WATER, MEGACITIES
AND GLOBAL CHANGE

NEW YORK CITY

One New York City: One Water

SUSTAINABLE WATER MANAGEMENT FOR NEW YORK CITY'S PEOPLE AND ENVIRONMENT

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Introduction

New York City's water supply system is one of the most extraordinary, and most efficient, water delivery systems in the world. The award-winning drinking water—prized by New Yorkers and its visitors—travels through an extensive network of aqueducts and tunnels, some dating back more than 150 years, flowing largely by gravity from sources that extend more than 125 miles (200 km) from the city and across a 2,000- square-mile watershed (5,180 sq km) (Figure 1). Wastewater and rain water collected in the five boroughs of New York City is then conveyed through a 7,500 miles (12,070 km) network of sanitary, storm, and combined storm and sanitary sewers before being treated, disinfected, and then discharged to New York City's waterways—leaving them cleaner than they have been in over 100 years.

Managing this extensive system is the job of nearly 6,000 Department of Environmental Protection (DEP) employees. Together they ensure that, on average, over 1 billion gallons (3.8 billion liters) of potable water are delivered to New York City and adjacent areas each day. Roughly that same volume will subsequently get treated at one of New York's fourteen wastewater facilities if it is a dry

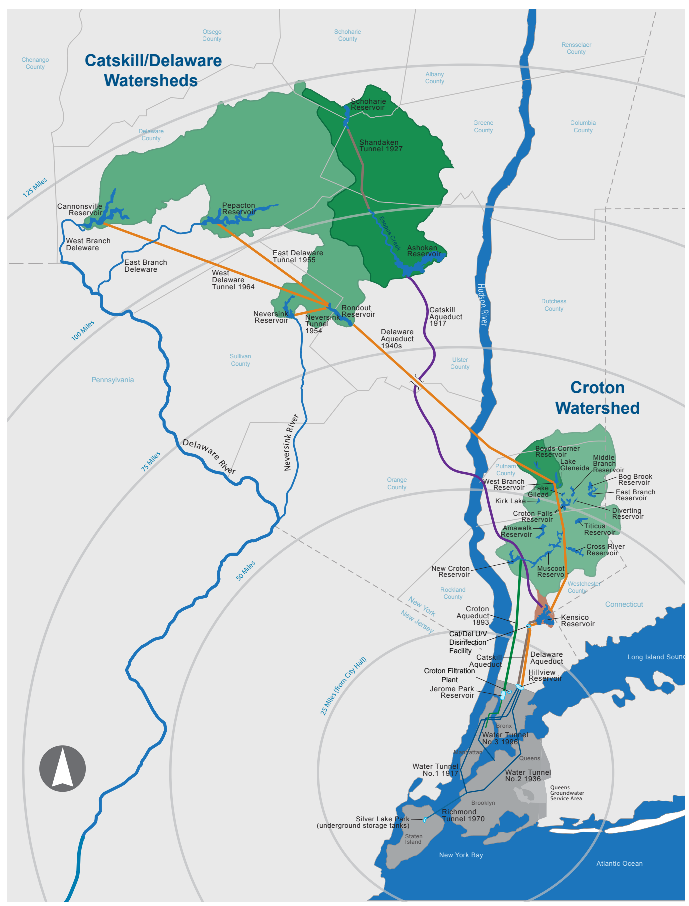


Figure 1. New York City's Water Supply System

day; on a wet weather day they can treat twice that much. DEP's systems are able to function even under extraordinary conditions. In the wake of storms that cause disruptions to one or several of its reservoirs, system operators are able to draw from other parts of the system, thereby maintaining an uninterrupted flow of potable water.

Of course, as recent events have demonstrated, even a system as robust as New York City's is vulnerable to extreme weather events. For example, Superstorm Sandy in 2012, though it was not a significant rain event, caused a storm surge that affected some of DEP's assets in low-lying areas, knocking out power and critical equipment at key wastewater facilities located along the waterfront. Tropical Storms Irene and Lee in 2011 caused extensive flooding in several of the City's upstate reservoirs, resulting in unprecedented degradation in water quality and challenging DEP's ability to deliver high-quality drinking water to the City. Climate scientists predict that this region of the world will experience sea level rise and more intense precipitation, along with extended dry periods or episodic droughts. Increased rainfall puts pressure on an already aging infrastructure system that was designed to drain our City. Storm surges and heavy rains can impair or damage critical equipment and result in overflows of untreated sewage into the city's waterways.

In response, the City has accelerated its efforts to mitigate climate risks to its water and wastewater systems. To prepare for the future, DEP began implementing climate change resiliency measures in 2008, when it issued its Climate Change Assessment and Action Plan. Working with academic partners at Columbia University, the NASA Goddard Institute for Space Studies, and subsequently the City University of New York, DEP has applied Global Climate Models at the regional scale to evaluate the potential impacts of climate change on New York City's reservoirs, and potential implications for operations. Understanding and adapting to the impacts of climate change are critical to maintaining DEP's ability to manage water systems without the expense of energy-intensive filtration facilities.

Continued innovation and investment are the keys to success. For that reason, DEP has made the case to its rate payers, regulators, and the public-at-large that its Watershed Protection Program is the most cost-effective strategy for protecting New York City's water supply system. The Watershed Protection Program leverages pollution prevention, land acquisition and environmental stewardship programs at less than the cost of a water treatment facility, thus providing great value for the investments made. Furthermore, DEP is pioneering green infrastructure in the public realm through partnerships with parks, schools, transportation and public housing agencies to manage increasing volumes of stormwater. DEP is also investing in new drainage plans and protecting wastewater treatment facilities from the impacts of coastal storms and sea level rise, adopting a design standard to protect against the 100-year storm of the 2050s. In conjunction with ambitious greenhouse gas reduction targets, including a goal to reach net-zero energy at in-city wastewater treatment plants by 2050, DEP is working to reduce its own contributions to climate change while preparing to withstand the probable impacts from future climate events.

Today, DEP continues to invest billions of dollars—from revenues collected through the water and sewer assessment charged to properties—in upgrading and maintaining the system to increase redundancy and reliability. The emerging challenges of climate change requires nimble and dynamic responses and add another dimension to the centuries-old job of managing the water needed to power one of America's most dynamic metropolises.

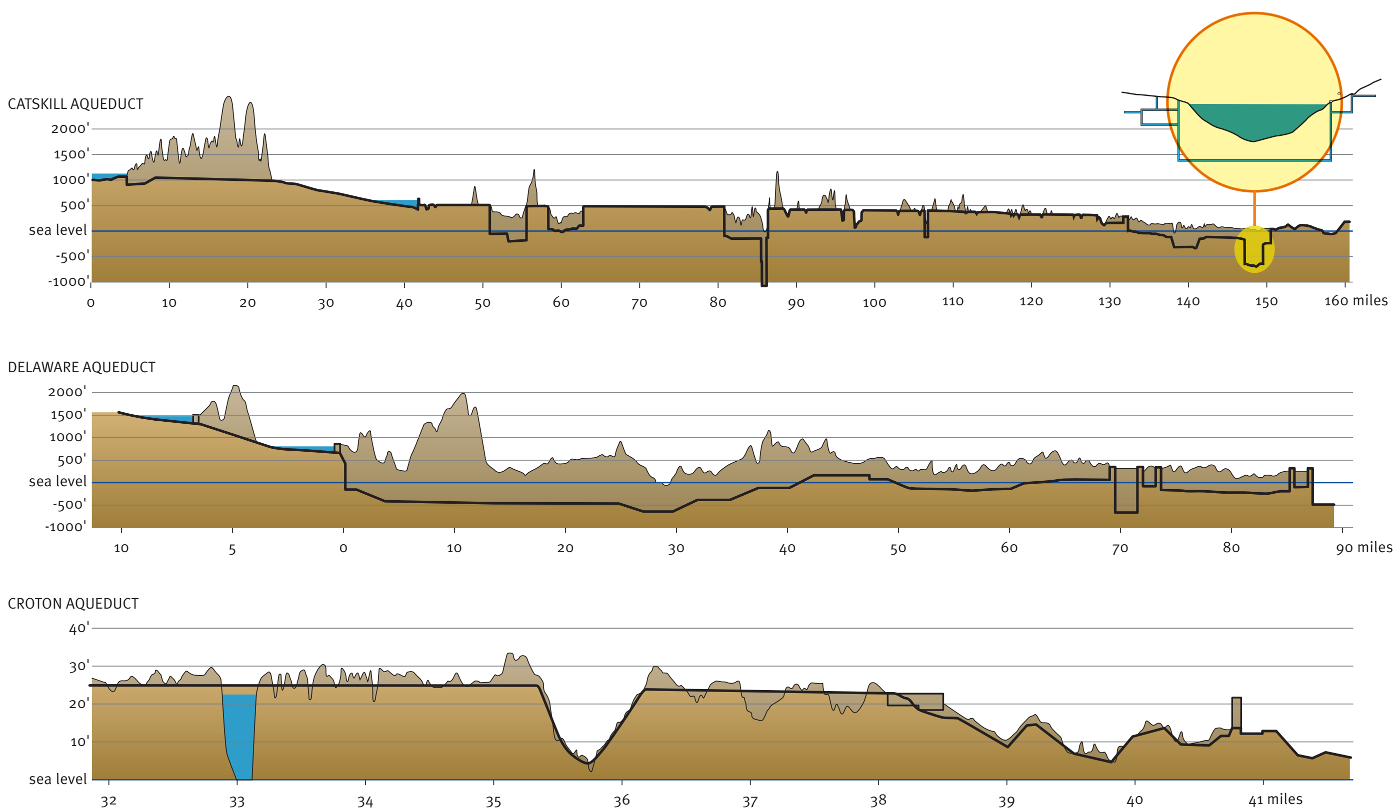
A Short History of New York City's Water

New York City has been a hub of commerce since its founding as a Dutch trading post in 1625. The first Europeans to arrive on the shores of what would become New York City found a landscape abundant with flora and fauna and a vast, pristine estuary that reached as far as the eye could see. With deep harbors and navigable rivers, and later connections to agriculture and industries inland by the Erie Canal, New York City grew to become a maritime powerhouse—responsible for almost two-third of the young nation's trade in the first half of the nineteenth century.

