

**EPIDEMICS, DEMONSTRATION EFFECTS,
AND MUNICIPAL INVESTMENT IN SANITATION CAPITAL**

Louis P. Cain
Loyola University of Chicago
and Northwestern University

Elyce J. Rotella
Indiana University

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Over the years 1899-1929, the three decades prior to the Great Depression, American cities made enormous capital investments in water and sewage treatment plants. Such investments would accelerate with the availability of New Deal dollars, but our focus is on the period when cities bore the entire cost. We examine not the construction of the basic works that *supply* water and sewage services, but rather the *treatment* of what passes through those works. By the end of the 19th century, most cities had already built systems to deliver water and remove sewage. Then attention shifted to treatment – especially filtration and purification. The development of the germ theory provided the intellectual basis for understanding the benefits offered by water and sewage services. In this paper, we focus on two effects that contributed to expansion of treatment -- epidemics and demonstration effects. We argue that epidemics have their greatest influence on the demand side of the political market in which the decision to invest in treatment works is made – i.e., epidemics caused urban residents to demand that politicians provide them with better sanitation services. By contrast, we argue that, by lowering information costs, demonstration effects have their greatest influence on the supply side.¹

In the first section of this paper we show that monies expended on water, sewage, and refuse disposal, both operating and capital expenditures had a large effect on reducing mortality attributable to waterborne diseases. In the second section, we summarize our previous work on the relationship between epidemics and waterborne disease, which leads to a more extended discussion of demonstration effects in the third section. The fourth section presents evidence on the clustering of extraordinary expenditures on water and sewage treatment capital, while the final section provides a summary and some conclusions.

¹ Of course, effects are not strictly limited to one side of the market. The politicians on the supply side of the market should be as aware of the consequences of epidemics as other citizens, and a city's populace may be as aware as

I

By the end of the 19th century, it was widely accepted that sanitation services reduced mortality from certain causes – among these are typhoid fever, diarrhea, and dysentery. In order to assess the relationship between urban deaths and municipal spending on sanitation, we collected mortality and expenditure data for the period 1899-1929 for all cities having a municipal water supply, populations over 100,000 in the 1920 Census, and nearly complete data on mortality experience and sanitation expenditures. This gives us a sample of 48 cities.

The mortality data comes from *Mortality Statistics of Cities*, an annual publication of death-by-cause statistics. We constructed a waterborne death rate series that includes deaths attributable to typhoid fever, diarrhea, and dysentery.² The data on municipal sanitation expenditures were published in various *Census Bulletins* to 1903 and in *Financial Statistics of Cities* beginning in 1905. We used data on annual operating costs and capital acquisition costs of water and sewage works. Not every series was reported every year. Few direct figures are available for 1903, and *Financial Statistics of Cities* was not published in 1913, 1914, or 1920.³

We used these data to estimate a fixed effects model of the determinants of mortality from waterborne diseases. The results are presented in Table 1. Using these results we calculate that a 1% increase in all categories of sanitation expenditures would have reduced the annual mortality rate from typhoid, diarrhea and dysentery by 3% in the average size city in this period.

their politicians of developments in other cities.

² This group of diseases will be referred to as "waterborne," even though water is not the exclusive means of transmission. They were spread by impure food, as well as water, and by contact with feces, flies and other filth. Although much of the historical evidence on death-by-cause is notoriously problematic because of the definitions of various diseases change, as do their diagnoses, these three diseases were well identified.

³ Data on both finances and mortality are contained in *Bureau of Labor Statistics Bulletin*, #24, 30, 36, and 42, for the years 1899-1902, and *Census Bulletin* #20 for 1902-03. The Bureau of the Census published *Mortality Statistics of Cities* annually between 1900-36 and *Financial Statistics of Cities* more or less annually between 1905 and 1931.

Citizens had good reason to demand sanitation services, and cities received a big payoff to their investments in sanitation capital. Cities could and did buy themselves lower death rates.⁴

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II

In the early nineteenth-century, it was the risk associated with fire that promoted the demand for urban water supplies. In the early twentieth-century, it was the risk associated with typhoid or cholera epidemics that promoted the demand for water supply improvements. The correlation between polluted water and disease, attributable to the work of Chadwick and others, was now explainable as a causal mechanism as a result of the germ theory.⁵ Experiments with filtration at places such as the Lawrence Experiment Station and experience with filtration in a number of European and North American cities provided the information to city dwellers that they were right to demand such improvements in their water works and sewage works. In a previous paper, we asked whether mortality crises (epidemics) caused changes in urban expenditures on sanitation.⁶ We approached the question through a straightforward counting approach: we counted the number of mortality shocks in a city that were closely followed by a notable expenditure increase in that same city.

We define a mortality shock as a year in which the actual waterborne death rate was more than one standard error above its trend in that city over the period 1899-1929. The waterborne

⁴ The results presented here are similar to and use the same techniques as in Cain and Rotella, "Death and Spending: Urban Mortality and Municipal Expenditure on Sanitation." *Annales de demographie historique*, 2000-1, 139-154. Details of the estimation and can be found in that article.

⁵ Edwin Chadwick, *Report of the Sanitary Condition of the Labouring Population of Great Britain*, ed. by M. W. Flinn (Edinburgh: University Press, 1965) and Lemuel Shattuck, *Report of the Sanitary Commission of Massachusetts, 1850* (Cambridge: Harvard University Press, 1948). Shattuck used the Chadwick report to make an analagous argument for sanitation in Massachusetts.

death rate shocks were grouped into 98 epidemic episodes (some lasting more than one year). They were heavily concentrated in the years 1906-10, with a few during World War I, and only 3 in the 1920s. We defined an expenditure "response" to be a situation in which an analogously defined shock in the expenditure series (i.e., an expenditure more than one standard error above trend) occurred within three years of a shock in the mortality series.

In 29 of the 98 episodes, there was no response from the affected city. Otherwise, an expenditure substantially above trend occurred within three years. We, therefore, count responses in 69 of the 98 mortality episodes. Of these, 13 are cases in which the response occurred in the same year as the shock.

