Preliminary and Incomplete

Water, Water Everywhere:
Water Reforms in American Cities

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Introduction

Samuel Taylor Coleridge wrote about an ancient mariner stranded at sea,[1] but he might as well have been writing about 19th Century American cities. Although large-scale municipal water supplies first emerged in the U.S. at the beginning of the 19th Century, water resource development and provision in American cities was still abysmal many decades later. A large share of households continued to rely on private wells and privies, which generally resulted in "circular water systems" that re-circulated household waste and perpetuated disease. (Melosi, 2000) Larger cities and wealthier neighborhoods had initially enjoyed an escape from this vicious cycle, but rapid urban growth, a weak understanding of the basis of many diseases, and rudimentary sanitary engineering resulted in the deterioration of water provision and sewage removal to the point that they merely reproduced circular water systems on a larger scale. (Duffy, 1990) Massive fires still wreaked havoc as early water systems failed to meet the needs of unprecedented urban growth (Anderson, 1988), and corruption in water contracting was widespread. (Blake, 1956)

By the 1930s, however, Coleridge was definitely out of the place. Scientific understanding of disease had made unprecedented strides. A large core of technocrats and municipal engineers had assumed important roles in city governments, and major conflagrations were no longer the scourge they had once been. (Melosi, 2000) Clean water technologies (filtration and chlorination) explain up to half of the enormous health gains in the early 20th Century prior to the revolution of new drugs and the advent of modern medicine. (Cutler and Miller, 2003)

What led to this dramatic transformation of municipal water provision? How did water systems go from a source of disease to a major protector of health? This paper examines these questions. Clearly there are multiple dimensions of a "good" water system – and hence potentially different explanations for improvements in each.

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[1] The title of our paper comes from the famous verse of Coleridge, "Water, water, every where/ And all the boards did shrink; / Water, water, every where, / Nor any drop to drink." Rime of the Ancient Mariner, 1797.

Important dimensions of water provision include preventing disease, combating fire, extending water supplies to previously unserved populations, and tapping larger sources as city populations grow. In the case of water system expansions, at least part of the answer appears to lie in the rise in local government ownership and control of water systems. Case histories of municipal water systems suggest that cities often created new water supplies or greatly improved existing ones when existing private supplies failed to perform well. The most rapid rise in public waterworks ownership occurred between 1890 and the 1920s, when major investments in water systems and clean water technologies were made. However, it is not clear that public ownership conferred other benefits such as health improvement (Troesken, 1999). Other research suggests that water filtration and chlorination produced enormous health gains (Cutler and Miller, 2003), but the relationship between clean water technologies and municipal ownership is not immediately apparent.

The importance of government just pushes the problem back a bit. What was so unique about the public sector that led it to achieve these gains – at least in some dimensions of water supply? We discuss several explanations for municipally-led improvement in water systems. The late 19th and early 20th centuries were a time of major advances in disease knowledge. It is possible that the public goods nature of clean water became clear at that time. But this theory does not seem right; the link between unclean water and disease was apparent long before the germ theory of disease, even if the mechanism underlying the link was not so obvious. Contracting between the public and private sector in the era prior to municipal ownership may also have been difficult. Water systems are a natural monopoly, so private firms that win the contract for them have incentives to under provide services (and charge a high price). This is particularly true if the private firms won the contract by bribery – very common in this era – or if private investment was held up by the threat of public expropriation (Troesken and Geddes, 2001). We suspect this cannot be the whole explanation, however. Private water companies had roughly equivalent levels of clean water technology to public systems late in the 19th century. Nor were other utilities privatized, even though they were also natural monopolies.

We propose an alternative explanation for large expansions of water systems that emphasizes growth and development in local public finance. In the late 19th century, there was enormous latent demand for expansion of water systems - to serve neglected neighborhoods, to find clean water for drinking, and to ensure sufficient water supplies to fight fires. The cost of building sufficiently large water systems was enormous, however. Building a modern water system frequently required transporting water from far away and investing in the latest filtering and sewage technologies. These costs were too large for private firms, and sufficiently large that only the largest cities or cities with access to sophisticated municipal finance techniques could afford them. While the large cities invested in water systems prior to the late 19th century, we propose that the development of municipal finance is the key to the provision of an adequate volume of water in many American cities. We provide some evidence for this theory using data on the cost of municipal water systems, the development of means of financing them, and the time pattern of investment in water resources. For other dimensions of water system improvement, local government involvement may have been less essential (for the adoption of filtration or chlorination, for example).

In this paper, our approach is informal; we present a variety of potential explanations for this rapid transformation in many aspects of water provision and then use some selected trends, illustrations, and case studies to help sort amongst them. The paper proceeds as follows. The first section presents a snapshot of how a typical American city addressed its water and sanitation needs shortly before the rapid development of modern water and sewage systems. The second section documents the consequences of clean water in subsequent years, focusing on health benefits. The third section presents case histories of Boston and New York, suggesting that city governments intervened to provide water when existing private ones failed to perform well. The fourth section elucidates some of the major potential explanations for local government ownership and control of water supplies and uses some informal evidence to evaluate them; the fifth section concludes.

A Snapshot of Municipal Water and Sewer Systems in the Late 19th and Early 20th Centuries

Household Wells and Privies

Households not connected to municipal water and sewer systems generally provided these services for themselves by digging wells and privies on their lots. Dry privies were generally used only for human waste and were generally placed a distance from homes. Cesspools received other types of wet waste and were generally placed in basements or immediately adjacent to homes, into which household drainage was emptied. (The terms privy and cesspool have come to be used interchangeably.) Privies and cesspools were generally constructed by digging a hole about 3 or 4 feet in diameter and at least 5 feet deep. Cesspool overflow was very common, saturating the earth around them with human waste. Privy vaults were generally lined with brick, stone, or wood. Over a period of time, vaults would rot or begin to disintegrate; even in their prime, they were porous enough to allow contaminants to escape. The common result was the tainting of nearby groundwater into which household wells generally drew. (Duffy, 1990; Melosi, 2000)

Not all waste material made its way directly into household water supplies or the surrounding soil. In many other cases, it journeyed to the streets in front of private lots. Liquid wastes were allowed to run into the open gutters of the alleys and into the streets. Here they mixed with cesspool contents removed from privies by hand and bucket and dead animals and refuse. (Duffy, 1990) City governments would sporadically send horse-drawn carts through residential areas to remove the buildup of waste that collected in the streets and gutters. Removed waste known as "night soil" was used as a fertilizer through the turn of the 20th Century, when an overwhelming preponderance of scientific evidence had demonstrated such practices not to be a good idea. Cities gradually began to introduce a new suction method of emptying privies using airtight hoses and cart removal, although these services were not often provided on a sufficiently regular basis. The prevalence of cobblestone streets also exacerbated the problems of festering garbage and waste dumped onto streets. Cobblestone surfaces did not wash or drain well, and they made waste removal considerably more difficult and less effective. (Duffy, 1990)

The Requirements of Constructing Water Systems

The challenges of constructing large municipal water systems were quite formidable during the 19th Century (indeed they are not trivial today). A variety of complex decisions had to be made; each one involved extensive research and planning together with a precarious balancing act in volatile political environments. An appropriate water source had to be identified. For most cities, there were generally many candidates, including surface water (streams, rivers and lakes) and ground water sources a various sorts. Survey work by geologists and engineers was a difficult and time-consuming task, and their findings were often controversial and subject to political pressure. Each potential source required estimates of supply volume and purity (particularly difficult before science elucidated what "purity" meant). Engineers would then attempt to estimate how water from each source could be delivered to city populations. This involved acquiring water using pumps and dams, transporting it via large aqueducts, raising it to sufficient elevation to facilitate flow by means of gravity, and storing sufficient quantities of water in large city reservoirs to smooth water consumption across periods of high and low demand. (Blake, 1956)

With this information, each potential water source would then require rough cost estimates. Not surprisingly, these estimates were often quite inaccurate. Private interests also commonly exerted considerable influence over these estimates and surveys. In most cases, the expense of such waterworks projects were staggering regardless of the source chosen, totaling many times annual municipal revenue in some cases. (Blake, 1956) Given the amount of information required, the uncertainty surrounding it, the sheer size of the financial commitment, uncertainty about future city needs, and strong political pressures from various directions, it is not surprising that many decades of debate often preceded significant waterworks projects.