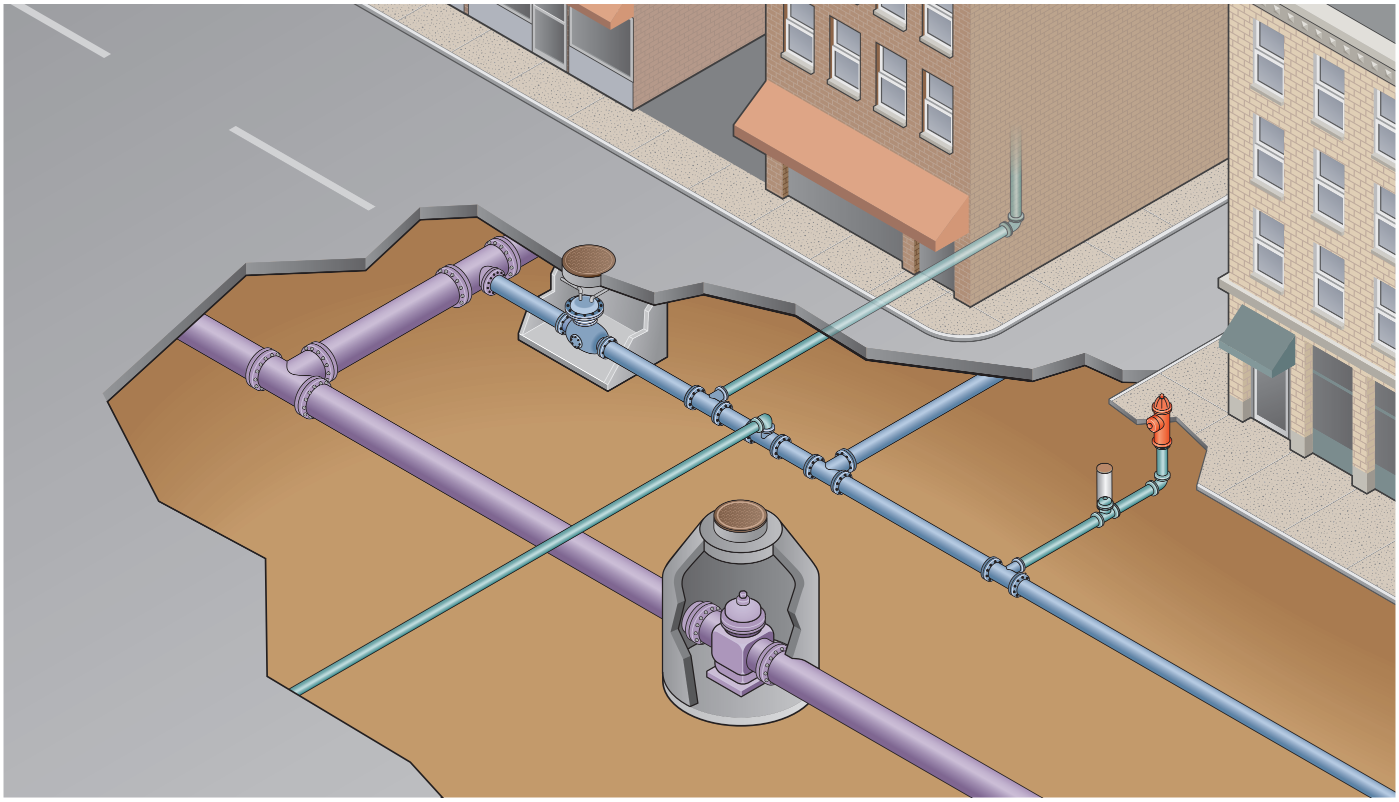
As industry surrounding the regional port grew, immigrants came and prospered—building new neighborhoods and a better life, often near the waterfront. The number of newcomers would escalate dramatically in the second half of the nineteenth century as the Industrial Revolution took hold. By 1900, nearly two million people lived in New York—many of them in crowded and unsanitary tenement conditions. Disease and health risks persisted in many of these poorer areas of the city, challenging the city's leaders to ensure more equitable ways of distributing clean water and removing waste and wastewater from these neighborhoods.

The evolution of water supply and demand

Early Manhattan settlers obtained water for domestic purposes from shallow privately-owned wells. In 1677, the first public well was dug in front of the old fort at Bowling Green, at the southern tip of Manhattan Island. In 1776, when the population reached approximately 22,000, a reservoir was constructed on the east side of Broadway between Pearl and White Streets in lower Manhattan. Water pumped from the wells that were sunk near the Collect Pond, to the east of the reservoir, and from the pond itself, was distributed through hollow logs laid in the principal streets. In 1800, the Manhattan Company (a distant ancestor of the Chase Manhattan Bank) sank a well at Reade and Centre Streets, pumped water into a reservoir on Chambers Street, and distributed it through wooden mains to a portion of the community. In 1830, a tank for fire protection was constructed by the City further north at 13th Street and Broadway, and was filled from a well. As the population of the city and manufacturing activity increased, the water supply became polluted and the need for water to fight fires became more acute—prompting a search for a new source of supply.



The three New York City aqueducts with corresponding topographical conditions and pressures as they carry water from as high as 1500 feet (457 m) above sea level and as far as 160 miles (257 km) away.



The New York City water distribution system as seen below street level.

Submain
Trunk main
Service line

The City, which at that time consisted only of Manhattan, looked north for water—beyond its boundaries to the rural areas of what is now Westchester County. It decided to impound water from the Croton River and to build an aqueduct to carry water from this new reservoir to the City. This aqueduct, known today as the Old Croton Aqueduct, had a capacity of about 90 million gallons (340 million liters) per day, and was placed in service in 1842. Reservoirs at the receiving end were located in Manhattan at 42nd Street, on the site of today's New York Public Library building, and in Central Park south of 86th Street. A second aqueduct from the Croton watershed (known as the New Croton Aqueduct) was constructed toward the end of the century, between 1885 and 1893. Not long after, in 1898, the Bronx, Staten Island, Queens and Brooklyn were unified with Manhattan into the City of New York. The water system we know today was consolidated from the separate and largely distinct water systems then operating in those communities.

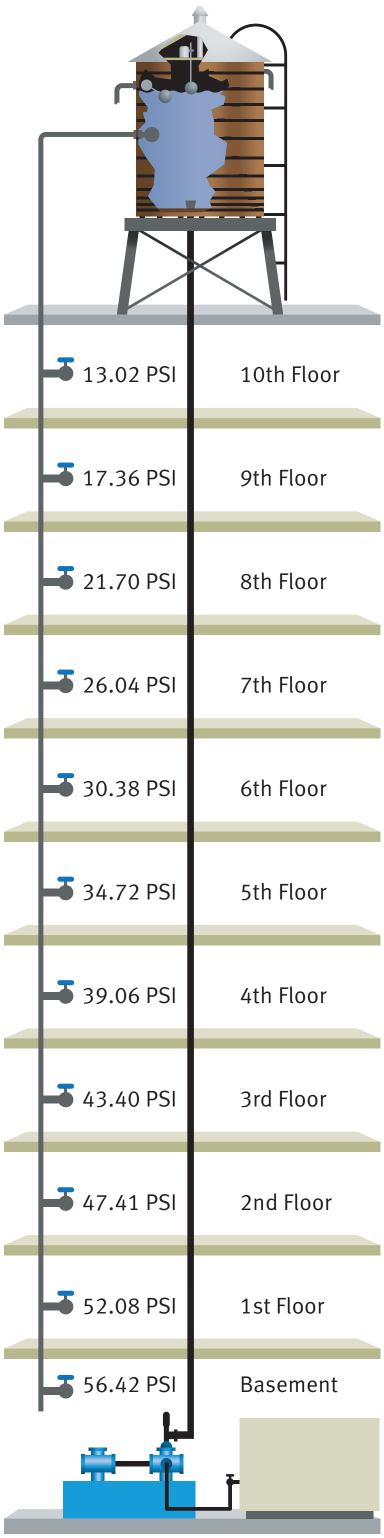
With demand continuing to grow, the City—under the authority of a newly formed and state-sanctioned Board of Water Supply—decided to develop the Catskill region as an additional water source. The Board impounded the waters of the Esopus Creek, one of the watersheds in the Catskills, roughly 100 miles (160 km) northwest of the city. This project, to develop what is now known as the Catskill System, began with the construction of the Ashokan Reservoir and Catskill Aqueduct (1915) and was followed by the completion of the Schoharie Reservoir and Shandaken Tunnel (1928).

