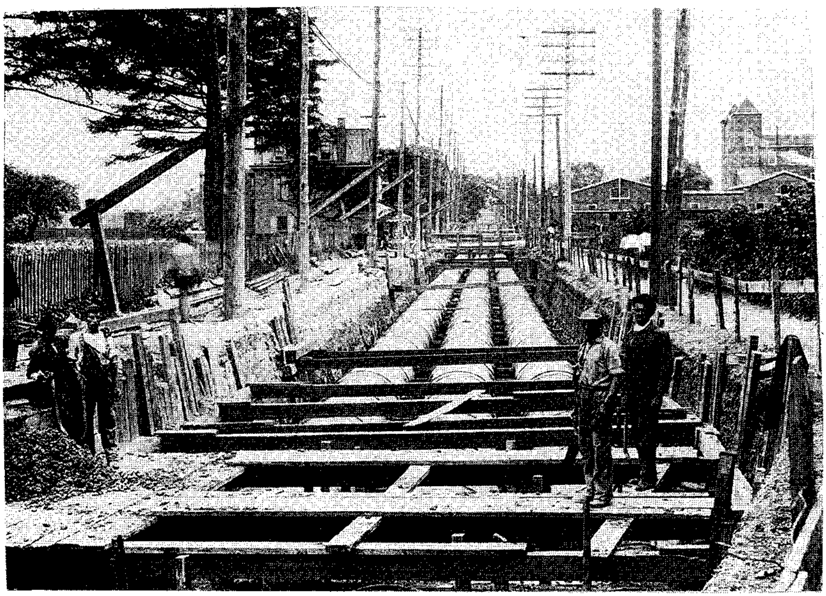
The Fairmount Water Works became one of the most visited American sites, and one of the most reproduced American images. Europeans were enamored with its success – a marriage of nature and industry for the good of Philadelphia's citizenry. Of course, Philadelphia had carefully tried to avoid the mistakes which European cities had made with regard to their water systems. Indeed, in the case of Fairmount, rational political decisions had resulted in a successful and elegantly engineered solution.

During this period, also, a vast improvement was made to the distribution system. Philadelphia's grid layout presented a particular problem for the wooden pipe distribution system – turning right angles with wooden pipes caused dramatic drops in pressure. In addition, the small size of the borehole in a wooden pipe limited the quantity of water, which could be delivered. As early as 1819, therefore, Philadelphia began to install only cast-iron pipes. Frederick Graff designed pipes, which gently curved at corners, and had considerably larger diameters than the wooden pipes they replaced (Gibson, p. 15). By the 1840's the city was served chiefly by a cast iron pipe distribution system. During his visit, Dickens was genuinely impressed with the high water pressure on the 4th floor of his hotel, an experience he had in no other city.

One of the more interesting aspects of Philadelphia water system was the creation of Fairmount Park, a very early attempt at watershed protection. From the beginning the engineers of Philadelphia's water system understood that residential, commercial and industrial development along the banks of the Schuylkill River, its chief source of drinking water, threatened the quality of that supply. They, therefore, supported acquisition of land above the Fairmount Water Works to be set aside for a public park (Gibson, p. 31). The North Garden in the 1830's, Lemon Hill in the 1840's, Sedgley in the 1850's and in 1867 huge tracts of land on the east and west banks of the Schuylkill, upstream of Fairmount were purchased as park land – 4,000 acres in all (Weigley, p. 376). This attempt at watershed management worked for a time to control the quality of the water in the Schuylkill River.

During the Civil War, however, communities and industries upstream of Philadelphia on the Schuylkill River grew exponentially. Not the least of which was the coal industry, which fueled the war efforts of the North. By the 1870's and 80's the quality of Philadelphia's drinking water was being compromised by the effluent of the communities and industries upstream. Water Department engineers began to champion filtration, which was being used successfully in European cities. But the high cost of building the facilities to supply such a large population with filtered water presented an immediate barrier to the politicians. The filtration debate continued until the later 1890's when, finally, the quality of Philadelphia's drinking water threatened public health. At the end of the nineteenth century Philadelphia suffered the worst typhoid epidemics of any American city (Weigley, p. 496). By this time the Schuylkill River was running black with coal culm, and scum rose to the water's surface, as it does today in a waste water treatment facility.