We turned to the *Engineering News* to see if we could find reports of the mortality shocks and/or the municipal expenditure responses that we identified in our data set. The *Engineering News*, was a widely-read weekly journal of "civil, mechanical, mining and electrical engineering" which regularly carried news of sanitation developments in the U.S. A typhoid outbreak might result in an article on causes and potential cures; the construction of a new water purification plant might be the subject of an essay complete with drawings and pictures.

We found discussions in the *Engineering News* of the waterborne disease shock in 14 of the 69 cases where there was a response (20%), and 6 of the 29 cases where there was none (21%). In each case, the disease was typhoid fever, and the role of pollution was often noted. We found a discussion of the response in 13 of the 14 cases where we found an article about the disease shock (93%), and in 28 of the 56 cases where we were unable to find mention of the shock (50%). In some of the 6 cases where we found mention of the disease shock, but in which there was no response, we were able to identify the reasons why there was no response.

⁶ Cain and Rotella, 2000-01.

So, although not every epidemic caused an expenditure response, we conclude that epidemics did often provide a “moment of crisis” to which cities responded by investing in large sanitation capital projects. We contend that the success of water treatment works in dealing with epidemics accounts for the fact that we observe so few mortality shocks in the later years of our sample. As sewage treatment technologies developed in the first half of our sample period, the waterborne disease death rate declined. The public demanded water and sewage treatment works to insure that those rates did not return to their nineteenth century levels.

III

While epidemics of waterborne diseases played a critical role on the demand side of the market, it was demonstration effects which caused important changes on the supply side. We define demonstration effects quite broadly as information that is obtained from elsewhere or from pre-construction experimentation within the city itself. There are many forms of demonstration effects, not the least of which is the experience of a different city with an epidemic. For example, in 1892, there was a cholera outbreak in Germany. In Hamburg, there were 17,000 cases of the disease (with 8,000 deaths) in a population of 640,000. In Altona, an adjoining city that became part of Hamburg in 1937, there were 500 cases (300 deaths) in a population of 150,000. The striking difference means that Hamburg suffered a rate of infection that was 8 times the rate in Altona. Both cities drew their water supply from the Elbe, but Altona filtered its supply. As a result of this clear demonstration of the efficacy of filtration, Hamburg and other German cities began to upgrade their waterworks.⁷ The episode revealed not only that

⁷ Martin V. Melosi, *The Sanitary City: Urban Infrastructure in America from Colonial Times to the Present*. (Baltimore: The Johns Hopkins University Press, 2000), p. 141.

filtration was effective, but it also provided information about the performance of the particular type of filters Altona had installed. We see demonstration effects as the ways in which such information was made available to cities, and we argue that demonstration effects lowered the cost of obtaining information thereby causing the supply of water and sewage capital to shift to the right.

A. The Grand Tour

American engineers in the first half of the nineteenth century either received formal training at a school like the U.S. Military Academy at West Point or received informal, on-the-job training, many of them by working on the Erie Canal. By mid-century, some engineers began specializing in waterworks or, less commonly, sewers.

The implementation of a sanitation strategy represents one of the largest expenditures cities made. Given the very high cost of the capital, both engineers and the cities that hired them felt they had to "get it right." While there was no foolproof way to be sure that a particular technology would be best for a particular set of local conditions, a good way to reduce the risk of making a costly mistake was to look at experiences elsewhere. Reports of tours of sanitation facilities were often published, thereby sharing the information more broadly.

After being hired as Chief Engineer to Chicago's Board of Sewerage Commissioners, Ellis Sylvester Chesbrough submitted a report in 1855. His report referred to the sewers of New York, Boston, and Philadelphia, and showed that he was familiar, through his reading, with the sewers of London, Paris, and other European cities. Even though most U.S. cities had sewers, none of them had a comprehensive sewerage system, so Chesbrough's recommendations relied on his training and intuition. In December 1856, he was sent to Europe in order to discover if the sewage disposal techniques used in several cities there were relevant to Chicago's needs. The

report of this trip, which Chesbrough submitted in 1858, represents one of the first sanitary engineering treatises.⁸ He concluded that none of the cities furnished an exact criterion to judge the effects of disposing sewage directly into the Chicago River, but he argued that their collective experience suggested that it would be necessary to keep the river free of sewage accumulations.

Shortly after the Civil War, James P. Kirkwood, an eminent water works engineer, was engaged by the city of St. Louis to recommend improvements in its water supply. In December 1865, Kirkwood, a strong advocate of filtration, then a new technology, was sent to Europe to gather information. His report, published in 1869, details the filters and filter galleries in nineteen European cities. It was the only source in any language on municipal water supply filtration until Allen Hazen, another American engineer, published a report of his European trip in 1895.⁹ At the time that Kirkwood's report was published, no U.S. city had constructed a complete water filtration filter system though a filter basin had been built in Hamilton, Ontario in 1859, and a second was under construction in Newark. In a short text and two plates Kirkwood summarized his design for St. Louis' filters. He concluded, on the basis of experiments, that 24 hours' detention in settling basins were enough and that four basins should be provided; one for filling; one for settling; one for decanting; and one being cleaned. Even before Kirkwood

⁸ *Report on the Results of Examinations Made in Relation to Sewerage in Several European Cities, in the Winter of 1856-57*, published in Chicago by the Board of Sewerage Commissioners (1858). Chesbrough visited and reported on the sewerage of Liverpool, Manchester, Rugby, London, Amsterdam, Hamburg, Paris, Worthing, Croydon, Leicester, Edinburgh, Glasgow, and Carlisle. See Louis P. Cain, "Raising and Watering a City: Ellis Sylvester Chesbrough and Chicago's First Sanitation System," *Technology and Culture*, Vol. 13, No. 3, July 1972.