But even these two extensive systems would not be sufficient to meet the demands of a growing metropolis. In 1928, a project to develop a new source of supply using the tributaries of the Delaware River in upstate New York was approved. In 1931, the Supreme Court of the United States upheld the right of the City to augment its water supply from the headwaters of the Delaware River, and construction of the extensive Delaware System of water supply and delivery was initiated. In 1954, five entities (NY State and City, New Jersey, Pennsylvania and New Jersey) agreed on protocols for coordinating water conditions and drought management in the new area

While the Delaware System was being developed, officials at NYC's Department of Water Supply, Gas and Electricity (DWSGE), a predecessor to the Department of Environmental Protection, began to focus on conservation. Thus, when Franklin Delano Roosevelt introduced a series of economic programs known as "The New Deal" to provide relief, recovery and reform to a country recovering from high unemployment and a depressed national economy, the DWSGE was poised to take advantage of employment opportunities under the newly minted United States Works Progress Administration (WPA)—the largest employer of all of the New Deal public works programs.

The DWSGE brought on WPA employees to make repairs to existing water distribution system infrastructure, as well as to conduct real estate and customer surveys in residences across NYC to assess water wastage and determine potential for expanding supply. DWSGE formalized its efforts by supplementing an existing Water Waste Force assembled in 1934 with skilled trade inspectors from the WPA, to travel to thousands of houses and buildings throughout the five boroughs of New York City to determine how unmetered water was being used and to identify where water was being wasted. Initial surveys conducted by the Water Waste Force resulted in complete inspection of approximately 80 percent of unmetered buildings in NYC, prompting a measurable decrease in water consumption in almost half of them.

As the agency was evaluating options for more sustainable long-term solutions to managing water demand, in 1939, the City was hit by a severe drought lasting three years. For the first time in history, demand reduction was needed to avoid depletion of the reservoirs. Coinciding with the start of World War II, DWSGE launched a massive water conservation campaign in order to get the word out to New Yorkers about the severity of the water shortage. Pamphlets and posters urging the public to conserve water and address leaky fixtures were distributed throughout the City,



Water pressure from New York City's gravity-fed system is usually sufficient to supply water at least 6 stories high (pressure units are in pounds per square, or PSI). Water towers atop roofs help to provide adequate building water pressure.

Figure 2. World War II messaging to inspire New Yorkers to save water during a wartime drought.

resulting in water savings of approximately 76 million gallons (288 million liters) per day (Figure 2).

The end of the water shortage in 1942 and the post-war boom resulted in substantial increases in water consumption in New York City. From 1950, citywide water demand increased by one percent year over year reaching 1.2 billion gallons (4.5 billion liters) per day by the early 1960s. The increasing demand, coupled with a 23 percent reduction in precipitation for a two-year period resulted in the drought of record for NYC between 1963 and 1965. An intense water conservation campaign seeking voluntary cooperation from New Yorkers was launched with some success between 1963 and 1964, however precipitation levels continued to drop to 49 percent below normal. In 1965, the federal government declared a "water shortage disaster" for New York City, making it New York State's only federal disaster declaration for a drought.

Increases in water demand through the late 1970s, combined with abnormally low watershed rainfall levels, prompted another drought emergency in 1980. According to a 1981 DEP study, average daily in-city water demand at the time was 1.5 billion gallons per day, consistently above the safe yield of the system (which was 1.29 billion). High levels of demand, coupled with a drop in average levels of rainfall, resulted in the system remaining significantly below capacity for most of the year.

It took five years and another drought (1985) to prompt the City to push for water metering—the ultimate conservation tool. In 1985, New York City passed Local Law 53/1985 to require metering of all new residential construction and metering during substantial renovation of residential properties. Additionally, the New York City Water Board established a metering requirement as a condition of receiving water and sewer service from the City. Pursuant to this requirement, DEP began issuing the first in a series of meter installation contracts in 1988 that brought the city to almost 90 percent metered status within 10 years. Since most small property owners found that their metered bills were lower than their fixed rate bills, they enthusiastically allowed their properties to be metered.

At the federal level, the Energy Policy Act of 1992 contained language regarding the prohibition of sale of high-flow plumbing fixtures nation-wide. The Act stated that, by 1994, new toilets sold in the US must use no more than 1.6 gallons (6.1 liters) per flush, and new shower heads were capped at flow rates of 2.5 gallons (9.5 liters) per minute. Building on other federal, State and City water efficiency and conservation laws, DEP developed and launched a successful city-wide Toilet Rebate Program that ran from 1994-1997.Today, New York City's demand is below 1 billion gallons (3.8 billion liters) per day—the lowest in the last 60 years and still continuing to drop (Figure 3).

Drainage and wastewater treatment

As the water supply system grew, so too did the city's sewer network. At the beginning of the 20th century, sewers discharged untreated wastewater containing a wide array of disease-causing microorganisms into the city's waterways. To address this public health issue, the City built its first wastewater treatment plant (WWTP) at Coney Island in Brooklyn in 1886 followed by two more in Jamaica Bay in Queens in 1894 and 1903. These plants treated only a fraction of the city's total wastewater flow, but they did marginally improve the quality of the hugely popular beaches at Coney Island. Between 1945 and 1965, five new plants were built to meet the needs of the growing population of New York City, which was approaching eight million.

By 1968, 12 wastewater treatment plants were operating in New York City and were capable of treating 1.4 billion gallons (5.3 billion liters) of wastewater each day. Spurred by passage of the Clean Water Act, federal funding, and support from the growing environmental movement, New York City continued to upgrade and expand its wastewater treatment system throughout the 1970s. With the completion of two new treatment plants

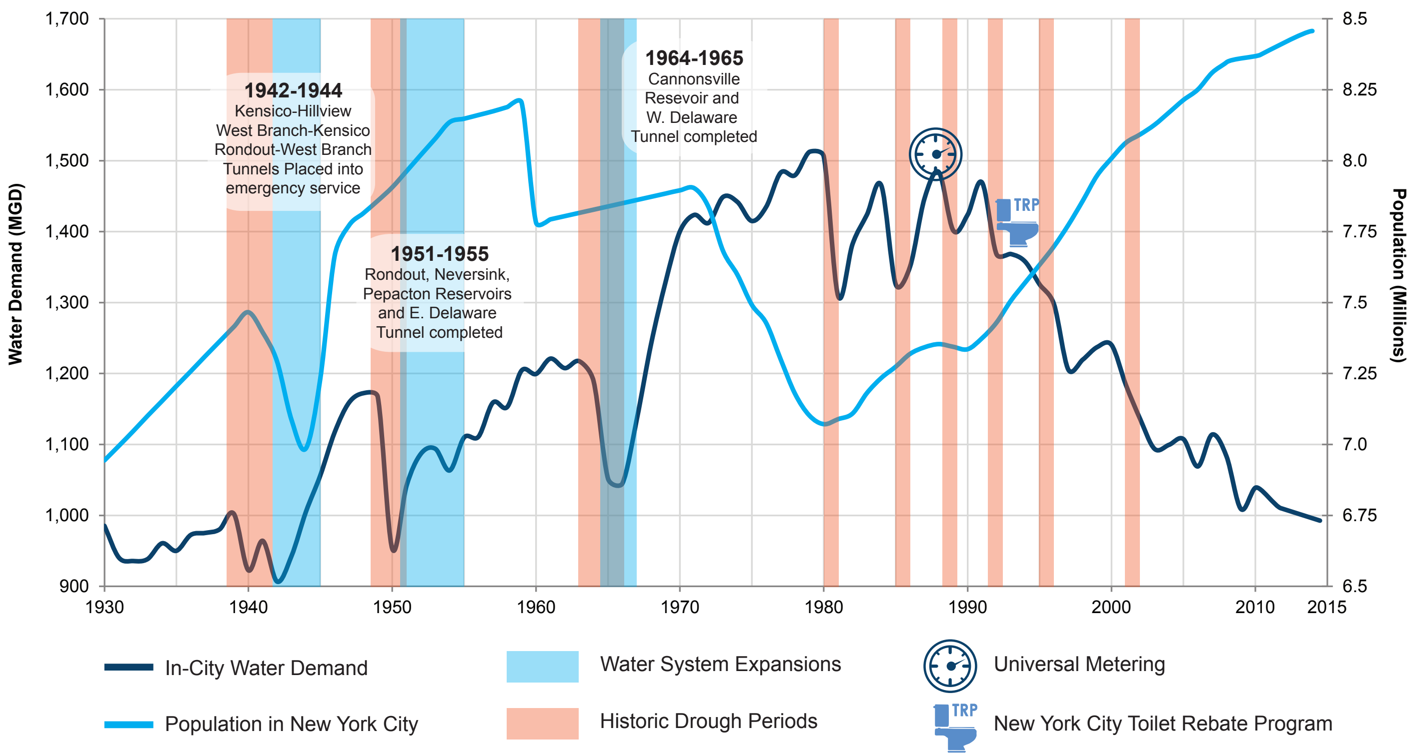
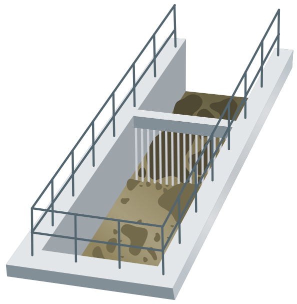
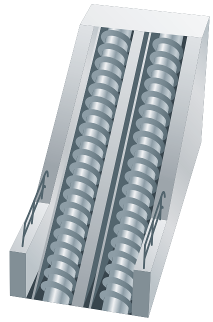


Figure 3. Timeline showing New York City water demand compared with population growth, and other factors affecting overall demand.

