Water and Wastes: A Retrospective Assessment of Wastewater Technology in the United States, 1800–1932

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During the 1970s, to a greater extent than ever before, the federal government attempted to regulate the effects of technology upon the society. The environment was a critical area of concern, and environmental quality ranked high on the policy agenda. In December 1970 a presidential order created the Environmental Protection Agency (EPA) to mount a coordinated attack on environmental problems. The broad legislative authority for the EPA programs is based primarily on nine separate acts dealing with air, land, surface and groundwater, and noise pollution passed during the decade. In large part, however, research and policy concerned with these acts have been devoid of a historical dimension that might increase knowledge of the evolution of environmental problems or inform policymakers.

In an attempt to provide such information on one environmental medium, a group of faculty and graduate students at Carnegie-Mellon University conducted a study for the National Science Foundation (NSF) entitled *Retrospective Assessment of Wastewater Technology in the*

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United States, 1800–1972.[1] This study utilized the technology assessment approach that developed in the late 1960s and early 1970s from concern over the negative effects of technology on society. Technology assessment is generally defined as the "systematic study of the effects on all sectors of society that may occur when a technology is introduced, extended, or modified, with special emphasis on any impacts that are unintended, indirect, or delayed."[2] Retrospective technology assessment attempts to utilize the technology assessment model in regard to past phenomena.[3]

[1]Joel A. Tarr, project manager and co–principal investigator, Francis C. McMichael, co–principal investigator, James McCurley III, and Terry Yosie, *Retrospective Assessment of Wastewater Technology in the United States, 1800–1972* (Pittsburgh, 1977). The literature on sewerage technology and on related questions of urban technology and planning has grown rapidly in recent years. For two excellent guides, see Suellen M. Hoy and Michael C. Robinson, eds., *Public Works History in the United States: A Guide to the Literature* (Nashville, 1982); and Eugene P. Moehring, *Public Works and Urban History: Recent Trends and New Directions*, Essays in Public Works History, no. 13 (Chicago, 1982). The present article diverges from most articles about sewerage technology by focusing on the range of the technology's effects on society as well as on its development. The most informative articles dealing with the social and institutional effects of sewerage technology are Jon A. Peterson, "The Impact of Sanitary Reform upon American Urban Planning," *Journal of Social History* 13 (Fall 1979): 83–103; and Stanley K. Schultz and Clay McShane, "To Engineer the Metropolis: Sewers, Sanitation, and City Planning in Late-Nineteenth Century America," *Journal of American History* 65 (September 1978): 389–411. For a useful historical case study of special district government, see Louis P. Cain, *The Search for an Optimum Sanitation Jurisdiction: The Metropolitan Sanitary District of Greater Chicago, A Case Study*, Essays in Public Works History, no. 10 (Chicago, July 1980). The critical and definitive work relating sewerage and water pollution to developments in public health is Barbara Gutmann Rosenkrantz, *Public Health and the State: Changing Views in Massachusetts, 1842–1936* (Cambridge, 1972). The relationship between sewers and urbanization is treated in several studies, the most perceptive of which are Stuart Galishoff, "Drainage, Disease, Comfort, and Class: A History of Newark's Sewers," *Societas—A Review of Social History* 6 (Winter 1976): 121–38; Geoffrey Giglierano, "The City and the System: Developing a Municipal Service, 1800–1915," *Cincinnati Historical Society Bulletin* 35 (Winter 1977): 223–47; Roger D. Simon, "The City-building Process: Housing and Services in New Milwaukee Neighborhoods, 1880–1910," in *Transactions of the American Philosophical Society* 68 (Philadelphia, 1978); and Eugene P. Moehring, *Public Works and the Patterns of Urban Real Estate Growth in Manhattan, 1835–1894* (New York, 1981). A study of one city's struggles to cope with its water supply and wastewater disposal problems is Louis P. Cain, *Sanitation Strategy for a Lakefront Metropolis: The Case of Chicago* (De Kalb, Ill., 1978); this is unfortunately limited by overreliance on an economic optimization model.

[2]For technology assessment, see the articles gathered in Albert H. Teich, ed., *Technology and Man's Future*, 2d ed. (New York, 1977), pp. 229–375; and Edward W. Lawless, *Technology and Social Shock* (New Brunswick, N.J., 1977), pp. 594–604.

[3]For retrospective technology assessment, see Joel A. Tarr, ed., *Retrospective Technology Assessment—1976* (San Francisco, 1977); Howard P. Segal, "Assessing Retrospective Technology Assessment: A Review of the Literature," *Technology in Society* 4 (1982): 231–46.

This article derives largely from our NSF report on wastewater technology. The specific objects of the research were to identify the processes and key decision points involved in the evolution of wastewater technology of human waste disposal, to explore both its primary and secondary social and institutional effects, and to examine the development of public policy toward water pollution problems. In addition, the report dealt with the role played by values in the implementation of technology, as well as the effect of the technology on values. The essential aims of the project were to increase our understanding of water-related environmental problems and to inform policymakers about the larger context of contemporary wastewater questions.

Water Supply and Waste Collection, 1800–1880

The following section considers the reasons for municipal adoption of the water-carriage technology of waste removal in the 19th century. Most technology assessments accept the technology under examination as a given, expressing concern only for its effects. In the case of wastewater technology, however, we examined the workings of the previous system used to dispose of human wastes and wastewater—labeled the "cesspool–privy vault" system—in order to gain insights into the reasons for the adoption of the new water-carriage technology.

Until well into the second half of the 19th century, most American urbanites depended for their water supplies on local surface sources such as ponds and streams, on rainwater cisterns, or on wells and pumps drawing on groundwater. Water consumption per capita under these supply conditions probably averaged between 3 and 5 gallons a day. Householders disposed of wastewater from household functions such as cleaning, cooking, or washing in the most convenient manner. Sometimes this meant simply throwing it on the ground, into a street gutter, or into a dry well or leaching cesspool—a hole lined with broken stone.[4]

Human wastes were occasionally deposited in cesspools but more often in privy vaults, which ranged from shallow holes in the ground to receptacles lined with brick or stone located close by residences, even in cellars.[5] Theoretically, they could be either permeable, so that the

[4]Nelson M. Blake, *Water for the Cities* (Syracuse, N.Y., 1956), pp. 12–13; Constance M. Green, *Washington: Village and Capital, 1800–1878* (Princeton, N.J., 1962), p. 95. The estimates of water usage are based on figures reported for cities without waterworks in John D. Bell, "Report on the Importance and Economy of Sanitary Measures to Cities," *Proceedings and Debates of the Third National Quarantine and Sanitary Convention* (New York, 1859), pp. 576–77.

[5]Jon Peterson calls the cesspool–privy vault system the "private-lot waste removal" system. Peterson (n. 1 above), p. 85.

ground could absorb the liquids, or impervious, requiring frequent emptying. Often the ground around the privy vaults and cesspools became saturated with wastes, and then they were covered over with dirt and new ones dug. In 1829 it was estimated that each day New Yorkers deposited over 100 tons of excrement into the city's soil.[6] Most large cities tried to institute periodic cleaning by private scavengers under city contract or by city employees, but services were very inefficient and irregular. The cleaning technology utilized for most of the 19th century was labor intensive and rudimentary—dippers, buckets, and wooden casks. The process created both aesthetic nuisances and health problems, primarily through pollution of groundwater and wells.[7] Scavengers collected the wastes in "night soil carts" and disposed of them in nearby watercourses or dumps or on farms, or they sold them to reprocessing plants to be made into fertilizer.[8]

Although both private and public underground sewers existed in the larger cities, such as New York and Boston, they were intended for storm-water drainage rather than human waste removal. These sewers were usually constructed of stone or brick, in circular or elliptical shapes, and were often large enough so that a man could enter them for cleaning. In some of these cities, ordinances prohibited the placing of human wastes in the sewers. The majority of 19th-century municipalities, however, had no underground drains. Street gutters of wood or stone, either on the side or in the middle of the roadway, provided for surface storm water and occasionally for human wastes. Private householders often constructed drains to the street gutter to remove wastewater from cellars.[9]

From approximately 1820 to 1880, demographic and technological factors combined to strain the cesspool–privy vault system and to cause

[6]B. A. Segur, "Privy-Vaults and Cesspools," *Papers and Reports of the American Public Health Association* (hereafter cited as *APHA*) 3 (1876): 185–87; Mansfield Merriman, *Elements of Sanitary Engineering*, 3d ed. (New York, 1906), pp. 139–42; Moehring, *Public Works and the Patterns of Urban Real Estate Growth in Manhattan*, p. 15.

[7]There is information on the "municipal cleansing" practices of over one hundred cities in U.S. Department of the Interior, Census Office, *Tenth Census of the United States, 1880, Report of the Social Statistics of Cities*, comp. George E. Waring, Jr., 2 vols. (Washington, 1887) (hereafter *Social Statistics of Cities, Tenth Census*), and in "Report of Committee on Disposal of Waste and Garbage," *APHA* 17 (1891): 90–119.

[8]Joel A. Tarr, "From City to Farm: Urban Wastes and the American Farmer," *Agricultural History* 49 (October 1975): 601–2. In 1880 the wastes of 103 of the 222 U.S. cities listed in the *Social Statistics of Cities, Tenth Census* (n. 7 above) were used on the land.

[9]See regulations cited in *Social Statistics of Cities, Tenth Census*; see also descriptions of sewers in Julius W. Adams, *Report of the Engineers to the Commissioners of Drainage* (Brooklyn, 1857); Henry I. Bowditch, *Public Hygiene in America* (Boston, 1877), pp. 103–9; Leonard Metcalf and Harrison P. Eddy, *American Sewerage Practice*, 3 vols. (New York, 1914–15), 1:15–19. For private sewers see Peterson, p. 85; Giglierano (n. 1 above), pp. 223–24.

its eventual breakdown and replacement. The two most important factors were urban population growth and new urban water-supply systems with the consequent adoption of household water fixtures. The most critical fixture was the water closet or flush toilet.

By 1860, about 20 percent of the U.S. population was found in communities of over 8,000, and by 1880 the percentage had risen to 28.[10] As cities grew in size, population was also more concentrated, especially in the original central cores. Transportation restricted the distance that population could spread from places of employment and essential urban institutions. Urban density and an explosion of building construction made the existing waste collection system increasingly inadequate. Overflowing privies and cesspools filled alleys and yards with stagnant water and fecal wastes. Often waste receptacles and their overflows were close to wells and other sources of water supply, causing a serious pollution hazard. In addition, paving reduced the ability of streets to absorb rain and increased the possibility of flooding.[11]

The cesspool–privy vault system of waste collection was further stressed by the adoption of another technology—piped-in water. This technology dates back at least to the ancient Roman aqueducts, with more modern examples from 17th-century London and several colonial towns. The movement in 19th-century cities away from a localized and labor-intensive water-supply system to a more capital-intensive system that utilized distant sources took place primarily for four reasons in addition to population increase: water from local sources used for household purposes was often contaminated, tasted and smelled bad, and was suspect as a cause of disease; more copious water supplies were required for firefighting; water was needed for street flushing at times of concern over epidemics; and developing industries required a relatively pure and constant water supply. In addition, rising affluence in the 19th century undoubtedly increased household demands for water.[12]

Philadelphia was the first city to build a waterworks, in 1802. Other municipalities, such as New York, Boston, Detroit, and Cincinnati,

[10]U.S. Department of Commerce, Bureau of the Census, *Historical Statistics of the United States. . . . to 1970*, 2 vols. (Washington, 1975), 1:11–12.