Sanitary Problems Linked to Municipal Water and Sewer Systems

During the 1870s and 1880s, major cities expanded or built new water and sewer, systems, instituted systematic garbage collection, and began paving cobblestone roads with smoother materials like granite and occasionally asphalt. Clearly these services – municipal water and sewers in particular – held promise for addressing the woes caused by household wells and privies. But their promise was not to be immediately realized.

Sanitary engineering was developing as a field during the 1870s and 1880s, which meant that many of the eastern cities with sewers and drains constructed in earlier years were done so in a haphazard and inadequate manner. (Melosi, 2000) A considerable amount of waste continued to be dumped into city streets, and these wastes were generally swept or washed down drains and into sewers. Water systems generally provided inadequate water or inadequate water pressure to wash streets and flush sewers on a regular basis. Moreover, because most sewer systems were only designed to carry storm water, they often became clogged because they lacked the sufficient capacity (many were not more than 2.5 or 3 feet in diameter). (Duffy, 1990) Rapid population growth during the 19^{th} Century greatly exacerbated the capacity problems of existing systems and often negated the benefits of investments made to improve existing systems. In addition to a large amount of waste introduced into sewers from city streets, the advent of water closets in the US in the 1870s added considerable strain to already overburdened sewers. The end result was often backflow from sewers into streets and gutters; some observers began referring to sewers as “elongated cesspools.” (Duffy, 1990)

Perhaps the worst sort of backflow was the emptying of sewer systems directly into drinking water supplies. In the late 19^{th} Century, the primary sewer outfalls of many American cities emptied upstream of river water intakes or directly into large water bodies (like the Great Lakes) in close proximity to water intakes. The few cities that addressed this problem early on also suffered from the dumping of untreated sewage by upstream communities. This phenomenon essentially reproduced the household circular water systems on the municipal level. (Duffy, 1990)

Service Provision at the Household Level

Household water and sewer connections were often poorly constructed, resulting in waste and the continued spreading of filth. Annual flat fees were paid for piped water, giving households no incentive to fix leaky connections. Not until early in the 20th Century did many cities make efforts to meter household water, charging rates per volume of water used (or wasted) rather than flat fees. Water pressure, turgidity, and taste varied greatly from moment to moment, and isolated reports of other irregularities emerged from time to time (for example, fish being delivered through infrastructure pipes into bathtubs). As water closets began replacing simple privies and chamber pots after 1870, many of them resulted in more unsanitary conditions than the use of privies and cesspools. Many were not properly installed (permits to install water closets were trivial to obtain) and resulted in considerable sewage leakage. (Melosi, 2000)

Water Systems and Fires

The importance of water systems to combat major fires was an issue that emerged early in the 19th Century. The growth of population and structures meant growth in the consequences of uncontrolled fires. Bucket brigades and water wagons were clearly inadequate to manage large conflagrations. In areas of cities served by water supplies, water for extinguishing fires was tapped in several ways. The most rudimentary method was to drill holes in wooden water pipes; these holes could be corked or opened as desired. A more sophisticated approach was the installation of fire hydrants. Arrangements for use of water ranged from cities paying hydrant rental fees to private water companies to water being made freely available for purposes of putting out fires. However, water pressure was inadequate to effectively combat fires with some regularity. Even in cities with well-developed water systems, they often did not extend to outlying areas, poor neighborhoods, and regions of high elevation. These areas were clearly particularly vulnerable to the destruction of fires, and fire insurance was more costly by several orders of magnitude. (Anderson, 1988)

The Changing Landscape of Water Provision in Subsequent Years

The construction of water systems progressed rapidly at the end of the 19th Century, and adequately engineered sewer systems more slowly replaced the older ones designed for storm water early in the 20th Century. Near the end of the time period that we examine, the 1932 federal Relief and Reconstruction Act authorized $1.5B to be lent to state and local governments for public works projects; a sizeable proportion of these resources were spent on improving water and sewer systems. (Melosi, 2000) Not only did nearly all cities build and greatly improve water and sewer systems by this point in time, but access to them across diverse neighborhoods within cities was also greatly expanded.

The consequences of vastly improved water systems are very difficult to estimate empirically for a variety of reasons, but they undoubtedly include superior protection against fires, vast health gains, and other stimuli of economic development. The availability of water to combat fires was no longer perceived as a problem at all. Great strides in health improvement also coincided with (and appear to be driven by) the development of water and sewer systems, as discussed below. In the short span of five or six decades, the sanitary environment of many American cities was transformed from one of filth to one that resembles a modern city.

The Health Benefits of Clean Water

Only in retrospect is it possible to try to assign importance to clean water in health improvement. In the early 20th Century, mortality in the United States declined dramatically (see Figure 1). Crude mortality rates fell from 1,780 per 100,000 in 1900 to 1,076 per 100,000 in 1940. (US Census Bureau source) The probability of dying before age five fell from 0.180 in 1895 to 0.077 around 1930 (Preston and Haines, 1991), and life expectancy at birth rose from 54.9 in 1900 to 72.6 in 1940. (UCB demography source on-line) This decline in the U.S. was intertwined with what is commonly known as the "epidemiological transition." In 1900, about 44% of deaths were caused by infectious disease. By 1940, prior to the revolution of new drugs and the advent of modern medicine, this share had already fallen to 8%. It also coincides with the disappearance of the "urban penalty," which refers to the higher mortality rates observed in urban areas from the 19th Century until about 1940. Although consistent mortality statistics are not available throughout the 19th Century, mortality in cities appears to have actually risen during the middle of the 19th Century as cities grew rapidly. (Haines, 2001) In seven states with more trustworthy death registration data before 1900, the ratio of urban mortality to rural mortality was 1.32 in 1890 and 1.17 in 1900; for children ages 1-4, death rates in cities were 94% higher in 1890 and 100% higher in 1900 than in rural areas. Living conditions in cities were poor, and dirty water certainly made a large contribution to this filth.

A complex array of forces were surely responsible for these great health strides, including the development of a few vaccines, massive public health clinic and hospital construction efforts, milk pasteurization and meat inspection, and broad housing and welfare programs. However, new evidence detailed elsewhere suggests that up to half of the mortality decline from 1900 through the 1930s was attributable to simple clean water technologies. (Cutler and Miller, 2003) An empirical investigation that exploits variation in the timing of the adoption of clean water technologies in major American cities finds that water filtration and chlorination are responsible for up to half of the total mortality decline, two-thirds of the infant mortality decline, and more than half of the child mortality decline. (Figure 2 illustrates the impact of clean water technologies on typhoid fever.) Under conservative assumptions about the value of life and the expenses of improving water quality, these reductions translate into a rough rate of return of about 47:1 or an approximate average cost per life-year saved of $440 in today's terms. Undoubtedly there were large productive benefits of these massive health improvements, but data limitations make them difficult to estimate.

Case Histories of Boston and New York[2]

[2] Both case histories are drawn from Blake, 1956

The evolution of waterworks construction and ownership is different in every city. Keeping this in mind we present case histories of Boston and New York below. In both cases, waterworks were clearly used to further private interests in a variety of ways, both legitimate and otherwise. Boston and New York were reluctant to make the initial investments necessary to build water systems and preferred that private investors instead lead the way. The water supplies of both cities began with small-scale private ventures that proved to be inadequate to meet the needs of growing cities. In the end, the governments of both cities intervened to purse grander projects than private companies were willing to embrace in order to increase the available supply of water. Both examples illustrate the enormous scale of water projects.

Boston

In 1794 a group of entrepreneurs submitted a petition to the Massachusetts legislature to be incorporated to deliver water from Jamaica Pond to residents of Boston. The City of Roxbury, in which Jamaica Pond is located, opposed this proposal to no end. The following year the state legislature approved the application and incorporated The Aqueduct Corporation; the City of Boston passed a resolution approving the project as well. The company's charter gave it the right to obtain water from anywhere in Roxbury and deliver it to any part of Boston. It also contained two important restrictions: both Roxbury and Boston reserved the right to draw water for free to combat fires, and water rates were subject to court regulation.

The Aqueduct Corporation project proceeded quickly; it had obtained pine logs and awarded a contract for laying wooden pipes within months. Although historical accounts are unclear, customers appear to have been served with water by the middle of 1798. But the project failed to produce returns for its investors (literally) for 12 years. When its first dividends were paid, rates-of-return were only about 1.5%. Business gradually improved, however, and over the next thirty years, stock in the company yielded about a 4% annual return.