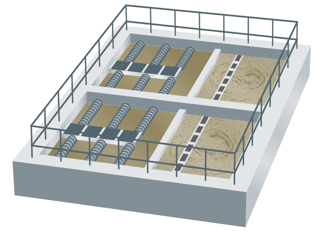
How a wastewater treatment plant functions



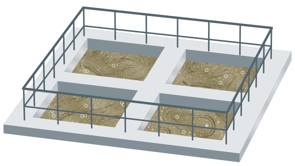
Bar screen



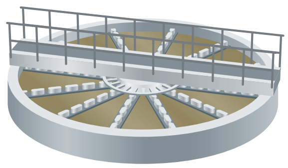
Sewage pumps



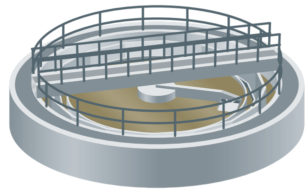
Primary settling



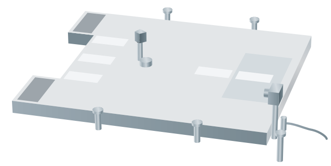
Aeration tanks



Sludge thickener



Final settling tank



Digesters

in 1987 (for a total of 14 wastewater treatment plants), virtually all of the city's dry-weather wastewater flows were captured and treated for the first time.

During this period, the City also began to address combined sewer overflows (CSOs). Many older cities like New York have a combined sewer system, in which the sewers accept a combination of both sanitary and stormwater flows. In dry weather, practically all of New York City's sewage is treated. During rainfall, however, the added volume of stormwater can exceed the capacity of the sewer infrastructure. This can result in untreated overflows from relief structures that are designed to protect the biological treatment process in treatment plants and to prevent sewage backups and flooding. Treatment plants are designed to manage twice the volume of wastewater on a wet day than on a dry day, but changes in precipitation, population, and impervious cover have increased the flow to the plants and therefore the volume of combined sewer overflow. In an effort to capture and treat more sanitary sewage flow during storms and prevent CSOs, in 1972 the City began to operate its first combined sewer overflow facility at Spring Creek, an inlet of Jamaica Bay. Infrastructure upgrades have enabled the City to increase stormwater capture rates from 18 percent in 1987 to 78 percent today.

As the City finished building wastewater treatment plants, it also began to move away from building new combined sewer systems, so that today almost 40 percent of the city is served by separate sanitary and stormwater systems—thus avoiding combined sewer overflows in these locations. Furthermore, starting in the 1990s DEP began to preserve natural drainage corridors, called "Bluebelts", including streams, ponds, and other wetland areas, to convey stormwater (Figure 4). The Bluebelt program, which began and has expanded most significantly in the borough of Staten Island, has saved tens of millions of dollars in infrastructure costs when compared to providing conventional storm sewers for the same land area.

In the early 2000s, the City committed to evaluate innovative stormwater management strategies through an interagency Best Management Practices Task Force. The Sustainable Stormwater Management Plan released by that Task Force in 2008 concluded that "green infrastructure" was feasible in many areas of the city and could be more cost-effective than certain large infrastructure projects such as CSO storage tunnels.

Figure 4. The Bluebelt system preserves natural drainage corridors to convey stormwater.

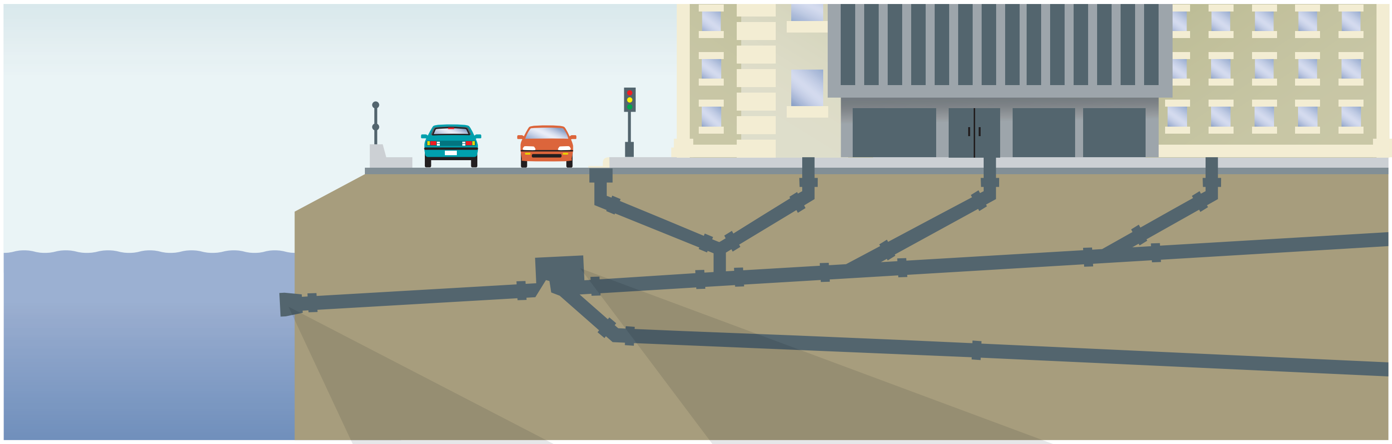
Figure 5. A green infrastructure "bioswale" intercepts stormwater runoff before it enters the combined sewer system.

(Green infrastructure uses plants, permeable areas, and other source controls, in a decentralized and integrated network to mimic the pre-development water cycle and to reduce stormwater runoff—see Figure 5). Based on these recommendations—and building upon the success of other efforts to build ecological systems to control pollutant discharges in the upstate watersheds, Staten Island Bluebelt, and Jamaica Bay—DEP released the NYC Green Infrastructure Plan in 2010. The plan proposes to utilize green infrastructure to improve the quality of waterways around New York City by managing runoff from impervious surfaces in combined sewer watersheds through detention and infiltration source controls.

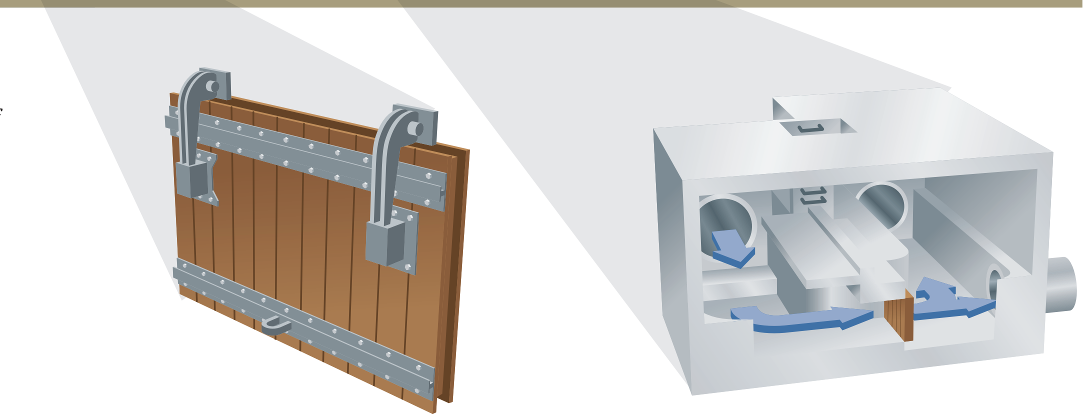
Governance, Funding and Regulation

Like many large cities, the entirety of New York City's water and sewer infrastructure is funded by revenue it collects through water and sewer rates—not through the City budget. The New York City Water Board is responsible for setting these rates, and must ensure that the City is able to fund (through a separate entity that issues debt against water revenues) the entirety of the water and sewer system's operating and capital needs. This includes salaries and benefits for nearly 6,000 City employees, as well as the capital costs associated with major construction initiatives and significant upgrades and repairs to treatment plants, sewers, and other water infrastructure. Board members are appointed to two-year terms by the Mayor, and in addition to establishing tariffs that provide sufficient revenue to operate and maintain the water and sewer system, strive to set rates that are equitable and fair, that encourage conservation, and that are easily understood by the City's water and sewer customers.

The NYC Municipal Water Finance Authority (MWFA) issues revenue bonds to finance NYC's water and wastewater capital programs, and the costs associated with debt service consume a significant portion of the system revenues. Total expenditures to operate and finance the water and wastewater systems are expected to reach $3.85 billion in 2016, with debt service representing a large percentage (approximately 44 percent) of the system's operating budget, and operations and maintenance representing 38 percent of the operating budget. The debt service is a direct result of DEP's massive capital investment program, which has been largely driven by unfunded mandates required by state and federal regulators. From FY 2005 to FY 2014, DEP committed $21.2 billion to its capital program with 59 percent of the capital investments directed to mandated projects such as the Croton Water Filtration Plant. While the ratio of mandated to non-mandated projects is falling, there are still many capital projects planned and underway to maintain the system.



