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# HUMAN SANITARY WASTES AND WASTE TREATMENT IN NEW YORK CITY

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**Abstract**

Henry Hudson first sailed to New York harbor 400 years ago. Since then, New York City has both affected and been affected by water quality in greater New York Harbor. In this paper, we focus on sewers, sewerage, and sewage treatment in Manhattan and their effects on the Hudson River. It is clear that feedbacks among drinking water quality and quantity, population, public perceptions, regulations, and estuarine water quality exist, although their strength and character have varied over time.

Early land uses damaged local water supplies found on Manhattan Island. New York then began to exploit the large fresh water resources available to its north, which helped the City to expand more rapidly. Water availability also allowed for water carriage sanitary practices, increasing discharges of wastes through a growing sewer network into local waters. The discharge of wastes degraded water quality, affecting natural resources in the harbor. Untreated wastes led to disease from contaminated seafood, and also more generalized effects on public health. Overall, New York lifestyles became largely detached from its shoreline, partly due to the industrial character of the waterfront, and partly because of odors and visual blight from pollution. Growing public distaste over poor harbor water quality, especially in the early 20$^{th}$ century, led to some sewage treatment. More and more comprehensive treatment followed regulatory and legal actions, beginning in mid-twentieth century. Concurrently, maritime

commerce declined, and the waterfront became underutilized. However, in the twenty-first century, natural resources are recovering, and New York City citizens once again flock to the shores of the Hudson River, to new and revitalized parks, new areas of development and older areas undergoing transformation, and into the harbor, now largely cleaned of its fouling from sanitary waste disposal. Today New York City public life has a much greater orientation toward the waterfront, which certainly was fostered by improved harbor water quality, and the opportunities for growth that were available with the disappearance of the City's maritime industries.

Thus, there has been a complicated relationship between the City and its rivers and harbor. One aspect has been continuing use of local water bodies as receptacles for wastes, which has benefitted those living in the City. Gaining these benefits has had continuing costs, however. Marine resources were damaged and some were lost, and quality of life on land was affected. Trying to undo the impacts, which has required great effort and much capital, has been hampered by technology decisions that appear suboptimal with the advantage of more than 100 years of hindsight. Still, modern sewage treatment, initiated by local efforts and concerns, but spurred on to completion by the forces unleashed by the great environmental awakening of the 1960s and 1970s, has made it possible for the citizens of New York to again fish, boat, and even swim in City waters.

**New York, Drinking Water, and Population Growth**

In 1609, Manhattan had several large ponds and some streams, predominantly fed by groundwater. Drinking water of good quality was thus available (Sanderson 2009). As the population of the City grew, the common practices of the day led to impacts to the shallow groundwater system and associated surface water bodies. Human sanitary wastes, for instance, were managed through permeable and solid wall privies. The first regulations regarding acceptable design for these devices were promulgated by the Dutch in 1657 (Loop 1964). The preferred and approved design was for impermeable pits, although it is understandable that not all privy pits proved to be water tight. In addition, there was no organized management of solid wastes. These were disposed onto streets, or into marshes, ponds, and other low-lying areas where fill might create more usable land, and sometimes directly into the surrounding waters of the Hudson and East Rivers (Melosi 1981). These practices affected local drinking water quality (Koeppel 2000).

Continuing increases in population (and population density) created greater impacts on local water supplies. Human wastes from privies, solid wastes, and wastes from various businesses and industries were directly disposed in bodies of water that also supplied drinking water. Wastes released into the subsurface directly contaminated groundwater-fed wells, and indirectly affected surface water bodies through groundwater discharges. The effects became greater in degree and geographical scope as the population growth rate increased in the mid-1700s (by 1800 the population of Manhattan exceeded 50,000) (Fig. 15-1) (data from Goldman 1997, Loop 1964, Burrows undated, New York City Department of Planning undated). Continued growth of the City was thought to be threatened by potable water shortages and the absence of a water system capable of supporting fire suppression. Entrepreneurial efforts to provide water from outside of the developed area of the City, and to construct distribution networks, were therefore encouraged by the City, beginning about the time of the Revolutionary War. The Manhattan Company, for instance, built a small reservoir around 1800 (this company is better known for being used by Aaron Burr for political purposes). Other small systems were also constructed, but the need for a City-wide system was recognized by both City and State governments. The

State Legislature chartered the Croton Aqueduct Board in 1833, and the Croton Aqueduct was completed in 1842, along with a nascent distribution network that radiated from the central reservoir at 42nd St. and 5th Ave. The Croton system could deliver up to 75 million gallons of water each day to the City, although subscribers for home delivery were slow to be added at first (most still took water from central distribution points such as fountains and hydrants) (Koeppel 2000).