Although successful, this first water system only served about 800 families, and its pipes were small and were too shallow, causing them to freeze during the winter.

Movement toward supplying most of the city with water had its origins in a fire in 1825 that destroyed 53 houses and stores and caused half a million dollars in damage. The city council responded by beginning serious debate on how an adequate water supply for the city might be obtained. The debate would continue for nearly 25 more years.

Boston's mayor at the time, Mayor Quincy Sr., assembled a committee to investigate the matter. An engineer conducting surveys for the city reported that two sources would be most suitable: the Charles River above the falls at Watertown and Spot Pond in Stoneham. Spot Pond would not require the complications of pumping or reservoir storage because of its elevation. On the issue of ownership, the committee was split. Mayor Quincy also sought advice from the chairman of the Philadelphia Watering Committee (the success and scale of the Philadelphia waterworks was of course renowned); the chairman's answer both questioned the adequacy of the Spot Pond supply during dry months and strongly encouraged municipal ownership of any water system that Boston might pursue. On this advice, the mayor began denying petitions from entrepreneurs to establish private water company. His own efforts were frustrated as well, however, and his tenure ended without further progress.

Several years later a new mayor named Theodore Lyman again brought the water issue to the forefront - and went on record favoring municipal ownership. Jamaica Pond was clearly too small a source to serve the entire city, so new surveys were begun. These new surveys were completed in 1834 and recommended larger, more distant sources over Spot Pond and the Charles River primarily because of concerns about volume. Farm and Shakum Ponds in Framingham as well as Long Pond were touted as the most suitable alternative water sources.

Mayor Armstrong, elected in 1835, frowned upon seeking water as far away as Framingham, so he assembled yet another committee to study the matter. He also charged the committee to make a recommendation for either public or private waterworks ownership. Their report favored building a more modest system than did earlier ones, making allowances for expansion as the city's population grew rather than investing in a larger system at the outset. It promoted Spot Pond with the proviso that if this supply became inadequate, the City of Boston could also draw water from Mystic Pond. Interestingly, attached to the report was the charter of the Boston Hydraulic Company, which had recently been incorporated by the Massachusetts legislature but was still subject to approval by the city council. Its charter gave it the authority to take water from any source north of the Charles River within twelve miles of Boston. It also gave the city the option of purchasing a considerable share of the new company's stock. The city council approved the charter but declined to buy any of its shares.

More mayors were elected, and more committees to study how to supply the city with water were appointed. In 1837, three city commissioners were appointed to develop a concrete water supply plan for the city. It considered four of the usual suspects: Spot Pond, Mystic Pond, Long Pond, and the Charles River. The Charles River was the most unattractive of the options because it would require more mechanical pumping – and was thought to be dirtier - than the others. The real choice was essentially between Long Pond and Spot Pond (which could be supplemented with water from Mystic Pond if necessary). The three commissioners could not agree amongst themselves; two of them recommended Spot Pond, and the mayor attempted to act on it.

In 1838, what was now the standing committee on water and the city board of aldermen approved a plan to draw water from Spot Pond under municipal ownership. Not surprisingly, the two private water companies strenuously objected and even plead that competition between them would best serve the city's interests. Small townships around Boston also vehemently protested, fearing that local interests would be hurt and that land for the project would be seized by condemnation. Investors in the Middlesex Canal (chartered in 1793 to build a waterway connecting the Merrimac River with Boston Harbor) also protested that water flow for their canal project would be diminished. The result of these objections was a series of protracted hearings.

In 1840 Mayor Jonathan Chapman was elected, and he frowned on the city's present water initiative because of the massive outlays required in light of the rapid growth of the city's debt in recent years. As the municipal effort was halted, private efforts were reinvigorated. In 1840, the rights of the Aqueduct Corporation were expanded to include Brookline and Brighton. The company also began modest expansions of its works and replaced its wooden pipes with more durable iron ones. But it also knew that it could never supply all sections of Boston from Jamaica Pond. Fearing a municipally-owned water system, it began fostering other private interests in complementary systems that would supply other areas of the city.

In early 1843, a member of the city council whose family owned Spot Pond for many years resigned together with colleagues to form a company to serve Boston from the pond. Several months later the Spot Pond Aqueduct Company was incorporated. The company had exclusive rights to Spot Pond, and it would provide Boston with free water to fight fires. The City of Boston was entitled to purchase up to one third of the company's stock or to seize the franchise and company property at any time at a price set by a pre-determined formula. Because of an unusual feature of the charter that made stockholders individually liable for company debts, the city decided not to purchase any shares of the Spot Pond Aqueduct Company.

In 1844 a city initiative to tap water in Long Pond (the only source now considered by the city administration to possess adequate supply for the entire city) was revived. Additional costs of supplementing Spot Pond water with Mystic Pond water reportedly made Long Pond the most appealing source in light of Boston's continued rapid population growth. The two commissioners who originally constituted a majority in favoring Spot Pond had now changed their minds; Long Pond was now the unanimous choice recommended by a new commission report. After considerable wrangling in the legislature and a few compromise amendments, in 1845 Boston was given approval by the legislature to construct a municipal water supply that tapped Long Pond. However, supporters of the private companies campaigned vigorously against it, and it was defeated by popular vote in the referendum.

The Spot Pond Aqueduct Corporation attempted to fill the vacuum, and it submitted a proposal to the city council offering to sell the city its water rights and Spot Pond itself. In considering the company's offer, the city once again reconsidered all of its options for water and once again sought outside help in assessing both the city's future water needs and the quality of each potential source. John Jervis, the chief engineer of the Croton Aqueduct Project, was chosen to conduct the new surveys. While awaiting the Jervis report, parties favoring each source were attempting to position themselves as well as possible. Promoters of Spot Pond invited members of the city council to an extravagant reception and viewing of the pond, but the viewing had precisely the opposite effect of what was intended because the pond happened to be at its lowest level for the occasion. (The small quantity of water available from Spot Pond was of course its primary drawback.) The group later claimed that the Long Pond faction had placed large stones to obstruct the flow of water into the pond at the time of the event.

In the end, the report headed by John Jervis strongly supported the Long Pond proposal. Shortly afterwards Josiah Quincy Jr., son of the mayor who had initially explored the construction of a municipal waterworks, was elected mayor and promised to pursue water from Long Pond. Under Mayor Quincy, the City of Boston had to obtain new authority from the state legislature again to pursue its project. It was virtually unopposed (save only by the township of Lowell), and in 1846 the legislature passed a new water act. A groundbreaking ceremony marked the beginning of the project shortly afterwards. In 1848, Boston celebrated the arrival of its new water with a tremendous festival and a large fountain gushing in the center of Frog Pond in the Boston Common.

As a small side matter, there was discontent that the city's future water source had such a mundane name. A little research uncovered the pond's previous Indian name: Cochituate. Miraculously, the word's etymology was discovered to mean "an ample supply of pure and soft water, of a sufficient elevation to carry into the City of Boston, at a moderate expense." The mayor's proposal that Long Pond should subsequently be known as Lake Cochituate was enthusiastically embraced.

The completion of Boston's municipally-owned water system created obvious problems for the private companies that still existed. In late 1848 the old Aqueduct Corporation asked that the city purchase its water rights and property, pleading that the city remember that private shareholders had made great sacrifice for the public good. The mayor originally planned to offer the corporation $100,000, but the city council knew that the old Aqueduct Corporation had no alternative but to sell its rights and property to the city. The council was therefore willing to go along with a purchase for $20,000, a price at which the company took great offense. The city and the Aqueduct Corporation failed to reach an agreement, and the company continued serving about 400 people who preferred water from Jamaica Pond to Cochituate water. In 1851, a new city body administering the waterworks negotiated to purchase the company for $45,000, and the company accepted the offer. This was effectively the end of private water in Boston, although some years later the city did sell the rights to supply the City of Roxbury with water from Jamaica Pond to a new private entity named the Jamaica Pond Aqueduct Corporation.