In areas of New York City where sewers are combined, excess runoff contributes to combined sewer overflows (CSOs) into the harbor, containing a mix of sanitary flow and stormwater.



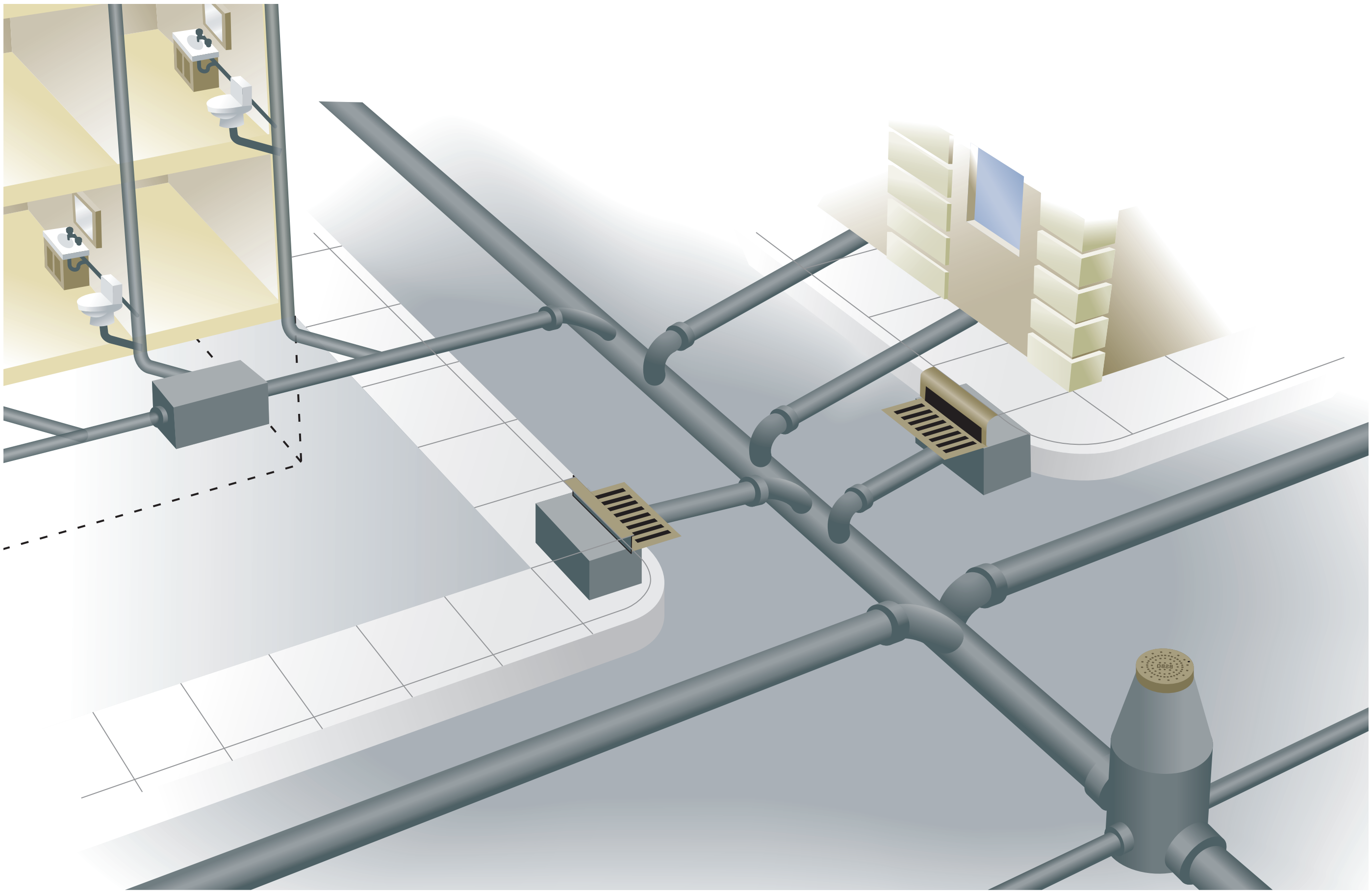
Tide gates prevent salt water from entering the sewer system and remain shut at the end of each outfall until water pressure inside the pipe forces it to open to release CSO.

Regulators control flow of wastewater to the Wastewater Treatment Plants during dry and wet days by adjusting to volume.

To cover the above expenditures, in 2016, most customers will be charged a uniform water rate of $0.51 per 100 gallons of water. Wastewater charges are levied at 159 percent of water charges ($0.81 per 100 gallons). There is a small percentage of properties that are billed at a fixed rate. Under the Multi-family Conservation Program, some properties are billed at a fixed per-unit rate if they comply with certain conservation measures. Some nonprofit institutions are also granted exemption from water and wastewater charges on the condition that their consumption is metered and falls within specified consumption threshold levels. Select properties can also be granted exemption from wastewater charges (i.e., pay only for water services) if they can prove that they do not burden the wastewater system (e.g., they recycle wastewater for subsequent use on-site).

Day-to-day responsibility for the safe management and operation of the water, wastewater and conveyance systems rests with the Department of Environmental Protection (DEP), which is a Mayoral agency and headed by a Commissioner appointed by the Mayor. DEP oversees one of the largest capital construction programs in the region, including the construction of a new water delivery tunnel that will facilitate maintenance and repair work on the existing two tunnels. As the City agency responsible for New York City's environment, DEP also regulates air quality, hazardous waste, and quality of life issues, including noise.

In the United States, public water systems such as the City's are regulated by the Safe Drinking Water Act (SDWA), which was originally passed by Congress in 1974 to protect public health. The law was amended in 1986 and 1996 and requires EPA to undertake many actions to protect drinking water and its sources: rivers, lakes, reservoirs, springs, and groundwater wells. The law sets national standards for drinking water based



The stormwater and wastewater collection network as seen below street level.

on sound science to protect against public health risks. Responsibility for implementing the SDWA and for compliance and enforcement can be delegated to states which provide laws, regulations and standards at least as stringent as the national program. As a result, the public water systems in New York State, including the City's, is regulated by the New York State Department of Health (DOH). Because of New York City's population size, and the fact that the City operates a largely unfiltered system, DEP's actions and operations are highly scrutinized by DOH.

A similar regulatory framework titled the Clean Water Act (CWA) exists for regulating discharges of pollutants into the ground and surface waters of the United States, such as from municipal and industrial wastewater and storm systems, and for establishing water quality standards for surface water. The basis of the CWA was enacted in 1948 and was called the Federal Water Pollution Control Act, but the Act was significantly reorganized and expanded in 1972 into the CWA. The New York State Department of Environmental Conservation is responsible for implementing the CWA, which includes among other things setting water quality standards for surface waters and for issuing discharge permits and establishing and enforcing discharge permit limits for municipal and industrial point source discharges.

DEP's responsibilities extend beyond city boundaries. DEP diverts or releases water from the system to supply communities outside of the city, maintain flow in the Delaware River, support fishery habitats and recreation, generate electricity, and further enhance the flood mitigation provided by the dams to downstream areas. These secondary purposes are all governed by an ever-evolving collection of agreements, operating protocols, state and federal laws and regulations, court decisions, and consent decrees. For example, releases from Delaware system reservoirs to maintain flow in the

Delaware River are governed by a 1954 Supreme Court decree and the Delaware River Basin Commission, which with subsequent agreements among the decree parties, allows the City to divert up to 800 million gallons (3 billion liters) per day from the river's headwaters for its water supply. Balancing the needs and requirements for downstream releases with City water supply demand is a critical function for DEP and necessitates cooperation and working relationships with numerous stakeholders, including states and other water utilities that draw from the Delaware River.

Managing the Water System Today

NYC's three upstate reservoir systems, with 19 reservoirs and three controlled lakes, have a total storage capacity of approximately 580 billion gallons (2.2 trillion liters). The systems were designed and built with various interconnections to increase flexibility and reliability by permitting exchange of water from one reservoir to another, and with intakes at multiple levels within the reservoirs to allow withdrawal of the highest quality water supply available. The numerous components of the city system combine to create a robust and flexible supply network. Under normal conditions, the Catskill and Delaware Systems west of the Hudson River contribute 90 percent of the city's surface water supply, while the Croton System east of the Hudson—now featuring a new filtration plant—provides the remaining 10 percent (at times, the Croton System supply can be increased to up to 30 percent of the total).

In addition to operational flexibilities, naturally occurring factors also contribute to the reliability and sustainability of the water supply. These natural foundations also support high water quality: the Catskill and Delaware watersheds are 75 percent forested, the system is almost exclusive gravity-fed, and it benefits from a historically temperate climate. These elements help safeguard the system against service interruptions by controlling water quality issues linked to turbidity, pathogens, and other contaminants which could impact millions of people and hamper some of the City's essential services.

Throughout the onset of national environmental regulations like the Safe Drinking Water Act, the City provided potable water that met increasingly stringent drinking water quality standards. The quality of the water supplied has continued to meet the requirements of ever-expanding regulations. Recently, City water supply operations have been recognized by federal and state regulators as qualifying for a hard-to-achieve exemption to the Surface Water Treatment Rule (SWTR) that requires surface water purveyors to filter potable water before distribution to consumers.