[11]George E. Waring, Jr., "The Sanitary Drainage of Houses and and Towns, II," *Atlantic Monthly* 36 (October 1875): 427–42, esp. 434; Clay McShane, "Transforming the Use of Urban Space: A Look at the Revolution in Street Pavements, 1880–1924," *Journal of Urban History* 5 (May 1979): 288.

[12]Blake (n. 4 above), pp. 3–17; "Community Water Supply," in *History of Public Works in the United States 1776–1976*, ed. Ellis L. Armstrong, Michael C. Robinson, and Suellen M. Hoy (Chicago, 1976), pp. 217–35; and Moehring, *Public Works and the Patterns of Urban Real Estate Growth in Manhattan* (n. 1 above), pp. 23–51.

followed, and by 1860 the sixteen largest cities in the nation had waterworks. There were then a total of 136 systems in the country; by 1880 this had increased to 598. The availability of a source of constant water in the household caused a rapid expansion in usage, as demand interacted with supply. Chicago, for example, went from 33 gallons per capita per day in 1856 to 144 in 1882; Cleveland increased from 8 gallons per capita per day in 1857 to 55 in 1872; and Detroit from 55 gallons per capita per day in 1856 to 149 in 1882.[13] These figures reflect unmetered usage and include industrial and other nonhousehold uses, yet they indicate greatly increased water consumption over a relatively short span of time.

While hundreds of cities and towns installed waterworks in the first three-quarters of the 19th century, few of them simultaneously constructed sewer systems to remove the water because it was believed that the technology was unnecessary, unproved, or too costly. In most cities with waterworks, wastewater was initially diverted into cesspools or existing storm sewers or street gutters; householders often connected their cesspools with the sewers via overflow pipes. The introduction of such large volumes of contaminated water into systems designed to accommodate much smaller amounts caused serious problems of flooding and disposal.[14]

This situation was exacerbated by the widespread adoption of a waste-disposal technology that had not been anticipated by the advocates of piped-in water—the water closet. The water closet actually dated back centuries, but was patented in the United States only in 1833.[15] In cities with waterworks, affluent families were quick to install closets and take advantage of their convenient inside location and comparative cleanliness. For example, in Boston in 1863 (population ca. 178,000), there were over 14,000 water closets out of approximately 87,000 water fixtures. In Buffalo in 1874 (population ca. 118,000), there were 5,191 dwellings supplied with water and 3,310 with water closets. By 1880, although the data are imprecise, it can be estimated

[13]J. T. Fanning, *A Practical Treatise on Hydraulic and Water-Supply Engineering* (New York, 1886), p. 625.

[14]Town of Pawtucket, Committee on Sewers, *Report, 1885* (Pawtucket, R.I., 1885), p. 15; E. S. Chesbrough, "The Drainage and Sewerage of Chicago," *APHA* 4 (1878): 18–19; Town Improvement Society of East Orange, *The Sewerage of East Orange* (East Orange, N.J., 1884).

[15]May N. Stone, "The Plumbing Paradox: American Attitudes towards Late Nineteenth-Century Domestic Sanitary Arrangements," *Winterthur Portfolio* 14 (1979): 284–85. See Reginald Reynolds, *Cleanliness and Godliness* (New York, 1974), for an amusing description of the evolution of the water closet; see also Lawrence Wright, *Clean and Decent: The Fascinating History of the Bathroom and the Water Closet* (Toronto, 1972).

that approximately one-quarter of urban households had water closets (usually of the pan or hopper type), while the remainder still depended on privy vaults.[16]

Water closets greatly increased both nuisance problems and sanitary hazard in urban areas. They were usually connected with cesspools, which were soon overcharged by the increased flow of waste-bearing water. If connected by overflow pipes with surface gutters or sewers intended as water drains, they contaminated them with fecal matter. Soil became saturated, cellars were "flooded with stagnant and offensive fluids," and the need for frequent emptying of cesspools and vaults greatly increased.[17]

The spreading of feces-polluted water created real and perceived health dangers. During most of the 19th century, physicians generally divided into two groups, contagionists and anticontagionists. Contagionists maintained that epidemic disease was transmitted by contact with a diseased person or carrier, while anticontagionists held that vitiated or impure air was the cause. The vitiated air could arise from any number of conditions, including miasmas from putrefying substances such as feces, exhalations from swamps and stagnant pools, or human and animal crowding. By the latter half of the 19th century, the majority of physicians were anticontagionists who believed that filthy conditions accelerated the spread of contagious disease, thus underscoring demands for urban environmental improvements.[18] Public health officials viewed overflowing cesspools with water-closet connections as a threat to a healthful environment. As late as 1894, the secretary of the Pennsylvania State Board of Health, Benjamin Lee, complained that householders persisted in connecting water closets to "leaching" cesspools, thereby distributing "fecal pollution over im-

[16]Boston, Cochituate Water Board, *Annual Report for 1863* (Boston, 1864), p. 43; City of Buffalo, *Sixth Annual Report of the City Water Works, 1874* (Buffalo, 1875), p. 47. The estimate for 1880 is based on information in *Social Statistics of Cities, Tenth Census.*

[17]William H. Bent, George H. Rhodes, and William Tinkham, *Report of Special Committee on Sewerage for City of Taunton* (Taunton, Mass., 1878), pp. 25–26; E. S. Chesbrough, *Report on Plan of Sewerage for the City of Newport* (Newport, R.I., 1880), pp. 5–6; Rudolph Hering, *Report on a System of Sewerage for the City of Wilmington, Delaware* (Wilmington, Del., 1883), pp. 5–6; Maryland State Board of Health, "The Sanitation of Cities and Towns and the Agricultural Utilization of Excremental Matter," *Annual Report, 1887* (Baltimore, 1887), pp. 229–30.

[18]Bell (n. 4 above), pp. 479–575; Charles E. Rosenberg, *The Cholera Years* (Chicago, 1962), pp. 75–81, 117, 202; Charles V. Chapin, "The End of the Filth Theory of Disease," *Popular Science Monthly* 60 (January 1902): 234–39; and George E. Waring, Jr., "The Sanitary Drainage of Houses and Towns," *Atlantic Monthly* 36 (November 1875): 535–51.

mense areas and . . . constituting a nuisance prejudicial to the public health."[19]

The adoption of two new technologies, therefore—piped-in water and the water closet—combined with higher urban densities to cause the breakdown of the cesspool–privy vault system of waste removal and to generate excessive nuisances and health hazards. Some cities attempted to alleviate these hazards by permitting householders to connect their water closets with existing storm sewers, but the latter were poorly designed for waste removal and merely became "sewers of deposit." Another approach, utilized in more than twenty cities, was the so-called odorless excavator, a vacuum pump that emptied the contents of cesspools and privies into a horse-drawn tank truck for removal. This "interim" technology, adopted between the time that cities turned to piped water systems and the time they installed sewers, was both labor intensive and capital intensive.[20] Engineers, public health officials, and other sanitarians realized that no existing system was capable of meeting the new demands. Increasingly, in the second half of the 19th century, they advocated the water-carriage technology of waste removal as a replacement.

Benefits and Costs of Water-Carriage Technology

The water-carriage system of waste removal (or sewerage) was essentially a system that used the wastewater itself as a transporting medium and as a cleansing agent in the pipe. As Jon Peterson notes, it "represented a specialized form of urban planning [that] gradually supplanted long-accepted, piecemeal methods of waste removal, particularly the reliance upon privately-built cesspools and privy vaults and the common municipal practice of constructing sewers without reference to a larger, city-wide plan."[21] In the 1840s, British sanitarian Edwin Chadwick advocated the adoption of a system of self-cleansing earthenware small-pipe sewers that would use the household water supply to dispose of human wastes. A convinced anticontagionist, he believed that odors from decaying organic matter caused the spread of many fatal diseases and that fecal matter had to be swiftly transported from the vicinity of the household. The sewage from this "arterial-

[19]Benjamin Lee, "The Cart before the Horse," *APHA* 20 (1895): 34–36. Lee was concerned with the bacterial danger presented by the fecal pollution.

[20]Azel Ames, "The Removal and Utilization of Domestic Excreta," *APHA* 4 (1877): 65–70. *Social Statistics of Cities, Tenth Census,* listed eleven cities using the odorless excavator in 1880, but this is probably an underestimate.

[21]Peterson (n. 1 above), p. 84.

venous system," he maintained, could be sold for agricultural purposes. Water-carriage technology, therefore, would provide a system of self-financing health benefits.[22]

Chadwick's system was never implemented as he planned, but his vision stimulated debate in Great Britain about technology and health and strongly influenced American sanitarians concerning the benefits of systematic sewerage.[23] The engineers for the earliest sewerage systems in Brooklyn, Chicago, and Jersey City drew heavily on the English sanitary investigations and debates of the 1840s and 1850s, as well as upon the actual experience of London with a system of large brick sewers constructed to remedy the sewage pollution of the Thames River. Throughout the remainder of the 19th century, visits to sewerage works in cities in Great Britain and Europe were almost mandatory for American engineers involved in planning new sewerage systems. Thus, water-carriage technology provides a good example of the international interchange and transfer of ideas and experience concerning an urban technology.[24]

The system of water-carriage removal of household wastes had a number of important characteristics that sharply differentiated it from the cesspool–privy vault system: it was capital rather than labor intensive and required the construction of large, planned public works; it utilized continuous rather than individual batch collection; it was automatic, eliminating the need for human decisions and actions to remove wastes from the immediate premises; and, because of its sanitary and health implications and its capital requirements, it became a municipal rather than a private responsibility.

Extensive debates and discussions concerning water-carriage technology were held by professional associations, municipal officials, and citizens' groups. These debates often dragged on for years and involved the preparation of a number of engineering reports that addressed the comparative advantages of various forms or designs of waste disposal technology.[25] The records of these discussions are

[22]Francis Sheppard, *London 1808–1870: The Infernal Wen* (Berkeley, 1971), pp. 250–78.

[23]Peterson, pp. 86–87.

[24]Probably the most influential report about European sewage systems by an American engineer was Rudolph Hering, "Report of the Results of an Examination Made in 1880 of Several Sewage Works in Europe," *Annual Report of the National Board of Health 1881* (Washington, 1882). For the background and influence of this report, see Joel A. Tarr, "The Separate vs. Combined Sewer Problem: A Case Study in Urban Technology Design Choice," *Journal of Urban History* 5 (May 1979): 308–33.