New York

Had it not been for the impediment of the Revolutionary War, a man named Christopher Colles may have succeeded in building a water system in New York late in the 18th Century. After the war, numerous citizen movements pressed the city council to construct waterworks for the city. In 1798, a proposal by a physician, scientist, and engineer named Joseph Browne to dam and tap water from the Bronx River was seriously entertained. However, Joseph Browne also proposed that a private entity carry the proposed project forward. The city council considered it undesirable to place a private company in such a powerful position, so it instead decided to request authority from the state legislature to build a water system itself. Through clever maneuvering of state Assemblyman Aaron Burr, however, the bill that the state legislature produced authorized a charter for a private water company instead. Ironically, it was Alexander Hamilton whose advocacy then persuaded the city council to accept the bill as produced by the state legislature. One of the main points that furthered its case was the avoidance of enormous expense and taxpayer burden.

The Manhattan Company was then quickly incorporated; its new charter placed far fewer requirements on it than did other contemporary private water company charters of the day (again, courtesy of the efforts of Aaron Burr). The charter did stipulate, however, that if the company did not provide a continuous source of "pure and wholesome" water for all citizens desiring it within 10 years, it would be dissolved. The other noteworthy feature of the charter was a carefully hidden section that gave the company the legal right to use all "surplus" capital for other purposes unrelated to water.

This obscure section of the charter opened the door for Aaron Burr to pursue banking through the Manhattan Company, which had been his intention from the beginning. Bank charters of the day were difficult to obtain through protracted political processes and were limited in duration; the Manhattan Company's charter had crept into existence below the political radar and was unlimited in duration. Although some other members of the state legislature apparently knew about the scheme, there was outrage when it was publicly discovered. Burr lost his position in a subsequent election, but the company lived on despite attempts of his political adversaries to undermine it.

To maintain its good-standing, it was clear that the Manhattan Company had to provide water to some degree. The real question remained how adequate it would be. Despite serious concerns about its purity, the company decided to tap groundwater with the use of wells and pumps. Some water was flowing as early as 1800. Ironically, Joseph Browne was the lead engineer of the project. Problems and complaints about irregular and unpredictable service began almost immediately. The quantity of water provided was also inadequate for street washing and gutter flushing, forcing the city to rely on older wells for this purpose. The company provided free water to the city to fight fires, although its adequacy is unclear.

By 1804, the city council decided that the Manhattan Company's supply was inadequate to keep pace with city growth and began revisiting other proposals to draw water from more distant sources such as the Bronx River. The company's banking business was booming, so its interest in water was waning even further. (Incidentally, by this time political and financial troubles had forced Aaron Burr to sell most of his stock in the company, and he had been removed from its board.) De Witt Clinton, mayor of New York at the time, proclaimed in 1808 that the company had not fulfilled the requirement of its charter (that it provide "pure and wholesome" water for all citizens desiring it) and thought that given the difficulties and low profitability of its water operations, it might be willing to sell its waterworks to the city. This would of course require the state legislature to amend the original charter for it to continue with its banking activities. Interestingly, De Witt Clinton was also one of the Manhattan Company bank's directors. One of the points upon which negotiations hinged was the price to be paid to the Manhattan Company to acquire its waterworks. Many on the city council believed that it operated at a loss, although its books suggested that it earned an annual return of just under 7% on its original investment.

With this issue unsettled, the city council made an application to the state legislature to alter the Manhattan Company's charter and to receive authority to purchase the waterworks. Amazingly enough, in addition to serving as mayor and as a bank director, De Witt Clinton was also a prominent state senator representing a southern district of New York. The legislature acquiesced to these requests. The Manhattan Company was given the right to lease or sell its waterworks and rights, the length of time it had to provide "pure and wholesome" water for all citizens desiring it was extended to 20 years, and its new charter gave it the right to continue with its banking and other activities even after divesting itself of its waterworks. Additionally, the charter would continue to be perpetual until the company sold the waterworks, at which point it would last for 30 years following the sale. The company therefore naturally tried to postpone the sale as long as possible.

Complaints about the company's water service were constant. Portions of the city (the ones with pipe infrastructure) received no water at all for prolonged periods of time. Repairs were made only to stave off crises public outrage. Water availability to fight fires was so poor that public funding was used to build cisterns for collecting rain water to be used to combat fires. Fires and disease epidemics (despite a poor understanding of the basis of disease) continued to push the inadequacy of water supply to the political forefront; public opinion was squarely opposed to the service provided by the company.

In subsequent years, the alliance between the Manhattan Company and the city government deteriorated. The city was highly indebted to the bank, and to meet its obligations it eventually resorted to selling off its stock in the company. De Witt Clinton himself also slowly sold his company stock, and in 1813 he declined to be re-elected as a bank director. By 1820, De Witt Clinton was governor of New York, and both he and the state legislature supported drawing water for New York City from upland rivers. But the city council continued to be conflicted about how to proceed.

In 1823, after several years of surveys and considering its options, the city council supported another private initiative to charter the New York and Sharon Canal Company to build a waterway from Sharon, CT to the Hudson River to join with a proposed canal to be built from Sharon to the Housatonic River. The state legislature approved the measure. Another private proposal to charter the New York Waterworks Company also gained momentum, alarming both the Manhattan Company and the Sharon Canal Companies. Although its charter was eventually approved, it was believed to be flawed because the Manhattan Company held exclusive rights to groundwater under Manhattan and the Sharon Canal Company held exclusive rights to surface water in Westchester County. The Manhattan Company clearly had the most to lose because of its profitable banking activities. Although it was unwilling to invest in drawing water from distant rivers, it did begin to seek new groundwater supplies by drilling a new well and began replacing its wooden pipes with iron ones.

To add to the confusion, a new report claimed that the water supplies of Rye Pond and the Bronx River, upon which both the New York Waterworks Company and Sharon Canal Company projects depended, was inadequate to meet the needs of New York City. After 1830, the water demand in New York had grown so much that serious attention began shifting from the Bronx River to the Croton River. Previous consideration of the Croton was limited by the daunting expense required to reach it.

With its eye on mounting a challenge to the Manhattan company, that year the city council appointed a committee to investigate whether or not the company had the right to discontinue providing water for fire plugs at will or any obligation to pay for its damage to streets and sidewalks – and more generally, if it had met the conditions of its original charter. The committee found that water was available to only one-third of the paved and built city and that its failure to seek more copious sources was inexcusable – in short, that it had not met its obligations. An additional blow to the Manhattan Company was a communication to the city council by a body of well-known and respected doctors and chemists. It concluded that all of the groundwater in Manhattan was horribly contaminated with filth from graveyards and privies.

By 1833 it was clear that the city was going to build its own waterworks, and after a considerable amount of debate and conflicting geological surveys and engineering reports, the Croton was agreed upon as the most promising source. The Manhattan Company therefore offered to sell all of its water rights to the city, leaving the price open to negotiation. After a devastating fire in 1836, the city opened negotiations with the company to obtain a temporary supply for fighting fires while the Croton Aqueduct was under construction. No agreement was ever reached, however. At the same time, the state legislature found that the company had violated its charter.

In the end the Manhattan Company's rights were never purchased because with the opening of the Croton Aqueduct in 1842, they were essentially not needed. The company had some legal claim to the groundwater in Manhattan, but the new source did not draw on Manhattan groundwater at all. When Croton water began flowing into the city, the company simply lost its customers. Ironically, it retained its wells for decades afterwards – not because it was actively providing water from them, but because it feared future challenges to its charter.

Theories and Informal Evidence on The Transformation of Water Systems

In the cases of Boston and New York, city government intervened to provide water when existing private ones failed to perform well – which generally meant failure to provide a sufficient supply to meet growing water demand. But Boston and New York were pre-eminent population centers in early America that are probably not representative of the typical American city. Improvements in water quality and quantity in the typical city occurred later and coincided with the sharpest rise in public waterworks ownership.

One large city in which this transformation occurred after the turn of the century – New Orleans – followed a course similar to that in Boston and New York. (Troesken and Geddes, 2001) A private company began providing New Orleans with water in 1878, but the company refused to extend its pipes to outlying areas of the city. Moreover, the water it did actually deliver was turgid and unfiltered. The city subsequently petitioned the Lousiana legislature to revoke the company's charter and eventually acquired the water system in 1908. Shortly afterwards the system was expanded dramatically, and filtration plants were constructed.

Statistics shown in Figure 3 demonstrate that public ownership had been increasing throughout most of the 19th Century, but that this trend accelerated from 1890 (when 43% of waterworks were publicly owned) through the 1920s (when 70% were publicly owned). In particular, the period of fastest public ownership growth (ignoring the first few decades of the 19th Century, when the absolute number of waterworks was very small) appears to have been the 1890s.