Since the early 1990s, federal and state regulators have issued a Filtration Avoidance Determination (FAD) for the Catskill and Delaware Systems based on the high quality of the City's source waters and the City's commitment and substantial funding of an adaptive management approach towards protecting water quality. This approach includes, but is not limited to: source water protection, pollution prevention and watershed management programs; science and research programs to understand and mitigate sources of environmental impairment in the watershed; and extensive monitoring programs to ensure that source water quality meets all of the requirements and conditions established under the SWTR for avoiding filtration. As a result, DEP operates the largest unfiltered water supply in the United States.

Source water protection is a particularly important aspect of the management program. It involves enforcement of watershed rules and regulations; physical upgrades of wastewater treatment plants in the watershed and operation of City-owned wastewater treatment plants at high levels of treatment; long-term protection of lands through acquisition in fee or easement; and partnership programs to support watershed residents (including farmers and foresters), communities, and businesses in protecting and investing in source water quality.

As a result of new requirements promulgated by the US Environmental Protection Agency under the Safe Drinking Water Act (specifically, the Long Term Enhanced Surface Water Treatment Rule), the City has extended its multi-barrier approach towards protecting water quality by building the world's largest ultraviolet disinfection plant which became operational in Autumn

2012. The facility is designed to disinfect up to 2.4 billion gallons (9.1 billion liters) per day, and provides an additional barrier of protection against potentially harmful microbiological contaminants such as *Cryptosporidium* and *Giardia*.

The FAD and the City's watershed protection programs could not have been successfully implemented without the cooperation of federal, state, and local authorities, and non-governmental organizations that were party to a Memorandum of Agreement (MOA) that provides the overall regulatory, financial and legal framework for managing the watersheds while protecting water quality and the viability of local watershed communities. The MOA resolved some long-standing conflicts between stakeholders. In particular, with the City's assets and watersheds extending into 8 separate rural and suburban counties in New York State, each location is characterized by different demographics and concerns regarding the City's activities in their jurisdictions. Ultimately, the MOA allowed the City to promulgate and enforce new Watershed Rules and Regulations and a voluntary land acquisition program, while also pledging to offset stringent environmental standards by funding a comprehensive range of environmental measures including upgrades to wastewater treatment plants, septic systems and stormwater management.

Other concerns were also addressed by the MOA to reduce conflict. For example, past recreational uses of lands acquired by the City, such as for hunting, fishing and hiking were maintained and expanded. The MOA also established institutional mechanisms for conflict resolution and cooperative programs that enable local authorities to play an active role in watershed protection: a Watershed Partnership and Protection Council, consisting of local, New York City and State representatives, provides a forum for discussing and resolving disputes, as needed; and the Catskill Watershed Corporation receives funding from the City to implement pollution prevention and economic development programs.

As part of DEP's long range planning efforts, DEP has developed and continues to expand programs to encourage water conservation as a responsible way to plan for long-term use of the City's water supply. As a result, water demand is down more than 30 percent since the 1990s, and DEP has set a new goal of achieving an additional 5 percent reduction by 2020. The efforts include municipal and residential water efficiency programs, and non-residential water efficiency programs such as the successful Hotel Water Conservation Challenge.

DEP is also expanding its use of information technology to communicate more effectively and quickly with the public and to encourage water conservation. The City's 311 system provides technology for customers to request City services or file complaints. This information, communicated to DEP online or by dialing 311, enables the use of enhanced analytics to monitor operations. Wireless automatic meter reading technology has also enabled DEP to provide leak notification services to alert customers about potential water leaks on their property. Since 2011, the program has issued 96,000 leak notifications saving customers more than $80 million.

The Population and Climate Change Challenge

New York City continues to grow at a rapid rate, in large part through immigration. With nearly 8.4 million people, the city's population is at an all-time high, and is expected to reach 9 million by 2040. This increased population will strain the city's older infrastructure and test the reliability of municipal services, including its water delivery system. To address these issues, DEP has—since 1970—been constructing a third water tunnel to further ensure reliability of the system overall. This mammoth undertaking, occurring below the busy streets of the city, is being completed in phases and will, when completed, allow the original tunnels to be shut down for maintenance and repair for the first time in history.

Beyond population growth, the city also faces increasing risks from the impacts of global climate change. In 2015, the New York City Panel on Climate Change (NPCC), released updated projections for the region in its publication *Building the Knowledge Base for Climate Resiliency*. Among them, the city can expect to see, by the 2050s, increased average temperatures (4.1 to 5.7° F, or 2.3 to 3.2° C), increased average precipitation

(4 to 11 percent), and rising sea levels (11 to 21 inches, or 28 to 53 cm). The average number of days per year above 90° F (32° C) is expected to at least double. Due to sea level rise alone, coastal flood events will increase in both frequency and intensity. The frequency and number of intense hurricanes across the North Atlantic Basin is also expected to increase.

Each of these changes will increase the risk of the city's residents, neighborhoods, businesses, and infrastructure to potential adverse public health, environmental and financial impacts. To help mitigate these risks, the City has established a two part program that includes: a) establishing clear goals and implementing programs to control and reduce greenhouse gas emissions; and b) adapting neighborhoods, particularly along the City's coastline, with critical investments in buildings and infrastructure to enhance redundancy and resiliency.

Reducing DEP's Carbon Footprint

The City's blueprint for sustainability and resiliency is outlined in *One New York: The Plan for a Strong and Just City* (OneNYC). This plan addresses the profound social, economic, and environmental issues that the City faces, including its needs for adaptation to climate change impacts and reducing greenhouse gas emissions. *OneNYC* establishes a goal for the City to reduce GHG emissions by 80% (base year 2006) by the year 2050.

DEP plays a crucial role in the success of *OneNYC*'s greenhouse gas reduction goal. Emissions from the water and wastewater system are responsible for nearly 20 percent of City government emissions, of which wastewater treatment accounts for 90 percent. In total, DEP facilities are estimated to consume nearly nine trillion British Thermal Units (BTUs) of energy each year. To reduce its carbon footprint, DEP is undertaking significant energy retrofit and efficiency projects. These include, but are not limited to, upgrading generators and installing new centrifuges at several wastewater treatment plants, increasing efficiency in lighting and other appurtenances, developing cogeneration facilities, and constructing an additional hydroelectric facility at an upstate reservoir. Furthermore, sustainability programs including water demand management and green infrastructure may reduce DEP's carbon footprint as well as that of buildings and the city as a whole.

DEP is also seeking net-zero energy at its 14 wastewater treatment by 2050, specifically through improvements to the efficiency of the wastewater treatment processes, and through beneficially recovering and using all biogas. To help achieve this goal, DEP aims to boost the production of biogas by processing as much as 500 tons of organic waste per day through anaerobic digestion. A pilot project is currently being developed to test the feasibility of reaching goals for anaerobic digestion of food waste at wastewater treatment plants.

Adaptation in Response to Climate Change Risks

One of the greatest climate change-related risks to the city's water supply is runoff from heavy rain affecting water quality in reservoirs. By contrast, one of the greatest risks faced by the city's wastewater system is storm surge inundation of critical assets, potentially leading to release of untreated or partially treated wastewater.

Depending on the time of year, the rain intensity, and the volume of rain falling over extended areas, heavy rains can pose a significant risk to the quality of the water in the city's reservoir systems. They produce increased runoff, which causes high pathogen and contaminant levels in reservoirs, and increase turbidity in some reservoirs due to the underlying geology of nearby lands. Excess turbidity can affect the drinking water disinfection system, and DEP has to make operational changes and take other actions to make sure that the water delivered to consumers meets all heath and disinfection requirements.

The system has enough flexibility that DEP is typically able to respond to such events by selective withdrawal and diversion of water so that the turbid water or water with higher levels of pathogens is isolated or not used extensively as part of the water delivered to City residents. However, these conditions are particularly challenging if extreme rainfall events happen one right