⁹ *Report on the Filtration of River Water for the Supply of Cities as Practiced in Europe*, New York: VanNostrand, 1869. Kirkwood provides information on the filters of Leicester, Wakefield and York in England, Edinburgh, Dublin, Marseilles and Nantes in France, Altona and Berlin in Germany, and Leghorn in Italy; he provides information on the filter galleries of Perth, Angiers, Lyon and Toulouse in France, and Genoa.

returned from abroad, a political change led St. Louis to decide not to build filters, but his report was used by other cities U.S. who wanted to copy European filtering techniques.

Following the publication of his book, Kirkwood was hired as a filtration engineer in Poughkeepsie and Hudson, N.Y. Later, he became the consulting engineer for the Lowell and Lawrence, Massachusetts, waterworks, both of which included filter galleries. Such filtration projects made an impression on American engineers, and, as a result, as Moses Baker discusses, the technology soon took hold:

Immediately following the appearance of the report, a number of filter galleries and two basins were built in America: in 1870 at Whitinsville, Mass.; in 1871, at Schnectady, N.Y. Columbus, Ohio, Indianapolis, Ind., and Des Moines, Iowa; in 1872 at Lowell, Mass., and (a filter basin) at Waltham, Mass.; in 1874 at Decatur, Ill.; in 1875 at Brookline and Lawrence, Mass.; in 1878 at Rutland, Vt.; in 1880 at Nashville, Tenn. and Ft. Wayne, Ind.; in 1888 at Green Island and Hoosick Falls, N.Y., and at Springfield, Ill.; in 1891 at Reading, Mass. This is not a complete list. After that, few natural filters were built in the United States. In Canada, Toronto built a filter basin in 1875.¹⁰

There was a second wave of construction of filtration facilities in the 1890s when perhaps twenty American cities built them. The most influential of these was the one Allen Hazen built in Albany, NY, in 1899, which served as the model for Washington, Philadelphia, and a number of other larger cities. Engineers such as Chesbrough, Kirkwood, and Hazen traveled widely throughout the U.S. in the role of consulting engineers. The information they collected and published was put to use in specific projects, and this was all the easier as transportation costs fell.

By 1896, filtration technology was a bit more familiar when Pittsburgh ordained that a study should be made to investigate the relation of the city's water supply to public health and to ascertain the desirability of sand filtration. The Filtration Commission hired Hazen, just returned

from his European trip, to be the Consulting Engineer. Two gentlemen associated with the Lawrence, Massachusetts, water system were hired to be resident engineer and bacteriologist. Hazen brought his extensive knowledge to bear on the subject, including the influential work that George W. Fuller did on mechanical (rapid sand) filters in Louisville. The reduced cost of transportation and the development of American works meant that it was possible for the Commissioners themselves to make an inspection trip:

The Commission as a body, on November 11, 1896, visited the city of Lawrence, Mass., for the purpose of inspecting the filtration beds in operation in that city, and on their return, devoted a day in the city of New York to the inspection of certain plants engaged in mechanically filtering private water supplies. On April 19 and 20, 1898, the Chairman of the commission, accompanied by the Chairman of the Committee on Water Analysis, the Mayor of Pittsburgh, and the Resident Engineer, visited the cities of Louisville, Ky., and Cincinnati, Ohio, for the purpose of investigating the methods and results of the extensive experimental plants established in these cities, and also visited the city of Covington, Ky., and examined the water works of that municipality.¹¹

In addition, and with a bow to the past, individual commissioners visited the filtration plants of London, Paris, Antwerp, Bremen, Hamburg, and Berlin.¹²

B. Other Publications

By the 1890s, the *Engineering News* was an important source of information about sanitation developments in the U.S. The construction of a new water purification plant might be the subject of a long essay complete with a many drawings and several pictures. The *Engineering News* was not afraid to take editorial stances. For example, in a 1907 article on the New York City water supply, the editors wrote:

¹⁰ Moses N. Baker, *The Quest for Pure Water: The History of Water Purification From the Earliest Records to the Twentieth Century* (New York: The American Water Works Association, 1948), p. 279.

¹¹ Report of the Filtration Commission of the City of Pittsburgh, Pennsylvania, January, 1899, p. 2.

¹² The report takes care to note that "The members of the Commission have borne all expenses involved in visits paid to other localities, whether in this country or abroad, without recourse to the funds placed at the disposal of the Commission" (p. 3).

Time was when a city might hesitate before launching upon the expenditure necessary to provide a water purification plant, lest its outlay should not prove to give the desired results, or in giving them be burdensome on account of needless expense that might perhaps have been avoided by a delay that would make available some improved and less costly method of treatment. Fortunately, there is no longer reason for hesitation on this account....¹³

One of the editors of *Engineering News* and an associate assembled a book entitled *Sewage Disposal in the United States*. In the Preface, Moses Baker and George W. Rafter note:

The chief object ...of this book is to specifically call the attention of sanitary authorities, engineers, and others interested in questions of public sanitation, to the fact that we have already accumulated a consider stock of experience in sewage disposal in this country, and that for the future Americans, who wish to study the subject in detail, will not be obliged, as until recently was the case, to go abroad for the purpose.¹⁴

The book's first twenty chapters discuss "Principles," with numerous examples from American practice. The remaining twenty-five chapters present descriptions of particular works, with details of plants. Individual chapter titles include "Chemical Precipitation and Mechanical Separation at Long Branch, New Jersey" and "Intermittent Filtration and Broad Irrigation at South Framingham, Massachusetts." Such books became the texts of the early twentieth century. This greater availability of information reduced the costs associated with developing water and sewage treatment works and thereby led to increased supply.

C. Testing Stations

A testing station provides space for full-size, working models of water or sewage treatment technologies. The first such station was established at Lawrence, Massachusetts, in 1887, and began what has been termed "the era of testing stations"¹⁵ Throughout the 1899-1929 period, more than thirty major testing stations for water and sewage works were built. The

¹³ "Filtration for the Croton Water Supply, New York City," *Engineering News*, 21 November 1907, p. 556.

¹⁴ Geo.W. Rafter and M. S. Baker, *Sewage Disposal in the United States*, (New York: D. VanNostrand, 1894)

Lawrence Station was established by the Massachusetts State Board of Health. A chemical laboratory was installed, and a bacteriological laboratory was added two years later.