[25]In some cities, such as Baltimore and Wilmington, opponents of water-carriage technology, by focusing on costs, design problems, and possible pollution effects, blocked construction for many years. In most cities, however, perceived advantages led

marked by a number of forecasts about the water-carriage system, both its benefits and its costs. Benefits forecast by its advocates can be summarized as follows:

1. Capital and maintenance costs of building sewerage systems would represent a savings for municipalities over the annual costs of collection under the cesspool–privy vault–scavenger system.[26]
2. Sewerage systems would create improved sanitary conditions and result in lowered morbidity and mortality from disease; such savings could often be translated into financial terms, further stressing the economic benefits to be obtained by adoption of water-carriage technology.[27]
3. Because of improved sanitary conditions, cities that constructed sewerage systems would grow at a faster rate than those without, by attracting population and industry.[28]

Opponents countered by enumerating these costs:

1. Water-carriage removal would waste the valuable resources present in human excreta that might otherwise be used for fertilizer.[29]
2. Water-carriage technology would create health hazards, such as contamination of the subsoil by leakage, pollution of waterways with

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to construction within a reasonable amount of time after the water-carriage system was proposed. For information on Wilmington, see Carol Hoffecker, *Water and Sewage Works in Wilmington, Delaware, 1810–1910*, Essays in Public Works History, no. 12 (Chicago, July 1981); for Baltimore, see Alan D. Anderson, *The Origin and Resolution of an Urban Crisis: Baltimore, 1890–1930* (Baltimore, 1977), pp. 68–72. In Baltimore, also, the politically influential odorless excavator companies were able to delay construction of a sewerage system.

[26]John Duffy, *A History of Public Health in New York City, 1625–1866* (New York, 1968), p. 415; Hering, *Report on a System of Sewerage for the City of Wilmington, Delaware*, p. 6; Joseph E. Nute, "The Sewerage of Malden" (unpublished B.S. thesis, MIT, 1884); Baltimore Sewerage Commission, *Second Report* (Baltimore, 1899), p. 30.

[27]George E. Waring, Jr., *Draining for Health and Draining for Profit* (New York, 1867), pp. 222–223; J. S. Billings, "Sewage Disposal in Cities," *Harper's New Monthly Magazine* 71 (September 1885): 577–84, esp. 580; Bell, pp. 478–83; F. H. Hamilton, "A Plea for Sanitary Engineering," *APHA* 2 (1876): 368–73; Town of Marlborough Sewage Committee, *Report* (Marlborough, Mass., 1885), pp. 7–8; Massachusetts Board of Health, "The Value of Health to the State," *Annual Report, 1875* (Boston, 1875), pp. 57–75, and "Political Economy of Health," *Annual Report, 1874*, pp. 335–90; Baldwin Latham, *Sanitary Engineering* (London, 1873), pp. 10–14; Henry E. Sigerist, ed., "The Value of Health to a City: Two Lectures, Delivered in 1873, by Max Von Pettenkofer," *Bulletin of the History of Medicine* 10 (October 1941): 473–503, 593–613; Samuel M. Gray, *Proposed Plan for a Sewerage System for Providence* (Providence, R.I., 1884), pp. 8–11.

[28]M. N. Baker, *Sewerage and Sewage Purification* (New York, 1896), p. 11; New London Board of Sewer Commissioners, *First Annual Report* (New London, Conn., 1887), p. 4.

[29]Tarr, "From City to Farm," pp. 601–6; C. A. Leas, "A Report upon the Sanitary Care and Utilization of the Refuse of Cities," *APHA* 1 (1875): 456.

threats to drinking-water supplies and shellfish, and the generation of disease-bearing sewer gas.[30]

3. The costs of sewerage systems would create a heavy tax burden. If financed with bonds, they would impose costs on future generations with no voice in the decision.[31]

It was possible to test the validity of these forecasts only on a very rudimentary basis. Projections of improved local sanitary conditions were accurate, as were those of local health benefits, although the latter often tended to be overstated.[32] The predicted cost savings of sewerage over the annual collection costs of the cesspool–privy vault system probably occurred, although comparisons are difficult; in regard to financial costs, perhaps the most crucial change was the transference of maintenance expenses from the individual householder to the municipality.[33] And forecasts about the risk of wasting the valuable materials contained in human excrement overlooked the difficulty of actually utilizing these wastes on American farms.[34]

The major failure of forecasting, as will be demonstrated, concerned the negative effects of sewage disposal by upstream cities on water supplies downstream. While there were a few critics who warned about the health hazards of water-carriage technology, they were largely ignored because of the belief that "running water purifies itself." This hypothesis depended on chemical and physical methods of analyzing water quality, which demonstrated that after sewage had been in a stream for a certain distance its physical elements dissipated.[35] In the late 19th and early 20th centuries, American urbanites found that the promised benefits of the technology outweighed the predicted costs, and cities embarked on a massive implementation of sewerage systems.

[30]"The Sewage Question," *Scientific American* 21 (July 24, 1899): 57.

[31]Estelle F. Feinstein, *Stamford in the Gilded Age* (Stamford, Conn., 1973), p. 169; Ernest S. Griffith, *The Conspicuous Failure: A History of American City Government 1870–1900* (New York, 1974), p. 20; New London Board of Sewer Commissioners, p. 4; City of Providence, *Report upon Sewer Assessments* (Providence, R.I., 1877), includes information on assessment practices in sixty-nine cities.

[32]For typhoid death rate figures see U.S. Department of the Interior, Census Office, *Report of the Mortality and Vital Statistics of the U.S., Tenth Census*, pt. 2 (Washington, 1886), p. xxvi; U.S. Department of Commerce, Bureau of the Census, *Mortality Statistics 1910, Thirteenth Census* (Washington, 1913), pp. 26–27.

[33]Hering, *Report on a System of Sewerage for the City of Wilmington*, p. 6; Nute, "Sewerage of Malden"; U.S. Department of Commerce, Bureau of the Census, *General Statistics of Cities: 1909* (Washington, 1913), pp. 20–23.

[34]Tarr, "From City to Farm," pp. 611–12. The leading difficulty was transportation, especially as cities grew larger.

[35]William T. Sedgwick, *Principles of Sanitary Science and the Public Health* (New York, 1918), pp. 213, 231–237.

Although the first municipal sewer systems intended for human wastes as well as storm water were built in the 1850s (Brooklyn, 1855; Chicago, 1856; Jersey City, 1859), construction rates accelerated after the 1870s. The first date for which aggregate figures are available is 1890, and in that year the U.S. census recorded 6,005 miles of all types of sewers in cities of over 25,000 population; by 1909, the mileage had increased to 24,972 for cities over 30,000, or from 1,832 persons per mile of sewer to 825 persons per mile. In the latter year, 85 percent of the population of cities with populations of over 300,000 was served by sewers; 71 percent in cities with populations between 100,000 and 300,000; 73 percent in cities with populations between 50,000 and 100,000; and 67 percent in cities with populations from 30,000 to 50,000 (see table 1).[36] Small-diameter sewers were constructed initially almost entirely of vitrified clay pipe, while sewers 42 inches or more in diameter were made of brick. Beginning around 1905, many sewers were constructed of reinforced concrete.[37]

Of the total mileage in 1909, 18,361 miles, or 74 percent, were combined sewers (human and storm wastes in the same pipe) and 5,258 or 21 percent were separate sanitary sewers; only 1,352 miles were solely storm sewers. The choice between separate or combined sewers was an important design question. For the most part, large cities that needed to remove storm water from the streets, as well as household wastewater, installed combined sewers, while smaller cities often constructed sanitary sewers alone, leaving the storm water to run off on the surface.[38] In the 1880s and 1890s, a number of smaller cities installed separate sewers because of the belief, spread primarily by the famous sanitarian Colonel George E. Waring, Jr., that they had superior health benefits compared with the combined sewers. Waring argued, as had Chadwick, that large combined sewers produced sewer gas by allowing the accumulation of fecal matter, while small-diameter separate sewers speeded the wastes from the vicinity of the household. By 1900, however, largely because of the work of sanitary engineer Rudolph Hering, most engineers believed that the two sewer designs had equal health benefits, and decisions regarding implementation of

[36]See the listing under "Sewers" in U.S. Department of the Interior, Bureau of the Census, *Report on the Social Statistics of Cities, Eleventh Census* (Washington, 1895), pp. 29–32; and under "Sewers and Sewer Service," in *General Statistics of Cities: 1909* (Washington, 1913), pp. 20–23.

[37]Harold E. Babbitt, *Sewerage and Sewage Treatment* (New York, 1932), pp. 132–33; H. F. Peckworth, *Concrete Pipe Handbook* (Chicago, 1959).

[38]Tarr, "Separate vs. Combined Sewer Problem," pp. 308–28, 332.

one system rather than another were based primarily on cost factors and on the need for subsurface removal of storm water.[39]

The use of combined rather than separate sewers, given the available treatment technology in the late 19th and early 20th century, made both wastewater treatment and resource recovery more difficult and expensive. The greater volume of wastewater from combined sewers was primarily responsible for the higher costs if treatment at the end of the pipe was planned. Most urban policymakers and their consulting engineers assumed, however, that dumping raw sewage into streams

TABLE 1

Sewer Mileage by Type and Urban Population Group, 1905, 1907, 1909

Population Group	Sanitary Sewers	Storm Sewers	Combined Sewers	Total Mileage by Population Group
1905:				
1. > 300,000	335.2	157.0	8,229.9	8,722.1
2. 100,000–300,000	809.0	120.5	2,961.0	3,890.5
3. 50,000–100,000	965.8	242.8	2,491.1	3,699.1
4. 30,000– 50,000	1,313.4	326.6	1,507.4	3,147.7
Total by type of sewer	3,423.4	846.9	15,189.4	19,459.7
1907:				
1. >300,000	554.8	352.0	9,242.3	10,149.1
2. 100,000–300,000	1,300.0	262.9	3,690.5	5,253.4
3. 50,000–100,000	1,097.1	181.6	2,627.1	3,905.8
4. 30,000– 50,000	1,611.3	383.9	1,562.9	3,558.1
Total by type of sewer	4,563.2	1,180.4	17,122.8	22,866.4
1909:				
1. >300,000	789.5	349.9	9,834.3	10,973.7
2. 100,000–300,000	1,404.4	284.2	4,405.8	6,094.4
3. 50,000–100,000	1,831.5	384.2	2,615.5	4,831.2
4. 30,000– 50,000	1,232.9	333.8	1,505.9	3,072.6
Total by type of sewer	5,258.3	1,352.1	18,361.5	24,971.9

Sources.—Moses N. Baker, "Sewerage and Sewage Disposal," App. A in U. S. Dept. of Commerce and Labor, Bureau of the Census, *Statistics of Cities Having a Population of over 30,000: 1905* (Washington, 1907), pp. 342–47; U. S. Department of Commerce and Labor, Bureau of the Census, *Statistics of Cities Having a Population of over 30,000: 1907*, "Special Reports" (Washington, 1910), pp. 458–63; and U. S. Department of Commerce, Bureau of the Census, *General Statistics of Cities with Populations Greater than 30,000: 1909*, "Special Reports" (Washington, 1913), pp. 88–93.

