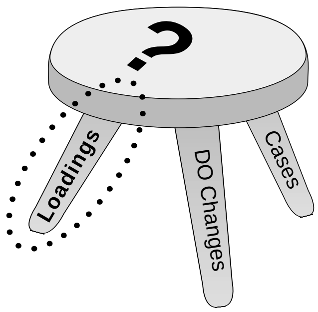
Chapter 2



An Examination of BOD Loadings Before and After the CWA

Chapter 1 introduced the "three-legged stool" approach to assess the success of the CWA's mandate for POTW upgrades to secondary and greater than secondary wastewater treatment. The premise is that each "leg" of the approach must provide cumulative support for the stool to stand up firmly and success to be declared. Chapter 2 presents the results of the first leg. Specifically, this chapter focuses on whether there was a significant reduction in the discharge of oxygen-demanding materials from POTWs to the Nation's waterways after implementation of the 1972 CWA.

To help put this analysis into perspective, Chapter 2 begins with a background discussion of the historical consequences of ignoring the wastewater treatment component of the urban water cycle on the aquatic ecosystem *(Section A)* and then explains how scientists and engineers eventually harnessed the power of decomposers and developed the process now known as secondary treatment *(Section B)*. *Section C* traces the legislative and regulatory history of the federal role in water pollution control and how the 1972 CWA accelerated the national trend of upgrading POTWs to at least secondary treatment. *Section D* presents national trends in influent BOD loading (BOD entering POTWs) and effluent BOD loading (BOD discharged from POTWs into surface waters) for select years between 1940 and 1996, as well as effluent loading projections into the 21st century.

During the mid-1990s (ca. 1995), pollutant loading from municipal wastewater treatment facilities accounted for only about one-fifth of the estimated total national point and nonpoint source load of BOD discharged to surface waters. *Section E* presents comparative estimates of the remaining four-fifths of the total national load accounted for by industrial wastewater dischargers, combined sewer overflows (CSOs), and nonpoint (rural and urban[1]) sources. *Section F* examines the national public and private investment costs associated with water pollution control. *Section G* provides a summary, conclusions, and a perspective on future trends for municipal wastewater loads.

[1] For the purposes of this comparison, urban "nonpoint" sources include areas within the National Pollutant Discharge Elimination System (NPDES) stormwater permit program that meet the legal definition of a "point" source in section 502(14) of the CWA.

A. Historical Consequences of Ignoring the Wastewater Treatment Component of the Urban Water Cycle

The urban water cycle can be divided into a *water supply side* and a *wastewater disposal side* (see Figure 1-1). The basic technological framework for the water supply side began as far back as 5,000 years ago when people from the Nippur of Sumeria, a region of the Middle East, built a centralized system to deliver water into populated areas (Viessman and Hammer, 1985). The Minoans at Knossos, some 1,000 years later, improved on the concept with the installation of a system of cisterns and stone aqueducts designed to provide a continuous flow of water from the surrounding hills to dwellings in the central city. Basic concepts and instructions related to purity of water, cleanliness, and public sanitation are also recorded in the books of Leviticus and Deuteronomy (23:12-13) in the Old Testament. Talmudic public sanitation laws were enacted in Palestine to protect water quality in the centuries before and after the early Christian era ca. 200 B.C. to 400 A.D. (Barzilay et al., 1999).

The ancient Athenians were some of the first people to develop the wastewater disposal side of the urban water cycle. The Greeks moved sanitary wastes away from their central city through a system of ditches to a rural collection basin. The wastewater was then channeled through brick-lined conduits for disposal onto orchards and agricultural fields. In the ancient world, though, the Roman Empire attained the highest pinnacle for developing the knowledge and technology to select the best water supplies and to construct far-reaching networks of aqueducts to bring water supplies to Rome for distribution through pipes to wealthy homes and public fountains. The Romans also built large-scale public sanitation projects for collecting and controlling sewage and stormwater drainage. The great Roman sewer *Cloaca Maximum* still drains the Forum in Rome today after 2,000 years of operation.

In expanding their empire throughout North Africa and Europe, the Romans introduced the technologies needed to develop water supplies and to construct aqueducts and urban drainage systems to promote rudimentary standards of public sanitation. With the collapse of the Roman Empire, however, the public sanitation infrastructure was neglected and the technology was lost and forgotten for a thousand years as the “Dark Ages” descended on the western world. Filth, garbage, excrement in the streets, polluted water sources, disease, plague, and high mortality rates were common consequences of the dismal public sanitary conditions that persisted well into the 19^{th} century (Barzilay et al., 1999).

Throughout history, two components of the urban water cycle were absent: wastewater treatment and the transport of treated wastewater for discharge back to natural waterbodies. For towns situated near coastal areas, estuaries, or large rivers, short-circuiting the cycle caused no immediate consequences because these waterbodies had some capacity to assimilate raw sewage without causing water pollution problems. For many inland communities, however, water pollution problems were more acute. As populations increased, even coastal towns were forced to reckon with the consequences of ignoring the wastewater treatment component of the urban water cycle (see Rowland and Heid, 1976).

Much of the blame for incomplete urban water cycles up until the middle of the 19th century can be traced to a general ignorance about the consequences of allowing untreated wastewater to flow into surface waters used for drinking water downstream. As the relationship between this practice and its effects on public health became better understood, however, a community's refusal to adopt effective wastewater treatment in its cycle was more often based in politics and economics, rather than a lack of technological knowledge (see Rowland and Heid, 1976). No matter the reason, bypassing the wastewater treatment side of the urban water cycle affected both water supply and water resource users.

Impacts on Water Supply Users and "The Great Sanitary Awakening"

The introduction of household piped water in the mid-19th century was the key technological development that cemented the two sides of the urban water cycle—water supply and wastewater disposal. Unfortunately, although piped water supply systems gave urban dwellers more convenient access to water, people were also held hostage to the water supply source chosen by the local water company. For many city dwellers, drinking piped water became hazardous to one's health as massive epidemics of waterborne diseases such as cholera and typhoid fever broke out in many cities in Great Britain and the United States (Table 2-1).

Table 2-1. Pathogens and their associated diseases. *(Adapted from Metcalf and Eddy, 1991)*

Pathogen	Disease	Effects
Bacteria		
Escherichia coli	Gastroenteritis	Vomiting, diarrhea, death in susceptible populations
Legionella pneumophila	Legionellosis	Acute respiratory illness
Leptospira sp.	Leptospirosis	Jaundice, fever (Weil's disease)
Salmonella typhi	Typhoid fever	High fever, diarrhea, ulceration of the small intestine
Salmonella sp.	Salmonellosis	Diarrhea, dehydration
Shigella sp.	Shigellosis	Bacillary dysentery
Vibrio cholerae	Cholera	Heavy diarrhea, dehydration
Yersinia enterolitica	Yersinosis	Diarrhea
Protozoa		
Balantidium coli	Balantidiasis	Diarrhea, dysentery
Cryptosporidium sp.	Cryptosporidiosis	Diarrhea
Entamoeba histolytica	Amedbiasis	Diarrhea w/bleeding, abscesses on liver, small intestine
Giardia lamblia	Giardiasis	Mild to severe diarrhea, nausea, indigestion
Naegleria fowleri	Amoebic meningoencephalitis	Fatal disease; brain inflammation
Viruses		
Adenovirus (31 types)	Respiratory disease	
Enteroviruses (67 types)	Gastroenteritis	Heart anomalies, meningitis
Hepatitis A	Infectious hepatitis	Jaundice, fever
Norwalk agent	Gastroenteritis	Vomiting, diarrhea
Reovirus	Gastroenteritis	Vomiting, diarrhea
Rotavirus	Gastroenteritis	Vomiting, diarrhea

Dr. John Snow, physician to England's Queen Victoria, was one of the first to scientifically link waterborne diseases to contaminated source water supplies. Examining records of some 14,600 Londoners who had died in an 1854 cholera epidemic, Snow found that people who had received water from an intake downstream of London's sewage outlets in the lower Thames River had a much higher death rate (8.5 times higher) than those receiving Thames River water from an intake upstream of the sewage discharges (Snow, 1936). The threat of contaminated water sources did little, however, to quell the construction boom of new water supply systems in the second half of the 19th century, especially in the United States. In 1850 there were about 83 water systems in the United States. By 1870, the count had risen to 243 systems (Fuhrman, 1984).