The Lawrence Experiment Station has its roots in the work of two scientists involved with the Massachusetts Board of Health - William Thompson Sedgwick and Theobald Smith. Both men recognized that the germ theory tied specific organisms to specific diseases, that humans were carriers of infection, and thus that the state had to enter into a new relationship with individuals because of the externalities issues involved.¹⁶ Sedgwick became an assistant professor of Biology at MIT in 1883, but there were few university resources for experimental work. In 1886, the Massachusetts legislature adopted a comprehensive water policy which required the Board of Health to adopt water pollution standards. This led to the establishment of the Lawrence Experiment Station because 1) it was recognized that one station would be more economical than multiple investigations by local water boards throughout the state and 2) uniform scientific standards could be assured through the adoption of new methods using the microscope. The first task of the Lawrence Experiment Station was to determine the effect of filtration as compared to natural oxidation. The Lawrence facilities afforded to Sedgwick and his students opportunities MIT could not provide.

In the first two years, Sedgwick and his students were able to develop and apply techniques for identifying and quantitatively analyzing the microorganisms in both water and

¹⁵ Samuel A. Greeley, "Testing Stations for Sanitary Engineering--An Outstanding Achievement," *Transactions of the American Society of Civil Engineers*, Paper No. 2610, Centennial Transactions, 1953, pp. 574-578.

¹⁶ See Barbara Gutmann Rosenkrantz, *Public Health and the State: Changing Views in Massachusetts, 1842-1936* (Cambridge: Harvard University Press, 1972), pp. 98-99. Sedgwick used bacteriologic techniques to refine both the scope and accuracy of environmental controls over waterborne diseases. Smith used immunological techniques to advance the laboratory as the source of diagnostic and preventive intervention.

sewage. The studies set the standards in Massachusetts, other states, and other countries.¹⁷ In 1893, when a typhoid epidemic came down the Merrimack River, a slow sand water filter, designed at the Lawrence Experiment Station by its leader, Hiram Mills, proved that polluted water could be made potable.

In the next thirty years, testing stations experimented with a wide variety of new technologies for both water and sewage treatment, determined safe operating loads for all sorts of works, and determined the effect of different raw water and raw sewage characteristics on processes and loads. The individuals who worked at these stations became the successors to Chesbrough, Kirkland, and Sedgwick.

D. Demonstration Projects

The testing station led to formal demonstration projects where the "experiment" was to build full-scale prototypes of particular technologies. Visits to other sites remain important, but field study at a particular site had become much more important:

The decision reached as a result of this study was that the cost was too high, the risk too great, and previous reported experience too slight for full-scale biological treatment to be recommended at the time. A prototype in the field ... was to be built and operated for about 6 months to obtain detailed data for the final design and to obtain greater certainty that the earlier findings were valid.¹⁸

Full-scale tests are demonstration projects that lie in the middle of the spectrum between pilot studies just beyond the conclusion of laboratory experiments and the construction of multi-

¹⁷ As Rosenkrantz notes, before 1890, the relevance of specific pathogenic organisms was not readily apparent, so the Board emphasized eliminating pollution as the proven method of disease prevention. In particular, although the typhoid bacillus was identified in 1880, there was a division among medical practitioners in Massachusetts as to whether the organism caused or merely accompanied the disease. Sedgwick's team was able to determine how typhoid fever was transmitted. *Ibid.*, pp. 103-105.

¹⁸ Nelson L. Nemerow, *Liquid Waste of Industry: Theories, Practices & Treatment* (Reading, MA: Addison Wesley, 1971). p. 177.

million dollar public works.¹⁹ Educated opinion may lead to the conclusion that a particular technology will prove successful, but often sufficient doubt exists to warrant a less than full-scale test. The crucial questions are feasibility, design parameters, reliability, and cost efficiency. These are issues that usually can not be resolved in a laboratory; they require "in the ground" demonstration projects. What is tested is often based on what can be found in the literature or on the experience of other cities. However, the expense of these works has grown to where cities no longer are willing to accept the uncertainty introduced by local conditions on technology that has worked well elsewhere.

E. The role of demonstration effects

The excursion through several forms of demonstration effects indicates that, as time went on, the information used by cities making decisions about investing in water and sewer capital became more extensive and specific. The cost of information was falling, and cities used more information to help them "get it right." In the middle of the 19th century, the Grand Tour enabled a city engineer to observe technology adopted by other cities. Cities like Chicago and St. Louis published the findings of their engineers thereby sharing information. By the end of the 19th century, by the time a national market has been created, publications such as the *Engineering News* served the information dissemination role on a more immediate basis. Also by the end of the 19th century, universities offered courses about sanitation issues, and textbooks for such courses were filled with case studies. The number of professionals working in the area increased, and they organized societies for sanitary engineers and public health workers.²⁰ The

¹⁹ See Louis P. Cain, "Metropolitan Sanitary District of Greater Chicago: Demonstration Projects for Design Criteria," in Howard Rosen and Jesse Britton, editors, "Demonstration Projects and the Development of Environmental Control Technology," unpublished report (Chicago: Public Works Historical Society, 1987).

²⁰ See Melosi, *op. cit.*, pp. 114-15.

late 19th and early 20th centuries were also the age of progressive reform politics and the municipal housekeeping movement. A large amount of information was created and disseminated in a short period of time.

This was also the age of rapid technological change and experimentation. Experiments on new water and sewer technologies were often conducted in public sector facilities by highly qualified scientists and the results were made available to the world. By the time of the First World War, demonstration projects for handling industrial wastes were underway in Chicago as joint ventures of the Chicago Sanitary District and a number of private companies including the major Chicago meatpackers and the Argo Corn Products Company.

In the middle of the nineteenth century, cities in search of sanitation information paid to send an expert to find the best practice technology. Fifty years later, they could find excellent information about water and sewage works in a textbook, and they could find much better data to help them decide whether a given technology was "best" practice. As the cost of information fell, cities were ever more willing to supply sanitation works to their citizens. And, as the complexity and cost of these works increased, they were willing to acquire more information to make sure they "got it right."