[39]Ibid., pp. 313–29. For an appreciation of Waring as an environmentalist, see Martin V. Melosi, *Pragmatic Environmentalist: Sanitary Engineer, Col. George E. Waring, Jr.*, Essays in Public Works History, no. 4 (Washington, April 1977). For a more critical appraisal of Waring, see James H. Cassedy, "The Flamboyant Colonel Waring: An Anti-Contagionist Holds the American Stage in the Age of Pasteur and Koch," *Bulletin of the History of Medicine* 36 (March–April 1962): 163–76.

was adequate treatment because of the self-purifying nature of running water. Although biologists, chemists, and sanitary engineers were seriously questioning the validity of this hypothesis by the 1890s, as late as 1909, 88 percent of the wastewater of the sewered population was disposed of in waterways without treatment. Where treatment was utilized at the beginning of the 20th century, it was only to prevent local nuisance rather than to avoid contamination of drinking water downstream.[40]

The consequence of the disposal of untreated sewage in streams and lakes from which other cities drew their water supplies was a large increase in mortality and morbidity from typhoid fever and other infectious waterborne diseases. Bacterial researchers, following the seminal work of Pasteur and Koch, were able to identify the processes involved in such disease. The work of William T. Sedgwick and sanitary engineers, biologists, and chemists at the Massachusetts Board of Health's Lawrence Experiment Station in the early 1890s was critical in clarifying the etiology of typhoid fever and confirming its relationship to sewage-polluted waterways.[41] The irony was clear: cities had adopted water-carriage technology because they expected local health benefits resulting from more rapid and complete collection and removal of wastes, but disposal practices produced serious externalities for downstream or neighboring users. Some of the more striking examples were Atlanta, Pittsburgh, Trenton, and Toledo, cities that constructed sewerage systems between 1880 and 1900 in the expectation of health benefits, all of which experienced substantial rises in typhoid death rates during the same years (see table 2).[42] This, then, was the primary unanticipated impact of sewerage technology—a rise in health costs where health benefits had been predicted. Because these costs were often borne by second parties or downstream users, however, cities continued to build sewerage systems and to dispose of untreated wastes in adjacent waterways.

Policy Options for Dealing with the Unexpected Impacts of Water-Carriage Technology

During the late 19th century, municipalities adopted a body of sanitary and plumbing codes in response to the nuisances and health

[40]"Sewage Purification and Storm and Ground Water," *Engineering News* 28 (August 25, 1892): 180–81; Sedgwick, pp. 231–37; Rudolph Hering, "Notes on the Pollution of Streams," *APHA* 13 (1888): 272–79; Moses N. Baker, "Sewerage and Sewage Disposal," App. A in Department of Commerce and Labor, Bureau of the Census, *Statistics of Cities Having a Population of over 30,000: 1905* (Washington, 1907), pp. 103–6.

[41]Rosenkrantz, *Public Health and the State* (n. 1 above), pp. 97–107.

[42]George C. Whipple, *Typhoid Fever* (New York, 1908).

TABLE 2

SEWER MILEAGE AND TYPHOID FEVER MORTALITY IN FIFTEEN AMERICAN CITIES LOCATED ON STREAMS AND LAKES, 1880–1905

	1880 Mileage	1880 Mortality	1890 Mileage	1890 Mortality	1900 Mileage	1900 Mortality	1905 Mileage	1905 Mortality	Response: Filtration (F); Change in Supply or Disposal Site (C)
Atlanta	...	66.8	24	72	...	74.6	122	70.1	1892, 1904, 1910 (F)
Chicago	337	33.9	525	72.2	1,453	21.1	1,633	16.5	1900 (C)
Louisville	41	65.7	52	75.7	97	64.0	122	49.4	1910 (F)
Nashville	...	133.7	24	64	...	49.5	79	71.2	1908, 1909 (F)
Newark	47	52.7	87	99.5	180	21.1	232	14.1	1889 (C), 1903 (F)
Philadelphia	200	58.7	376	73.6	887	37.2	1,041	51.1	1902, 1913 (F)
Pittsburgh	22.5	134.9	87	127.4	275	144.3	365	107.9	1908 (F)
Richmond	...	61.3	35	61	...	104.6	85	44.9	1909 (F)
Rochester	...	23.4	138	39.6	...	17.2	241	11.5	...
Salt Lake City	0	...	5	...	...	39.2	56	101.8	...
San Francisco	126	35.4	193	55.5	307	30.3	332	23.9	...
Spokane	...	...	3	...	...	45.9	23	86.1	...
Toledo	...	35.9	61	36	156	41.0	191	45.7	1910 (F)
Trenton	0	17.1	4	16	...	32.7	65	24.9	1911, 1914 (F)
Washington	169	53.4	266	86.8	405	79.7	484	48.2	1906 (F)

SOURCES.—U. S. Department of Commerce and Labor, Bureau of the Census, *Statistics of Cities Having a Population of over 30,000: 1905* (Washington, 1907), pp. 104–5; U. S. Department of Commerce, Bureau of the Census, *General Statistics of Cities: 1915* (Washington, 1916), pp. 152–53.

NOTE.—Typhoid fever mortality rates expressed per 100,000.

risks of the cesspool–privy vault system and the supposed dangers of sewer gas generated by decaying organic matter. In addition, they created local boards of health because of concern over epidemic disease.[43] Regulations and health boards had been promoted primarily by a sanitary coalition composed of physicians, engineers, plumbers, and civic-minded citizens, and this coalition was instrumental in securing the implementation of the new sewerage technology.[44]

The sanitary coalition also pushed for laws and institutions to deal with the threats to health from urban sewage-disposal practices. The transference of infectious disease carried in waste material from one user to another via sewerage technology, and then through the water medium used for disposal, necessitated an extralocal response. Legal redress for damages was possible in the case of nuisance, but difficulties in specifying the origins of waterborne disease prevented the affected individuals from seeking relief in the courts.[45] The institutional response entailed the creation of state boards of health (beginning with Massachusetts in 1869) and the passage of legislation to protect water quality. In 1905 the U.S. Geological Survey published its *Review of the Laws Forbidding Pollution of Inland Waters in the United States*, listing thirty-six states with some legislation protecting drinking water and eight states with "unusual and stringent" laws. Legislatures had generally passed the stricter statutes in response to severe typhoid epidemics. Supervision of water quality, whether through merely advisory powers or through stricter enforcement provisions, was usually entrusted to the state boards of health.[46]

By 1900, municipal policymakers, public health officials, and sani-

[43]Howard D. Kramer, "Agitation for Public Health Reform in the 1870s," pts. 1, 2, *Journal of the History of Medicine* 3, 4 (Autumn 1948, Winter 1949): 473–88, esp. 474–76; 75–89.

[44]Barbara G. Rosenkrantz, "Cart before Horse: Theory, Practice and Professional Image in American Public Health, 1870–1920," *Journal of the History of Medicine and Allied Sciences* 29 (January 1974): 55–56, and *Public Health and the State*, pp. 1–127; Stephen Smith, "The History of Public Health, 1871–1921," in *A Half Century of Public Health*, ed. Mazyck P. Ravenel (New York, 1921), pp. 1–12; George Rosen, *A History of Public Health* (New York, 1958), pp. 233–50.

[45]"Sewage Purification and Water Pollution in the United States," *Engineering News* 47 (April 3, 1902): 276; "Sewage Pollution of Water Supplies," *Engineering Record* 48 (August 1, 1903): 117. After 1910, the courts awarded damages against municipalities in cases where negligence in the operation of public waterworks resulted in individuals' contracting typhoid fever. See James A. Tobey, *Public Health Law*, 2d ed. (New York, 1939), pp. 277–80.

[46]Edwin B. Goodell, *Review of Laws Forbidding Pollution of Inland Waters in the United States*, U.S. Geological Survey Water Supply and Irrigation Paper, no. 152 (Washington, 1906). A useful summary of Goodell is "Pollution of Streams," *Municipal Journal and Engineer* 21 (October 3, 10, 17, 1906): 333–34, 364–65, 384.

tary engineers had several alternatives for dealing with the threat of sewage to the water supplies of inland cities. One option was to secure the municipal water supply from a distant and protected watershed, a course followed by cities such as Newark and Jersey City, New Jersey.[47] Another option was sewage treatment or "purification," although this was more effective in preventing nuisance than in protecting drinking-water quality. Sewage treatment technology was at an early stage of development, and the two methods most commonly used in 1900, sewage farming and intermittent filtration (a physical/chemical microbiological process), were both land intensive and impractical with sewage output from combined systems such as possessed by the great majority of cities. Only one city with a combined system treated its sewage.[48] In addition, while sewage treatment provided benefits for the downstream city, it imposed the costs on the upstream community in an era when there were neither state nor federal programs to subsidize waste treatment.

In the late 1890s another option became available for municipalities seeking to protect their water supplies—filtration at the intake. Experiments in the 1890s at the Lawrence Experiment Station and at Louisville, Kentucky, showed the effectiveness of both slow sand and mechanical filters in treating sewage-polluted waters. As a result of these successful demonstrations, many inland cities installed mechanical or sand filters in the years after 1897. The use of water-filtration technology resulted in an impressive decline in morbidity and mortality rates from typhoid fever, as well as other diseases.[49]

The choice confronting municipalities and health authorities faced with polluted water supplies was whether to filter their water *and* treat their sewage, in order to protect both their own water supply and that of downstream cities, or to filter the water alone, leaving the downstream user with the responsibility of guarding the safety of its own water supply.[50] This decision involved both public health and munici-

[47]Stuart Galishoff, "Triumph and Failure: The American Response to the Urban Water Supply Problem, 1860–1923," in *Pollution and Reform in American Cities, 1880–1930*, ed. Martin V. Melosi (Austin, 1980), pp. 46–47.

[48]Metcalf and Eddy (n. 9 above), 3d ed., 3:190–231; "Sewage Purification and Storm and Ground Water" (n. 40 above), pp. 180–81.

[49]Allen Hazen, *Clean Water and How to Get It* (New York, 1907), pp. 68–75; George C. Whipple, "Fifty Years of Water Purification," in Ravenel, ed. (n. 44 above), pp. 161–80. See George A. Johnson, "Present Day Water Filtration Practice," *Journal of the American Water Works Association* 1 (March 1914): 31–80, for figures on typhoid death rates for leading cities before and after filtration.

[50]In some cities there was heated conflict over whether to filter the water from local polluted rivers or to seek a pure source in a distant locality. For a discussion of this dispute in Boston, see Fern L. Nesson, *Great Waters: A History of Boston's Water Supply* (Hanover, N.H., 1983).

pal financial structures. Debate over the question caused a major rift in the sanitary coalition that had been responsible for the implementation of sewerage systems and the creation of local and state boards of health. This split was most evident in states such as Minnesota, New York, and Pennsylvania, where state boards of health dominated by physicians came into conflict with consulting sanitary engineers and their municipal clients. This dispute continued from about 1905 to 1914; its resolution set the pattern for dealing with water pollution problems and the public health into the 1930s.[51]

In the first years of the 20th century, sanitary engineers took the position, expressed editorially by the *Engineering Record*, that "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 sewage treatment works."[52] Sanitary engineer Allen Hazen expressed the rationale for this position in his 1907 book, *Clean Water and How to Get It*, by noting that "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." Rather, said Hazen, downstream cities should filter their water to protect the public health, and sewage purification should be utilized only to prevent nuisances such as odors and floating solids.[53]

As sanitary engineers were adopting Hazen's stance on water-quality policy, a considerable body of public and professional opinion was moving in a different direction. A number of business and professional groups, for instance, as well as politicians and representatives of the media, were calling for state and national legislation to protect the purity of waterways.[54] Their demands for legislation protecting water quality reflected the thrust of the Progressive movement toward mea-

[51]This case is treated more fully in Joel A. Tarr, Terry Yosie, and James McCurley III, "Disputes over Water Quality Policy: Professional Cultures in Conflict, 1900–1917," *American Journal of Public Health* 70 (April 1980): 427–35. Sanitary engineers also wanted equal representation with physicians on state boards of health.