Like Londoners, American city dwellers with piped water faced an increased risk of waterborne diseases. Beginning in 1805, the New York City Council had the authority and responsibility for sanitary conditions in the city. Despite this early recognition of governmental responsibility for public health, epidemics of typhoid fever broke out in 1819, 1822, 1823, and 1832 and cholera ravaged workers on the Erie Canal (Rowland and Heid, 1976). Between 1832 and 1896, cities in North America and Europe suffered four devastating outbreaks of cholera that were spread by polluted urban water supply systems (Garrett, 1994). Cholera epidemics in New York City in 1832 and 1849 claimed 3,500 and 5,000 lives, respectively. In 1891 typhoid fever caused the deaths of 2,000 people in Chicago (Fair et al., 1971). Hundreds more succumbed to typhoid in Atlanta and Pittsburgh in the 20-year period between 1890 and 1910 (Bulloch, 1989). The importance of an unpolluted source water for public drinking water was clearly shown in the earliest public health studies of waterborne diseases and drinking water supplies. Typhoid death rates in 61 cities of the United States during 1902-1906, for example, ranged from a high of 120 per 100,000 for a run-of-river supply for Pittsburgh, Pennsylvania, to a low of 15 per 100,000 for the upland watershed supply of New York City (Okun, 1996).

This trend would have certainly continued for a few more decades if not for the discovery of a new purification technology: chlorination of drinking water. As a disinfecting agent, chlorine gained widespread use in the years 1908-1911, soon bringing typhoid fever and cholera outbreaks under control in virtually all communities that adopted chlorination. Detailed mortality records and public water supply records compiled by the Commonwealth of Massachusetts, for example, clearly illustrate the link between the introduction of filtration and disinfection of public water supplies and the sharp reduction in typhoid fever deaths (Figure 2-1) from a peak of 125 per 100,000 in 1860 to less than 5 per 100,000 by 1920 and essentially zero from 1940 to the present time (Fair et al., 1971; J. Higgins, Massachusetts DEP, personal communication, September 1998; USCB, 1975).

Influenced by the Enlightenment and democratic movements of the late 18th century in Britain, France, and the new United States, the concept that a government had the moral and ethical responsibility to protect the general welfare of its citizens, including public health, arose in Britain and the United States during the first half of the 19th century. Motivated by the bleak urban conditions chronicled by Charles Dickens, Chadwick's (1842) *Report on the Sanitary Condition of the Labouring Population of Great Britain* marked the beginning of the "Great Sanitary Awakening" (Okun, 1996). Chadwick's report directly influenced passage of Great Britain's Public Health Act of 1848 and its formation of the

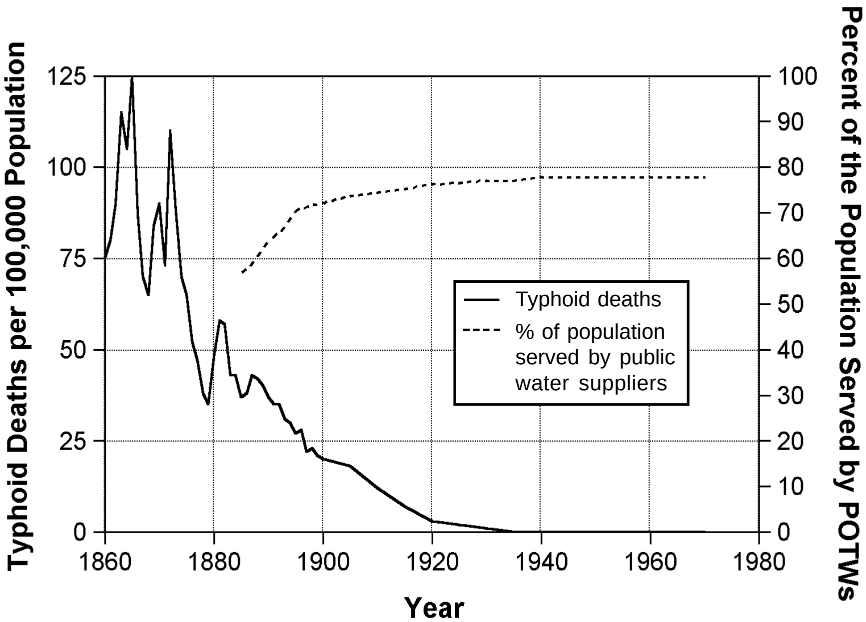


Figure 2-1

Comparison of the death rate due to typhoid and the percentage of population served by public water suppliers in Massachusetts from 1860 to 1970.

Source: Fair et al., 1971; USCB, 1975.

General Board of Health, and, in the United States, the creation of the Massachusetts State Board of Health in 1869 (Okun, 1996) and the New York State Board of Health in 1880 (Rowland and Heid, 1976).

The technological impacts of the "Great Sanitary Awakening" on the origins of drinking water treatment and water pollution control systems are well documented in the records of a series of international sanitary conferences held from 1851 through 1938. The conferences addressed scientific issues related to public health, the environment, and the need to control diseases spread by contaminated food and water. The conferences highlighted serious public health and environmental issues that have since evolved as the foundation of the numerous state, local, federal, and international environmental laws and programs enacted in the latter half of the 20th century (Howard Jones, 1975).

Impacts on Water Resources Users

Sewer is an Old English word meaning "seaward." As the name suggests, from the 1500s through mid-1800s, London's sewers were nothing more than open ditches draining wastewater seaward via the Thames River. The year 1858, also known as the year of "The Great Stink," brought matters to a head. That summer the stench from the Thames drove people out of the city by the thousands. The windows of the Parliament building had to be draped with curtains soaked in chloride of lime. By the end of the summer session, even the most traditional members had to agree: something had to be done about wastewater.

In response, London officials abolished cesspools and made the use of water closets, drainage pipes, and centralized sewer collection systems mandatory. Over in the United States, city officials were also feeling the pressure of a populace weary of the noxious conditions associated with open sewers. In 1910 about 10 percent of the urban population was serviced by centralized collection systems

(FWPCA, 1969). This number increased steadily in the following decades; by 1940, 70.5 million persons (53 percent of the population) were served by them.

Unfortunately, treating drinking water with chlorine and developing efficient sewage collection systems did little to help water resources users. Raw sewage deposited into streams, lakes, and estuaries was still raw sewage, whether it was discharged through an engineered wastewater collection system or through an open ditch. Collection systems just made the dumping more efficient and complete. And though chlorine proved to be a godsend for public health, it treated only a pollution symptom, not the cause. Its success, unfortunately, tended to divert attention away from installing wastewater treatment as a means of protecting public health (Bulloch, 1989).