IV

A. Water treatment

The most important question is: Which technology is best for a particular city? At the turn of the twentieth century, there were several technologies available to purify water.²¹ One

²¹ One that tells us what contemporaries knew is M. N. Baker, *Municipal Engineering and Sanitation* (New York: The Macmillan Company, 1906). This book was published in Macmillan's "The Citizen's Library of Economics, Politics, and Sociology" series, which included several books by Richard T. Ely and Jane Addams. More recent treatments of this subject can be found in Ellis L. Armstrong, editor, *History of Public Works in the United States*

was to store it for a long period, but most cities did not have that option. Sterilization by boiling and distillation was not practicable for municipal water supplies. The three techniques used most commonly were sedimentation, coagulation, and filtration.

Sedimentation is short-term storage to remove suspended matter from water to clarify it. Either the water rests or passes slowly through shallow settling basins where the sediment precipitates to the bottom of the reservoir from which it can be removed on a regular basis. The amount of time involved depends on the quality of the water.

Coagulation is the use of chemicals (coagulants) that accelerates the process of sedimentation. One of the most commonly used coagulants was alum. It was usual to adopt filtration together with coagulation, but in some cities (e.g., Kansas City between 1900 and 1911) sedimentation and coagulation were used without filtration. Coagulation is never used alone, but always in conjunction with sedimentation and/or filtration.

Filtration is used to remove remaining suspended matter. It is not an effective technique by itself if there is a large amount of suspended matter because the filters have to be cleaned often. The popularity of filtration grew rapidly following the 1892 cholera epidemic when the dramatic difference in the experience of Hamburg (without filters) and neighboring Altona (with filters) convinced many its effectiveness.

There were several types of filters available in the early 1900s. Slow sand filters used beds of sand that rested on beds of gravel. Below the gravel bed was a system of collection pipes. This process eliminated almost all the bacteria from the water. Mechanical (or rapid sand) filtration used coagulants combined with rapid filtration. Mechanical filters processed

(Chicago: American Public Works Association, 1976) and Martin V. Melosi, *The Sanitary City: Urban Infrastructure in America from Colonial Times to the Present* (Baltimore: Johns Hopkins University Press, 2000).

100-125 million gallons of water per acre of filter per day as opposed to 2-3 million gallons for slow sand filters.²² While sand filters were laid in the ground, mechanical filtration generally took place in wooden or steel tanks. Given the amount of water processed, mechanical filters clogged rapidly and required cleaning at least daily. This was accomplished by reversing the flow of the water, stirring the filter material, and wasting the dirtied water. While such cleaning eliminated impurities at the surface of the filters, those which penetrated deeper were scraped from the mechanical parts, but this did not have to be done daily.

The famed Lawrence Experiment Station began examining slow sand filters in 1893.²³ Lawrence drew its water from the Merrimac River which was relatively clear but highly polluted. In the early years of the twentieth century, experiments on a scale comparable to actual practice were conducted by Cincinnati, Louisville, Philadelphia, Pittsburgh, New Orleans, and Washington in order to assess the relative merits of the two types of filters. All these cities drew their water supplies from rivers that had large amounts of suspended matter and sewage pollution. Providence, Rhode Island, experimented with mechanical filters. Its water, drawn from the north branch of the Pawtuxet River, was low in suspended matter, but polluted with domestic and industrial wastes. From the results of these experiments, plus evaluation of European experience, the consensus developed that slow sand filtration was more efficient for relatively clear water, while mechanical filtration was more efficient for silt-laden water. There was also general agreement that slow sand filters were preferred for smaller cities, while mechanical filters were preferred for larger cities.

²² Baker's five eras of water treatment in the U.S. and the rivalry between slow and rapid sand filters is discussed in Melosi, *op. cit.*, pp. 139-145.

²³ This facility, initially under the leadership of Hiram Mills helped train engineers Allen Hazen, George W. Fuller, and others.

In addition to coagulants, chemicals were added to water for many purposes, particularly sterilization. Both types of filters made use of oxygen in the water, but heavily polluted water had little free oxygen. Aeration was used to improve the taste and odor of low-oxygen water. Water is aerated either by spraying the water into the air or by forcing small air bubbles into it. By the end of the nineteenth century, acceptance of the germ theory and the realization that some diseases were waterborne led to the use of chemical sterilization, usually chlorination.²⁴ Hard water was softened through either chemical precipitation or ion exchange to remove iron, calcium, and magnesium.

Table 2 uses information on municipally owned water supply systems from the *General Statistics of Cities: 1915* to report dates at which cities adopted various techniques of water treatment.²⁵ Cities drawing their water supplies from rivers are over-represented in this table, while those drawing their water supplies from fresh-water lakes are underrepresented. Cities most likely to be affected by upstream pollution were early adopters of water treatment. In 1900, a little over six percent of the nation's water supply was filtered; by 1914, over forty percent was. Eventually, almost every city would filter its water supply. Notice that on Table 2 the clustering moves diagonally from upper left to lower right. This represents the chronology of the development of water treatment technologies, and the larger clusters associated with the newer technologies shows the adoption of advanced treatment methods by more and more cities.

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²⁴ Melosi, *op. cit.*, p. 144, notes the correlation between the use of hypochlorite and a decline in typhoid fever death rates.

²⁵ U.S. Department of Commerce, Bureau of the Census, the *General Statistics of Cities: 1915* (Washington: Government Printing Office, 1916).

Of the 33 cities included in Table 2 during the years 1899-1912, 22 are among the 48 cities in our sample. For these 22 cities we have information on annual capital expenditures and annual operating expenditures on waterworks and water treatment. By examining the patterns of change over time in per capita outlays on capital and operations, we can observe the effect of adopting the new technologies on expenditures. In most instances we see that adoption of sedimentation and filtration shows up as a jump in capital expenditures whereas adoption of coagulation and chemical treatment leads to jumps in operating expenditures.