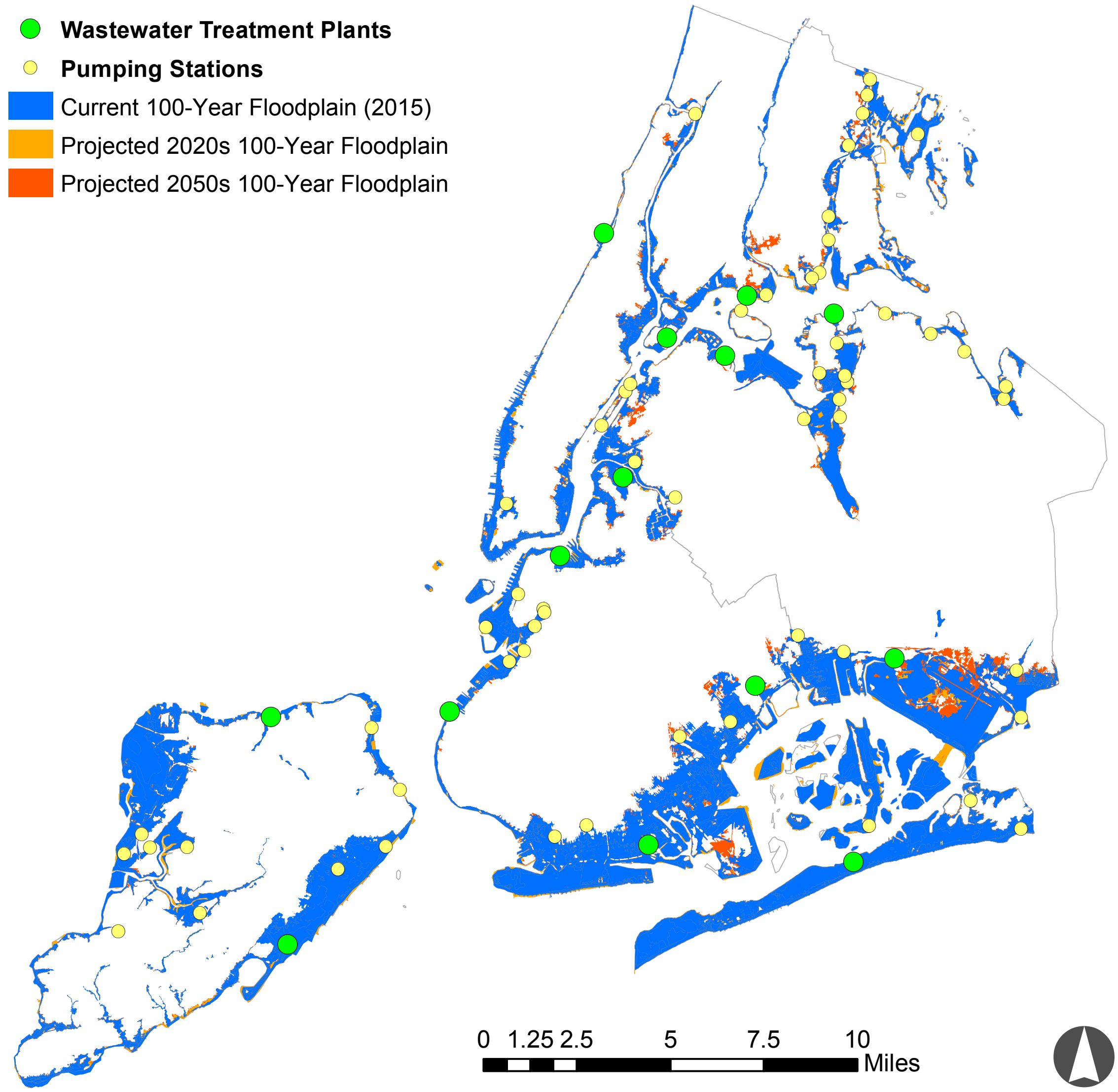


Figure 6. Wastewater facilities at risk of storm surge inundation.

after another, before the impacts of a previous event have been controlled fully.

The events of the summer of 2011 illustrate this risk. In late August, Tropical Storm Irene dumped up to 16 inches (41 cm) of rain in some parts of the New York City watershed, flushing large volumes of sediment into reservoirs. Just ten days later, before the system could recover from Irene, Tropical Storm Lee produced more heavy rain, prompting unprecedented levels of reservoir turbidity and coliform bacteria. While DEP was ultimately able to maintain an adequate supply of high-quality drinking water for the city, the combination of two heavy rain events in a 10-day period led to unprecedented operational measures—including a record 260-day treatment regime for the Catskill system. This risk to the water system, particularly the Catskill system, is expected to be tested with greater frequency through the 2050s with increases in heavy rain in the New York region.

Storm surge, on the other hand, poses a major risk for the city's wastewater treatment plants and pumping stations. When Superstorm Sandy hit New York City in 2012, 10 of DEP's 14 wastewater treatment plants were damaged or lost power and released untreated or partially treated wastewater into local waterways. Three of these facilities were non-operational for some time as a result of the storm—two for several hours, with one facility down for three days. The other facilities maintained at least partial treatment, including removal of pollutants and disinfection of effluent before water from these plants was discharged into waterways. Although, collectively, wastewater treatment plants operated at more than twice their normal flow rate at the height of the storm, Sandy's surge led to the release of approximately 560 million gallons (2.1 billion liters) of untreated combined sewage, stormwater, and seawater from sewers, and another approximately 800 million gallons (3 billion liters) of partially treated and disinfected wastewater into New York City waterways.

Given their waterfront locations, all of the city's 14 wastewater treatment plants will, by 2050, have at least some of their equipment located below the Base Flood Elevation (BFE), or the height to which floodwaters are expected to rise during a "100-year flood" (a flood with a 1 percent or greater chance of occurring in any given year). As sea levels rise, expected flood heights will also increase, putting a greater percentage of treatment facility equipment at risk of flooding and increasing the likelihood that surge from a coastal storm would disrupt or even shut down DEP facilities (Figure 6).

The percentage of critical equipment that is estimated to be below expected flood heights, based on New York City Panel on Climate Change "high end" sea level rise projections for the 2050s, varies by facility from as little as less than one percent at Jamaica WWTP to potentially as much as 70 percent at Hunts Point WWTP. Meanwhile, of the city's 96 pumping stations, 37 are located in the 100-year floodplain indicated in the Federal Emergency Management Agency (FEMA) Preliminary Flood Insurance Rate Maps. That number is expected to grow over time—to 48 by the 2020s and 58 by the 2050s.

The city's wastewater system is also at risk from gradual sea level rise—without storm surge. Sea level rise itself may cause flow to back up during heavy rain and limit the ability of some wastewater treatment plants to operate at full capacity, leading to CSO events and release of partially treated sewage into area waterways. The impacts of compound flooding, when drainage systems cannot discharge by gravity to elevated receiving water levels, are expected to increase.

Increased precipitation alone, regardless of sea levels, also could lead to CSO events. Furthermore, short, intense rainstorms ("cloudbursts") can overwhelm the sewer system and cause flooding and backups. The city's drainage systems, however, are designed to handle heavy rainfall, with capacities for rainfall intensities of 1.5 inches (3.8 cm) per hour in most areas of the city, where sewers were built prior to 1960, and 1.75 inches (4.4 cm) per hour in locations with sewers built after 1960. Relying on sewers alone to manage cloudbursts will not be sufficient; controlling impervious areas and protecting properties, for instance, will help reduce flood damage.

While increases in temperature can have an effect on water quality in reservoirs, such as increased algae growth that can lead to changes in water color and taste, it can also lead to more severe water quantity impacts, including droughts. Currently, New York City designates the 1963–1965 drought as the "drought of record," or the city's anticipated worst-case scenario. Though precipitation in the New York City area generally is expected to increase going forward, the City does need to monitor drought patterns, and changes in winter snowpack which may limit the ability of reservoirs to refill sufficiently to meet summer demand.

Finally, potential disruptions to power supply resulting from storms and heat waves are another challenge that the city's water and wastewater systems may face going forward as the climate changes. However, many facilities have backup generators. Wastewater treatment plants, for instance, are required to have backup generators and maintain partial treatment during a blackout or brownout, thereby limiting the net impact of this risk.

Uninterrupted access to high-quality drinking water and continuous treatment of wastewater are critical to the viability of New York City. As a result, DEP is accelerating its resiliency efforts across a range of initiatives, including both building upon existing programs and initiating new strategies and programs to make infrastructure more resilient. DEP's strategies include protecting wastewater treatment facilities from storm surge, improving and expanding drainage infrastructure, and investing in the projects which increase the redundancy and flexibility of the water system.

Protecting wastewater treatment facilities from storm surge

The City's investments in wastewater treatment over many years have resulted in dramatic improvements in the waterfront's ecological conditions, making the area a safer place to live and enhancing opportunities for public recreation. However, a substantial number of critical wastewater treatment assets are located, by design, in low-lying areas at risk of flooding in an extreme weather event. To minimize disruptions to its wastewater systems and protect its waterfront, the City must protect its vulnerable facilities from flooding impacts that may occur from future storms.

Prior to Sandy, in 2011 DEP initiated a study to understand the impacts of climate change on drainage and wastewater treatment in New York City. As part of this pilot study, DEP looked at the potential risk of storm surge and sea level rise to one of its fourteen wastewater treatment plants. This conceptual study quickly became a reality when Superstorm Sandy struck. After Superstorm Sandy, DEP expanded its study to consider all fourteen treatment plants and ninety-six pumping stations. The study considered how to protect facilities damaged by the storm, as well as those that may become vulnerable if future storms were to approach from different directions, or if sea level rise was to increase flood heights.

The result of the study is a portfolio of adaptive approaches described in the 2013 NYC Wastewater Resiliency Plan, including elevating and flood-proofing critical equipment. The Plan showed that by investing $315 million in flood protection, DEP could avoid over $1 billion in damages if all of these assets were inundated by flood waters. Factoring in the probability of flooding from multiple storm events, DEP estimated that the damages avoided over fifty years could amount to approximately $2.5 billion.

Improving and expanding drainage infrastructure

Increased rainfall and cloudbursts may contribute to increases in street flooding, sewer backups, and combined sewer overflows. Improving the city's sewer systems will enhance the ability of the existing infrastructure to cope with environmental changes. To this end, DEP will continue to implement a number of its programs that are already underway and, where opportunities exist, will seek to expand these programs.