In general, municipal takeovers of existing private water systems involved either the outright purchase of private companies or the introduction of a municipal competitor to a private water company (essentially bankrupting the private company). The specifics of how this was done depended on the private company's charter. For example, if a private company had exclusive legal rights to provide water to residents of a city, these rights would generally have to be purchased. If a private company had exclusive legal rights to a given water source, a municipal water company could either buy this right or find another source. City governments could also petition state legislatures to revoke private water company charters under extreme circumstances.

Once a water company was municipally owned, it had to be operated. This usually required the establishment of a standing municipal water board that wasn't subject to changes with every electoral cycle (although appointment to boards was of course political), as opposed to being operated directly by a city council. Water boards would manage systems in conjunction with hired engineers and contractors. Rates would be set and collected from citizens and firms. Improvements or expansions would often begin with surveys and draft proposals prepared by engineers retained by the board. The board would decide which ones it preferred to pursue and would seek political permission and financing from the city council or other relevant municipal government authority. Once political permission was obtained and financing was approved, the water board would solicit bids for municipal contracts to actually conduct the work.

There are a variety of potential explanations (not mutually exclusive) for the sharp increase in municipal waterworks ownership and coincident improvement in water quantity from 1890 through the 1920s (see Troesken and Geddes, 2001, for an excellent discussion). These explanations include externalities; contracting problems (natural monopoly, incomplete or costly contracts, and hold-up); and reduced municipal costs of ownership (lower capital costs, professionalization in municipal government, or lower corruption costs).

Externalities and New Knowledge about Disease

There are clearly large external benefits of water supplies not captured by private water companies. The most obvious ones are disease reduction and improved capabilities of combating fires (a less-clear one is that water systems were an economic stimulus through other pathways, for example). On the surface, it is unclear why the existence of externalities would explain a sharp rise in municipal waterworks ownership beginning around 1890. Fires and epidemic infectious diseases had been serious problems in cities for as long as cities have existed. It is possible, however, that the bacteriological revolution of the 1870s and 1880s may have provided a new impetus for concerns about disease externalities. As knowledge of the basis of waterborne diseases became clearer, concerns about the socially-inefficient incentives of private companies may have intensified.

But there are several reasons that call this line of reasoning into question. One is that dirty water was believed to be causally linked to disease long before the bacteriological revolution. The first demonstration of the link between unclean water and disease was John Snow's demonstration of how cholera spread from a single water pump in London in the 1850s. Snow had premonitions of the germ theory, but it was a few decades before the theory became fully articulated.

The prevailing theory at the time, the miasma theory of disease, held that a variety of illnesses are the result of poisonous, malevolent vapors ("miasmas") that are offensive to the smell. (Anderson, 1984; Duffy, 1990) The widespread acceptance of the miasma theory appears to have been based on Pavlovian learning. People exposed to foul odors were more likely to get sick, foul-smelling areas tended to have more sick people, and more people seemed to get sick during the summer seasons during which offensive odors were more common. This leap of logic from correlation to causation led to both misdirected sanitary interventions, and some successful ones as well.

The externality argument is also difficult to reconcile with the empirical observation that private water companies were more likely to possess expensive water filtration plants than were publicly-owned companies early in the 20th Century (Troesken and Geddes, 2001). And private water companies were ostensibly legally liable for damages attributable to large waterborne disease outbreaks (Troesken and Geddes, 2001), although it is not clear how enforceable this liability was in practice.

Contracting Failures

A variety of contract failures have been put forward to timing of municipal ownership of water, and could be extended to justify the slow development of clean water.

Natural Monopoly

The cost structure of public utility provision is generally characterized by declining average costs. Hence, one firm could in principle serve an entire market most efficiently. Of course, monopoly power held by a profit-maximizing firm will lead to inefficient service provision. As will all monopolists, a monopoly water supplier will raise prices as high as possible. In addition, the municipal supplier will restrict quantity, to elicit the higher price. Public ownership may be preferred to natural monopoly.

However, a natural monopoly explanation fails both in explaining the timing of the increase in municipal waterworks ownership and in explaining why waterworks were increasingly city-owned while gas and electrical utilities were not. On the timing, it is not clear why either welfare losses or city government losses should have suddenly accelerated around 1890, producing the observed increase in municipal waterworks ownership. Similarly, the same natural monopoly issues were apparent in gas and electricity service, but these were rarely privatized.

Incomplete or Costly Contracts

Although some dimensions of water provision can easily be observed and monitored or stipulated in a contract ex ante (water pressure, rates, etc.), many others cannot. For example, it is difficult to specify in advance that certain new population centers not yet in existence should be served or what new water sources should be tapped to meet future demand growth. Additionally, as the provision of water historically became increasingly complex and regulatory requirements became more onerous, contracting costs may have reduced the profitability of the water business, making it less attractive to private firms.

Troesken and Geddes (2001) report some suggestive findings that litigation against private water companies is positively related to municipal take-over during the period of rapid waterworks municipalization. The basic inference drawn is that contacting costs may have been an important motivation for these municipal takeovers. It is unclear why contract incompleteness would have become more problematic at the end of the 19th Century, but there is some historical suggestion that contracts became more elaborate – and potentially more costly – shortly before 1900. <Discuss the national urban government league's model contract prepared in the 1890s.> Once again, however, a contracting cost explanation does not square with the continuation of predominantly private ownership in gas and electricity.

Hold-Up

A specific form of contracting problem, city governments may have had difficulty credibly committing not to expropriate the enormous idiosyncratic infrastructure investments required of private water companies. It may have been the case that following the bacteriological revolution and subsequent technological innovations to combat waterborne disease (such as filtration), the investments required to build and operate water systems increased substantially. Hence losses (or fears of losses) due to municipal expropriation could have potentially grown at the very end of the 19th Century.

Troesken and Geddes (2001) report findings that the probability of municipal take-over of private water supplies between 1897 and 1915 was positively related to the extensiveness of a water system and negatively related to financial difficulties of private water companies. The interpretation placed on these findings is that cities were more likely to seize private waterworks that promised greater rents. Along these lines, the dynamic effect of fear of expropriation was that it induced private companies to rationally under-invest in their water systems, resulting in inadequate service provision and an additional rationale for municipal ownership.

Countering this hypothesis is the fact that private water companies were more likely than public ones to own expensive filtration facilities. According to an 1899 federal government survey of water companies, 19% of the private companies had filters while only 6% of the public ones did. (Troesken, 1999) It is also unclear why municipal seizures or fear of expropriation would have risen in the 1890s and early 20th Century if it was truly a period in which corruption in municipal government was actually falling. Moreover, the absence of municipal takeovers of other public utilities (gas and electricity) also seems to contradict this view.

The Costs of Municipal Investment

Our final set of theories has to do with declining costs of municipal provision of water. Governments initially contracted out water to the private sector to meet private demand. Over time, demand remained high or grew. The costs of public ownership and investment fell, however. Thus, there was a natural tendency towards municipal ownership of water and investment in new water resources.

Corruption Costs

Administrative reform that began at the very end of the 19th Century may have reduced the corruption costs associated with municipal ownership of waterworks. As a number of city government scandals were exposed in the 1870s, cities began experimenting with administrative reforms that aimed to reduce corruption. These reforms appear to have been at least partially responsible for the creation of standing boards to perform specialized functions like operating water systems. Board members were surely corruptible, but probably less so than city council members (who operated municipal water systems before professional boards really emerged).

Of course, it is not clear if delegation of authority to city boards was actually purposeful (to reduce corruption) or coincidental (driven by the increasingly technical and complex nature of city functions and growth of technically-trained professionals). Moreover, the problem with a falling corruption costs explanation is that the sharpest rise in public waterworks ownership occurred in the 1890s. Much of the effective administrative reforms came in the early decades of the 20th Century at the dawn of the Progressive Era.

Professionalization of Local Government

The water revolution in the public sector was made possible by the hiring of professionals and technocrats to manage the water system. Of course, the hiring of professionals is a choice that cities made. But it is possible that exogenous increases in the available supply of engineers influenced local government decisions to get involved in water provision.