Table 3 presents water capital expenditures for our sample of 48 cities from 1899 through 1929. Using annual capital expenditures by urban water departments, we identified those years when cities made particularly big investments. We defined a year of high expenditure as one in which a city reported per capita expenditure on water capital that was more than one standard deviation above the mean for the period. Often projects took multiple years to complete, but we include in Table 3 only the initial year of extraordinary expenditure for multi-year episodes. The capital expenditure data does not reveal what kind of capital the city bought. The money could have been spent on a variety of capital investments – e.g., building new filtration beds, extending the water delivery system to new neighborhoods, enlarging the main waterworks, building new pumping stations. That we found notable expenditure increases which match the timing in Table 2, gives us confidence that expenditure data can reveal dates when cities were adopting new water treatment technologies.

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We can see clustering patterns in Table 3 that suggest the influence of demonstration effects. New England cities are prominent among cities that make large capital expenditures early in the period. These cities were located in the same geographical area, they had easy access to the information being generated at the Lawrence Experiment Station, and they shared water sources and sewage discharge outlets. Two New Jersey cities located on the same river also made large early investments. The first decade of the 20th century saw heavy investment in water capital by Midwestern cities (Ohio cities are particularly well represented) and by cities located on lakes. Few cities undertook large water capital investments during the years of U.S. involvement in World War I. The 1920s saw many cities make large expenditures updating and enlarging (or replacing) their original waterworks, extending their delivery systems, and adding capacity to water treatment facilities as cities increased in size and prosperity swelled municipal coffers.

B. Sewage treatment

Sewage treatment technologies developed at a later date than water treatment.²⁶ Initially, sewage was either discharged into water or onto the land. In a world with relatively few industrial wastes, the oxygen contained in a moving body of water will help purify the wastes. The same is not true of sewage discharged onto the land. At the turn of the twentieth century, the two major systems of land disposal were sewage farming (irrigation) and intermittent filtration. Sewage farming is very labor intensive. Consequently, it was quite expensive in a high wage environment such as that in the U.S

²⁶ Melosi, *op. cit.*, discusses the evolution of sewage treatment on pp. 167-73. A survey of sewage treatment, found in U.S. Department of Commerce, Bureau of the Census, the *General Statistics of Cities: 1909* (Washington: Government Printing Office, 1913) comes when only a small number of cities had begun to treat their sewage. It therefore contains little useful information for the purposes of this paper.

In intermittent filtration, the filters are prepared beds of sand, cinders and other porous materials under-drained by open-jointed tile conduits. As sewage passes through the filter, it is operated on by aerobic bacteria. Filtered sewage is discharged continuously for a period onto one bed, and then the flow is diverted to another bed so the first can drain. The time the sewage flows could be hours if the material in the bed is fine or days if it is coarse. Experiments at the Lawrence Experiment Station by the State Board of Health led to the adoption of this technique in Massachusetts and elsewhere. Although intermittent filtration needed only five percent of the land needed by sewage farming, most cities considered the land area required to be a problem.

To further reduce the land area used by intermittent filtration, cities increasingly used preliminary processes that would remove most of the suspended matter, whether organic or mineral. Both screening and settling were used for this purpose. Screening was considered to do a reasonably good job at preliminary treatment, but settling created problems because the sewage needed to stand a long time in costly reservoirs or tanks and emitted an offensive odor as the suspended matter decomposed. To deal with this problem, it became common to add chemicals to both accelerate the precipitation process and kill some of the bacteria. Chemicals by themselves left roughly half the organic matter for secondary decomposition and accumulated with the organic and mineral matter in the bottom of the tank. This mélange, known as sludge, still had to be disposed.

One solution was to modify the basic notion of the cesspool in which anaerobic bacteria are the working agent. In a septic tank, sewage passes through a preliminary grit chamber of sand or other material and the suspended organic matter is retained so that anaerobic bacteria can do its work. The (partially) clarified effluent goes on through. Sludge accumulates relatively

slowly in the tank because much of the organic matter is either converted to gas, passes out in the water, or dissolves. The resulting sludge was more readily treated via aeration.²⁷

In the absence of septic tanks, contact (filter) beds work much faster than intermittent filters. Instead of treating sewage in a single bed, contact beds use a series of multiple beds. First the sewage goes to a bed where the anaerobic bacteria do their work. Then it moves to a second (and perhaps a third) bed where the aerobic bacteria do their work. This cycle is repeated two or three times on a daily basis, with each bed given a period of rest between cycles.

It was in the first decade of the twentieth century that American cities began to reach a population size where sewage purification was recognized as necessary. Before 1909, most sewage filters were sand filters, although both Columbus and Reading had recently installed sprinkling (trickling) filters in which the sewage is sprinkled onto the bed and Auburn, NY, was in the process of installing contact filters. Technology was changing rapidly during these years, and new technologies (e.g., activated sludge) were available within the next decade.²⁸ Cities such as Chicago, which began investigating sewage treatment for industrial wastes during these years, did not build major works until after World War I. When they did build, the engineering of the works embodied the experience of the cities that had pioneered sewage treatment technology. In 1900, 3.3 percent of the urban population, and 1.3 percent of the total population

²⁷ The most popular tank, the Imhoff tank, was introduced in the first decade of the twentieth century. In this tank, solids fell through slots in the bottom of the sedimentation chamber into the sludge compartment. The sludge was allowed to digest until the majority of the organic matter turned to gas or liquid. The remaining solid matter was dried and, in some cases, used as fertilizer.

²⁸ This involves combining raw sewage with a concentration of aerobic microorganisms. Air was then pumped into the combination to stimulate bacterial reduction. At the end, the activated sludge and the residual were removed, and the activated sludge recycled to be combined with new sewage. Experiments on this technique were made at the Lawrence Experiment Station in 1912 and at the Chicago Sanitary District in 1914. The first plant was constructed in San Marcos, TX, in 1916.

lived in urban areas with sewage treatment. Twenty years later, those percentages had grown to 17.5 and 9.0 respectively.