Several studies conducted around the turn of the century documented increasingly noxious conditions in several well-known rivers receiving untreated urban discharges. These included the Merrimack River (1908), Passaic River (1896), Chicago Ship and Sanitary Canal (1900), and Blackstone River (1890). Looking beyond water quality, scientists also began to examine the effect urban discharges were having on stream biota. Studies were conducted in places like the Sangamon River in Illinois (1929) (Eddy, 1932), the Potomac River (1913-1920), and the Shenandoah River (1947-1948) (Henderson, 1949). These and other early investigations are an invaluable starting point for assessing long-term trends in the surface water environment.

At the turn of the century, public officials focused most of their attention on water supply users. The users demanded and received the two services most important to them: the delivery of clean water and the collection and removal of wastewater. Support for water resources users, on the other hand, was minimal. Generally these users captured the attention of city leaders only when conditions reached crisis levels. Then, in most cases, the response was to deal with ways to alleviate the symptom rather than the cause of water pollution.

In Chicago, for example, officials became concerned about the increasing amount of urban water pollution flowing into their backyard water supply source, Lake Michigan. In response, they built the Chicago Drainage Canal, which diverted sewage away from the lake and directed it to the Des Plaines River, a tributary that emptied into the Mississippi River.

After the canal opened in 1900, officials in the downstream city of St. Louis fumed. They quickly initiated proceedings in the Supreme Court of the United States against the state of Illinois and the Sanitary District of Chicago. Though St. Louis eventually lost its case because the city could not prove direct harm to its water supply from its upstream neighbor, the episode underscored the fact that effective wastewater treatment was a critical component in the modern urban water cycle.

B. Evolution of Wastewater and the Use of DO and BOD as Indicators of Water Quality

European history as far back as 400 years ago tells of sewage being collected, dewatered, and transported as "night soil" away from population centers. In 1857 a British royal commission, in response to noxious conditions in the Thames, directed Lord Essex to report on alternative ways to dispose of urban wastewater. Essex concluded that applying wastewater to crops would be preferable to the current practice of draining it into the river. Wastewater treatment technology has progressed tremendously since those times. Today's facilities employ a variety of sophisticated physical, chemical, and biological processes to reduce domestic and industrial wastewater to less harmful by-products.

Primary Treatment

The march toward effective wastewater treatment began in the late 1800s when municipalities began to build facilities for the purpose of physically separating out solids and floating debris from wastewater before releasing it to a waterbody (Rowland and Heid, 1976). In many cases, this construction was promoted by city officials and entrepreneurs, who were rapidly learning that unsightly urban debris and a delightful growing phenomenon, tourists with leisure dollars to spend, did not mix. By no coincidence, one of the first of these treatment facilities was constructed in 1886 next to New York's famous Coney Island beaches. Other cities with prominent waterfront areas followed suit, and by 1909 about 10 percent of the wastewater collected by municipal sewer systems underwent some form of physical separation process, now known as *primary treatment* (OTA, 1987).

The practice of physically screening and settling out solids and floating debris was a critical first step in incorporating the wastewater treatment component into the urban water cycle. Even though primary treatment facilities were simple in concept, they reduced the concentrations of contaminants entering urban waterways.

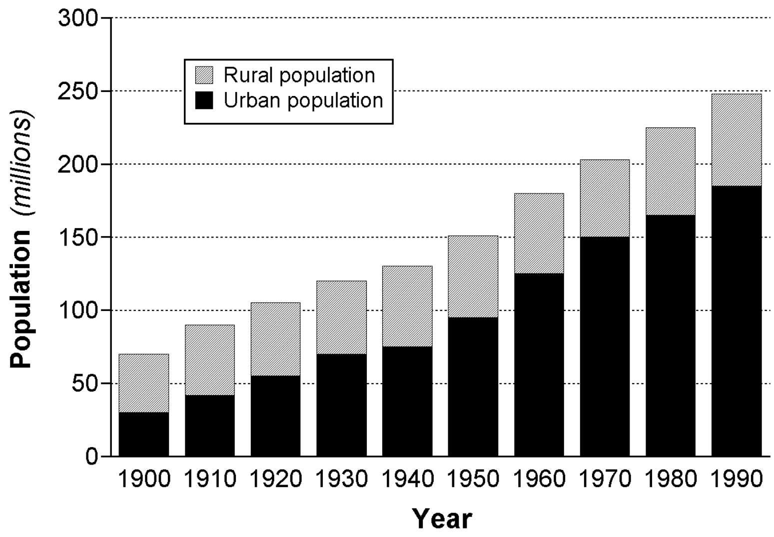
Dissolved Oxygen as an Indicator of Water Quality

In 1900 the United States was primarily an agrarian society, with the majority of the population living in rural areas (Figure 2-2). In the 1920s and 1930s, a combination of population growth, the Great Depression, and the rise of urban industries with the increased employment opportunities they afforded caused the rural/urban population balance to shift in favor of cities. The increasing volumes of wastewater generated by this influx of people soon overwhelmed the primary treatment capacity of POTWs, many of which had been underdesigned from the start. Consequently, the modest water quality gains achieved in many cities by primary treatment technology were soon overwhelmed by greater volumes of sewage.

Figure 2-2

Population in the United States organized by urban and rural components from 1900 to 1990.

Source: U.S. Census Bureau, Population Division (USCB, 2000).



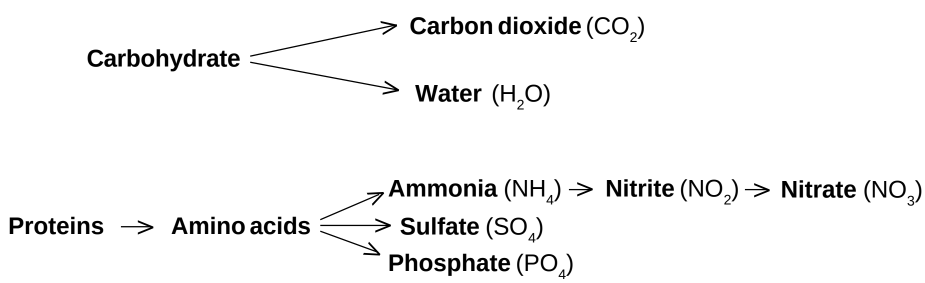
Water quality conditions grew so bad in New York Harbor that in 1906 the state legislature created the Metropolitan Sewerage Commission of New York City for the purpose of studying and dealing with the effects of municipal water pollution. Of immediate concern was the decline of fish and shellfish catches. The Commission concluded that a lack of oxygen in the water was the reason, and two years later the group initiated what is now one of the longest-running water quality monitoring programs in the world. Sampling proved them right, and in 1911 the Commission set 70 percent oxygen saturation as their criterion for defining polluted waters (Cleary, 1978).

The need for adequate dissolved oxygen for aquatic respiration was well known in the late 1800s. Scientists at that time, however, were just learning about the element's critical role in the decomposition of organic matter into simple, stable end products such as carbon dioxide, water, phosphate, and nitrate (Figure 2-3). In natural waters this process occurs when leaves, bark, dead plants and animals, and other natural carbon-based materials are eaten by bacteria, fungi, and insects. The population of these organisms rises and falls according to the amount of food available. Importantly, because the organisms are aerobic creatures, they require oxygen to breathe and carry on the task of decomposition. In

Figure 2-3

General forms of reactions involving the breakdown of carbonaceous and nitrogenous organic matter.

Source: Dunne and Leopold, 1978.



addition to the carbon cycle of production and decomposition, the nitrogen cycle also influences DO through a series of sequential reactions wherein organic nitrogen compounds are hydrolyzed into ammonia and ammonia is oxidized to nitrite and nitrate (nitrification) by autotrophic nitrifying bacteria, with DO consumed as part of these sequential reactions.