<We plan to look for data on the number of engineers over time>

Financial Costs

Municipal finance developed and grew rapidly near the end of the 19th due both to rapidly growing tax bases and revenue, and to increasing financial sophistication of city budgeting. One explanation for water expansion at this time period is thus that the costs of building suitable water systems were prohibitively high; private water companies could not afford to build systems to serve entire municipal populations, and only the largest cities could afford adequate water systems until the development of municipal finance. It may not be a coincidence that municipal finance became increasingly sophisticated – as did public acceptance of municipal debt – at the end of the 19th Century.

Waterworks were exorbitantly expensive in general and much more costly than other utilities to build or operate. In 1915, the mean value of municipal waterworks exceeded annual city government revenue (see Table 1). (Statistics of Cities Having a Population of Over 30,000: 1905; Historical Statistics of the United States: Colonial Times to 1970). Mindful of the fact that most water systems were built long before 1915, the expenses of constructing a water system relative to annual municipal receipts were undoubtedly much larger than suggested here. In 1905, waterworks were also the largest debt line item in city budgets (Statistics of Cities Having a Population of Over 30,000: 1905)

Several different strands of evidence support this view. The time series of municipal investment in water is a first piece of evidence. Figure 4 shows municipal ownership over time by city size among all cities with publicly-owned water systems in

1915. In general, large cities generally municipalized their waterworks earlier than smaller ones. For example, all of these cities with over 500,000 people in 1915 had a public water system by the end of the 1850s, while the share of smaller cities with public water systems at that time was below 20 percent.

Throughout the 1880s and 1890s, larger cities issued more debt than smaller ones. Figure 5 shows reported debt as of 1905 by year of issue. The largest cities had the largest amount of debt outstanding. The chart grossly understates the magnitude of debt issued by the largest cities (cities with populations over 300,000) relative to smaller ones. More than 70% of municipal debt in cities over 300,000 was not reported by year of issue and hence is not incorporated in Figure 5 – as opposed to 3% in cities between 100,000 and 300,000, 12% in cities between 50,000 and 100,000, and 6% in cities between 30,000 and 50,000.

In addition, the decline in municipal ownership of water systems in the 1880s lends support to this argument. In the early and middle 1870s, unprecedented revelations of widespread corruption in municipal government were made public. Combined with an economic slump in 1873 on the tail of rapid municipal spending growth in previous decades, many states imposed tight new restrictions on municipal indebtedness. These indebtedness restrictions were followed by the only drop in municipal waterworks ownership during the entire 19^{th} Century during the 1880s (see Figure 3).

Summary

Conclusion

References

Anderson, Letty. 1984. "Hard Choices: Supplying Water to New England Towns." *Journal of Interdisciplinary History*. 15:2, pp. 211-234.

Anderson, Letty. 1988. "Fire and Disease: The Development of Water Supply Systems in New England, 1870-1900." In Joel Tarr and Gabriel Dupuy (eds.), *Technology and the Rise of the Networked City in Europe and America*. Philadelphia, PA: Temple University Press.

Baker, M. N. 1948. *The Quest for Pure Water: The History of Water Purification from the Earliest Records to the Twentieth Century*. New York, NY: The American Water Works Association.

Blake, Nelson Manfred. 1956. *Water for the Cities: A History of the Urban Water Supply Problem in the United States*. Syracuse, NY: Syracuse University Press.

Cutler, David and Grant Miller. 2003. <Unpublished manuscript on clean water interventions.>

Duffy, John. 1990. *The Sanitarians*. Urbana and Chicago, IL: University of Illinois Press.

Galishoff, Stuart. 1980. "Triumph and Failure: The American Response to the Urban Water Supply Problem, 1860-1923." In Martin Melosi (ed.), *Pollution and Reform in American Cities, 1870-1930*. Austin, TX and London: University of Texas Press.

Melosi, Martin. 2000. *The Sanitary City: Urban Infrastructure in America from Colonial Times to the Present.* Baltimore, MD and London: The Johns Hopkins University Press.

Preston, Samuel and Michael Haines. 1991. *Fatal Years: Child Mortality in Late Nineteenth-Century America*. : Princeton University Press.

Troesken, Werner. 1999. "Typhoid Rates and the Public Acquisition of Private Waterworks, 1880-1920." *The Journal of Economic History*. 59:4, pp. 927-948.

Troesken, Werner and Rick Geddes. 2001. "Municipalizing American Waterworks, 1897-1915." <unpublished manuscript>

Figure 1: Mortality in American Cities, 1900 - 1936

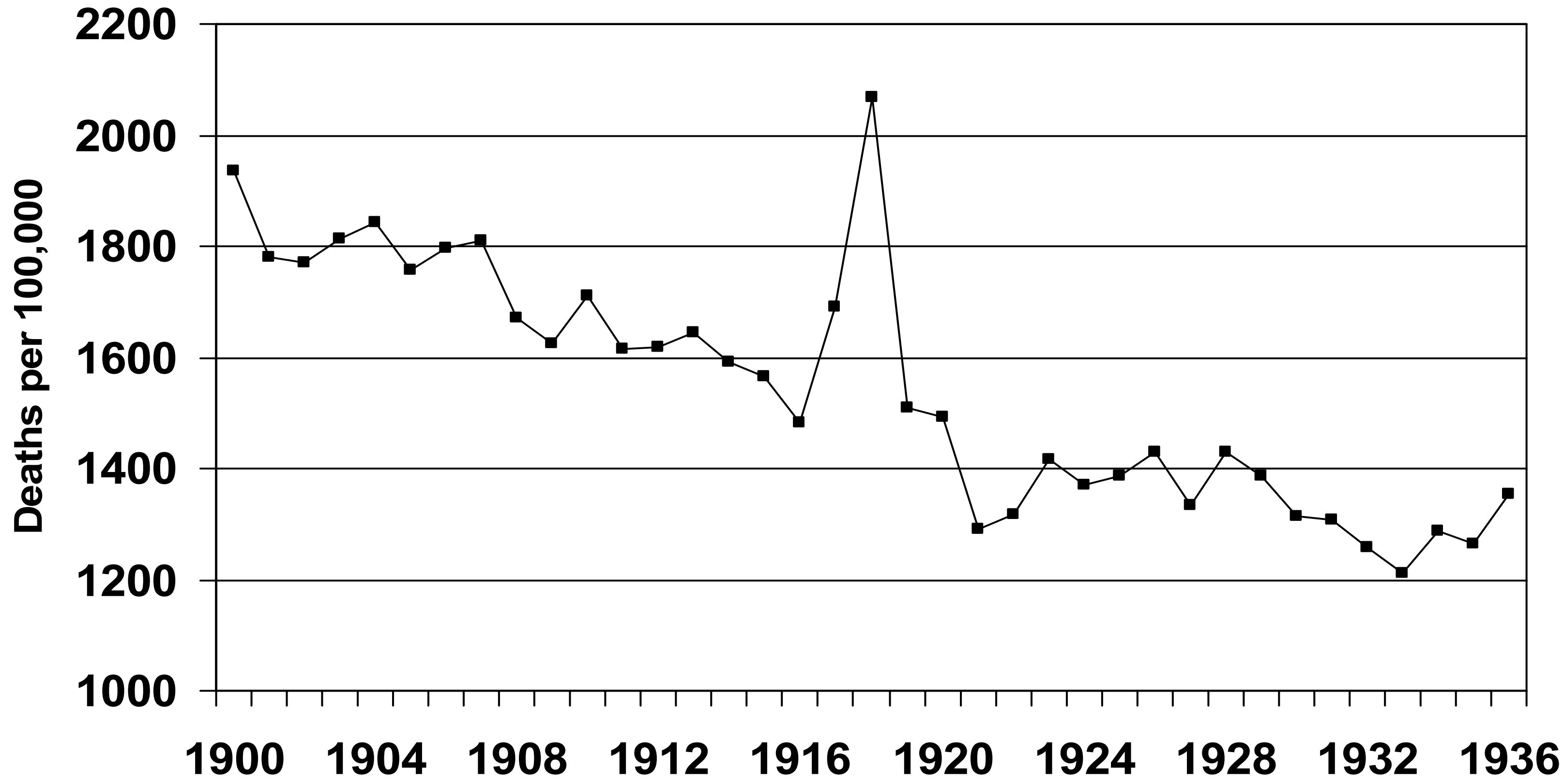


Figure 2: Pittsburgh Typhoid Fever Mortality Rates (Deaths per 100,000)