As with the yellow fever epidemics a century before, it took a major public health crisis to build the political will to take action. Between 1900 and 1911 Philadelphia built, what was then, the world's largest filtered water system. It included five major slow sand filter plants, four on the Schuylkill River, one on the Delaware. Three were later converted to rapid sand filters. Four heavy duty pumping stations were built to move water through the system efficiently. The size of the filters – the Torresdale plant on the Delaware covered 58 acres – meant that the five plants were at the edge of the city where cheaper land was available. A huge project of laying the distribution mains to bring the filtered water into the built sections of the city was undertaken at the same time. The cost of the new system was nearly $28 million dollars. Before filtration 95% of the city's water was taken from the Schuylkill. After filtration 70% of the city's water was taken from the Delaware. It was felt that relying on the larger, faster moving Delaware River would improve the water quality situation (Bureau of Water, 1909). As each of the plants went on line, the typhoid death rates dropped steadily. In 1912 with the addition of chlorine to the filtered water, the annual typhoid and cholera epidemics were brought to a halt.



Construction of the Distribution System to Bring Filtered Water to Philadelphia

Now that Philadelphia could deliver water to its citizens that would not make them sick, the city turned its back on the rivers. We could filter the polluted water. Making it safe to drink. No longer was there the need to try to protect the rivers.

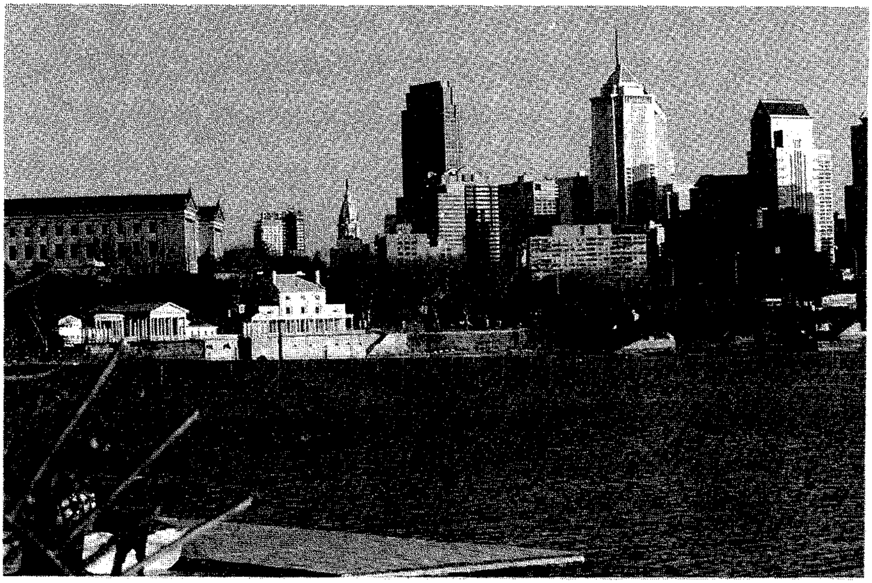
Indeed, in the first half of the 20th century pollution in both the Delaware and Schuylkill Rivers increased. Both rivers became open sewers (Lewis, 1924). The problem with this turn of events, was that although one would not die from drinking Philadelphia's tap water, the source was so polluted that the taste and odor of the water made it a less than desirable beverage. No longer "water of uncommon purity" as Latrobe first characterized it; Philadelphia's water was now called "Schuylkill Punch".

In 1951, Philadelphia's sewer system became the responsibility of the Water Department. In many respects this was a good political move. The Water Department had an incentive to get a handle on the city's sewage. Through most of the twentieth century, Philadelphia's Department of Public Works, in which the responsibility for sewage resided, struggled to fund the sewage collection and treatment plan which had been state-mandated in 1914. That plan was a remarkable engineering undertaking. It included building enormous interceptor sewers along the banks of the Delaware and Schuylkill Rivers which would direct the city's wastewater to one of three planned treatment plants. World War I, the Depression, World War II, as well as "sexier" City projects like a subway system that vied with the sewer projects for bond issues - all conspired to slow progress in improving the quality of Philadelphia's drinking water sources. Under the Water Department, and with City Council approval to raise sewer rents (Weigley, p. 627), the 1914 plan was finally realized in 1957 with the completion of the City's three primary wastewater treatment plants.

The Clean Water Act of 1972 set the stage for further improvements. By 1984, Philadelphia was on-line with secondary wastewater treatment. And by the 1990's most communities upstream of the city has gone to secondary treatment, as well. This has resulted in a remarkable turn around in the quality of Philadelphia's source water. Dissolved oxygen has returned to the levels of 1880. More than eighty varieties of fish have returned to the rivers at Philadelphia. Rowers can now overturn without the fear of having to receive painful tetanus shots. And, of course, the aesthetic quality of Philadelphia's drinking has improved with improvement of its source water. Today the city's drinking water is no longer the "Schuylkill Punch" of years past, but rather is more in line with Latrobe's original characterization of "water of uncommon purity".