**Fig 15-1 placeholder: put around here**

This development unleashed an unforeseen effect, an outgrowth of the perception of an unlimited water supply, and the development of new technologies to manage human septic wastes. These changes meant population growth no longer impacted City drinking water quality, but, rather, increasingly affected water quality in its surrounding water bodies. This was the result of the installation of sewers, and changes in their use.

**Sanitary Waste Management in the 1600s, 1700s, and early 1800s**

Dutch colonists began to recreate familiar urban infrastructure from Holland within 25 years of settling New Amsterdam, including street gutters to convey storm water to nearby rivers, and canals. The first true underground sewer was created under the English in the 1680s when the Broad Street Canal was covered over. In 1703, it was classified as a "common sewer" – a portal for many sources of waste water, which was to be managed by local government. Common sewers were intended to be used only for storm water, not human wastes (Loop 1964).

Sewer construction continued through the 1700s as impervious surfaces increased (Loop 1964). At first, sewering was an entirely private enterprise, where open trenches were dug to the closest shoreline, but by the middle of the century the trenches were replaced by underground pipes. These pipes were made both of wood and fired clay. Clay pipes needed to be pre-formed, and were less expensive when many were fabricated at one time. Wooden pipes were easier to create for custom jobs, but required greater skill to fit lengths together (Goldman 1997).

By the 1800s formal procedures were established for new sewer construction. The applicant, generally a group of landowners in a particular area, would petition for a project to the City Common Council. The Common Council would hold a hearing to determine if there were objections from other residents to the proposed sewer. If objections were limited, the Council would approve the project. The construction process included the City soliciting bids and then contracting for approved materials and labor from private sector sources. The City used municipal staff to oversee construction. The participating property owners were billed following project completion for all contract costs (Goldman 1997).

Thus, underground piping was installed unsystematically, usually only in wealthier neighborhoods. Sometimes, multiple pipelines set down in the same street. Until the 1840s, these sewers were intended to drain storm water from property, or sometimes to dewater groundwater; human sanitary wastes were explicitly banned (Goldman 1997).

Impermeable cesspits continued to be the preferred means of managing human wastes. Household wastes were collected in chamber pots, or from enclosed water closets, and brought to these cellar or backyard structures (Loop 1964). Wastes were cleaned from the cesspits as needed, although these intervals were widely spaced, because water-carrier technologies for wastes were not used. The contents of the pits were only human wastes; other organic materials, such as kitchen wastes and household slops, were managed separately. Thus, the cesspits were much slower to fill than would be the case today. Wastes collected from cesspits were sometimes dumped into the closest river. At times, the City contracted with collection companies so that cesspit wastes could be sold as fertilizer. These contracts specified that the City would make sure wastes were set out curb side for collection (Goldman 1997).

By the late 1700s, it was fairly clear that the privy system had not protected drinking water supplies from contamination (Koeppel 2000). However, it was not until 1820 that City government formally took notice of soil pollution from privies, and the associated pollution of groundwater drinking supplies (Loop 1964).

**Waste Crisis Caused by Abundant Water**

The Croton Aqueduct began delivering water to Manhattan in 1842 (Koeppel 2000). Unlimited, widely distributed water radically changed sanitary practices and led to a waste management crisis. Water closets and sinks had been rare because City regulations forbade the use of sewers for sanitary wastes. A mechanism to enforce this ban was that all household lines were required to have screens where they connected to street sewers, thus creating barriers to the transport of solid materials. Also, it had been difficult for most households to provide enough water to make “water carriage” systems practicable. However, with seemingly unlimited water supplies, installation of these household technologies was rapid. Although flush toilets were not invented for another 25 years, large quantities of household water now made it possible to carry human wastes away from living quarters rapidly and efficiently. This, in turn, quickly overwhelmed the holding capacity of privy systems (Melosi 2000). Therefore, in defiance of City regulations, many homeowners connected their new waste lines to household storm water sewers. Only three years after the opening of the Croton water system (1845), new regulations allowed sanitary wastes to be sent through sewer systems. This led to a 50 percent expansion of sewers over the next decade, installed through the permit process discussed above. Thus, some streets had multiple lines, and others had no service (Goldman 1997).

Relatively few of the effluent pipes were extended as far as the end of the piers that surrounded lower Manhattan, and so wastes were discharged close to shore. This enhanced sedimentation in the berthing areas, and led to accumulations of wastes along the shoreline and in and around ships. Regulations in 1849 ordered outlet extensions to open waters to try to minimize these shoreline impacts. The regulatory revisions, however, did not address other technological issues such as the grates on household lines, right angled turns that clogged with solids, and over-capacity pipes lacking sufficient gradients to flush, especially when battling tidal ebb and flow. These unaddressed problems led to many odor and overflow problems in the early sanitary sewers (Goldman 1997).