The amount of oxygen water can hold at any one time is limited, however, by the saturation concentration of oxygen. The saturating amount of oxygen gas from the atmosphere that can be dissolved in water is limited by water temperature, salt content, and pressure (elevation above sea level). In a sense, then, all the aerobic aquatic life in a waterbody is in competition for that limited amount of oxygen. In natural streams there are usually no losers because dissolved oxygen is continuously replenished from the atmosphere at about the same rate at which it is used up by aquatic organisms. A problem arises, however, when large amounts of organic material from sewage or other pollution sources enter the water and the decomposer population (especially bacteria) explodes in response. These organisms have the potential to lower, or even completely exhaust, oxygen in the water. When this occurs, life that depends on the presence of oxygen (aerobic) in the waterbody dies or, where possible, the biota moves on to waters with higher oxygen levels.

In the absence of oxygen in water, anaerobic bacteria further break down organic matter. These organisms obtain energy from oxygen bound into other substances such as sulfate compounds. Anaerobic processes are much slower than aerobic decomposition, however, and their end products, such as hydrogen sulfide, are usually noxious.

Secondary Treatment

Harnessing the power of decomposers to break down organic matter in wastewater is at the heart of a treatment process now known as secondary treatment. Two distinct methods of this treatment type evolved around the turn of the century. The Lawrence Experiment Station in Massachusetts pioneered the first method in 1892. Called the trickling filter method, it involves spraying wastewater onto a column of crushed stone on which a community of bacteria, fungi, protozoa, and insects resides. The organisms take in a portion of the organic matter and break it down. Some of the breakdown products, such as carbon dioxide, escape to the atmosphere. Others, like nitrate, remain in solution. Still other products are absorbed into the organisms themselves. This latter material is eventually collected in settling tanks as sludge after the organisms die or is otherwise detached from the stone.

A second method of secondary treatment was advanced around 1913 by the Lawrence Experiment Station and Ardern and Lockett in England. Known as activated sludge treatment, it follows the same principles as the trickling filter but instead of cultivating decomposers on the surface of rocks, organisms are simply suspended in a tank by a continuous flow of wastewater.

Both methods of secondary treatment result in discharges with substantially less organic matter than is produced by primary treatment. City officials having problems with litigious neighbors downstream were especially eager to adopt this new technology into their urban water cycles. One of the first trickling filter facilities in the Nation was constructed in the city of Gloversville, New York, in

1907. The motivation was not so much citizen demands in Gloversville for a cleaner river as it was the need to respond to a riparian rights suit filed by the downstream city of Johnstown. Chicago officials also grew tired of their ongoing battle with St. Louis and in 1916 constructed the first activated sludge treatment plant in the Nation (Metcalf and Eddy, 1991).

Officials in most other U.S. cities, however, did not have neighbors like Johnstown or St. Louis forcing them to upgrade their wastewater treatment capabilities. Consequently, they were content to embrace a theme reflected in a leading textbook of the time, *Sewage Disposal*. The authors of the 1919 publication argued that municipal dollars were much better spent on health programs than on sewage purification, and they chided sewage treatment proponents for being unrealistic in their demands.

Biochemical Oxygen Demand (BOD) as a Measure of Organic Wasteload Strength

One reason communities were slow to adopt secondary treatment into their urban water cycle was perception. There was no way to articulate the link between the organic wastes in wastewater and DO levels in natural waters. In the 1920s these relationships became clearer with the development of an indicator called the biochemical oxygen demand (BOD). Performed in a laboratory, the BOD test measures the molecular oxygen used during a specific incubation period for the biochemical degradation of organic material, the oxidation of ammonia by nitrification, and the oxygen used to oxidize inorganic chemical compounds such as sulfides and ferrous iron.

Historically, the BOD was determined using an incubation period of 5 days at 20 degrees Celsius (ºC). For domestic sewage and many industrial wastes, about 70-80 percent of the total BOD is decomposed within the first five days at this temperature (Metcalf and Eddy, 1991). Because of the incubation period, BOD_5 has been adopted as the shorthand notation for this measurement in the literature. Expressed as a concentration, the BOD_5 measurement allows scientists to compare the relative pollution "strength" of different wastewaters and natural waters. The widest application of the BOD_5 test, however, is for measuring the strength and rates of wastewater loadings to and from POTWs and evaluating the BOD_5 removal efficiency of the treatment system.

Because of widespread problems with oxygen depletion in many urban rivers, several states, especially those in the more populated Northeast, Midwest, and far West, took a leadership role in the 1930s to encourage municipalities to upgrade from primary to secondary treatment. By 1950, 3,529 facilities, or about one-third of the 11,784 municipal treatment plants existing at that time, provided secondary treatment for 32 million people. At the same time, however, 35 million people were still connected to systems that discharged raw sewage and 25 million people were provided only primary treatment (USPHS, 1951). Increasing the number of facilities that provided at least secondary treatment became a national issue as the technology was seen as a solution to the pervasive problem of low levels of DO.

C. The Federal Role in Implementing Secondary Treatment in the Nation's POTWs

The story of federal involvement in water pollution control, and specifically the secondary treatment issue, is best told in two parts—*before* and *after* the passage of the Federal Water Pollution Control Act Amendments of 1972, also known as the Clean Water Act (CWA). Before 1972 regulatory authority for water pollution control rested with the states. Federal involvement was limited to cases involving interstate waters. Unfortunately, there was a great diversity among the states in terms of willingness to pay the costs of building and upgrading POTWs and to enforce pollution control laws.

At the center of the problem was the idea that water pollution could be controlled by setting ambient water quality standards and that states would go after dischargers who caused those standards to be violated. In retrospect, this approach was an enforcement nightmare for several reasons (WEF, 1997):

- The enforcing agency had to prove a particular discharger was causing a waterbody to be in violation of the ambient water quality standard. This was difficult because waste loads were allocated among all dischargers based on methods that were often open to interpretation.
- Most of the time, data with which to support the case against a discharger had to come from the discharger itself. Usually there were no independent monitoring programs.
- Many waterbodies lacked water quality standards.
- There were few civil or criminal penalties that could be levied against dischargers who caused water quality standards to be violated.

As the state-led water quality standards approach continued to fail and water quality conditions continued to spiral downward, both water supply and water resource users looked to the federal government for leadership and relief. The CWA was designed to turn the water pollution control tables around completely, and it did. The following two subsections describe the federal role before and after passage of the CWA.

The Federal Role in Secondary Treatment Before the Clean Water Act

The public's concern about raw sewage in the Nation's waterways was not entirely lost on the U.S. Congress before the turn of the century. Because of the U.S. Constitution, however, they felt powerless to act on any water resource issue unless it dealt in some way with interstate commerce. Accordingly, the first federal legislation dealing with the abatement of water pollution was tied to the fact that pollution sometimes got so bad that it impeded navigation. The Rivers and Harbors Act of 1890 specifically prohibited the discharge of any refuse or filth that would impede navigation in interstate waters. Unfortunately, this act was greatly "watered down" with the passage of the amended Rivers and Harbors Act in 1899. It conveniently exempted "refuse flowing from streets and sewers and passing therefrom in a liquid state" from the navigation impedance prohibition. After the Rivers and Harbors Act of 1899, the Public Health Service Act of 1912 authorized the federal government to investigate waterborne disease and water pollution. In 1924 the Oil Pollution Act was enacted to control discharges of oil causing damage to coastal waters.