Table 4 is constructed in the same way as Table 3. It presents years of particularly high sewer capital expenditure for the 48 cities in our sample. Again we see the early leadership of New England cities. The most striking result of the regression model reported in Table 1 is that investments in sewer capital had a large and statistically significant effect on reducing urban mortality from waterborne diseases in this period. Many cities responded to this fact by building and extending sewer systems and by adopting new treatment technologies. Over time more and more cities spent to increase their sewer capital although few cities undertook large capital projects during World War I. High expenditures on sewer capital are evident throughout the 1920s as many cities in all regions invested in treatment, particularly the activated sludge technology, the last major technology to be innovated.

-----INSERT TABLE 4 HERE-----

V

During the first 30 years of the 20th century, American cities invested heavily in sanitation capital and experienced dramatic declines in deaths from diseases associated with bad water and poor sewage disposal. Death rates from typhoid fever, dysentery, and diarrhea fell by 88% going from 8.9% of urban deaths in 1902 to only 1.4% on 1929.²⁹ Cities bought this reduction in mortality by spending huge amounts on their sanitation systems. In the period on

²⁹ See Cain and Rotella, 2000-01, p 139, 151

which we focus, most sanitation expenditures were directed at treatment of water and sewage in a period when new treatment techniques were being developed rapidly.

We have shown that the payoff (in terms of averted deaths) for expenditures on sanitation capital in this period were large. Especially notable is the big effect of spending on sewer capital. We examined the role of epidemics and demonstration effects as causes of decisions by cities to undertake these massive expenditures and use a simple demand/supply model to argue that both led to increases in sanitation services, but through different channels. Epidemics shift the demand curve for sanitation, and demonstration effects shift the supply curve.

Empirical examination of epidemics reveals that many cities experiencing an episode of increased mortality from waterborne diseases responded with large expenditures on sanitation capital. Demonstration effects took place in a number of ways. In the middle of the 19th century, prominent engineers who traveled to visit sanitation works in European and U.S. cities issued reports that spread the news about treatment techniques and their results. Later, publications such as the weekly *Engineering News* put out articles and editorials that were read by a growing group of sanitation professionals. In these ways the experience of cities with different techniques received wide publicity. Formal testing sites like the Lawrence Experiment Station undertook careful studies of new techniques as they developed and provided evaluations about what worked and what did not. Later some cities entered into partnerships with private industry to experiment with ways to handle wastes. Formal demonstrations projects have been, and are still used to try out new methods before they are built on a large scale.

It is difficult to find systematic evidence of demonstration effects in our data on expenditures because we don't know what type of capital was purchased. Still, our examination of the dates when cities undertook major expenditures on sanitation capital reveals patterns

consistent with reasonable conclusions drawn from the many specific instances of information sharing that we detail. Clusters of early adoption by New England cities and somewhat later adoption by Midwestern cities, and the flowering of investments in the 1920s suggest that cities were learning from each other and from published sources.

We see epidemics as having their biggest impact on the demand for sanitation services. Frightening episodes of high mortality from diseases identified as related to bad water and poor sanitation caused citizens to demand action from their governments.

Demonstration effects have their biggest impact on the supply of sanitation services. Because the cost of sanitation capital was typically very large, cities wanted very badly to “get it right”. Investing in the wrong technique would be an expensive, and politically disastrous, mistake. By lowering the cost of information about the ways that water and sewer technologies work, demonstration effects increase the willingness and ability of cities to adopt those new technologies and thereby increased the supply of sanitation.

Together these two forces created the conditions where American cities allocated vast sums of money to dramatically reduce deaths in the early 20th century.

TABLE 1
Waterborne Disease Death Rate Regression Results
 Dependent Variable is natural log of the Waterborne Disease Death Rate

Variable	Coefficient	t-ratio	Mean
WATKALL	-0.00087	-0.53	33.327
WATERAV3	0.0413	1.66	1.477
SEWKALL	-0.0120**	-5.58	13.915
SEWERAV3	-0.0812	-1.17	0.287
REFUSE	-0.0603**	-2.19	1.00
YEAR	-0.0788**	-20.02	1915.5
ASSDPC	0.0061*	2.00	11.03
LANDAREA	0.00019	0.81	270.53
WAR	0.2634**	7.29	0.143
LATE 20	-0.0810**	-2.10	.107

R² 0.834 ** statistically significant at the 95% confidence level
 n 1109 * statistically significant at the 90% confidence level

Definitions of Independent Variables

WATKALL	Sum of all capital expenditures on waterworks prior to the year under observation plus the value of municipal waterworks in 1899 (or in the year acquired) in per capita terms
WATERAV3	Average operating expenditures on waterworks and water treatment over the two preceding years and the year under observation in per capita terms
SEWKALL	Sum of all capital expenditures on sewage facilities up to the year under observation in per capita terms
SEWERAV3	Average operating expenditures on the sewer system over the two previous years and the year under observation in per capita terms
REFUSE	Average expenditures on refuse collection and disposal over the two preceding years and the year under observation in per capita terms
YEAR	A trend variable, the year under observation
ASSDPC	Assessed valuation in hundreds of dollars per person
LANDAREA	Square miles in hundreds of square miles
WAR	A dummy variable equal to 1, if year = 1917 - 20
LATE20	A dummy variable equal to 1, if year = 1925 - 27

