatment thus became the standard method of sewage disposal for many British towns outside London during the late 1800s.

Although Dibdin, Dupre, and other biological treatment advocates presented compelling ideas that were well-received in nineteenth century Britain, they were overshadowed by conventional engineering solutions for the better part of the twentieth century. It has only been in recent years that several of their basic tenets have resurfaced under the guise of "new" environmental planning ideas. First, Dibdin had arrived at the conclusion that chemicals did not substantially improve the removal of solids from sewage during treatment, and so may have been one of the first to advocate for non-chemical treatment. After experimenting with various types of chemicals, he concluded that neither chemical type nor quantity contributed as significantly to sewage breakdown as did biological decomposition (Hamlin 1988). Another strikingly prescient practice of Dibdin's in the 1890s was his adaptive management of the sewage and water quality in the Thames River. Rather than add a fixed quantity of chemicals to the river in regular intervals, Dibdin's team ran weekly tests of biological oxygen demand (BOD), dissolved oxygen (DO), and fish life in the river, to custom tailor how much chemical treatment was necessary at different times. His three years of testing oxygen and organic matter proportions in the Thames is hailed as the first systematic exploration of oxygen balance in a large water body (Hamlin 1988). Perhaps most interestingly, Dibdin used organic metaphors to describe sewage treatment, presenting an alternative paradigm to standard chemical sterilization schemes. In describing the biological contact filter, "the life of the filter, in fact appears to be practically without limit, providing always that the balance between aeration and food supply to the organisms be preserved" (Hamlin 1988, 215). By describing this filter form of wastewater treatment as a living thing that sometimes needs rest in order to recuperate after an effluent overload, these scientists had begun to conceive of sewage as a nutrient with possible intrinsic value.

In stark contrast to London's deliberate attempts to minimize water pollution in the late 1800s, American engineers viewed treatment of municipal effluent as superfluous. In a rather ironic excerpt, sanitary engineer Allen Hazen stated in his 1907 book *Clean Water and How to Get It*, "the discharge of crude sewage from the great majority of cities is not locally objectionable in any way to justify the cost of sewage purification" (Tarr 1984, 243). Hazen then advised that it should be the downstream city's responsibility rather than the polluter's to clean its water before drinking it. Although a faction of Progressive reformers at the time was beginning to demand legislation to protect water quality, Hazen's popular theory generally prevailed with American cities and sanitary engineers.

In San Francisco, for example, engineers in the 1890s remained convinced that dilution was the solution to pollution. For San Francisco's primary engineer Carl Grunsky, the intense flux of tides through the Golden Gate channel seemed a perfect natural toilet flush. He wrote:

> through the Golden Gate, along the northern part of the city, there is a daily tidal inflow and outflow of enormous magnitude, and there can be no question that when the city has so increased in population … it will always be possible to concentrate the entire volume of sewage proper for discharge at the most suitable points into the ebb flow (Grunsky 1909, 359).

By the 1890s however, as in London, contamination of San Francisco's receiving waters began to draw attention. The 1893 Progress Report on the city's sewerage system noted that as a result of direct Bay discharge from sewerage pipes "this city is gradually being encompassed by a margin of filth deposits" (Grunsky 1909, 306). Unfortunately, these observations yielded little change in the attitude favoring conveyance over treatment in San Francisco, even as treatment strategies arose. American engineers in the late 1800s seemed entirely uninterested in, though not uninformed about, alternative or biological means of treatment. With respect to experiments in non-chemical and biological methods of sewage treatment, Platt (2004) claims that during the 1890s no knowledge gap existed between British and American engineers in the area of wastewater technology.

Despite advances in technology around the turn of the century, many U.S. cities remained unwilling to invest in actual waste treatment infrastructure, favoring the engineering solutions of waste removal. Between 1908 and 1925, policy makers in major U.S. cities:

> stubbornly refused to install even a single water filtration station or full-scale sewage treatment plant. Instead, they continued to build one gigantic project of hydraulic engineering after another, justifying their actions with the outmoded notion of nature's boundlessness (Platt 2004, 159).

Thus, the dominant paradigm in American wastewater infrastructure from the 1880s to today has entailed massive and permanent structural changes to streets and building arrangements that guide and limit patterns of urban development (Konvitz 1985). Repeatedly, single-purpose design strategies were developed without thought to potential consequences on other system elements, either at the time or in the future.

Some aspects of the engineers' environmental legacy should be highlighted. Their efforts were instrumental in incorporating infrastructure planning agencies and policies into urban governance, and they facilitated public acceptance of local government control over comprehensive city planning (Schultz and McShane 1978). Nevertheless, contemporary planning theory struggles to integrate these heavily engineered municipal sewage treatment facilities, created for a single purpose, into the urban fabric to maximize multiple public benefits such as recreation, education, environmental enhancement, and to minimize public harm from disease and environmental and social injustice.

Early Regulation

Once these municipal sewer systems were established in San Francisco and London, regulations began to shape early wastewater management policy. By 1866, all London houses were required connect to main sewers. London's progressive 1876 Rivers Pollution Prevention Act stipulated that "sewage can be discharged to rivers only if the best practicable and available means have been used to render sewage matter harmless" (Crichton 1994, 186). In contrast, San Francisco trailed thirty years behind London in its wastewater regulations, and even then did not share London's concern over environmental pollution.