The next few decades were lean ones in terms of federal involvement in water pollution control—but not for lack of effort. Between 1899 and 1948 more than 100 bills about water pollution were introduced. Most languished and died in the halls of Congress. One, sponsored by Senator Alben W. Barkley and Representative Fred M. Vinson (later Chief Justice of the Supreme Court), actually made it to the President's desk. It, however, received a presidential veto because of budgetary concerns. The 80th Congress finally broke the impasse and enacted The Water Pollution Control Act of 1948. This act, along with five amendments passed between 1956 and 1970, shaped the national vision and defined the federal role regarding the treatment of wastewater in the United States. It also set the stage for passage of the landmark Water Pollution Control Amendments of 1972. Figure 2-4 summarizes the key legislation enacted between 1948 and 1971.

The Water Pollution Control Act of 1948, PL 80-845

The Water Pollution Control Act of 1948 was significant on three accounts. For the first time Congress accomplished the following:

- Expressed a national interest in abating water pollution for the benefit of both water supply and water resource customers.

  "*The pollution of our water resources by domestic and industrial wastes has become an increasingly serious problem due to the rapid growth of our cities and industries. Large and increasing amounts of varied wastes must be disposed of from these concentrated areas. Polluted waters menace the public health through the contamination of water and food supplies, destroy fish and game life, and rob us of other benefits of our natural resources.*"

  — Senate Report No. 462 of the 80th Congress
  Report on the Water Pollution Control Act of 1948

- Established the view that states were primarily responsible for the control of water pollution and that the federal government's role would be to provide financial aid and technical assistance—a policy concept that has continued to the present.

  "*That in connection with the exercise of jurisdiction over the waterways of the Nation and in consequence of the benefits resulting to the public health and welfare by the abatement of stream pollution, it is hereby declared to be the policy of Congress to recognize, preserve, and protect the primary responsibilities and rights of the States in controlling water pollution . . . and to provide . . . financial aid to State and interstate agencies and to municipalities, in the formulation and execution of their stream pollution programs.*"

  — The Water Pollution Control Act of 1948 (PL 80-845)

Figure 2.4

Timeline of federal water pollution control acts, 1948 - 1971.

Water Pollution Control Act of 1948 (1948)

The Water Pollution Control Act of 1948 authorized the US Public Health Service to develop comprehensive basin plans for water pollution control and to encourage the adoption of uniform state laws. $l00 million of loans annually to municipalities were authorized, but no appropriation for treatment facilities under this act was ever made. However, the act influenced the states to apply more control over the discharge of pollutants into their waters.

Water Pollution Control Act of 1956 (1956)

Grants for assisting in the construction of municipal treatment works were authorized and, for the first time, funded with federal appropriations. The Surgeon General was directed to prepare comprehensive programs for pollution control in interstate waters in cooperation with states and municipalities, and the state was to prepare plans for prevention and control of water pollution. If there was no approved plan, no grant was to be made for constructing treatment facilities. $50 million annually in grants was authorized. Grants were limited to 30% of the cost of construction, or $250,000, whichever was smaller. Legislation in the states increasingly required secondary treatment for polluted waters.

Water Pollution Control Act of 1961 (1961)

Comprehensive programs and plans for water pollution abatement and control were still required. Grants were limited to 30% of the cost of construction or $600,000, whichever was less, or $2.4 million for multiple municipal plants. At least half of the appropriation was to go to cities of 125,000 or less. The Congress advocated 85% removal of pollutants in the hearings.

Water Quality Act of 1965 (1965)

For the first time, each state, to receive grants, was required to have water quality standards, expressed as water quality criteria applicable to interstate waters. If the state did not develop standards, the FWPCA was required to do so. To comply with these standards and criteria, secondary treatment was increasingly necessary. Construction grants were raised to 30% of reasonable costs, and an additional 10% was allowed where the project conformed with a comprehensive plan for a metropolitan area. At least 50% of the first $100 million in appropriations had to go to municipalities of less than 125,000 population. Individual grants were limited to $1.2 million, with a limit of $4.8 million for multiple municipalities.

Clean Water Restoration Act of l966 (1966)

The requirements for state water quality standards were continued. Each state planning agency receiving a grant was to develop an effective, comprehensive pollution control plan for a basin. The Federal Water Pollution Control Administration, in a guideline, attempted to require states to conform to a national uniform standard of secondary treatment or its equivalent. This action was challenged and the guideline was not enforced. Secretary Udall stated at House hearings that the states had agreed to the requirement for secondary treatment. Grants for POTWs are set at 30% with an increase to 40% if the state paid 30%. The maximum could be increased to 50% if the state agreed to pay 25%. A grant could be increased by 10% if it conformed to a comprehensive plan for the metropolitan area. The limitation of $1.2 million and $4.8 million for grants was waived if the state matched equally all federal grants. At least 50% of the first $100 million in annual appropriations had to be directed to municipalities of <125,000 people.

Water Quality Improvement Act of 1970 (1970)

The Water Quality Improvement Act of 1970 did not contain any new provisions regarding required standards. The requirements for state water quality standards were continued. However, in hearings for the act, the authority of EPA to require uniform treatment limitations for discharges, such as secondary treatment, was questioned.

- Developed activities that required states and the federal government to work as partners in solving pollution problems in interstate waters.

The act set forth a loan program designed to provide up to $100 million per year for states, municipalities, and interstate agencies to construct needed wastewater treatment works. Each loan was not to exceed $250,000 and was to bear an interest rate of 2 percent. Unfortunately, the loan program never saw the light of day because the program was never funded.

More successful, however, were the partnership programs developed between the states and the U.S. Public Health Service. The act required the Surgeon General to

- Work with states and municipalities to prepare and adopt comprehensive programs for eliminating or reducing the pollution of interstate waters and improving the sanitary conditions of surface and underground waters.
- Encourage the enactment of uniform state laws relating to the prevention and control of water pollution.
- Take action against polluters of interstate waters, with the consent of the affected state.

In 1952 the Congress acknowledged that these partnership efforts were paying off and passed Public Law 82-579, which extended the activities authorized by the 1948 act for another 4 years. In 1955 the Senate issued a report that stated that the act caused more than half the states to improve their pollution control legislation and programs to better protect their water resources (Sen. Rep. No. 543, 84th Congress). The report also noted that some states were establishing water quality standards so stringent that they left municipalities with no choice but to implement secondary treatment at their facilities.

The Water Pollution Control Act of 1956, PL 84-660

This act was significant because it authorized a grant program for the construction of wastewater treatment facilities—and then actually funded it. A total of $l50 million was earmarked over the life of the program with a provision that no more than $50 million could be spent per year. Individual grants were not to exceed 30 percent of the reasonable cost of construction, or $250,000, whichever was smaller. There was one important caveat to obtaining a grant, however: to be funded, the project must be in conformity with a plan prepared by the state water pollution control agency and approved by the Surgeon General.

Though language in the act emphasized that the law should not be "construed as impairing or in any manner affecting any right or jurisdiction of the States with respect to the waters (including boundary waters) of such States," the requirement for federal approval of a state's water pollution control plan nonetheless established a new leadership role for the federal government. If a state did not follow an approved plan, grant payments could be held up pending an appeal to a federal court.

The Federal Water Pollution Control Act of 1961, PL 87-88

Only a few changes were made in the 1961 amendment to the Federal Water Pollution Control Act. Congress's basic intent with this legislation was to extend the act through to 1967. Construction grants were authorized to the states in the total amount of $60 million for FY 1962, $90 million for FY 1963, and $100 million for each of the fiscal years 1964 through 1967.