TABLE 2
Dates of adoption of water treatment techniques

Year	Sedimentation	Coagulation*	Slow Sand Filtration	Mechanical Filtration	Chemical Treatment
1863	Washington				
1879	Louisville				
1883	Council Bluffs, IA				
1889		Omaha, NE		Oshkosh, WI	
1890	Oshkosh, WI				
1892	Atlanta				
1893			Lawrence, MA		
1894	Knoxville, TN	Knoxville, TN	Knoxville, TN Altoona, PA		
1896		Cedar Rapids, IA		Cedar Rapids, IA Charlotte, NC	
1899	Albany		Albany	Norfolk, VA	
1900	Kansas City	Kansas City			Mobile, AL
1902	Philadelphia		Philadelphia	Philadelphia	
1903			Providence Washington Reading Yonkers	New York City	
1904	St. Louis	St. Louis			
1905	Youngstown Washington Harrisburg, PA Columbia, SC	Atlanta Harrisburg, PA Columbia, SC Charlotte, NC		Youngstown Harrisburg, PA Columbia, SC	Harrisburg, PA
1906			New York City		
1907				San Diego, CA	
1908	Pittsburgh Cincinnati New Orleans, LA Nashville Richmond	Cincinnati New Orleans, LA	Pittsburgh Wilmington	Cincinnati New Orleans, LA Columbus	Columbus Omaha, NE Charlotte, NC
1909		Louisville Pittsburgh Nashville		Louisville Albany	Nashville
1910	Springfield	Springfield Washington	Springfield	Atlanta Toledo	Pittsburgh Milwaukee Cincinnati Kansas City Trenton Albany
1911					New York City Chicago St. Louis Detroit Wilmington Cedar Rapids, IA Philadelphia Cleveland Louisville Hartford
1912				Fort Worth, TX	Buffalo Dallas, TX Columbia, SC
1913	Minneapolis			Minneapolis	
1914	Trenton	Dallas, TX Trenton Albany		Baltimore Dallas Trenton St. Louis	
1915					

* Coagulation is never used alone, but always in conjunction with one or more other processes

Source: U.S. Department of Commerce, Bureau of the Census, General Statistics of Cities: 1915 (Washington: Government Printing Office, 1916), p. 45.

Table 3
Years of High Expenditure on Water Capital

1899	Cambridge	Camden	New Bedford	Trenton					
1900	Worcester								
1901	Lowell	Seattle							
1902	Washington								
1903	DATA NOT AVAILABLE								
1904	Atlanta	Cincinnati	Kansas City M	Philadelphia	Richmond	Washington	Yonkers	Youngstown	
1905	Cambridge	Columbus	Pittsburgh	Spokane	Wilmington				
1906	Salt Lake	Youngstown							
1907	Buffalo	Chicago	Cincinnati	Columbus	Louisville	Philadelphia	Seattle	Trenton	
1908	Atlanta	Spokane	Springfield M	Toledo					
1909	Milwaukee	Pittsburgh	New York	Syracuse					
1910	New Bedford	Portland O	Reading	Rochester	Trenton	Youngstown	Wilmington		
1911	Grand Rapids	Jersey City	Lowell	Minneapolis					
1912									
1913	DATA NOT AVAILABLE								
1914	DATA NOT AVAILABLE								
1915	Baltimore	Cleveland	Fall River	Hartford	Rochester	Trenton	Worcester	Youngstown	
1916	Chicago	Dayton	Lowell						
1917	Hartford	Rochester	Wilmington	Youngstown					
1918									
1919	Denver								
1920	DATA NOT AVAILABLE								
1921	DATA NOT AVAILABLE								
1922	DATA NOT AVAILABLE								
1923	Atlanta	Baltimore	Cambridge	Cleveland	Columbus	Fall River	Grand Rapids	Milwaukee	Richmond
1923 continued		St. Paul	Yonkers						
1924	Buffalo	Camden	Denver	Jersey City	Minneapolis	Newark	Portland O	Providence	Seattle
1924 continued		Toledo	Washington	Worcester					
1925	Boston	Dayton	Fall River	Salt Lake					
1926	Atlanta	Chicago	Detroit	Hartford	Kansas City M	Louisville	Milwaukee	Nashville	Philadelphia
1926 continued		Reading	St Louis	Toledo					
1927	Louisville	Newark	Syracuse	Worcester					
1928	Albany	Fall River	Hartford	Springfield M	Yonkers				
1929	Milwaukee	Newark	Wilmington						

Table 4
Years of High Expenditure on Sewer Capital

1899	Boston	Lowell	Providence	Syracuse	Toledo	Worcester				
1900	Buffalo	Pittsburgh								
1901	Lowell	Springfield M								
1902										
1903	DATA NOT AVAILABLE									
1904	Boston	Cambridge	Columbus	Lowell	Nashville	Trenton	Youngstown			
1905	Columbus	Dayton	Washington							
1906	Reading									
1907	Dayton	Denver	Jersey City	Reading	Salt Lake C	Wilmington	Youngstown			
1908	Baltimore	Spokane								
1909	Louisville	Seattle	Wilmington							
1910	Grand Rapids	Louisville	Salt Lake C	Spokane						
1911	Atlanta	Hartford	Portland O	Rochester	Seattle					
1912	Kansas City M	Nashville	New Bedford	Newark	St. Louis					
1913	DATA NOT AVAILABLE									
1914	DATA NOT AVAILABLE									
1915	Albany	Baltimore	Cincinnati	Hartford	New Bedford	Newark	St. Louis	Washington	Wilmington	Yonkers
1916	Rochester	Salt Lake C								
1917	Albany	Columbus	Hartford	New Bedford	Rochester	Salt Lake C	St. Louis	St. Paul		
1918	Youngstown									
1919	Newark	Spokane								
1920	DATA NOT AVAILABLE									
1921	Nashville	Rochester	Youngstown							
1922	Detroit	Fall River	Jersey City	Spokane						
1923	Atlanta	Cambridge	Denver	Louisville	Milwaukee	Minneapolis	New Bedford	Newark	Portland O	Richmond
	1923 continued	Worcester	Youngstown							
1924	Camden	Lowell	Syracuse	Toledo	Youngstown					
1925	Baltimore	Buffalo	Chicago	New York	Philadelphia	Providence	Springfield M	St. Paul	Yonkers	
1926	Cleveland	Dayton	Grand Rapids	Hartford	Jersey City	Kansas City M	Louisville	St. Louis		
1927	Cambridge	Chicago	Cincinnati	Detroit	Nashville	Portland O	Syracuse	Toledo	Trenton	Washington
1928	Atlanta	Buffalo	Camden	Chicago	Columbus	Dayton	Louisville	Lowell	Pittsburgh	Springfield
	1928 continued	Wilmington	Worcester							
1929	Cincinnati	Reading	Seattle	St. Paul						