Although the City had regulated sewers and managed their use since the late 1600s in various ways, it was not until 1870 that the City assumed ownership and complete responsibility. This change was part of a general reform of City institutions, but also it was in response to public health concerns. The perceived need to convey wastes away from people grew as the miasma theory of disease gained wider acceptance ("miasmas," or vapors and gasses, were the cause of illness, and septic wastes clearly emanated vapors). In addition, in poorer areas of town, tenements still dumped sanitary waste water directly onto streets, because there had been no private enterprise to install sewers (Goldman 1997).

As a result, sewers were extended into many parts of Manhattan, and the existing pipe jumble was simplified. Many outfalls were extended and otherwise modified to try to address shoreline issues (Goldman 1997). Manhattan privy counts fell from 15,000 in 1875 to less than 1,000 in 1891. Still, much work remained in older sections of the City, so that when the subway building boom in the early 20$^{th}$ century occurred, another priority was to rebuild the sewers downtown (Loop 1964).

Few complaints regarding harbor water quality near Manhattan were recorded until well after fresh water supplies began to become unpotable from pollution in the 1700s (Koeppel 2000). However, there is indirect evidence that sewers, and the septage emanating from them, caused disagreeable water quality, even before human wastes were allowed to be disposed through them. Throughout the early 1800s, some new sewers were opposed at public hearings; testimony was presented on odors and explosions. In the 1830s, the design of outfalls was codified to encourage flushing by tides. In 1841, certain industries were forced to disconnect from the sewers, because the sewers they used impacted local air quality and discharged especially objectionable wastes.

The use of sewers for human wastes increased shoreline impacts. When the Common Council considered this change, among the comments was a concern for impacts to shoreline fish populations if there was insufficient tidal flushing. By 1849, complaints from residents led to new rules requiring outfalls to be extended past the pier line. In 1864, "pools of decomposing animal and vegetable offal" were described at the shoreline and by 1870 sewage created "white stringy slimes" and gray films near the shore (Goldman 1997). In 1875, the New York Herald opined it was "fallacious to assume that the discharge of sewage to rivers was borne away to the ocean" (Loop 1964).

Another source of contamination to the City's surface waters was garbage and other solid waste. Before the 1860s there was no organized, municipal solid waste collection system. Then, the City began to experiment with various schemes to harness entrepreneurial skills. These early efforts never entirely succeeded, mostly because they depended on implementing grand, complicated technologies. Although they all eventually failed, most of the companies removed some of the solid wastes accumulating at residences, businesses, and on streets. It was not until late in the century that City management of solid waste removed this loading from the storm waters that ran into the sewers, and then into the harbor (Miller 2000).

The City's animal populations, including pigs which ran free eating trash, cattle, oxen, and especially horses, also contributed to the pollutant loading on City streets. Some of these wastes were collected from streets for household gardens, but the remainder washed into the storm sewers. The number of horses per person increased with the introduction of street cars in the early 1800s, and again with expansions of freight transport in the middle portion of the century, due to growth of railroads (McShane and Tarr 1997). This led to there being more than 125,000 horses in the City around 1900 – 1 for every 25 people (Tarr and McShane 2005). Each horse produced 15 to 30 pounds of manure and a quart of urine each day, and only lived 2 to 3 years. It was easier to remove a horse when it could be disarticulated after rotting a little (Morris 2002); thus, even when dead, horses continued to affect the quality of urban run-off.

**The Impacts Increase and Reach a Nadir**

In the late 1800s, the population growth rate (Fig. 15-2), housing densities, and industrialization of Manhattan increased, causing growing effects on harbor water quality from additional waste waters. In 1891 beaches and open waters were called "unsightly" and the "stench was unbearable." Proposed re-routing of sewage outfalls from the Passaic River in New Jersey to New York Harbor caused the New York Legislature to create the New York Pollution Commission. In 1906, it found that the harbor was "heavily polluted," with navigation obstacles and "local nuisance conditions," because dispersion and diffusion of sewage was incomplete. There were only three small chemical precipitation plants for the wastes of 10 million people in the harbor basin. The Commission found that dissolved oxygen levels throughout the harbor were insufficient to support oxidative degradation of wastes (Loop 1964).

**Fig 15-2 placeholder: put around here**

The New York State Legislature created the Metropolitan Sewerage Commission in 1906 for follow-up work, replacing the Pollution Commission. The Sewerage Commission thoroughly described water conditions, qualitatively and quantitatively. The harbor above the Narrows was called "dangerous to health," local nuisance conditions were "innumerable," and several waterways were "open sewers." Impacts included declines in fisheries and shellfisheries so that the Commission advocated abandonment of the local oyster industry. There was also contamination of municipal baths (which were located along the shore and which used the ambient river and harbor waters). Visible garbage, offal, and solid matter were present throughout the harbor. The waters of the harbor generally were found to be discolored, turbid, effervescent, oily, and odorous (Loop 1964).