A grant to a municipality was limited to $600,000 or 30 percent of the reasonable costs, whichever was less, with a limit of $2.4 million when the project would serve more than one municipality. At least one-half of the funds appropriated for projects were to go to cities of 125,000 population or less. The requirements for comprehensive pollution control programs and plans were carried over from the act of 1956.

Perhaps the most interesting development concerning federal involvement in water pollution control appeared not in the act itself, but in language contained in the accompanying Senate report. Here, for the first time, the Senate mentioned its desire to see secondary treatment used in municipal waste treatment plants. The same document also presented a vision for the future and an expression of hope for completion of the urban water cycle:

> *"There is every reason to believe that a vigorous research attack on waste treatment problems would lead to breakthroughs and new processes which will make it possible to handle ever-increasing wasteloads, and even to restore streams to a state approaching their original natural purity . . . If all waste or all water deteriorating elements could be removed by treatment, a region's water supply could be used over and over."*
>
> — Senate Report No. 353, 87th Congress
> Report on the Water Pollution Control Act of 1961

The Water Quality Act of 1965, PL 89-234

Two important elements were established with the passage of the Water Quality Act of 1965. First, it created the Federal Water Pollution Control Administration (FWPCA) as a separate entity in the Department of Health, Education and Welfare. FWPCA did not reside there long, however. In 1966 it was transferred to the Department of the Interior. Then, in 1970, its functions were folded into the new United States Environmental Protection Agency (USEPA).

Second, the act required each state desiring a grant to file a letter of intent with the FWPCA committing the state to establishing, before June 30, 1967, water quality criteria applicable to interstate waters and submitting a plan for the implementation and enforcement of water quality criteria. If the state chose not to do this, the FWPCA would do it for the state.

The state's criteria and plan were to be the water quality standards for its interstate waters and tributaries. The act mandated that these standards must protect the public health or welfare and enhance the quality of water. Consideration was also to be given to the use and value of public water supplies, propagation of fish and wildlife, recreational purposes, and agricultural, industrial, and other legitimate needs.

The construction grants program was continued in this act. The federal contribution was raised to 30 percent of the reasonable costs, plus an additional 10 percent when the project conformed with the comprehensive plan for a metropolitan area. The authorized amounts for construction grants were set at $150 million for FY 1966 and FY 1967, with at least 50 percent of the first $100 million appropriated in those years used for grants for municipalities of 125,000 people or less. Grants to municipalities were limited to $1.2 million, with $4.8 million set as the limit when two or more municipalities were served by the same facility.

The Clean Water Restoration Act of l966, PL 89-753

Basin planning was a key focus of the Clean Water Restoration Act of l966. Each state planning agency receiving a grant had to develop an effective comprehensive pollution control and abatement plan for basins. A basin was defined as rivers and their tributaries, streams, coastal waters, sounds, estuaries, bays, lakes, and portions thereof, as well as the lands drained thereby. Congress mandated that the plan must:

- Be consistent with water quality standards.
- Recommend effective and economical treatment works.
- Recommend maintenance and improvement of water quality standards within the basin, as well as methods for financing necessary facilities.

Grants for wastewater treatment facilities were set at 30 percent of the reasonable cost, which could be increased to 40 percent if the state agreed to pay not less than 30 percent of the reasonable costs. This maximum could be increased to 50 percent if the state agreed to pay not less than 25 percent of the estimated reasonable costs of all such grants. A grant could also be increased by 10 percent of the amount of a grant if it was in conformance with a plan developed for the metropolitan area. To be eligible for any grant a project must be included in a comprehensive water pollution program and the state water pollution control plan. Grants were again limited to $1.2 million for individual projects and $4.8 million for multi-municipal projects. This limitation was waived, however, if the state agreed to match equally all federal grants made for the project.

Authorized amounts for grants gradually increased from a total of $550 million for FY 1968 to $1.250 billion for FY 1971. The total of $2 billion was authorized for FY 1972 by the Extensions of Certain Provisions of the Federal Water Pollution Control Act of 1971, PL 92-240.

The Water Quality Improvement Act of 1970, PL 91-224

On March 18, 1968, FWPCA announced that the water quality standards of 28 states had been approved, and all of the states were expected to have approved standards by June. Soon afterwards, however, FWPCA attempted to cause states to amend their standards to include an effluent limitation of "best practicable treatment" or its equivalent for all discharges:

> "*No standards shall be approved which allow any waste amenable to treatment or control to be discharged into any interstate water without treatment or control regardless of the water quality criteria and water use or uses adopted.*

Further, no standard will be approved which does not require all wastes, prior to discharge into any interstate water, to receive the best practicable treatment or control unless it can be demonstrated that a lessor degree of treatment or control will provide for water quality and enhancement commensurate with proposed present and future water uses."

— FWPCA Guideline, 1968

People questioned what authority the FWPCA thought they had to set "best practicable treatment" as the minimum level of treatment and what they meant by that term. In House hearings leading up to the Water Quality Improvement Act of 1970, Secretary Udall explained that "in practice, this guideline usually, but not always, means secondary treatment of municipal wastes . . . generally the States have agreed with us with regard to the requirement of secondary treatment." A number of officials from different states begged to differ with Secretary Udall and FWPCA's guideline. Not surprisingly, states offered up legal opinions that bluntly concluded that the FWPCA had no authority to set discharge limitations.

Against this backdrop, the Water Quality Improvement Act of l970 was passed. The act continued the authority of the states to set standards of water quality and the authority of the FWPCA to approve such standards. Congress, however, chose not to include any new provisions regarding standards or treatment levels.

Deciding that the battle for secondary treatment in municipal wastewater plants would be best fought on another stage, the FWPCA stepped back and issued a new construction grant regulation (36 FR 13029) in July 1971 that called for primary treatment as the minimum level of treatment:

"*To be eligible for a grant, a project must be designed to result in an operable treatment works, or part thereof, which will treat or stabilize sewage or industrial wastes of a liquid nature in order to abate, control, or prevent water pollution . . . such treatment or stabilization shall consist of at least primary treatment, or its equivalent, resulting in the substantially complete removal of settleable solids."*

— FWPCA Construction Grant Regulation
July 1971 (36 FR 13029)

After the FWPCA was reorganized out of existence, USEPA aggressively picked up the secondary treatment torch. In June 1972, prior to the passage of the Federal Water Pollution Control Act of 1972 in October, the Agency issued regulations that required grant projects to conform to secondary treatment requirements that included the removal of 85 percent of BOD_5 from POTW influent.

The Agency ruled that secondary treatment could be waived only for projects that:

- Discharged wastes to open ocean waters through an ocean outfall if such discharges would not adversely affect the open ocean waters and adjoining shores, and receive primary treatment before discharge.
- Treated or controlled combined sewer overflows if such projects were consistent with river basins or metropolitan plans to meet approved water quality standards.

The Federal Role in Secondary Treatment After the Clean Water Act

Enactment of the 1972 Amendments to the Federal Water Pollution Control Act, now popularly known as the Clean Water Act (CWA), by the 92nd U.S. Congress redirected national policy for water pollution control onto a new path. Sparked by publication of Rachel Carson's *Silent Spring* in 1962 (Carson, 1962), national publicity about environmental issues during the 1960s led to public awareness of the existence of nationwide air and water pollution problems and political demands by the "Green Movement" for governmental action to address pollution problems (Zwick and Benstock, 1971; Jobin, 1998).