As much credit as we can give to the success resulting from the highly engineered solution of secondary wastewater treatment, more needs to be done to improve and protect the quality of our drinking water. Today, 80 to 90% of the pollution in the Delaware and Schuylkill Rivers is the result of non-point sources, stormwater runoff.

Today, the Philadelphia Water Department, through neighborhood watershed improvement projects undertaken by its Office of Watersheds, and through its award-winning public education programs at the Fairmount Water Works Interpretive Center, is attempting to improve water quality by encouraging rational political decisions that will lead to successful – perhaps even elegant – solutions. But that is another story for another time.



Philadelphia From the Schuylkill River,
the Fairmount Water Works in the Middle-ground

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John B. Jervis and the Development of New York City's Water Supply System

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Abstract

New York City became the nation's largest city at the end of the 18th century. Its population exploded after the completion of the Erie Canal in 1825 opened its protected port to midwestern markets. But without a dependable, adequate water supply system, the city could not grow. That water supply system was due to the engineering genius of John Bloomfield Jervis (1795-1885). Jervis, the leading American civil engineer of the antebellum period, built or managed three canals, seven railroads and two major urban water supply systems. In addition to the original Croton Water Supply System, Jervis engineered other projects important to the city, including the Delaware and Hudson Canal and the Hudson River Railroad. His career spanned more than half a century. The Croton Water Supply System (1842) was the most outstanding municipal water supply system in the United States at the time and was the prototype for later projects throughout the world.

Introduction

New York City is the nation's largest city. In the 2000 census, for the first time the city's population exceeded 8 million souls, while the metropolitan region is home to some 20 million people, A vast infrastructure, designed and built by civil engineers, is needed to support the economy of the city: 374 km (231 mi) of subway routes, 14 underwater subway tunnels, four rail tunnels, four vehicular tunnels, over 2,000 bridges, nearly 10,400 km (6,400 mi) of streets, 11,300 ha (28,000 acres) of parks, 14 waste water treatment plants, more than 10,200 km (6,300 mi) of sewers, and most importantly, the world's best water supply system reaching over 200 km (125 mi) to the headwaters of the Delaware River in the Catskill Mountains. Not surprisingly, many of these projects are ASCE National Historic Civil Engineering Landmarks (NHCEL).

Early Water Supply

The nation's metropolis had humble beginnings. Following Henry Hudson's exploratory excursion up his namesake river in 1609, the Dutch West India

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Company established a small trading post, which they called Nieuw Amsterdam, at the tip of Manhattan Island in 1625. Taken over by the British in 1664 and renamed New York, this company town grew into the largest metropolis in. and the United States. By 1800, New York had surpassed Philadelphia as the nation's largest city.

Early Manhattanites got their water from rainwater collected in cisterns, privately owned shallow wells and later from street pumps. Well water was important to the Dutch as they needed fresh water to brew Nieuw Amsterdam's favorite beverages, beer and Dutch hot chocolate. A few public wells were dug in 1660s and 1670s, but the first systematic effort began in 1677. Lower Manhattan's greatest natural feature of the time was the 18-m (60-ft) deep, 19-ha (48-acre) spring-fed pond known as the Fresh Water Pond or "Collect". As the city grew in size, its citizens drew water from the pond and nearby wells. It was on Collect Pond that in 1796, John Fitch successfully demonstrated his steamboat a decade before Robert Fulton. But New Yorkers soon began filling in the pond, drained by a canal along today's Canal Street, by dumping their garbage, debris and animal carcasses into the lake, and then wondered why they got sick. It was filled in by 1811. Early sketches show the Collect Pond as a rustic place. One observer wrote, "...there was no more beautiful spot on the lower island." Too bad the City Beautiful and Parks movements came a century too late to save this idyllic spot for posterity. Instead, the pond's legacy gives today's civil engineers headaches in unstable building foundations and leaking subway tunnels.