The Commission found that a dissolved oxygen concentration of 3 milligrams per liter (mg/l) was a critical concern (Loop 1964). There is some evidence that low dissolved oxygen concentrations were affecting fish populations (Limburg et al. 2006), because low dissolved oxygen levels make it impossible for fishes and shellfish to respire (US Environmental Protection Agency 2000). In addition, it was understood that if the harbor was to provide waste treatment, higher oxygen levels were important because aerobic decomposition of matter is much more efficient than anaerobic decay processes, and so as oxygen levels decreased there was less biological decomposition of wastes (Loop 1964). There was such robust debate, however, on whether to enshrine the 3 mg/l level as a standard that no official action was taken.

Entangled in the debate over the point to establish a standard, and associated with the survival of fishes and other macro-organisms, was the issue of defining water quality impacts based on saturation concentrations or absolute concentrations of dissolved oxygen. Some declines in absolute oxygen levels result only from seasonal or tidal changes in temperature and salinity that limit the amount of oxygen the water can contain. In the early days of the twentieth century, one proposed indicator of major water quality impacts was depletion of dissolved oxygen to 50 percent of saturation. Impacts to this level were measured in some parts of the harbor (the Harlem River, parts of the East River, and certain embayments) in summer sampling conducted at and around 1910, but generally most areas were not impacted to that degree (Loop 1964). Conditions worsened, however, and the lowest dissolved oxygen levels were measured in the late 1920s through the mid-1930s (Suszkowski 1973).

The Metropolitan Sewerage Commission advocated for waste treatment, because it was clear that sections of the harbor, such as the lower East River, could not reach adequate waste treatment in situ. The level of treatment would have to be sufficient to support desired end uses of the water bodies. An interstate commission to administer the plans was recommended, as problems crossed state lines, and activities in New York affected New Jersey, and vice versa. No comprehensive action followed, so that although mitigations were prescribed before the First World War, conditions continued to deteriorate into the 1920s as the City grew and discharges increased. In 1925, co-incident with the imposition of national standards, New York State closed all shellfish beds (Loop 1964) (New Jersey kept some areas open but under strict supervision). By 1928, the five-year, running average of summer, bottom-water dissolved oxygen was only 35 percent of saturation for Hudson River monitoring stations. Hudson River and inner harbor areas reached the lowest dissolved oxygen values then, although water quality in the East and Harlem Rivers continued to decline into the mid-1930s (Suszkowski 1973).

Some actions to provide treatment were made in the 1920s. Screening plants in Manhattan removed gross contamination from nearly 20 percent of 150 million gallons of Manhattan sewage each day, and nine other screening plants operated elsewhere in the harbor. These screening plants removed the more visible indicators of waste discharges. In doing so, they improved aesthetics slightly and also removed some of the organic matter formerly loaded into the waters (Loop 1964).

As of 1930, nearly 1.5 billion gallons of sewage were discharged from the City and other areas fronting on New York Harbor, receiving no treatment, except for the fraction treated by screening plants. Thus, there were solids and visible turbidity traceable to sewage throughout the harbor, and slack waters were gassy and black. The City Department of Health banned swimming from the mouth of the harbor northward throughout its jurisdiction (Loop 1964). The population of Manhattan leveled off and began to decrease about this time (Fig. 15-2), because of changes in immigration law, the early stirrings of suburbanization, and the Great Depression. Smaller numbers of people in Manhattan, coupled with greater waste treatment levels, signaled the end of the long declining trend in water quality, because septic waste generation is generally proportional to population.

**Modern Sewage Treatment**

Modern treatment methods for sanitary wastes brought about the recovery of water quality measured in the latter part of the twentieth century, although it took more than 50 years to build enough facilities to cover all of New York City. Wards Island was the first. Its construction begun in 1931, but it did not achieve full operational status until 1937, because of City financial difficulties caused by the Depression (Gould 1951). Ward's Island was designed to use "activated sludge" technology (Loop 1964), which is the predominant process in use at large sewage treatment plants in the 21$^{st}$ century. Activated sludge treatment generally results in 80 percent less consumption of oxygen in receiving waters affected by effluent (biological oxygen demand, BOD), and approximately 80 percent of dissolved and settlable solids are also removed (total suspended solids, TSS). This level of treatment level is known as "secondary treatment," because it employs a biological process as well as the physical process screening and settling solids from sewage (Nathanson 2007).