On October 18, 1972, a new era for POTWs began when the 1972 Amendments to the Federal Water Pollution Control Act (PL 92-500) were unanimously passed by the U.S. Congress and, despite a veto by President Richard M. Nixon, who thought that the $24 billion investment over 5 years was "excessive and needless overspending," the act became law (Knopman and Smith, 1993). The act established a new national policy that firmly rejected the historically accepted use of rivers, lakes, and harbors as receptacles for inadequately treated wastewater. Congress's objective was clear. They wanted to "restore and maintain the chemical, physical and biological integrity of the nation's waters" and to attain "fishable and swimmable" waters throughout the Nation. With PL 92-500, the federal government took control of directing and defining the Nation's water pollution control programs. This commitment led to the completion of the urban water cycle in many communities across the United States.

Congress recognized that success or failure of PL 92-500's lofty objectives hinged on a combination of money, compliance, and enforcement. Consequently, the basic framework of the act included the following.

- Establishment of the National Pollutant Discharge Elimination System (NPDES), a program that requires that every point source discharger of pollutants obtain a permit and meet all the applicable requirements specified in regulations issued under sections 301 and 304 of the act. These permits are enforceable in both federal and state courts, with substantial penalties for noncompliance.
- Development of technology-based effluent limits, which serve as minimum treatment standards to be met by dischargers.
- An ability to impose more stringent water quality-based effluent limits where technology-based limits are inadequate to meet state water quality standards or objectives.
- Creation of a financial assistance program to build and upgrade POTWs. PL 92-500 authorized $5.0 billion in federal spending for fiscal year 1973, $6.0 billion for fiscal year 1974, and $7.0 billion for fiscal year 1975. In contrast, the year before the act was passed, a total of $1.25 billion (federal dollars) was spent. Under the construction grants program, the federal share was 75 percent of cost from fiscal years l973 to l983 and 55 percent thereafter. Additional funds were made available for projects using innovative and alternative treatment processes.

The story of the Clean Water Act and its evolution from 1972 to the present day is richly complicated. The purpose of this section is not to summarize all aspects of this landmark act. Rather, the objective is to focus on the role it played in implementing secondary treatment in the Nation's POTWs. Other sources, such as *The Clean Water Act, 25th Anniversary Edition*, published by the Water Environment Federation (WEF, 1997), should be consulted for a complete overview of the act. Figure 2-5 summarizes the key amendments and regulations that occurred from 1972 to the present.

The Water Pollution Control Act Amendments of 1972 (PL 92-500) and Secondary Treatment Information (38 FR 22298-22299), published in final on August 17, 1973

After debating the merits of secondary treatment for the better part of two decades, Congress finally put the issue to rest in the Federal Water Pollution Control Act Amendments of 1972. Section 301 *required* POTWs to achieve effluent limitations based on secondary treatment.

A simple, aggressive schedule was set to meet this requirement. By July 1, 1977, all existing POTWs and all facilities approved for construction before June 30, 1974, must incorporate secondary treatment. Then, by July 1, 1983, POTWs must meet an additional level of treatment described in the act as "best practicable wastewater treatment."

While developing the 1972 Amendments, Congress understood that the term *secondary treatment* needed to be carefully researched and clearly articulated before regulations could be drafted. At the time, several "working" definitions existed, including one offered by Congressman Vanik in the House debate on the amendment. He defined secondary treatment as a process that removes 80 to 90 percent of all harmful wastes from POTW influent.

Section 304(d)(1) directed USEPA to investigate and publish in the *Federal Register* "information, in terms of amounts of constituents and chemical, physical and biological characteristics of pollutants, on the degree of effluent reduction attainable through the application of secondary treatment." USEPA assembled a work group the next year to accomplish this task and invited outside commentators and contractors to participate.

Early on, the group decided that the effluent limitations to be used to define secondary treatment needed to include concentrations of key parameters as well as percent reduction limits. Also weighing in on the minds of the group was a congressional and public concern that if percent removal targets were set too high, incremental environmental benefits would not be worth the cost. Consequently, economic considerations became an important part of the decision-making process. Figure 2-6 is an example of how costs were analyzed in relation to percent removal targets for BOD_5. The graph shows that costs rise rapidly beyond the 85 to 88 percent removal level. Analyses such as these helped the work group put technical capabilities in a practical (i.e., economical) context.

In April 1973 USEPA published a proposed regulation based on the group's report. After comments were addressed, the Agency issued its final regulation on August 17, 1973. It defined secondary treatment effluent concentration limits for the following parameters:

Figure 2.5: Timeline of federal water pollution control acts, 1972 - 1996

1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996

Federal Water Pollution Control Act Amendments of 1972

The Federal Water Pollution Control Act of 1972 (later to be renamed the Clean Water Act) contained the first statutory requirement for a minimum of secondary treatment by all POTWs. The act also established the National Pollutant Discharge Elimination System (NPDES), under which every discharger of pollutants was required to obtain a permit. Under the permit each POTW is to discharge only effluent that had received secondary treatment. EPA defined secondary treatment in a regulation as attaining an effluent quality of at least 30 mg/L BOD_5, 30 mg/L TSS, and 85% removal of these pollutants, in a period of 30 consecutive days.

Clean Water Act Amendments of 1977

The Clean Water Act Amendments of 1977 created the 301(h) program, which waived the secondary treatment requirement for POTWs discharging to a marine environment if they could show that the receiving waters would not be adversely affected. Extensive requirements had to be met before such a waiver could be issued.

Clean Water Act Amendments of 1981, PL 97-117

The Clean Water Act Amendments of 1981 amended the Clean Water Act to the effect that “such biological treatment facilities as oxidation ponds, lagoons and ditches and trickling filters shall be deemed the equivalent of secondary treatment.” EPA is directed to provide guidance on design criteria for such facilities, taking into account pollutant removal efficiencies and assuring that water quality will not be adversely affected (Sec. 304(d)(4)). Regulations to this effect were published in final on September 20, 1984. Also, a notice was issued to solicit public comments on "problems related to meeting the percent removal requirements and on five options EPA was considering for amending the percent removal requirements.

National Municipal Policy, January 30, 1984

The EPA National Municipal Policy was published on January 30, 1984. It was designed to ensure that all POTWs met the compliance deadlines for secondary or greater treatment of discharges. The key to the policy is that it provides for POTWs that had not complied by the July 1, l988, deadline to be put on enforceable schedules. The policy has been outstandingly successful and has resulted in significant increases in compliance.

Secondary Treatment Regulations, June 3, 1985

The secondary treatment regulation published in final on June 3, 1985, revised the previous regulations published in Title 40, Part 133, of the Code of Federal Regulations. Specifically, on a 30-day average, the achievement of not less than 85% removal of BOD_5, $CBOD_5$ and suspended solids for conventional secondary treatment processes was required. However, for those treatment processes designated by the Congress as being equivalent to secondary treatment (such biological treatment facilities as oxidation ponds, lagoons, and ditches, and trickling filters), at least 65% pollution removal was required, provided that water quality was not adversely affected. Waste stabilization ponds were given separate suspended solids limits. Special consideration was provided for various influent conditions and concentration limits.

Secondary Treatment Regulations, January 27, 1989

This secondary treatment regulation allows adjustments for dry weather periods for POTWs serving combined sewers.