The English apparently were more concerned with tea than beer, and "tea water" became a euphemism for good water. Of course, the fact that water had to be boiled to make tea may have helped prevent disease. Some tea water was carted in from the "suburbs" in casks, but several entrepreneurs ("tea-water men") dug their own wells and marketed tea water. The most famous was the Tea Water Pump near Chatham Square, which was the city's main source of water until the late 1700s. But as the city grew and water became more polluted, the need for a better system was apparent. In 1774, Christopher Colles (1739-1816), an engineer, proposed building a water system "for furnishing the City of New York with a constant supply of fresh water" consisting of a large well north of town, a reservoir able to store 4,500 m^3 (1,200,000 gal), later increased to over 7,500 m^3 (2 million gal,), steam pumps capable of raising 750 m^3 (200,000 gal) per day, and a distribution system of hollow wooden pipes. Work began, but the Revolutionary War intervened before the plan was completed. Incorporated in 1799, the Manhattan Company built the city's first real, but limited, water supply system in the early 1800s. It dug a well near Reade and Centre Streets, built an impressive 2,100-m^3 (550,000-gal) reservoir on the north side of Chambers Street and a distribution system consisting of 40 km (25 mi) of hollow wooden mains. The Manhattan Company's franchise was a subterfuge. Promoted by Aaron Burr, a political opponent of Alexander Hamilton, the company really wanted to establish a bank and had legislation passed to allow them to build a more politically acceptable water supply system and incidentally engage in other activities. The company became the Chase Manhattan Bank. Remains of the company's well were unearthed while excavating for an office building in 1926.

Fires, disease and an expanding population made the need for a new water supply system urgent. Yellow fever epidemics in 1798 and 1822 and cholera epidemics in 1832 and 1834 killed thousands. No one was sure what caused cholera. It was not until 1849 that a London doctor concluded that polluted water was the culprit. The Great Fire of 1835 destroyed 674 buildings and leveled a good chunk of the city. But there had been major fires in 1776 and 1828, and smaller fires almost yearly. Water for fighting fires, or just cleaning streets of filth, was badly needed.

Finally, the city began investigating proposals in earnest. City officials began looking at streams north of Manhattan in Westchester County, including the Bronx River, Saw Mill River and Croton River as sources. The New York City Common Council appointed a commission 1833 to plan the Croton system. Major David Bates Douglass, a West Point professor and War of 1812 veteran, initiated the design and began surveys for the route for the aqueduct. The voters of the City of New York approved the Croton proposal in April 1835 and Douglass was appointed chief engineer, a position he held until replaced by John B. Jervis in 1836. The replacement was controversial. While there may have been political overtones, it was said that Douglass was too professorial and lacked practical experience, while Jervis had earned a "can do" reputation.

John B. Jervis

John B. Jervis, said to be America's greatest civil engineer of the antebellum period, whose career spanned over half a century, left his imprint on the American landscape: a legacy of canals, railroads, bridges and perhaps most importantly, the Croton Water Supply System. He was involved in an early unsuccessful attempt to found a national civil engineering society in 1839, 13 years before ASCE was founded in New York City in 1852.

John Bloomfield Jervis, the son of a carpenter, was born in Huntington, Long Island, N.Y. on December 14, 1795. When he was three, his family moved to Fort Stanwix in upstate New York, where he worked in his father's sawmill and farm. Fort Stanwix was a frontier town, a military outpost in the French and Indian War (1754-1763) and the site of a Revolutionary War battle in 1777. An event of historical engineering significance took place on July 4, 1817 near Fort Stanwix, by then known as Rome: the beginning of construction of the Erie Canal. Lacking trained civil engineers, the 590-km (365-mi) Erie Canal was the first engineering "school" in America where many of the young nation's early engineers got their training through practical experience gained on the canal's construction. Young John Jervis was one of them. His engineering "education" and career began in 1817 when the canal's chief engineer, Benjamin Wright, a fellow Fort Stanwix resident, hired young Jervis as an axman for a canal survey party. He worked his way up the ladder to rodman in 1818 (where he was paid $12 a month), and later became resident engineer in charge of several sections of the canal. ASCE calls Benjamin Wright (1770-1842), "the Father of American Civil Engineering".

Delaware and Hudson Canal

When the Erie Canal was completed in 1825, Benjamin Wright hired Jervis as Principal Assistant on another canal that was important to New York's economy, the Delaware and Hudson Canal. The 170-km (105-mi) D&H Canal, which opened in 1829, was built to convey coal from anthracite mines near Honesdale, Pennsylvania, to New York City. When Wright moved on to other work in 1827, Jervis became the Delaware and Hudson's Chief Engineer. The D&H was Jervis' first exposure to the new technology of railroads, a technology that soon made most canals obsolete. Jervis built the 26-km (16-mi) "gravity" railroad, a unique system of inclined planes, to carry coal from the mines near Carbondale to the beginning of the canal at Honesdale. Four steam locomotives were purchased from England; the Stourbridge Lion was the first locomotive to run on a track in the United States. But it proved to be too heavy for the track (or the track too light for the locomotive) and the locomotive became a museum piece. One of Jervis' notable achievements was the development of a steerable truck for locomotives to enable them to negotiate sharp curves found on American railroads.