In 1936, the Interstate Sanitation Commission (ISC) began to regulate sewage impacts on the harbor. With Wards Island beginning to operate then, the City was treating 13 percent of its sewage flow, removing about 1 percent of the total amount of dissolved solids in influents Citywide (treatment levels were so low because most waste water being treated was only being screened). By the beginning of World War II, with a total of three plants online, treatment resulted in 32 percent of dissolved solids were being removed (Loop 1964).

In 1948, Congress updated the 1899 Federal Rivers and Harbors Act (which prohibited the dumping of garbage into navigable waterways). This allowed the US Public Health Service to monitor and assist in situations where there was interstate pollution, and authorized financial assistance to municipalities that voluntarily participated in such programs (Melosi 2000). It gave an impetus for the City to sign an "order on consent" with the ISC to "virtual[ly] eliminate pollution" in Class A recreational waters by 1953 (Loop 1964). New York State had codified uses of waterways, and created differential water quality standards to allow those uses, meeting another of the goals of the Metropolitan Sewerage Commission. In New York State, "Class A" waters were the "highest and best" use waterways, suitable for fishing, swimming, and shellfishing.

The reform of sewage treatment financing accomplished in 1950 was a breakthrough, essential as a means for the City to fund its plans. A dedicated funding source was created by explicitly linking sewage fees for system users to water usage. Although the measurements of water use were only approximate, based on building size and tenancy (until water meters were required in the 1990s), sewage plant operational monies, and, more importantly, capital expenses for plant construction, had been made independent of other City taxes and fees. Five new major projects, expansions at other plants, and upgraded sewer infrastructure were quickly accomplished, because construction bonds were no longer limited by City debt limits (Gould 1951, Loop 1964).

Later in the 1950s, the City had difficulty meeting all requirements set by the ISC. Industrial waste water inputs resulted in plant process failures, because secondary treatment requires healthy microorganisms, and many of the chemicals dumped into the municipal sewer system by factories were toxic. Newtown Creek, the largest plant constructed in New York, used "modified aeration treatment," a less effective process than full activated sludge treatment used in an attempt to reduce plant size and overall construction costs. Newtown Creek, as a result does not achieve the standard 80 percent reductions in BOD and TSS (Loop 1964) and has been targeted for an upgrade ever since it began operations in 1967 (construction began in the middle 2000s) (ISC, 2009).

In 1972, Congress passed the landmark 1972 Clean Water Act amendments. An important element of the Act was a requirement that all discharged sewage needed to meet secondary treatment levels for BOD and TSS (with very few exceptions). Over 50 percent of waste waters discharged to open waters in New York City already met the standard, and 75 percent of City waste waters regularly treated because of the previous 40 years of effort (Gross 1974).

New York City's fiscal crisis of the 1970s prevented completion of its sewage treatment system immediately following the 1972 legislation. This meant that for many years a large proportion of discharged City waste waters did not meet standards. In the 1980s, the last two large City treatment plants, North River and Red Hook, were built. General upgrades and expansions of the systems meant all of the City (except for parts of Staten Island) have sanitary sewers. The wastes from sewered areas, with the exception of those treated by the Newtown Creek plant, all receive secondary treatment (Brosnan and O'Shea 1996).

In 2009, there were a total of 14 sewage treatment plants in New York City (Fig. 15-3, adapted from Swanson et al. 2000), nine of which discharge to the inner harbor and the Hudson River, or tributaries to the inner harbor such as the East River and Kill van Kull (Adamski and Deur 1996) (Table 15-1) (Tonjes 2005).

**Fig 15-3 placeholder: put around here**

Table 15-1. New York City Wastewater Treatment Plants (directly or indirectly discharging to the Hudson River)

| WPCP | Primary Treatment | Secondary Treatment | Last Upgrade | Current Capacity (MGD) |
|---|---|---|---|---|
| Wards Island | 1937 | 1937 | 1998 | 275 |
| Bowery Bay | 1939 | 1942 | 1973 | 150 |
| Tallman Island | 1939 | 1939 | 1976 | 80 |
| Hunts Point | 1952 | 1952 | 1979 | 200 |
| Owls Head | 1952 | 1952 | 1995 | 120 |
| Port Richmond | 1953 | 1978 | 1979 | 60 |
| Newtown Creek | 1967 | 2009* | On-going | 310 |
| North River | 1986 | 1991 | 1991 | 170 |
| Red Hook | 1987 | 1989 | 1990 | 60 |

*Upgrades to full secondary treatment were to be completed by February 2009 (ISC, 2009) but no official notice of the project completion could be found