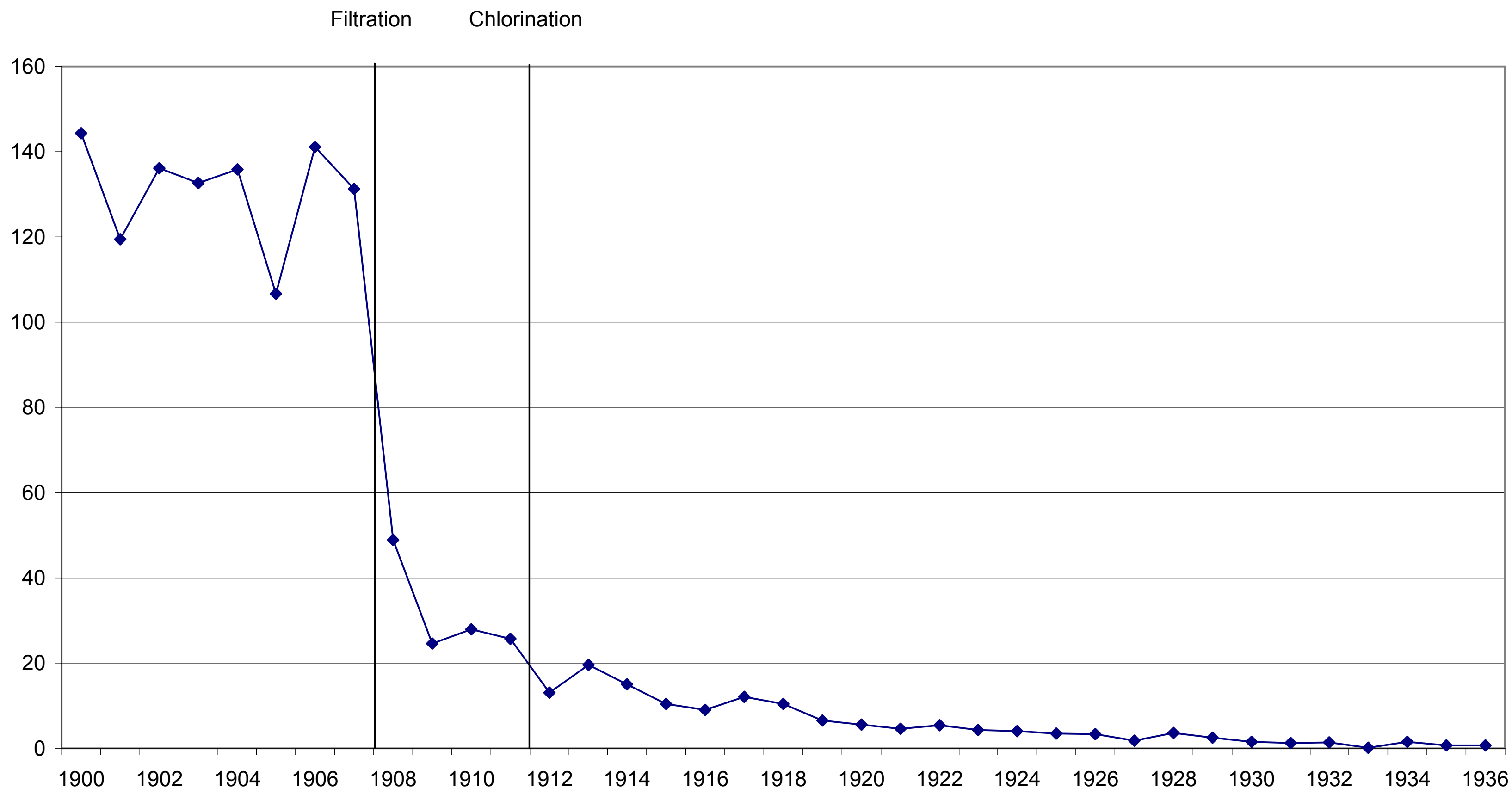
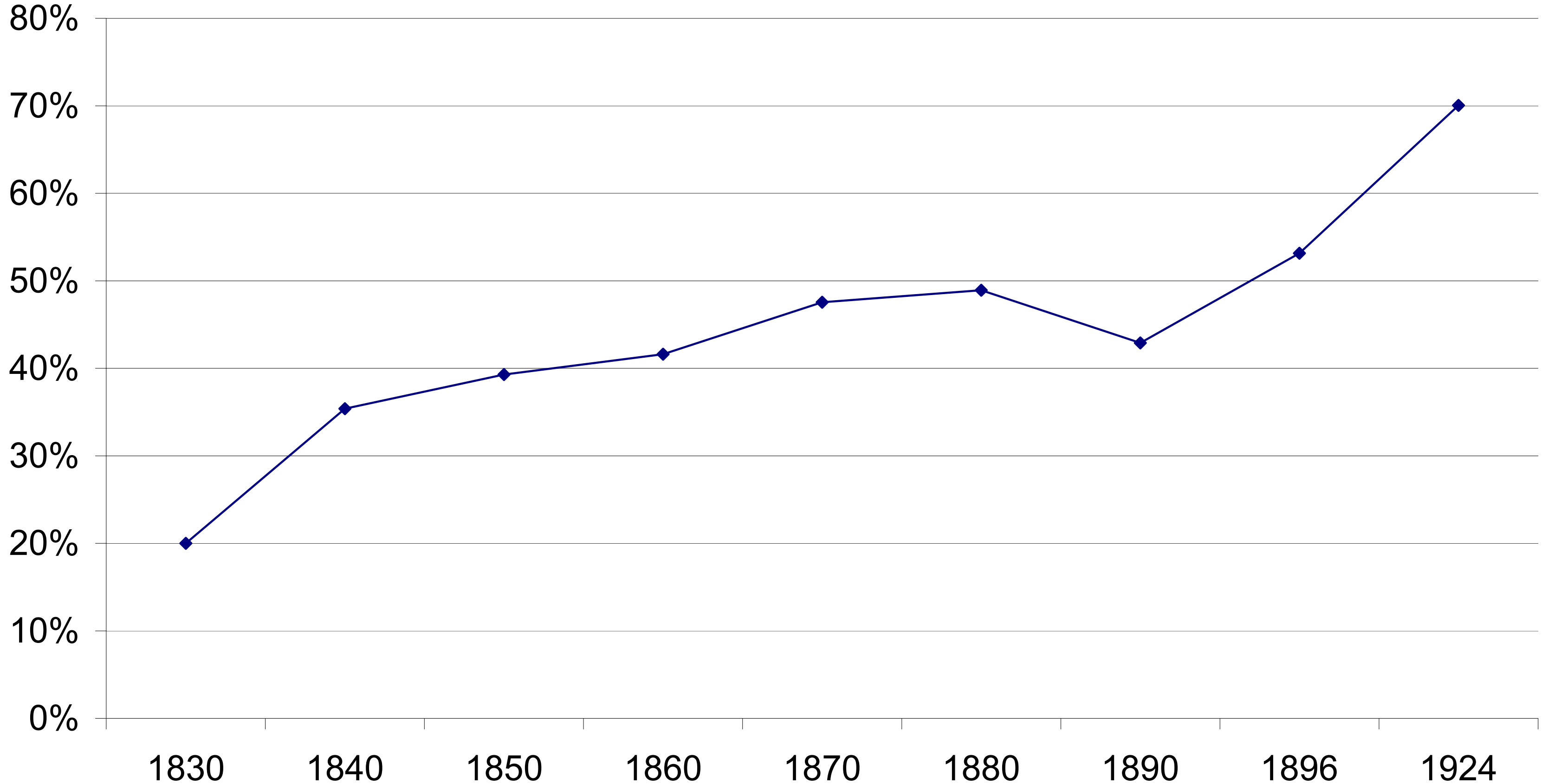
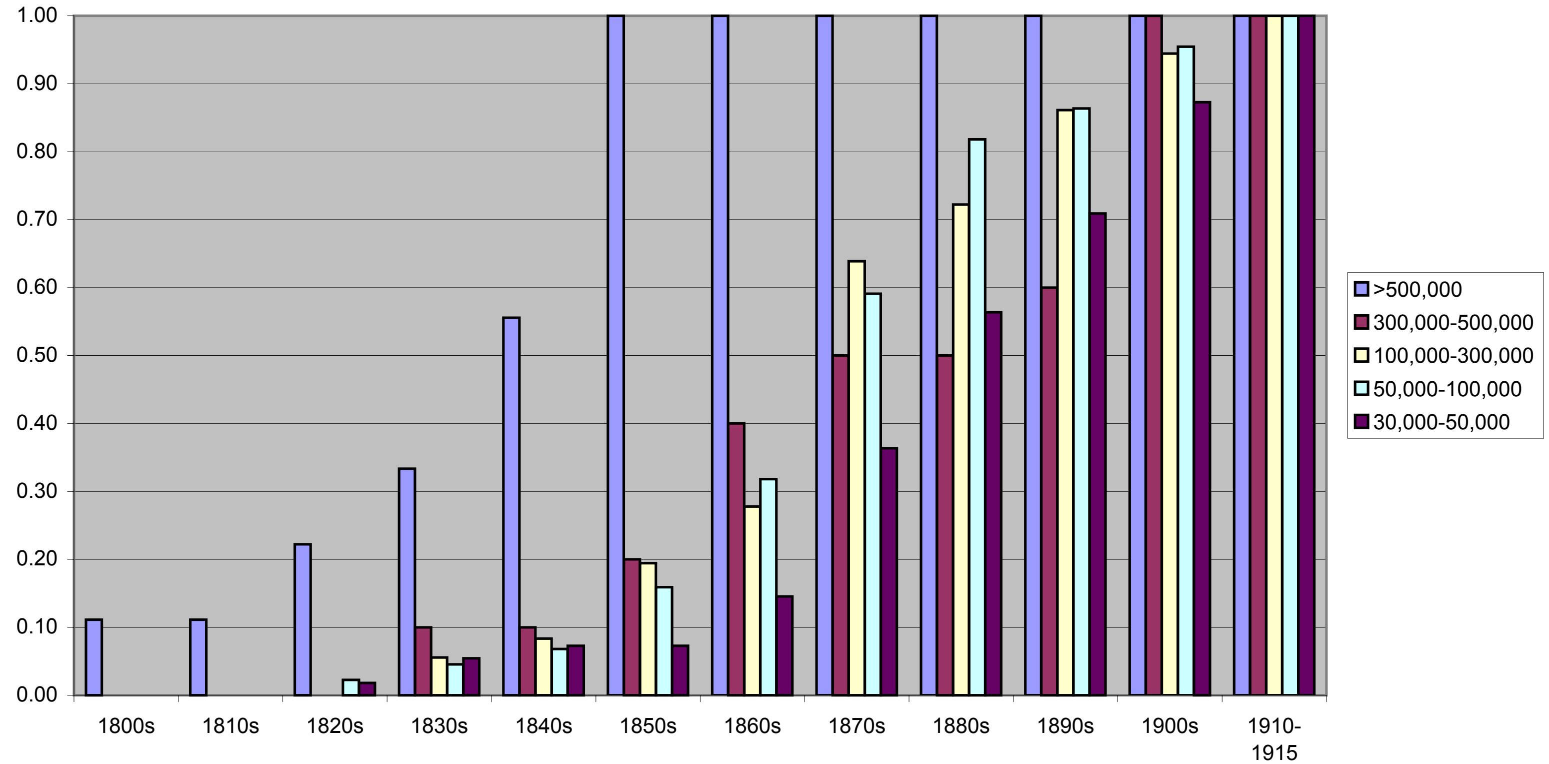