The D&H Canal was abandoned in 1898. Its outstanding remaining feature is the Delaware Aqueduct, a wire suspension bridge built by another great engineer, John Roebling, in 1848 to carry the canal across the Delaware River. An ASCE NHCEL since 1972, it is Roebling's oldest surviving suspension bridge. It was restored by the National Park Service in 1983.

After the D&H, Jervis continued his career as chief engineer of the first railroad in New York State, the Mohawk and Hudson RR between Albany and Schenectady; the Schenectady and Saratoga RR; the upstate New York Chenango Canal between Binghamton and Utica; and was consulted on he first enlargement of the Erie Canal. On the Chenango Canal project, Jervis devised improved rain and stream gauges to determine the relationship between rainfall and runoff more precisely, a hallmark in American hydrology. In 1836, he embarked on a new career as chief engineer of the Croton Water Supply System.

The Croton Aqueduct and Water Supply System

The Croton Water Supply System was a remarkable achievement for its day. The main features of the system were a dam across the Croton River, a tributary of the Hudson, about seven miles upstream from its mouth near Ossining; a 66-km (41-mi) gravity aqueduct, essentially an enclosed canal, to convey the water to the city; the impressive High Bridge; and three reservoirs, the Croton Reservoir, a receiving reservoir in what is now Central Park, and a distributing reservoir at 42nd Street.

Work on the dam, the first large masonry and earth-fill dam in the nation, began in 1837. The dam was nearly washed out in a flood in 1841. To protect against future floods, Jervis devised a now common innovative feature. He designed the masonry spillway with a reverse or ogee curve, and added a stilling basin to dissipate the water's energy. The 15-m (50-ft)-high dam was completed in January 1843. It created Croton Reservoir, an eight km (five-mile)-long, 160 ha (400-acre) lake with a storage capacity of about 225,000 m^3 (600 million gal).

Construction of the aqueduct began in May 1837. The work was divided into four divisions with 96 subdivisions. The horseshoe-shaped stone and brick aqueduct is about 2.6 m (8 ½ ft) high and about 2.3 m (7 ½ ft) wide. The profile drops at about 20 cm per km (13 inches per mile). The alignment follows the contour of the land where possible, but several tunnels, embankments and bridges were needed to penetrate ridges or to cross over valleys. For example, the 23-m (76-ft)-high stone arch that carries the aqueduct across Sing Sing Kill in the village of Ossining spans 27 m (88 ft). It is known locally as the "Double Arch" because the aqueduct arch spans a second arch that carries a village street (Broadway) across the same stream. A visitor's center, which houses an exhibit on the aqueduct, is nearby. In order to prevent air pressure from building up in the enclosed aqueduct, thirty-three 4.3-m (14-ft) high stone ventilators were built at about 1.6 km (one mi) intervals. Six waste weirs provide overflow protection. Meanwhile, the two Manhattan reservoirs were placed under construction. The 12-m (38-ft)-high earth embankments of the 14-ha (35-acre) Receiving (or Yorkville) Reservoir had a storage capacity of 68,000 m^3 (180 million gallons). Discontinued in 1890, the reservoir has been replaced by the Great Lawn in Central Park. The Murray Hill Distributing Reservoir at 42nd Street and Fifth Avenue was the end of the line, 68 km (42 mi) from the Croton Dam. This masonry structure reservoir, designed in an Egyptian architectural style, held 90,000 m^3 (24 million gallons) of pure water. Since 1911, the site has been occupied by the New York Public Library.

Perhaps the most impressive feature of the Croton system is the signature High Bridge across the Harlem River. Douglass and others had proposed a high viaduct to cross the Harlem, but Jervis initially argued for a low-level bridge carrying an inverted siphon on the basis of cost. Nevertheless, Jervis, studied both options: a 442 m (1,450-foot)-long high bridge just below the hydraulic grade 42 m (138 ft) above high water, or a 24-m (80-ft)-long arch 15 m (50 ft) above the river. At half the cost, the water commissioners preferred the low bridge, but there was concern about the impact on navigation. (The courts had just declared the Harlem River navigable in 1839.) Jervis was caught in the middle. In 1839, the state legislature dictated either a high bridge or a tunnel. Jervis prepared estimates for building a tunnel using cofferdams, and a high bridge. Although he believed that the tunnel would be cheaper, he was concerned over the many uncertainties and contingencies in building such a tunnel, and recommended the high bridge. Since either proposal would take longer to build than the aqueduct itself, temporary pipes were placed across the river. Construction on High Bridge commenced in 1839. The bridge consisted of 15 Roman-style semi-circular masonry arches, eight of which spanned