Water quality was still not good in 1980s in the H, as illustrated by average summer dissolved oxygen concentrations less than 4 mg/l some years, and generally high fecal coliform bacteria counts. Fecal coliform, used an indicator of human pathogen contamination, decreased geometrically at the 42$^{nd}$ St. monitoring point in the river as the North River sewage treatment plant became operational in 1985-1986, for instance (Fig. 15-4). (Swanson et al. 2000). Fecal coliform concentrations are reduced partly due to the biological activity of a sewage treatment plant, but primarily because of disinfection practices at the plant outfall (Nathanson 2007). Dissolved oxygen concentrations for bottom waters just south of the North River treatment plant improved as the plant increased its treatment level through the late 1980s (Swanson et al. 2000) (Fig15-5). Generally, similar trends are found across almost all New York City waters, because all dry weather flows go through sewage treatment plants under normal operating conditions, engineering improvements and regulatory reforms on discharges are in place, and the City has made a clear commitment to other practices that result in improved harbor water conditions (Brosnan and O'Shea 1996, NYCDEP 2009).

**Fig 15-4 placeholder: put around here**

**Fig 15-5 placeholder: put around here**

**Chronic Problems**

Much municipal infrastructure is maintained and kept in good operating order. However, this ensures it never requires replacement or is supplanted by newer models, even though it was built to outmoded designs. Much important infrastructure is never determined to be "obsolete," and required to be replaced. Therefore, early, long-lived decisions result in technology lock-ins where changes to meet new conditions or address uncovered problems are difficult to implement.

For instance, there was debate in the 19th century over whether to install separate storm water and waste water sewer systems, or keep the combined approach. Combined sewers had a perceived economic benefit, because separate systems required installing two sets of pipes. A specific analysis for Memphis, Tennessee, after the Civil War actually forecast slightly lower costs for the separate sewer systems. Most public health advocates also favored separate systems. Separate sewers resulted in smaller pipes, and especially for sanitary systems, less airspace in the pipes (large pipes were needed for combined systems to manage unusual storm events on top of the daily production of septic wastes). The miasma theory of disease, which had more adherents than the competing germ theory, was based on vapors and gases transmitting illness. Vapors and gases could be minimized in the septic sewers if the pipes were smaller and better fitted to typical volumes, and it was anticipated storm sewers would mostly be empty (except when it rained). Despite these analyses that seemingly favored separate systems, New York like all other large eastern North American cities (including Memphis) chose to stay with combined sewers, even as it greatly expanded its system (Melosi 2000).

Combined sewers presented technical and economic problems as treatment plants came on line, as it was impractical to size plants to meet maximal flows. Generally, plant designs called for a capacity of two times dry weather flow (Loop 1964). Thus, small amounts of rainfall lead to diversions of flow. As little as 0.1 inch of heavy rain can cause diversions of sewage in modern-day New York City (New York City 2007). One report prepared for the New York City in the 1960s estimated that as much as 30 percent of annual loadings associated with sewage may bypass treatment because of wet weather overflows; although the report claimed it only rains three percent of the time in the northeast United States, wet weather causes outsized effects because storm water carries its own pollutants and washes out accumulated sedimentation (Loop 1964). Thus, water quality tends to be better in many areas of the harbor in drier summers (Tonjes and Swanson 2001a), which can be a factor especially in interpreting long-term trends for fecal coliform (such as Fig. 15-4). For the past 75 years, the City has faced the challenge, as combined sewers were connected to treatment plants, to create enough capacity during wet weather to store the combination of human waste water and storm water to allow treatment after rains end (IEC 2009). One incremental step was to adopt water conservation programs in the

1990s, which reduced influents by nearly 20 percent and allowed for storm water treatment rates City-wide to exceed 50 percent (Swanson and Tonjes 2001b). By 2000, the City estimated that 60 to 80 percent of all wet weather flows in Manhattan were treated (Swanson and Tonjes 2001a).

Eutrophication of coastal waters is most often associated with effluents discharge (Cleorn 2001). Eutrophication problems in Long Island Sound have been closely tied to New York City waste water nutrient releases (Long Island Sound Study 2008). Nutrient removal from waste water is well-understood, and the technology is well-tested (Nathanson 2007). However, space limitations at existing City sewage treatment plants, and cost projections that range from $500 million to several billion dollars, have made the City slow to implement these additional treatment steps (Andersen 2002).

Solids in sewage are removed from the influent, but this creates a solid waste (sewage sludge) which then requires disposal. The City relied on ocean dumping to mitigate sewage sludge disposal effects on local waters. The wastes were first dumped 12 miles southeast of the harbor entrance until the 1980s. In 1986, a site 106 miles southeast of the harbor entrance was adopted, and it was used until 1992, following the passage of the Ocean Dumping Ban Act. The ban on ocean dumping of sewage sludge has resulted in additional treatment of sludge in the treatment plants to make the sludge more amenable to transport by truck. This sludge dewatering resulted in approximately 30 percent more nitrogen loadings in plant discharges, which makes the task of overall nitrogen removal that much more difficult (Swanson et al. 2004). This increase in nitrogen releases in the 1990s probably contributed to some areas continuing to experience low dissolved oxygen concentrations, particularly in western Long Island Sound (Wilson et al. 2008). There is no mention of nitrogen removal in the environmentally-oriented, twenty-year "PlaNYC" (New York City 2007), although in 2010 the City reached an agreement with the Natural Resources Defense Council to implement nutrient removal at its four Jamaica Bay treatment plants (NRDC 2010).