[52]"Sewage Pollution of Water Supplies" (n. 45 above), p. 117. See also "The Water Supply of Large Cities," *Engineering Record* 41 (January 27, 1900): 73.

[53]Hazen, pp. 34–37.

[54]See, e.g., Pittsburgh Chamber of Commerce, *Sewage Disposal for Pittsburgh* (Pittsburgh, 1907); George Soper, "The Sanitary Engineering Problems of Water Supply and Sewage Disposal in New York City," *Science* 25 (April 19, 1907): 601–5; "Up Stream or Down Stream?" *New York Times*, September 25, 1910; Constance D. Leupp, "To the Rescue of New York Harbor," *Survey*, October 8, 1910, pp. 89–93; Merchants Association of New York, Committee on Pollution of State Waters, *Protest against the Bronx River Valley Sewer* (New York, 1907), and *The Battle of the Microbes: Nature's Fight for Pure Water* (New York, 1908); and Samuel P. Hays, *Conservation and the Gospel of Efficiency* (Cambridge, 1959), esp. pp. 122–46.

sures for conservation of the nation's natural resources. Foremost among these groups were physicians active in the public health movement, who directed boards of health in several states. These officials were influenced by the New Public Health, a movement generated by the bacteriological advances of the 1890s, which stressed the need to control the diseased individual, or carrier.[55] In the case of waterborne infectious disease, advocates of the New Public Health argued for restricting or abandoning the use of streams for sewage disposal, especially if they were also the source of a water supply. At the 1908 conference of State and Provincial Boards of Health, the Committee on the Pollution of Streams, for instance, maintained that both water filtration and sewage treatment were required in order to provide a double safeguard for the public health.[56]

In a number of cases during the years from 1905 to 1914, the most important of which involved the city of Pittsburgh, several state boards of health attempted to compel municipalities to cease discharging untreated sewage into neighboring streams and to convert combined sewer systems into separate ones.[57] In cases where the problem was one of nuisance, municipalities usually constructed sewage treatment plants in order to avoid legal damages. In cases involving assumed threats to water supplies, however, boards of health were unsuccessful in their attempts to change municipal practice. Cities objected, not only because they did not want to adopt costly improvements that primarily benefited downstream communities, but also because state constitutional debt limits restricted their capital-improvements capability. The engineering press and engineering groups gave municipalities their enthusiastic support in these situations. *Engineering News* maintained, for instance, that questions involving water supply and sewage disposal should be decided by engineers rather than by physicians, because engineers had a superior conception of the "relative needs and values" of municipalities. The Committee on Standards of Purity of the National Association for Preventing the Pollution of Rivers and Waterways, a group dominated by sanitary engineers, observed that it was

[55]H. W. Hill, "The New Public Health," *Engineering News* 67 (February 29, 1912): 378, and "The Relative Values of Different Public-Health Procedures, *Engineering News* 66 (October 12, 1911): 436; Robert W. Bruere, "The New Meaning of Public Health," *Harper's Monthly Magazine* 124 (April 1912): 690–95.

[56]"The Pollution of Streams," *Engineering Record* 60 (August 7, 1909): 157–59.

[57]H. M. Bracken, "Sewage Pollution Made Compulsory by the Minnesota State Board of Health," *Engineering News* 51 (February 11, 1904): 138, and "Editorial," p. 129; R. Winthrop Pratt, "The Work of the Ohio State Board of Health on Water Supply and Sewage Purification," *Engineering News* 57 (June 20, 1907): 680; George Gregory, "A Study in Local Decision Making: Pittsburgh and Sewage Treatment," *Western Pennsylvania Historical Magazine* 57 (January 1974): 23–36.

impossible to maintain or restore rivers and waterways to "their original and natural condition of purity." Only if water supplies were not filtered, the committee maintained, should untreated sewage be prohibited from streams.[58]

By the beginning of the First World War, the perspective of the sanitary engineers on the question of the disposal of raw sewage into streams had triumphed over that of the "sentimentalists and medical authorities" (sanitary engineer George W. Fuller's characterization) who opposed the use of streams for disposal. Essentially, the engineering position was that the dilution power of streams should be utilized to its fullest for sewage disposal so long as no danger was posed to the public health or to property rights and no nuisance created. Water filtration and/or chlorination could serve to protect the public from waterborne disease.[59]

The practical consequences of this position can be seen in the aggregate figures for sewered population, population served by sewage treatment, and population served by water treatment from 1910 to 1930 (see table 3). In this period, while the population newly served by sewers rose by over 25 million, the additional number whose sewage was treated rose only 13.5 million. At the same time, the increase in the population receiving treated water was approximately 33 million. In

TABLE 3

U. S. POPULATION, URBAN POPULATION, AND POPULATION WITH WATER TREATMENT, SEWERS, AND SEWAGE TREATMENT, 1880–1940

Year	Total Population	Urban Population	Water Treatment	Sewers	Sewage Treatment
1880	50,155,783	14,129,735	30,000	9,500,000	5,000
1890	62,947,714	22,106,265	310,000	16,100,000	100,000
1900	75,994,575	30,159,921	1,860,000	24,500,000	1,000,000
1910	91,972,266	41,998,932	13,264,140	34,700,000	4,455,117
1920	105,710,620	54,157,973	. . .	47,500,000	9,500,000
1930	122,775,046	68,954,823	46,059,000*	60,000,000	18,000,000
1940	131,669,275	74,423,702	74,308,000	70,506,000	40,618,000

SOURCES.—Compiled from miscellaneous federal, state, and professional reports.
*1932 data.

[58]"Standards of Purity for Rivers and Waterways," *Engineering News* 26 (October 31, 1912): 835–36; "Conference on Pollution of Lakes and Waterways," *Engineering Record* 66 (November 2, 1912): 485–86.

[59]George W. Fuller, "Relations between Sewage Disposal and Water Supply Are Changing," *Engineering News Record* 28 (April 5, 1917): 11–12. See also George W. Fuller, "Is It Practicable to Discontinue the Emptying of Sewage into Streams?" *American City* 7 (1912): 43–45.

1930, not only did the great majority of urban populations dispose of their untreated sewage by dilution in waterways, but their numbers were actually increasing over those who were treating their sewage before discharge. Because of the successes of water filtration and chlorination, however, waterborne infectious disease had greatly diminished and the earlier crisis atmosphere that had led to the first state legislation had disappeared.

Professional Impacts of Wastewater Technology: Sanitary Engineering

The implementation of any large-scale and capital-intensive technology, such as sewerage, will produce a range of institutional, economic, and social changes. Some of these are logical and predictable, while others are unintended and unanticipated. As was noted earlier, negative health effects were the largest single unanticipated effect of the implementation of sewerage systems and produced attempts to regulate water pollution. This section will deal with the development of the profession of sanitary engineering; the following sections will address the effects of wastewater technology on governmental structure, administration, planning, and forecasting. In these realms, changes sometimes were based on perceptions of the needs of the technology and sometimes conceived as adaptations to the impacts of the technology.

The development of a new technology with a set of unique characteristics requiring a special body of knowledge and techniques inevitably produces a community of practitioners. This community, or a more specialized subset of the community, may in time attempt to create a profession—a group of people who profess to hold a body of specialized knowledge that enables them to treat a certain class of problems or phenomena. Although a broad class of practitioners may initially claim to have relevant competence, eventually this group is narrowed down, is institutionalized, sets standards to determine entrance into the group, and acquires professional autonomy.[60] When it achieves that autonomy, it may attempt to extend its domain as well as preventing others from encroaching on its territory.

This was essentially what happened with sanitary engineering, which originated in England as part of the broader public health and sanitation movements. Its basic concern had been cleansing the environment by means of technology. British civil engineers Baldwin Latham and J. Bailey Denton published the first books with the words "sanitary en-

[60]Everett C. Hughes, "Professions," *Daedalus* 92 (Fall 1963): 655–68; George H. Daniels, "The Process of Professionalization in American Science: The Emergent Period, 1820–1860," *Isis* 58 (Summer 1967): 151–66.

gineering" in their titles in 1873 and 1877, respectively. In 1881, civil engineer E. S. Philbrick published the first American text with "sanitary engineering" in the title, although the Latham book had been reprinted in Chicago in 1877 as a special supplement to *Engineering News*. At the outset, sanitary engineering was a loosely organized field that included plumbers, plumbing contractors, and sanitarians, as well as engineers. The first journal in the field, founded in 1877, was entitled *The Plumber and Sanitary Engineer*; its name was changed to *The Sanitary Engineer* in 1880.[61] The amorphous nature of sanitary engineering in its early days was noted in 1880 by an English writer: "There is no lack of wisdom in the sanitary world now, for a host of 'sanitary engineers' have sprung up . . . at a moment's notice. It is true they have been following other professions all their life; but a 'fresh door is open here,' and 'right about face!' is the order of the day, which they gladly obey, and turn in to 'fresh fields and pastures new.'"[62]

During the 1880s sanitary engineering as a field began to define itself more explicitly in a scientific and disciplinary sense. A critical step in the profession's evolution was the formation in 1887 of an institution already noted, the Lawrence Experiment Station, by the Massachusetts State Board of Health. Though under the guidance of civil engineer Hiram Mills, the Lawrence Experiment Station united experts in the areas of engineering, chemistry, and biology and also brought the new knowledge of bacteriology to bear on the problems of water purification and sewage treatment. Researchers at the station made important discoveries in sewage treatment (intermittent filtration) and water filtration (slow sand filtration) in the 1890s, and the station served as a training ground for many of the great names in sanitary engineering and public health of the next thirty years, including Allen Hazen, George W. Fuller, E. O. Jordan, Thomas M. Drown, and Ellen H. Richards.[63]

The consulting biologist to the Lawrence Station, and the director of many of its most significant investigations, was William T. Sedgwick, head of the Department of Biology at the Massachusetts Institute of Technology. Sedgwick oriented his department toward sanitation and

[61] Henry C. Meyer, *The Story of the Sanitary Engineer* (New York, 1927), pp. 2–7; Rosenkrantz, "Cart before Horse," pp. 55–56. For an excellent discussion of the relationship of sanitary engineering to refuse collection, see Martin V. Melosi, *Garbage in the Cities: Refuse, Reform, and the Environment, 1880–1980* (College Station, Tex., 1981), pp. 79–104.

[62] Quoted in Stone (n. 15 above), p. 289.