Figure 3: Public Water Ownership In American Cities During the 19th and Early 20th Centuries



Cumulative Share of Cities with Public Water Systems Among Those with Public Systems by 1915, by Population by Decade



Outstanding REPORTED Funded Debt as of 1905, by Population by Year of Issue

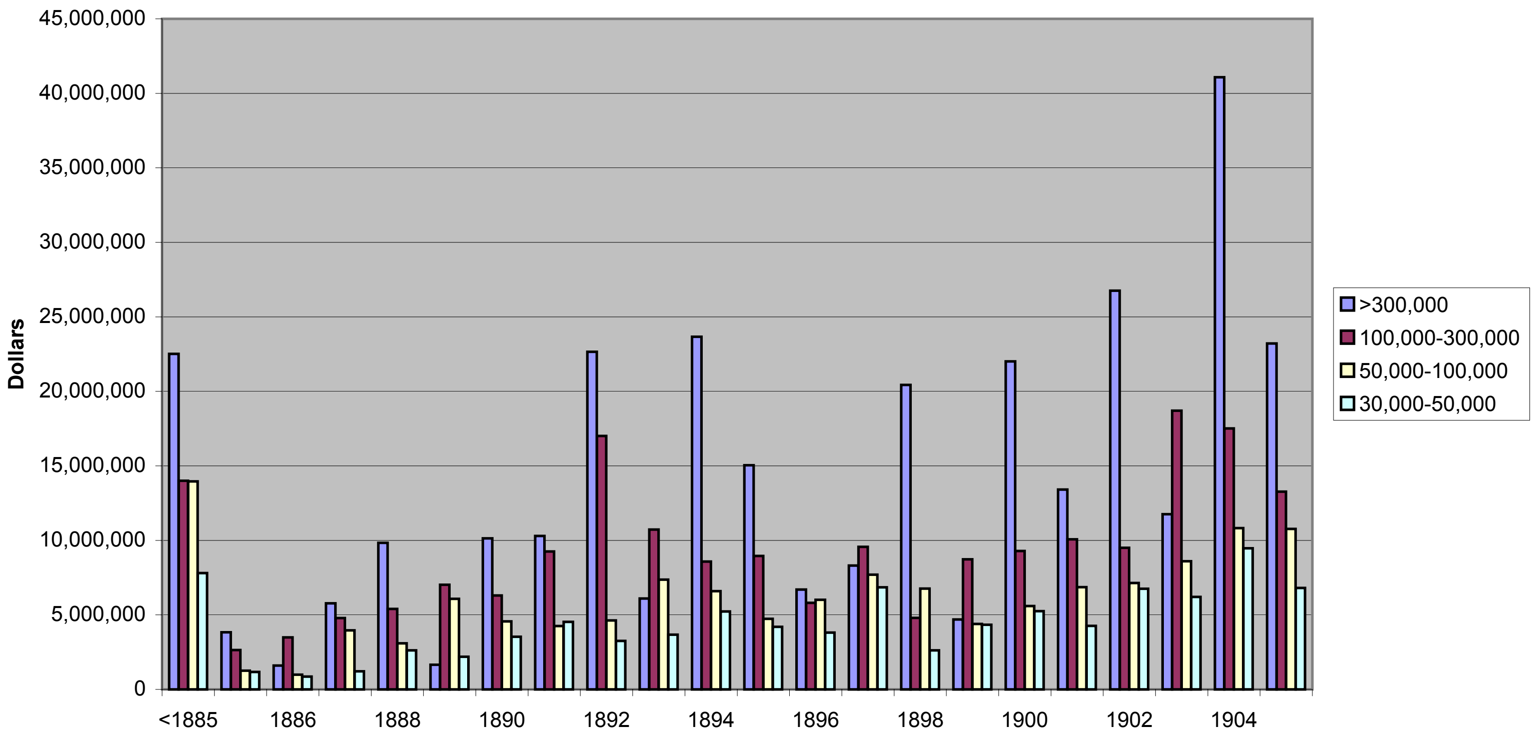


Table 1: The Value of Water Systems and Annual Revenue in Selected American Cities, 1915 (in 1915 dollars)

	Value of Water System	Revenue	Value/Revenue
All Cities Over 500,000	569,727,688	462,077,044	1.23
New York	350,004,152	206,010,937	1.70
Chicago	52,557,484	80,622,887	0.65
Philadelphia	30,000,000	45,242,379	0.66
All Cities 300,000 - 500,000	149,222,136	146,467,942	1.02
Buffalo	15,702,219	15,184,834	1.03
Los Angeles	36,058,144	24,405,199	1.48
Cincinatti	17,366,561	13,785,166	1.26
All Cities 100,000 - 300,000	186,574,699	171,787,677	1.09
Jersey City	12,448,453	6,792,713	1.83
Kansas City	8,967,124	10,296,283	0.87
Rochester	9,768,056	7,408,794	1.32
All Cities 50,000 - 100,000	93,665,860	89,950,262	1.04
Ft. Worth	3,937,893	1,694,390	2.32
Somerville	1,017,365	1,916,006	0.53
Harrisburg	2,487,150	1,481,848	1.68