Sewage also has contributed to poor harbor sediment quality and toxicity. This affects the literal base of the marine food chain (Long et al. 1995). Concentrations of contaminants in the water column, especially metals, have declined (Sanudo-Wilhemy and Gill 1999). The Clean Water Act specified that generators of industrial effluents needed to pre-treat wastes prior to release into sewer systems. Pre-treatment programs have been very effective. In addition, New York City has a "track-down" program – painstaking efforts to find the source of metals in plant influents by testing in the sewer lines. When sources are determined, modifications of practices follow to eliminate the inputs (Swanson et al. 2000). Removing contamination inputs is one element in the overall program to remediate harbor sediments.

Recently, advances in analytical chemistry have allowed the detection of "organic waste water contaminants" (OWCs) in aqueous samples, including pharmaceuticals and personal care and other household products that are not entirely degraded in waste water systems. The concentrations of most OWCs are well below therapeutic levels, so that direct human health concerns appear to be unlikely (Benotti et al. 2009. However, OWCs have caused endocrine effects in marine organisms, because many are hormonally-active substances, or are functionally similar to them. Measured impacts include gravely skewed sex ratios or developmental problems in fishes where concentrations of these compounds are highest (Sumpter 1995). Treatment does not affect certain OWCs, and may in fact make some compounds more potent endocrine disruptors (Auriol et al. 2005). Endocrine system responses and changes in those responses have been measured in fishes exposed to New York City effluents (Todorov et al.

2002). In areas like the harbor that receive so much sewage effluent, it is probable more effects will be detected as analyses continue. Thus, it is likely that OWCs will come under more regulation, leading either to societal changes to reduce influent quantities or major treatment process modifications.

One intent of the Clean Water Act is to restore "biologic integrity" to impacted waterways (Karr 1991), and it seems unlikely that harbor ecosystems will ever be restored to that degree. In practice, compliance with regulations is determined by measuring water quality indicators, a process assumed to ensure ecological quality. Most water bodies that are not used as drinking water supplies have routine indicator testing for the two obvious measures of water quality: dissolved oxygen and fecal coliform, and most of New York Harbor, under average conditions, now meets standards. However, complete compliance with water quality regulations requires that all regulated contaminants conform to regulated levels. Routine comprehensive testing is rarely required due to the costs; if such testing were made regularly, it is unlikely that the harbor would ever achieve full compliance, because of contaminated sediments, continuing combined sewer overflows under wet weather conditions, and the inability of standard sewage treatment to remove nutrients and many OWCs.

**Polluted River Impacts on New York City**

The focus thus far has been on the impact of people on the river, and not the effect of the impacted river on City residents. The colonial-era settlers of New York ate local shellfish and fishes. Diamond Jim Brady was famous for his oversized oyster feasts and the City was also well known for other seafood (Boyle 1969). But by the mid-1800s, pollution of the harbor had brought disease, typhus and cholera. As early as the 1860s New York death rates were documented to be higher than other cities with better sewers, an indirect indictment of the effect of rising pollution of an important food source (Melosi 2000). By 1900, people were able to make connections among water pollution, shellfish, and intestinal illnesses, and so harbor fisheries declined (Andersen 2002). Still, at least some City residents continued to exploit available resources, and Robert Boyle made a vivid, unsettling description of striped bass fishing at the 42nd Street untreated sewage outfall in the 1960s, with fish being caught and eaten despite "an oily flavor" (Boyle 1969).

Maritime businesses were certainly aware that sewer effluents caused shoaling, and nuisance odors and other aesthetic concerns. Wood waste gathered from the harbor around 1900 often had an inch or more of accreted sewage on it, an illustration of potential effects (Loop 1964). Certainly the luxury passenger lines with dockage at West Side piers in the mid-20th century must not have relished collecting upscale passengers while nestled in among the raw sewage outfalls there (these outfalls were used into the 1980s, and still serve as outlets for untreated wastes when the system receives too much rain today).

Sewers affected everyday life in the City, from earliest times. Odor complaints were raised in the 1830s, and shoreline odors disturbed residents enough in the 1840s that the matter was brought to the Common Council (Goldman 1997). In the early 1900s, the Metropolitan Sewerage Commission decried "objectionable conditions" in the harbor, making it clear that citizens were disturbed by how bad water quality was. Activities such as sanitary bathing and recreational swimming in City rivers were banned (Loop 1964).