[63] Rosenkrantz, *Public Health and the State*, pp. 99–100; E. O. Jordan, G. C. Whipple, and C. E. A. Winslow, *A Pioneer of Public Health: William Thompson Sedgwick* (New Haven, Conn., 1924), pp. 57–60.

public health and introduced courses in the 1880s in germs and germicides, sanitary biology, water supply and drainage, and hygiene and the public health. In 1889 he offered his first course in sanitary engineering.[64]

For Sedgwick, however, and for other pioneers in the field, sanitary engineering was more than another engineering discipline—it was a combination of engineering and science that utilized the contributions of each to solve public health problems. Speaking before the Franklin Institute in 1895, William Paul Gerhard, a sanitary engineer with broad interests, articulated this conception of a new breed of professional. Gerhard observed that sanitary engineering was "the art and science of applying the forces of nature in the planning and construction of works pertaining to public or individual health." Sanitary engineers needed to add a knowledge of a wide range of physical and natural sciences to their training in civil engineering. Those who worked in a single branch of sanitation, such as plumbing, said Gerhard, were not entitled to be called sanitary engineers, since the one was a trade and the other a profession. Neither, he added, could physicians engaged in preventive medicine be called sanitary engineers, for they lacked the technical experience and training required to qualify them for executing engineering works.[65]

Gerhard's comments reflected the struggle of a newly emerging profession to free itself from the craft or shop image and to establish its distinctiveness from another emerging profession, public health medicine. Within the universities, the movement toward professionalization proceeded. In 1911, Harvard appointed George C. Whipple, a former student of Sedgwick's at MIT, as professor of sanitary engineering. In 1912, Harvard and MIT joined together to create a school for health officers that united the Division of Sanitary Engineering at Harvard, the Department of Preventative Medicine at the Harvard Medical School, and the MIT Department of Biology and Public Health. The school was directed by William T. Sedgwick.[66]

George C. Whipple's attempt, in 1912, to define the field reflected the continued quest of sanitary engineering for disciplinary and professional status. Whipple noted that the new profession represented "the application of a new science to a new product of civilization. The

[64]Jordan et al., pp. 31–41, 57–64, 72.

[65]William Paul Gerhard, "Sanitary Engineering," *Journal of the Franklin Institute* 139, 140 (June, July, August 1895): 457–75, 56–68, 90–105; William Paul Gerhard, "A Half-Century of Sanitation," *American Architect and Building News* 63 (February 25, 1899): 62.

[66]Samuel C. Prescott, *When M.I.T. Was "Boston Tech," 1861–1916* (Cambridge, Mass., 1954), pp. 281–83.

new science is bacteriology; the new product of civilization is 'The Modern City.'" Whipple called for the broad training of sanitary engineers and observed that engineering was "fast coming to be regarded as one of the learned professions, and the education required of one who enters this profession must be not only scientific and technical, but broad and humanitarian." However, he added, sanitary engineers must be trained primarily in engineering and secondarily in sanitation. "The wisely arranged curriculum will . . . cover the field of sanitation in a broad and general way, without taking too much of the student's time from his detailed studies in structures and hydraulics." Such training would enable the sanitary engineer to interact with those educated in other disciplines in order to improve the total field of sanitation.[67]

Concurrent with the institutionalization of sanitary engineering in the universities, the first decades of the 20th century witnessed the establishment of institutional bases outside. In 1906 the American Society of Sanitary Engineers was founded, although it allied itself to the craft as well as to the engineering tradition by accepting plumbers, plumbing officials, and plumbing contractors for membership. The American Public Health Association formed a sanitary engineering section in 1911, while at approximately the same time the U.S. Public Health Service organized its own staff of engineers and the title "Sanitary Engineer" was given a civil service classification. In 1920, the Conference of State Sanitary Engineers was formed, composed of the chief sanitary engineer in each of the state departments of health and the chief sanitary engineer in the United States Public Health Service. And in 1922 the American Society of Civil Engineers (ASCE) authorized the formation of the Sanitary Engineering Division. In its first year of existence, the division registered a membership of 526; within a decade this figure had tripled. By the 1920s, approximately fifty years after it first emerged as a profession, sanitary engineering had firmly established itself as an engineering discipline.[68]

Leaders in the field, however, had expected that sanitary engineering would become more than an engineering specialty with a focus on

[67]George C. Whipple, "The Training of Sanitary Engineers," *Engineering News* 68 (October 31, 1912): 805–6; "Sanitation More than Medicine," *Literary Digest* 45 (November 16, 1912): 899.

[68]"American Society of Sanitary Engineering," and "Conference of State Sanitary Engineers," in *Encyclopedia of Associations*, 11th ed. (New York, 1977), 1: 413; figures on the enrollment in the Sanitary Engineering Division of the ASCE were supplied by the ASCE. See also Frank Woodbury Jones, "The Sanitary Engineering Division of the American Society of Civil Engineers: Its History 1923–1952," a talk delivered before the Centennial of Engineering Meeting of the Sanitary Engineering Divison, ASCE, Chicago, September 8, 1952.

sewage, water supply, and refuse collection. In 1924, for example, following in the tradition of Sedgwick and Whipple, sanitary engineer Abel Wolman, then chief engineer of the Maryland State Department of Health, proposed to the American Public Health Association (of which he later became president) that it rename sanitary engineering "Public Health Engineering"; he called for engineers to move into new areas of environmental control.[69] This attempt to broaden the field was essentially unsuccessful. In 1948, in the second edition of his work *Public Health Engineering*, Earle B. Phelps, professor of sanitary science at Columbia College of Physicians and Surgeons, laid the responsibility for provincialism directly on the sanitary engineers: "Through his textbooks and his professional activities [the sanitary engineer] has defined and limited his field, not as the engineering of sanitary science, but as the engineering of water supply and . . . sewage disposal."[70] Thus, through the immediate postwar period, most engineers were still narrowly linked to the two technologies that had originally led to the growth of sanitary engineering in the 19th century—sewerage and water supply.[71]

Governmental Structure and Administration

Sewerage systems have characteristics of economies of continuous collection and of scale that often ignore municipal boundaries and require centralized administration. The same irrelevance of political boundaries is naturally true of the health hazards created by waste disposal and water pollution. Ideally, then, wastewater collection and disposal should be dealt with on a regional basis, and yet many American urbanized areas were (and are) characterized by political fragmentation.[72] In order to secure cost and design advantages as well

[69]Abel Wolman, "Values in the Control of the Environment," *American Journal of Public Health* 15 (March 1925): 194; George W. Fuller, "The Place of Sanitary Engineering in Public Health Activities," *American Journal of Public Health* 15 (December 1925): 1069.

[70]Earle B. Phelps, *Public Health Engineering*, 2 vols. (New York, 1948), 1:5. See also three articles by Abel Wolman: "The Engineer and Society," *Johns Hopkins Alumni Magazine* 25 (June 1937): 343; "The Public Health Engineer and the City Health Officer," *American Journal of Public Health* 31 (May 1941): 435–39; and "Sanitary Engineering Looks Forward," *Journal of the American Water Works Association* 38 (November 1946): 1219–25.

[71]For attempts to change both the image and content of sanitary engineering in the 1960s and 1970s, see James W. Patterson, "Environmental Engineering Education: Academia and an Evolving Profession," *Environmental Science and Technology* 14 (May 1980): 524–32; and Gerard A. Rohlich, "Environmental Engineering—A Distinct Discipline?" in *Fourth Conference on Environmental Engineering Education, Toronto, June 19–21, 1980*, ed. James W. Patterson and Roger A. Minear, pp. 21–28.

[72]Paul Studenski, *The Government of Metropolitan Areas in the United States* (New York, 1930), p. 18.

as efficiency and safety of disposal, sanitary engineers and public health officials pushed for unification of these fragmented districts. As early as the 1870s, the engineering press began urging regional cooperation in sewer and water services, and throughout the late 19th and early 20th centuries it pushed for new regional administrative arrangements. The requirements of sewerage systems for efficient operation offered a powerful argument for overcoming the fragmentation produced by political boundaries that did not conform to environmental needs.[73]

Three means of achieving this unity were actually employed: intermunicipal and interstate cooperation, annexation of or consolidation with suburban areas by a central city, and special district governments. The chief example of intermunicipal cooperation was the Passaic Valley Sewerage and Drainage Commission, formed in 1896, in which seven northern New Jersey municipalities united in construction of a joint outlet sewer; by 1927 seventeen towns were members. There were, however, few other examples of joint action among municipalities because of the difficulty in obtaining agreement on apportionment of responsibilities and costs.[74] An inability to agree on joint responsibilities also inhibited the development of interstate water pollution compacts before 1920, although in the second quarter of the century such pacts were instituted in important regions such as the Ohio River Valley.[75]

A more common method of solving sewerage problems involving several governmental jurisdictions entailed suburban annexation or consolidation. Sewerage and water supply are costly capital systems, and there was a financial incentive for suburban communities with weak tax bases to consolidate with central cities that could supply these services. As a further inducement, the annexed territories often received services at the regular city rate, even though the costs of installation exceeded revenues. Thus, as Jon Teaford observes, the desire for improved service was a "countervailing force for unity" against the forces of fragmentation in the metropolis.[76]

[73]Stanley K. Schultz and Clay McShane, "Pollution and Political Reform in Urban America: The Role of Municipal Engineers, 1840–1920," in Melosi, ed. (n. 47 above), pp. 160–67.

[74]"Municipal Cooperation as a Possible Substitute for Consolidation," *Enginering News* 41 (February 16, 1899): 104–6; "Sewerage of the Passaic River Valley," *Engineering Record* 44 (December 28, 1901): 60; and Studenski, pp. 47–48. States such as Ohio and California passed legislation providing for intergovernmental contractual relations. See Jon C. Teaford, *City and Suburb: The Political Fragmentation of Metropolitan America, 1850–1970* (Baltimore, 1979), p. 81.

[75]Edward J. Cleary, *The ORSANCO Story: Water Quality Management in the Ohio Valley under an Interstate Compact* (Baltimore, 1967).

[76]Teaford, pp. 39–40, 59–60; Studenski, pp. 166–67.

The most readily adopted institutional means to handle sewerage and water-supply projects has been the special district government, a fiscally and administratively independent authority of limited function and extent. Examples include the Chicago Sanitary District (1889), the Boston Metropolitan Sewerage Commission (1889), and the Washington Suburban Sanitary Commission (1918). Sanitary engineers and public health professionals, as well as governmental reformers, pushed for the creation of the special authorities because of the need for a functional structure independent of political boundaries and the wish to escape tax or debt limits and be free of municipal political control. Special district governments were an alternative to central city annexation, and they were preferred by suburban authorities for this reason.[77]

Sewerage technology, therefore, with its characteristics of efficiency of continuous collection, scale economies of treatment, and capital intensiveness, as well as its requisite for central administration, was an important factor in facilitating governmental integration. It encouraged consolidation of urban areas and promoted a new governmental form, the special district government. It has also been argued, however, that specialized districts have actually retarded full metropolitan integration.[78] Such institutional innovations may have evolved without wastewater technology, but its requirements undoubtedly accelerated institutional adaptation that provided a model for further innovation.

Planning and Forecasting

When sewerage systems were constructed, engineers had to take into account future urban population growth and changes in city functions in order to avoid constant rebuilding. This required long-range planning and forecasts of population growth. The new technology further required a permanent bureaucracy for day-to-day administration, for data collection, and for efficient planning. In addition, the massive costs of these public works demanded fiscal planning by professionals. Ideally, the works could be constructed and maintained best by experts who could survey the topography scientifically, evaluate alternate materials, plan for probable population change, and keep the system efficiently functioning.

Before the city-planning movement was well begun, major expositions on sanitary reform argued the virtues of planned sewerage. By the 1870s and 1880s, this form of planning was firmly rooted as a major

[77]Robert B. Hawkins, Jr., *Self-Government by District: Myth or Reality* (Stanford, 1976), p. 25; Studenski, pp. 256–62; Teaford, pp. 79–81, 173–74; and Cain, *The Search for an Optimum Sanitation Jursidiction* (n. 1 above), pp. 1–5.