In the southeastern portion of the Borough of Queens, DEP is developing an action plan to resolve long-standing flooding conditions that affect over 400,000 residents. Here, flooding is caused by the interplay of several conditions including lack of storm sewers, improperly graded streets, high impervious cover, and high groundwater. Furthermore, the area is subject to tidal flooding that, with sea level rise, may exacerbate chronic stormwater flooding conditions. The plan will consist of an intensive and accelerated program to build new storm sewers, complemented with innovative, site-specific solutions, such as Bluebelts and green infrastructure, and will serve as a model for other flood-prone neighborhoods of the city.

Throughout the city, New York is in the process of re-inventing its public spaces to include stormwater management among other uses, through interagency and public-private partnerships to improve public property using green infrastructure retrofits. One such partnership with the Trust for Public Land, a national not-for-profit open space conservation organization, is transforming old asphalt playgrounds by updating the play equipment and incorporating green infrastructure to enhance the space with rain gardens, porous paving material, and vegetation. Similarly, DEP is investing in stormwater enhancements as part of the City's Department of Parks and Recreation Community Parks Initiative to improve under-resourced public parks located in New York City's densely populated and growing neighborhoods with higher-than-average concentrations of poverty.

This shifting land use approach highlights the benefits of pooling resources to manage water while improving public spaces, reducing the urban heat island effect, and enhancing air quality. While the City's green infrastructure program was initially focused on reducing stormwater runoff to control combined sewer overflows, this approach of incorporating stormwater management into the design of public spaces and streets is being expanded to areas like southeastern

Queens for the purpose of reducing street flooding and controlling pollutants.

As climate change will likely continue to bring large rainfall events that exceed the capacity of drainage systems, it will become more critical to optimize land use and funding to achieve multiple objectives. Communities that are subject to regular flooding due to heavy rainfall and high tides will likely flood more often, and areas that will be protected from flooding by increasing coastal edge elevations must ensure that there is sufficient capacity to retain rainwater behind the edge.

Given the global nature of these problems as well as the opportunities to rethink public space, DEP has entered into cooperation with the City of Copenhagen to advance the exchange of information and knowledge on the development and management of urban solutions which address these and other climate change challenges. The cooperation will seek to advance: the co-production of information between scientists and practitioners; neighborhood-level pilot projects; integrated urban water management, green infrastructure, and land use planning for cloudbursts; and equitable communities and disaster preparedness.

Promoting redundancy and flexibility to ensure a constant supply of high-quality water

The City owns and operates an extensive water supply network that may increasingly be affected by climate change. However, redundancy and flexibility, which are already built into the system, allow the City to draw upon the largest quantity of water from the highest-quality sources in varying weather conditions. Building on this redundancy and flexibility, the City will protect critical infrastructure and watershed lands and improve upon the physical connections between different parts of the system to enable the use of the most appropriate source of water at any given moment in time.

In order to continually supply top-quality water, DEP works to anticipate and address potentially recurring problems in the system through design elements. For example, DEP has implemented measures to address turbidity in the Catskill System streams, a naturally occurring phenomenon due to the geology of the region. When New York City's engineers designed the Catskill water supply system, episodic turbidity was recognized as a water quality issue and ways to combat it were incorporated into infrastructure design. Simple approaches were then implemented to let turbidity from the Catskill's clay soils naturally settle in reservoirs before entering system intakes. For instance, the Ashokan dividing weir separates the reservoir to allow sediment time to settle in the west basin, before water enters the east basin on its way to the Catskill Aqueduct.

Despite efforts to anticipate operational difficulties, extreme events and climate change may bring potential challenges to the long-range operability of the supply system and the City's continued ability to meet the criteria of the federal regulations governing its operation. As a result, DEP has been devoting increasing resources towards studying how even gradual shifts in climate might affect the system in the future. The Climate Change Integrated Modeling Project, or CCIMP, was initiated in 2008 to evaluate the effects of future climate change on the quantity and quality of water in the New York City water supply. The CCIMP is designed to address three issues of concern to NYC: (1) overall quantity of water in the entire water supply; (2) turbidity in the Catskill System and Kensico reservoirs; and (3) eutrophication in Delaware System reservoirs.

In the first phase of the project, an initial estimate of climate change impacts was made using available global climate model data sets and DEP's suite of watershed, reservoir, and system operation models. Initial results from the CCIMP suggest that streamflow would increase during the late fall and winter and decrease in spring due to a shift towards more rain and less snow during the winter, as well as earlier melting of the typically smaller snowpack that does develop. Greater winter streamflow could cause reservoirs to fill earlier in the year and spill from the reservoirs to increase during the winter. This could in turn reduce available supply in the summer, when demand increases. The shifting seasonal pattern in streamflow could also result in increased turbidity in the autumn and winter, but decreased turbidity in the spring.

DEP is employing a "multi-barrier" approach to managing turbidity to meet water quality standards. As part of this approach, DEP is using cutting-edge technology to make the best operational decisions in order to minimize turbidity incidents. The Operations Support Tool (OST) is DEP's state-of-the-art decision support system that integrates multiple sources of critical near-real-time operations data—streamflow data, in-reservoir water quality data, SCADA data, and current infrastructure information—into an advanced version of DEP's existing water supply/water quality model. OST combines current system data with inflow forecast data and system operating rules to make probabilistic projections of reservoir levels and water quality over the coming weeks and months. This look-ahead capability provides system analysts, operators, and managers with information to support decisions concerning reservoir diversions and releases, and allows operators to test the risk and reliability of actual operations decisions "on paper" before implementing them.

DEP is taking action to enhance redundancy and flexibility to ensure a sufficient supply of high-quality water even when a turbidity event is unavoidable. A new connection between the Catskill and Delaware Aqueducts, known as the Shaft 4 Connection, will allow DEP to divert Delaware System water into the Catskill Aqueduct. This will occur at the existing Shaft 4 Connection site located at the point where the two aqueducts cross. This will allow DEP to reduce the flow of water from Ashokan Reservoir when turbidity is elevated while still maintaining sufficient flow to provide service to outside communities and meet overall system water demand. This increases operational flexibility, reduces turbidity levels entering the Kensico reservoir (by blending Catskill diversions with low turbidity Delaware water), and improves water quality for outside communities.

Optimization and efficiency of the existing infrastructure is fundamental to the sustainability of the system, particularly in times of drought and other extreme weather events. To enhance resiliency and redundancy, the City is preparing for repairs to the Delaware Aqueduct, which conveys, on average, 50 percent of the city's water from upstate sources. This aqueduct has been leaking between 15 and 35 million gallons of water a day for many years. DEP is constructing a three-mile bypass tunnel around the section which has the largest leak. While the bypass is connected and the aqueduct is out of service, DEP will repair other sections of the tunnel. The tunnel shutdown, repairs, and reactivation are expected to be completed in 2022.

In preparation for the shutdown, DEP is increasing the capacity and use of the Catskill and Croton systems and adopting both a new Water Demand Management Plan to conserve water citywide, and water shortage rules to impose use restrictions during droughts and infrastructure repairs. The Demand Management Plan targets a five percent overall reduction in water consumption citywide by 2020 through municipal, residential, and non-residential water efficiency programs, and water distribution system optimization. Although designed to meet the more immediate needs for the Delaware Aqueduct repairs, DEP's demand management strategies provide long-term benefits by reducing the overall throughput of water and therefore the energy used in the new Catskill Delaware Ultraviolet Disinfection and Croton Water Treatment Plant facilities, and in the in-city wastewater treatment plants. In addition, it allows DEP to accommodate population growth and increase drought resiliency.

Looking Forward

There is little doubt that climate change will affect water resources in New York City from the upstate watershed to New York Harbor. It will demand an innovative response by the City's water managers, planners, and regulators to meet stringent water quality standard requirements under the Clean Water Act and Safe Drinking Water Act while advancing the City's sustainability and resiliency objectives. As the largest municipal water utility in the United States, in a city with 520 miles (837 km) of at-risk coastline and approximately 2,000 square miles (5,180 sq km) of watershed protecting drinking water, DEP must find new ways to maximize its investments by incorporating the latest climate science, affordability, population and water demand projections, tightening regulations, and associated uncertainty.

Climate change also presents challenges in the form of competing funding needs and a moving target for meeting regulatory requirements. Meeting water quality criteria may become a greater challenge as rainfall increases and as the physical and chemical characteristics of waterbodies shift. Furthermore, as the risks from heavy rainfall, sea level rise, and storm surge increase, DEP will need to advance a new paradigm shift that is already in progress for managing stormwater runoff to meet water quality, drainage, and coastal protection objectives.

DEP is integrating new tactics to manage both the extreme and chronic events, through approaches like such as system optimization, green infrastructure, demand management, and flood protection of critical facilities. These techniques can be adapted and expanded as monitoring reveals their efficacy and as new information about climate change emerges. However, investments in resiliency and water quality continue to compete with the need to maintain state-of-good-repair, build new infrastructure, and invest in energy improvements to meet the City's ambitious greenhouse gas reduction goals.

Moving forward, DEP continues to pursue long-term solutions that optimize capital, maintenance and operating costs while minimizing environmental impacts. These solutions will leverage public and private partnerships, re-envision urban land use, improve existing infrastructure, and allow the City to develop tools to optimize and enhance the existing water and wastewater systems to adapt to a changing climate.

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