Although the overall lack of residential or recreational use of the waterfront was mostly due to commercial appropriations, there was, for example, growing residential development along the East River at Tudor City and north in the 1930s (Loop 1964), including luxury apartments such as the River House at East 52nd St., which was said to be the "best apartment house" in the City when it was built (Bower 2009). This kind of development was said to be an added impetus for sewage treatment (Loop 1964).

By 1936, as reported by Loop (1964), the need for treatment was justified because of "common standards of decency," such that citizens along the waterfront should not be exposed to recognizable human wastes. In the 1940s, the ISC had a clear goal to recover City waters for boating, fishing, and even shellfishing and swimming (Loop 1964). With the development of a comprehensive sewage treatment system, most waters in the City met dissolved oxygen and pathogen standards by the 1990s (Swanson et al. 2000). Fish populations and other marine life had made notable recoveries (Waldman 1999), and there have even been pilot programs to try to restore oysters in some areas of the harbor (Swanson and Tonjes 2001a).

Advancing levels of sewage treatment have clearly coincided with decisions to expand waterfront uses and access for both City residents and visitors. Growing citizen distaste with the condition of New York City water quality led to municipal action; the potential for further improvement has continued to change perceptions. Urban waterways are no longer considered suitable for untreated waste or as treatment facilities. As water quality improves, potential use of the shoreline and waters increase. And, as more people use and appreciate the shoreline, there is more support for programs that increase the scope of use of the harbor. In the 1960s and 1970s, newspaper stories about swimmers or kayakers or fishers in New York City waters were novelty feature items. Now these activities, while not commonplace for most New Yorkers, are widely advertized, and no longer qualify as news.

As commercial use of waterfront areas has declined, projects like Battery Park City and the South Street Seaport have received much attention and achieved commercial success, and areas such as Battery Park, Riverside Park, and the Brooklyn Promenade have regained lost luster

(Freudenberg and Pirani 2007). Although New York still is not a city like Paris or London where its riverside is an essential part of its image and appeal, there is growing awareness of the magnificent New York shoreline. This appreciation will grow as the Hudson River Park develops, and water-oriented construction, especially along the West Side, continues. New York City has already rezoned (or is planning to rezone) most of the west side waterfront and the shoreline along the Harlem River to increase densities and mixed residential-commercial uses, for instance (New York City 2007). It is difficult to imagine these projects being pursued if there were not effective treatment of the City's wastes. Nonetheless, although PlaNYC discusses the need (and State requirements) to upgrade capture rates and decrease the generation of stormwater to reduce the amount of untreated sewage released under wet weather conditions, it does not address the potential for additional treatment of nutrients or OWCs (New York City 2007).

**Conclusions**

In its earliest days, the relatively small population of New York City could manage wastes and minimize impacts to the environment, especially key natural resources that people depended on for daily life. As the population grew, however, waste management practices especially impacted important water resources. Declining drinking water quality and increasing demand for water supplies forced the City to create a distribution system based on supplies from outside its own borders. The availability of the harbor as receiving waters for wastes, with tides and currents that made many of the wastes "disappear" as they were discharged, made it a natural catchment for the great increase in waste water disposal needs that occurred with the public water distribution system in the 1840s. The use of stormwater sewers for sanitary wastes alleviated impacts on people from growing pollution levels around their dwellings. However, the increasing City population increased its use of sanitary sewers, and the associated waste burden on harbor waters. Although it was slow to be recognized, eventually this waste loading also affected human health, albeit not enough to slow City growth rates.

The long rehabilitation of the harbor only began when public distaste for its degradation forced the initiation of waste treatment. Although New York began work on its sewage treatment system before many other American cities, its slow progress (50 years of construction following 30 years of planning) appears to be an indictment of the degree its citizens were disengaged from its shoreline. City engineers deserve credit, however, for once the plants began to be built, the selected technologies reached treatment levels that were not mandated until the Clean Water Act was passed in 1972.

Although Manhattan is an island, for much of the 20$^{th}$ century it had few public spaces and little public activity along the banks of its rivers; waterfront uses were largely restricted to shipping and related commerce. But these vast industries declined, and by 2000 they had essentially vanished. As water quality has improved, perceptions of the harbor have changed from a waste receptacle to a natural resource (once again). Certainly, many more elements of New York life, such as parks and recreation, include the harbor and there is much recent commercial and housing redevelopment, replacing empty and underused spaces that appeared as the maritime industries withered away. The malodorous, fouled waters of the harbor circa 1920 would not support the civic life that now is found using the recovering shoreline.

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