[78]For a discussion of this literature, see Cain, *The Search for an Optimum Sanitation Jurisdiction*, p. 31, n. 4.

urban art, and sanitary engineering was established as an important branch of civil engineering concerned with sewerage and water supply. The sanitary engineers' view of planning was restricted to sewage collection and disposal and to water supply, but inherent in this view was the concept of the city as a physical container to be organized to provide more efficient delivery of services and disposal of wastes.[79] The engineering ideal was the comprehensively planned city, staffed and managed by disinterested experts such as themselves. Not surprisingly, sanitary engineers played important roles in the emergence of the city-planning profession at the start of the 20th century, with thirteen of the fifty-two charter members of the American Institute of Planners listed as engineers.[80]

Planning involves making predictions and dealing with probabilities and uncertainties, and sanitary engineers more than other engineers had to be planners. Writing in 1915 and 1916, sanitary engineers Allen Hazen and George C. Whipple noted the special concern with variation that characterized sanitary engineering and which placed it between the natural and the exact sciences. They also pointed out the importance of probability theory to sanitary engineering problems.[81] Sanitary engineers were concerned with rainfall prediction, water use, and demographic change, all categories that shared the characteristic of high uncertainty. Unique among urban professionals, they attempted long-range urban population predictions, making such calculations considerably before city planners utilized the technique.[82]

[79]Peterson (n. 1 above), p. 89.

[80]Mel Scott, *American City Planning since 1890* (Berkeley, 1969), pp. 163–64; Nelson P. Lewis, *The Planning of the Modern City* (New York, 1916), esp. chap. 21, "The Opportunities and Responsibilities of the Municipal Engineers." William Paul Gerhard was notable among sanitary engineers for directly addressing the question of city planning. See William Paul Gerhard, "The Laying Out of Cities and Towns" *Journal of the Franklin Institute* 140 (August 1895): 90–99.

[81]George C. Whipple, "The Element of Chance in Sanitation," pts. 1, 2, *Journal of the Franklin Institute* 182 (July, August 1916): 37–59, 205–27.

[82]For examples of population forecasting by sanitary engineers, see Henry N. Ogden, *Sewer Design* (New York, 1899), pp. 93–101; and George W. Rafter and M. N. Baker, *Sewage Disposal in the United States* (New York, 1894), pp. 129–31. Most of the early population forecasts were based on straight-line extrapolation of past trends. They were often faulty. In 1895, e.g., civil engineer Frederic P. Stearns made 186 population forecasts for twenty-seven cities and towns within 10 miles of Boston. A later check on the accuracy of his predictions showed that he had underestimated growth in twenty-seven cases, overestimated in 156, and made three accurate predictions. Writing in 1928, sanitary engineers Leonard Metcalf and Harrison P. Eddy noted that "forecasts of population based upon experience of the past are likely to prove somewhat too high in about 85 percent of the cases and too low in the remainder" ([n. 9 above], 2d ed., 1:191–92). For the Stearns estimates, see Paul M. Berthouex, "Some Historical Statistics Related to Future Standards," *Journal of the Environmental Engineering Division, Proceedings of the American Society of Civil Engineers* 100 (April 1974): 423–24.

The experience of sanitary engineers with population forecasting, social factors such as water use, and public health considerations, as well as their participation in planning large-scale capital works, prepared them for key roles in city government. They adhered to a set of values and procedures which stressed efficiency within a benefit-cost framework, and this appealed to late-19th- and early-20th-century reformers attempting to restructure municipal government along lines of professionalism, efficiency, and bureaucratization. Sanitary engineers served in city government not only as municipal engineers but also as administrators and were a principal group from which the majority of city managers were recruited before World War II.[83]

Values and the Technology of Sewerage

This section will consider the relationship between sewerage technology and broader social values. Following Talcott Parsons, we define value as an element of a "shared symbolic system" which serves as a criterion for selection among alternatives. The material is structured to correspond to the model suggested by Theodore J. Gordon in his essay "The Feedback between Technology and Values."[84] This model depicts the mechanism relating values to technology and technology to values as a feedback system in which values help determine the direction of technological development. Once established, the technology, through its effects, influences the formation of new values. Five areas of involvement will be considered:

1. state of society values leading to sewerage implementation;
2. technology-specific values encouraging the adoption of sewerage systems;
3. the effects of sewerage technology on values;
4. policy adviser and practitioner values; and
5. user values.

The *state of society values* that are pertinent to this study are those related to the development of 19th-century technology generally and therefore to sewerage technology specifically. A belief in progress was widespread in 19th-century America, and increasingly throughout the century progress was linked with technology. Modernization and prog-

[83]Schultz and McShane, "To Engineer the Metropolis" (n. 1 above), pp. 409–10; Martin J. Schiesl, *The Politics of Efficiency* (Berkeley, 1977), pp. 171–88. For a discussion of the role of engineers in regard to city government in an earlier period, see Raymond H. Merritt, *Engineering in American Society 1850–1875* (Lexington, Ky., 1969), pp. 136–76.

[84]Theodore J. Gordon, "The Feedback between Technology and Values," in *Values and the Future: Impact of Technological Change on American Values*, ed. Kurt Baier and Nicholas Rescher (New York, 1969), pp. 148–92; see also Nicholas Rescher, "What Is Value Change? A Framework for Research," in Baier and Rescher, eds., pp. 68–109.

ress were considered synonymous, with the belief that the present was better than the past and that the future would represent an even greater improvement. Sewerage technology was important in the context of urban improvement and boosterism and was strongly linked to city progress by a number of commentators. Sanitary engineer M. N. Baker noted, for instance, that "a village or town without waterworks and sewers is at great disadvantage as compared with communities having these conveniences and safeguards. Industries and population are not so quickly attracted to it. . . ."[85] Or, as the engineer for New London, Connecticut, observed, with the building of a sewerage system the "good name" of the city appreciated, "thus attracting population and business, thereby increasing the value of real estate. . . ."[86]

Another important value held by most 19th-century Americans about technology was a belief in its beneficent nature. As one student of technology and ideas has noted, by the 1840s "the machine"—in this case steamboats, locomotives, and telegraphs—had captured the public imagination and gave evidence that mankind would "realize the dream of abundance."[87] Sewerage technology had strong implications of beneficence because of its associations with health improvements and nuisance abatement. By the late 19th century public health physicians and sanitary engineers as well as many municipal officials and citizens viewed sewerage as a life-protecting and -extending technology.

Americans believed not only that technology was beneficial but also that nature and its resources were meant to be exploited for material benefit. This value originally derived from the frontier experience and was tied to the concept of progress, playing a central role in its formulation.[88] As a value, it was associated with sewerage technology by the assumption that waterways could be utilized almost without restriction for waste disposal. The so-called scientific justification was that running water purified itself. As it turned out, this hypothesis was true only in a limited sense and under special conditions. Before that became clear, however, it seemed that urban progress and a healthful environment would be achieved through the utilization of the natural resource at the city's edge for waste disposal.

Turning to *technology-specific values,* we can see that a set of values deriving from the sanitary movement had a specific causal reference to

[85]M. N. Baker, *Sewerage and Sewage Purification* (n. 28 above), p. 11.

[86]New London Board of Sewer Commissioners (n. 28 above), p. 4.

[87]Leo Marx, *The Machine in the Garden* (New York, 1964), pp. 191–92. Marx discusses intellectuals who question the worth of technological advance.

[88]Arthur A. Ekirch, Jr., *Man and Nature in America* (New York, 1963), p. 45.

the widespread construction of sewerage systems in American cities in the late 19th and early 20th centuries. The sanitary movement began in Great Britain in the 1840s and 1850s with the work of Sir Edwin Chadwick and his followers to promote a healthful urban environment by cleansing the cities. It was essentially a social movement by elites and professionals that aimed to change people's ideas about their own personal habits of cleanliness, to create an enlarged role for government in areas related to health and sanitation, and to promote the construction of urban public works to achieve a healthful city. Chadwick's ideas greatly influenced the pioneer group of American sanitarians and public health reformers. Important among this group were men such as John H. Griscom and Colonel George E. Waring, Jr.; Griscom promoted sewerage as "not only the most economical, but the *only* mode in which the immense amounts of filth generated daily in . . . [large cities] can be effectively removed."[89]

The American sanitary movement had its origins in the pre–Civil War period, and its concerns were reflected in *The Report of the Sanitary Commission of Massachusetts* (the "Shattuck Report") of 1850, in the surveys of the American Medical Association of urban conditions in the late 1840s, and in the work of the Sanitary Commission during the Civil War. After the war, sanitarians and physicians actively propagated the concept of health through cleanliness. Books on personal hygiene, home sanitation, public health, and sewerage flowed from the presses, and articles on sanitation filled the technical and popular magazines. Leypoldt's *American Catalogue of 1875*, for instance, lists only five works on public health ("hygiene") as printed between 1850 and 1865, but fifty-four published between 1865 and 1875. In addition, these years saw the publication of nine works on sewerage, two on drainage, and six on water supply, whereas there had been none listed for the earlier period.[90]

The institutional and organizational embodiments of the sanitary movement were the American Public Health Association (1871), the National Board of Health (1879–83), and the multitude of local and state boards of health that appeared in the late 19th century. Municipalities and states passed laws regulating a range of activities relating to sanitation and health, such as cesspool and privy construction and cleaning, sewerage construction, plumbing, and water supply. These laws clearly reflected the acceptance by the informed public of the importance of sanitation. Thus, the sanitary movement helped initiate a value change, convincing many urbanites that filth was not a nuisance

[89]Griscom, quoted in Peterson (n. 1 above), p. 86.
[90]Kramer (n. 43 above), pp. 474–76.

to be tolerated but rather a hazard to their health that could be eliminated. And, in this process, sewerage, which one public health historian has called "the most popular sanitary topic of the day" from 1875 to 1895, was a critical element.[91]

As to the *effects of the technology on values*, we see confirmation of the model of the interaction of values and technology: societal values first encourage the development of the technology, while feedback from the technology to the society reinforces the original values and may also create new ones. Some of these values have already been dealt with in the previous section on governmental and institutional impacts and will only be summarized here. Among the beliefs that the technology advanced were the virtues of planning; the requirement for engineering expertise rather than amateur, popular, or political direction; the desirability of bureaucracy and centralization; the applicability of engineering management to city government; and the need for state and federal regulation to deal with the negative effects of sewerage technology. In addition, the technology, by aiding in the creation of a sanitary and nuisance-free local environment, reaffirmed the American belief in the efficacy of technology to secure desired goals. While water-carriage technology did produce severe health externalities for downstream communities, another technology—water filtration—effectively reduced the risk, further reaffirming the utility of the cycle of technological fixes. Sewerage technology also reinforced the equation between cleanliness and health, with its most concrete embodiment being the modern sanitary bathroom, full of devices reflecting the strength of the belief.[92]

As *policy advisers*, sanitary engineers shared with other professional engineers a set of values that stemmed from their training. They viewed society in problem-solving terms and emphasized efficiency, expertise, and technical solutions. In regard to water use and sanitation, they stressed quantifiable variables rather than nonquantifiable values and other hard-to-measure elements. They differed from other engineers, however, in the broader and interdisciplinary nature of their training, especially in health-related areas. In addition, they frequently worked with public rather than private bodies, serving as city engineers, as engineering representatives on boards of health, and as consultants. As public employees or consultants, they were sensitized to the cost constraints imposed by limited municipal resources and constitutional budgetary restrictions. Their interaction with the political process in city councils and state legislatures often caused them to

[91]Ibid., pp. 473–88, 75–89.