San Francisco's first Board of Public Works was created in 1900 to manage street-and-sewer construction with the thought that a professional and salaried staff could efficiently improve sewerage conditions in the city (Grunsky 1909). The Board wasted no time in creating city ordinances to regulate urban wastewater; during its first year it passed Ordinance 136, "Declaring it the Duty of Property Owner to Repair Side Sewers or Drains, and Making it a Misdemeanor to Neglect the Repair of Same After Notice Received from the Board of Public Works" (SFBS 1924). Under this ordinance, property owners must repair their portion of the system within three days of Board notice or be charged with a misdemeanor. San Francisco enacted an early environmental quality provision in 1901, though its main focus was on protecting sewer worker health; it prohibited the dumping of steam, hot gases, or toxic chemicals into sewers, with a penalty of a $500 fine (SFBS 1924).

After this initial phase of differences in analysis, experimentation, and early regulation between 1850 and 1900, municipal wastewater management in both London and San Francisco progressed largely in parallel. Both cities decided that combined systems, as designed by Bazalgette and Grunsky respectively, afforded the most relief of the risks posed by sewage at the time, both enlisted expert advice from professional engineers through city sewerage commissions and boards, both invested little in new technologies during the twentieth century, and both are still plagued with high maintenance costs of 150-year-old predominantly brick sewers.

Twentieth Century Development

As the twentieth century progressed, the field of urban wastewater management did not keep pace with technological and theoretical innovations in other scientific and planning disciplines. As denounced in a 1958 issue of Fortune magazine, America's water supply and sewerage:

> remain a signal failure in public works. These vital deficiencies are being attacked haphazardly, reluctantly, and locally, instead of on an area-wide basis, which is the only effective approach. And not only are water and sewerage facilities woefully deficient, their potential as a powerful tool for shaping communities is being almost totally overlooked (Melosi 2000, 296).

Contemporary urban storm water and sewage planning policies in cities such as San Francisco remain disappointingly similar to the ideas of the original founding sanitary planners in the United States over a century ago. Since its inception, the concept of wastewater management as a capital-intensive system maintained by specialized professional engineers has been accepted as an unchanging element of the urban landscape (Tarr 1984). Consequently, little effort was made during the twentieth century to develop more effective alternative wastewater technologies.

Despite their original appeal, changing population size and environmental values have steered San Francisco and London's municipal sewer systems back into disfavor. San Francisco's combined system now handles wastewater from 740,000 residents, while London's struggles with over 13 million; San Francisco has 1,000 miles of sewer pipes in contrast to London's 40,000 miles; and San Francisco relies on three treatment facilities fed by 20 pump stations, while London manages 349 treatment plants fed by 2,478 pump stations. Furthermore, the City of San Francisco experiences an average of ten combined sewer overflow (CSO) events annually, in which minimally treated sewage enters the Bay, while London experiences 60 CSOs each year (TWU 2005; SFPUC 2007). Both cities are currently in the process of upgrading their systems, with the San Francisco Wastewater Master Plan by the San Francisco Public Utilities Commission (PUC), and the Thames Tideway Strategic Study (TTSS) by the private Thames Water Utility. According to the San Francisco PUC, 70 miles of the city's sewers are undersized and require replacement. The PUC website shows images of several street cave-ins from underlying pipe failure (SFPUC 2007). Similarly, the TTSS Chairman asserts in the Study's introduction that "Bazalgette's visionary approach of combined sewers that discharge to the Thames during heavy storm rainfall, instead of flooding the streets and properties of London, is today at the root of a problem that many believe is no longer acceptable in the 21st Century" (TTSS 2005, i).

Though the legacy of this century-old wastewater infrastructure has created significant challenges for modern planners in San Francisco and London, it may also be viewed as a singular opportunity to create new amenities in the urban fabric that serve multiple functions. In the past 20 years, a cautious exploration of alternative treatment methods has begun to grow worldwide, with the rise of constructed wetlands for wastewater treatment. Already being attempted in Bay Area cities such as Petaluma, this biological treatment technology offers immense potential to 'close the loop' in an ecological sense, through the transformation of waste to nutrients in ways that provide multiple public and ecological benefits.

Conclusion

In light of the historical context in which London and San Francisco developed their municipal combined systems, some of the detrimental impacts of these heavily-engineered infrastructural elements on today's urban environment are better understood. Fears of epidemic disease outbreaks and odor nuisance escalated with the cities' rapid population growth, fueling the push towards engineering sewage out of the urban landscape altogether. However, the formative influences of public opinion and professional engineering shaped the development of massive infrastructural solutions to wastewater management in San Francisco, whereas London's top-down government structure provided protection and encouragement of experimental and often innovative sewage conveyance and treatment solutions.

If voices like Dibdin's had contributed to nineteenth century sanitation conversations in San Francisco, would today's system be any different? Maybe not, but perhaps a small window might have been left open to the possibility of using biological processes as powerful engineering forces in their own right. Only recently have engineers and scientists begun to revisit the value of nature's closed-loop cycles, experimenting with how to most efficiently re-use scarce resources. In San Francisco, new wastewater solutions are being explored, such as decentralized constructed wetlands for wastewater treatment (SFPUC 2007). Elsewhere in the Bay Area, constructed wetlands already treat and polish municipal wastewater while simultaneously regenerating valuable wetland habitat. Local examples include Ellis Creek Water Recycling Facility in Petaluma, the Hayward Marsh, the Chevron refinery Martinez Marsh, and the Las Gallinas Sanitary District plant. The burgeoning experimental technology of using constructed wetlands to both treat wastewater and provide recreation, education, and habitat restoration opportunities, may provide a glimpse towards future visions of urban wastewater systems as multiple-benefit living amenities that urban residents and wildlife alike can appreciate.

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