[92]Reynolds (n. 15 above), passim.

be skeptical of politics and suspicious of popular causes, although this attitude was also shaped by their professionalism and shared with other engineers.[93]

By the beginning of the 20th century, sanitary engineers and physicians in public health departments had become the principal professionals involved in decisions about sewerage, water supply, and control of water pollution. (A few cities and states employed bacteriologists and chemists.) In cities and states with an active program to protect the public health, these professionals worked together and shared a number of values in regard to sanitation and health. Both, for instance, largely accepted the germ theory of disease diagnosis and both advocated extensive state measures in disease control. During the second decade of the 20th century, however, they diverged in their attitude toward risk in regard to the protection of drinking-water quality.[94]

The latter dispute has already been discussed in a policy context and will only be reviewed here in regard to the values component. As noted earlier, followers of the New Public Health argued that utilizing streams for sewage disposal created the risk of exposing populations to typhoid fever and other waterborne disease. The "foremost duty of health officers," observed Charles V. Chapin, was "the direct control of communicable diseases."[95] This perspective derived from their training in the new methods of bacterial science, from their efforts to distinguish themselves from earlier environmental sanitarians, and from their attempts to capture "the center of action and the criteria for professional identity within the public health movement."[96]

Sanitary engineers, on the other hand, while they agreed on the worth of bacterial science, had a different attitude on the question of water quality standards: they believed that the risks involved in using streams for sewage disposal were not sufficient to justify the costs of

[93]Schultz and McShane, "Pollution and Political Reform in Urban America," p. 165; Edwin T. Layton, Jr., *The Revolt of the Engineers* (Cleveland, 1971), pp. 6–8, 64–65; and Charles W. Eliot, "One Remedy for Municipal Government," *Forum* 12: 153–68.

[94]Many state and local health departments were headed and staffed by physicians without any particular public health training or orientation. According to sanitary engineer Morris Knowles, such departments were characterized by "narrowness of scope; incompleteness of work from the broader sanitary point of view; emphasis on cure rather than prevention; and insufficient realization of the importance of reliable statistics. . . ." Knowles and other sanitary engineers argued that engineers and trained public health professionals (not necessarily physicians) should be appointed to these boards. See Morris Knowles, "Public Health Service Not a Medical Monopoly," *American City* 7 (December 1912): 527–29.

[95]Charles V. Chapin, "History of State and Municipal Control of Disease," in Ravenel, ed., pp. 136–37, 142.

[96]Rosenkrantz, "Cart before Horse," p. 68.

construction of sewage treatment plants. They argued for full utilization of the natural dilution power of waterways, for adopting water filtration technology to protect drinking-water quality, and for reserving municipal funds for purposes other than the construction of sewage treatment plants unless there was a severe nuisance. This position derived not only from their professional training but also from their close relationship with municipalities, which heightened their sensitivity to fiscal limits. In addition, since the sanitary engineering profession was struggling to gain position and prominence within the field of public health, value considerations involving risk were reinforced by considerations of professional prominence. As *Engineering News* boasted in a 1912 editorial, the sanitary engineer combined prudence about both health and dollars—he was "a true and the greatest of conservationists, zealous to safeguard health and prolong life, but sparing no pain to see that each dollar is spent to the best advantage. . . ."[97]

Finally we come to *user values*—the values of municipalities, industries, and the general public. Water users benefited from sewerage technology and also helped create negative externalities from whose consequences they suffered. The extent of benefit or cost depended largely on upstream or downstream location. The most critical values in regard to municipalities and industries seemed to relate to their attitude toward the externalities they created for downstream communities through their waste-disposal practices. Municipalities were likely to construct sewers because they improved local aesthetic and health conditions, increased property values, and helped the city's image. Industries benefited from the ease of disposing their process wastes in sewers. Both, however, resisted the construction of waste treatment facilities unless necessary to help protect their own water supplies, because these created advantages for downstream populations that paid nothing in return.[98]

As for the articulate public, it had three important values in regard to sewerage technology and water usage. These values favored local conditions of cleanliness and nuisance elimination; drinking water that was clear, free from odor, and potable; and unpolluted waterways for

[97]George C. Whipple, "How to Determine Relative Values in Sanitation," *American City* 11 (1914): 427–32; "A Plea for Common Sense in the State Control of Sewage Disposal," *Engineering News* 67 (February 29, 1912): 412–13.

[98]As noted on p. 243, in 1903 the *Engineering Record* suggested that "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 sewage treatment works" ("Sewage Pollution of Water Supplies" [n. 45 above], p. 117).

recreational purposes.[99] The latter value gained strength after the turn of the century, when, with growing affluence and a reduced work week, opportunities for leisure-time recreation increased for members of the middle and working classes. Through the 1920s, however, in the rating system of many sanitary engineers and state agencies concerned with water use, recreation held a lower priority than did other stream uses such as sewage dilution. As the New York Conservation Commission noted in 1923, recreational and industrial uses of streams were incompatible, and recreation "usually causes pollution of the water such as to unfit it for drinking." (Sanitary engineers believed that industrial wastes caused nuisances and impaired the workings of sewage treatment plants but did not result in health problems. In fact, it was argued that wastes such as mine acid drainage neutralized bacterial wastes.) Man could live without recreation, added the commission, but "could not and should not live without work; so, in general, recreational purposes are subordinate to the other uses of streams."[100]

Conclusions

The experience of sewerage technology suggests certain conclusions about both technology and technological systems. The negative effects of new water-supply technology and the unexpected adoption of the water closet illustrate the risk of introducing elements into a balanced technological system without attempting to calculate the impacts of the innovation. Clearly, items that appear to promise only benefits may have severe secondary costs, although these may be difficult to foresee. To anticipate and understand the possible consequences of new technology, it is critical not only to comprehend fully the scope of the innovation but also to understand the operations and interrelationships of the previous system.

When the cesspool–privy vault system was overwhelmed by wastewater from newly installed water closets and other water fixtures, the system itself was replaced by capital-intensive sewers. This decision was based on forecasts of the benefits and costs of the new technology. In the process, forecasts of pollution costs tended to be disregarded because most often they would have to be borne by others, downstream. Municipalities were quite willing to shift the burden of pollution if it meant improving their local environment.

[99]"The Pollution of Streams" (n. 56 above).

[100]Quoted in "Discussion on Policy regarding Stream Pollution," following Abel Wolman (chairman), "Domestic and Industrial Wastes in Relation to Public Water Supply: A Symposium," *American Journal of Public Health* 16 (August 1926): 103–7.

Policy choices in regard to sewer design—specifically the question of separate or combined sewers—and choices involving sewage disposal illustrate the manner in which faulty scientific concepts can effect technology implementation and operation. For instance, advocates of separate sewers in the 1870s and 1880s urged adoption of their system because it supposedly prevented the generation of disease-producing sewer gas. Large cities that built combined systems often discharged their sewage into adjacent waterways on the assumption that the streams were self-purifying, a concept that obtained only under very specific and limited conditions. Thus, in each case, assumptions about disease etiology that later proved faulty encouraged the installation of capital systems which required retrofitting or reconstruction in order to deal with resulting problems.

When municipal sewage-disposal practices had negative health and nuisance effects, especially for downstream communities, public health and engineering groups demanded state regulation of water quality. Legislation was usually enacted in response to crisis situations. The conflict that developed between sanitary engineers and municipalities and state boards of health dominated by physicians over methods of maintaining drinking-water quality illustrates how professionals with varying types of training and perspectives took different attitudes on health risks. The resulting policy reflected the more limited and cost-effective sanitary engineering position rather than the longer-term and more costly public health approach. Water quality policy, therefore, was shaped by the value perspectives of involved professionals and bounded by the financial limitations of municipalities and an in-place capital technology.

The various characteristics and effects of capital-intensive sewerage technology required governmental and institutional adaptations. Three areas were most important: measures needed to overcome the political fragmentation of urban areas, such as suburban annexation and special district governments; a strengthening of the planning and managerial components of city government; and the development of regulatory bodies on the state, regional, and federal levels to deal with negative consequences. In regard to regulation, there has been a progression to higher and higher governmental levels. Since 1972, the regulatory and standard-setting focus has been at the federal level, and federal grants and subsidies have been required to enable states and municipalities to meet federally mandated standards.

In regard to technology and values, this article has utilized a model emphasizing a two-way feedback. That is, it argues that the 19th-century sanitation movement was an important "value change initiator" which facilitated the acceptance of sewerage technology by urban decision makers and voters. By propagating the filth theory of disease, and by convincing urbanites that sewerage technology was a means to improve health as well as eliminate nuisance, it made taxpayers more willing to accept the financial costs of the capital-intensive system. Value change, therefore, was a critical predecessor to technology implementation.

The model also posits that the developing technology itself shaped and reinforced other values: values such as a belief in the need for planning, expertise, bureaucracy, and centralization in government, as well as for an expanded state regulatory role, were all supported by the technology. The profession of sanitary engineering developed around sewerage and water-supply technologies. As a group, sanitary engineers shared with other engineers a belief in technological solutions to problems, in efficiency as a concept, and in the primacy of cost considerations in construction. They differed from many engineers in that they often had public rather than private employers and clients, and they had a professional concern with public health. In its initial decades, the founders of the sanitary engineering profession shared a vision of their discipline as involving more than engineering perspectives. Much of this orientation was lost after World War I, and through the 1950s sanitary engineering remained narrowly wedded to the areas of sewer construction and sewage disposal, water-supply engineering, and municipal refuse collection. Recent decades, however, have witnessed a return of the profession to its early broader and interdisciplinary roots, as symbolized by the replacement of "sanitary engineering" by "environmental engineering."[101]

Ultimately, water-carriage technology, complete with various retrofits, may have been the most efficient and cost-beneficial system the society could have devised to deal with its human waste removal problems. The system was retrofitted in an incremental manner, often following health crises, and only after considerable damage had been done both to the public health and to the environment. Since its introduction and development, the existence of this capital-intensive system, regulated and governed by a group of special institutions and maintained by a specialized professional group, has been accepted as an unchangeable element in urban America. As a result, little attempt

[101]The Sanitary Engineering Division of the ASCE changed its name to the Environmental Engineering Division in 1972. A convenient summary of developments in the field, although lacking a historical perspective, is Patterson, "Environmental Engineering Education" (n. 71 above), pp. 524–32.

has been made until recently to search for waste removal and disposal alternatives.[102] The society therefore continues to struggle with the problems of a waste removal technology based on concepts over a century old.

[102]A useful summary of innovative systems including a list of firms manufacturing new systems for human wastes is *Beyond the Pipe Dream: New and Different Ways to Treat Sewage* (Providence, R.I.: Save the Bay, Inc., n.d.). See also U.S. Environmental Protection Agency, *Alternatives for Small Wastewater Treatment*, 2 vols. (Washington, 1977).