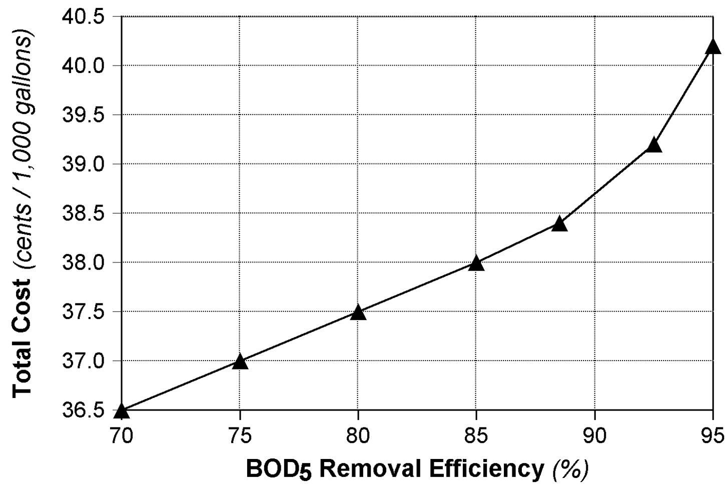


Figure 2-6

Cost versus BOD_5 removal efficiency of a new 1 million gallon per day POTW.

Source: USEPA, 1973.

- *5-day biochemical oxygen demand (BOD_5).* Average value for BOD_5 in effluent samples collected in a period of 30 consecutive days shall not exceed 30 milligrams per liter (mg/L). The average value for BOD_5 in effluent samples collected in a period of 7 consecutive days shall not exceed 45 mg/L.
- *Total suspended solids (TSS).* Average value for TSS in effluent samples collected in a period of 30 consecutive days shall not exceed 30 milligrams per liter (mg/L). The average value for TSS in effluent samples collected in 7 consecutive days shall not exceed 45 mg/L.
- *Fecal coliform bacteria.* Geometric mean of fecal coliform bacteria values for effluent samples collected in a period of 30 consecutive days shall not exceed 200 per milliliter (mL). The geometric mean of fecal coliform bacteria values for effluent samples collected in a period of 7 consecutive days shall not exceed 400 per milliliter (mL).
- *pH.* Effluent values for pH shall remain within the limits of 6.0 and 9.0.

Also included were percent removal limits for BOD_5 and TSS. Specifically, average values for BOD_5 and TSS in effluent samples collected in 30 consecutive days may not exceed 15 percent of the mean of influent samples collected at approximately the same times during the same period (85 percent removal).

The BOD and TSS limits were chosen based on an assumption that the wastewater entering a POTW (influent) contains about 200 mg/L of BOD_5 and TSS. Knowing this assumption did not hold true in every case, USEPA made a couple of allowances. Specifically, the Agency allowed a POTW to have higher BOD_5 and TSS concentrations in its effluent if the facility received more than 10 percent of its design flow from industrial facilities for which less stringent effluent limitations had been promulgated.

Special consideration was also given, on a case-by-case basis, to treatment works served by combined storm and sanitary sewer systems where increased flows during wet weather prevented the attainment of the defined minimum level of secondary treatment. Of chief concern was the 85 percent removal requirement. In stormy weather, storm water runoff dilutes the normal volume of influent, lowering BOD_5 and TSS concentrations. Expecting to reduce already reduced concentrations by 85 percent was beyond the means of many facilities.

Two subsequent amendments to the secondary treatment information were promulgated on July 26, 1976 (41 FR 30788) and October 7, 1977 (42 FR 5665). These changes provided for:

- Deletion of the fecal coliform bacteria limitations and clarification of the pH requirement.
- Special consideration for the TSS effluent limitations applicable to waste stabilization ponds with wastewater flows of less than 2 million gallons per day (mgd).

Publishing the regulation defining the minimum level of secondary treatment to be implemented by POTW facilities by 1977 was a major accomplishment for USEPA. On the horizon, however, loomed the prospect of developing a second, more stringent, level of requirements for implementation by July 1, 1983. Congress fortunately realized that this second set of requirements, or best practicable treatment, might not be needed. Section 315(b) of PL 92-500 established a national study commission to help them make this determination. Composed of five Senators, five Representatives, and five members of the public, the commission was given 3 years to accomplish this task. In the end, the group issued several general recommendations, one of which was that the secondary treatment effluent limits developed for the 1977 deadline not be changed for the 1983 deadline. Essentially, the commission determined that secondary treatment was the best practicable treatment for POTWs. Thus, the headaches associated with setting a second level of requirements were avoided.

The Clean Water Act Amendments of 1977 (PL 95-217)

The tight timetable Congress established for implementing secondary treatment proved to be unrealistic for many municipalities. In fact, only about 30 percent of major POTWs (those processing 1 million (or more) gallons of wastewater per day) were in compliance when the July 1, 1977, deadline rolled around. In many cases, upgrade schedules were slowed due to delays in receiving federal funds. The Clean Water Act Amendments of 1977 (PL 95-217) responded to this situation by allowing time extensions for municipalities encountering funding problems.

Time extensions aside, probably the most significant aspect of PL 95-217 in terms of secondary treatment was the fact that Congress backed off from PL 92-500's original objective of having all POTWs implement secondary treatment as a minimum technology-based standard. Municipalities discharging into ocean waters had been arguing that the benefits associated with their upgrading to secondary treatment were not worth the cost. The vastness of the marine environment, they said, effectively dilutes and incorporates wastes into the water and sea bottom without harming uses or the environment.

Congress agreed and added Section 301(h) to the Clean Water Act, allowing marine dischargers to apply for a waiver of secondary treatment requirements. EPA would subsequently review the application and issue modified NPDES permits to POTWs that met certain environmental criteria and received state concurrence. These criteria included

- Existence of and compliance with water quality standards.
- Protection and propagation of a balanced indigenous population of fish, shellfish, and wildlife.
- Allowance of recreational activities.
- Establishment of a monitoring program.
- Satisfactory toxics control programs, including an approved industrial pretreatment program.
- No additional treatment requirements for other sources.
- Acceptable discharge volume and pollutant limits.
- Protection of public water supplies (desalinization plants).

Municipal Wastewater Treatment Construction Grants Amendments of 1981 (PL 97-117) and Secondary Treatment Regulations (49 FR 36986-37014), published in final on September 20, 1984

When the decade of the 1980s dawned, the goal of implementing secondary treatment in the Nation's POTWs seemed a long way off. About half of the 20,000 municipal discharges, including more than 100 larger cities, were still not in compliance with the 1977 deadline. Construction projects were bogged down with funding problems, complicated regulatory procedures, and lack of staff at state and federal agencies. To address these and other problems, Congress passed the Construction Grants Amendments of 1981. Section 301(i) recognized that funding issues were still holding up secondary treatment compliance and therefore extended the implementation deadline to July 1, 1988, on a case-by-case basis.

PL 97-117 and its companion regulations also addressed another concern involving USEPA's definition of secondary treatment effluent requirements. In theory, the requirements were not intended to favor one treatment process over another, yet they did. As it turned out, activated sludge facilities were the only ones that could consistently meet the requirement of 85 percent removal of BOD_5 and TSS limits. This situation caused an immediate problem for the many smaller communities that had invested in trickling filters, waste stabilization ponds, and other types of biological wastewater treatment. Even when their facilities performed as designed, they were in noncompliance according to USEPA's standards for secondary treatment.

Upgrading or replacing these facilities was an expensive proposition. Many questioned whether environmental benefits gained would be worth the cost. Congress agreed and PL 97-117 and its companion regulations included the following:

- Introduced the concept of "equivalent of secondary treatment" to describe facilities that use a trickling filter or waste stabilization pond as a principal treatment process and which were not meeting the secondary treatment requirements as promulgated by USEPA in 1973.
- Lowered the minimum level of effluent quality to be achieved by those facilities during a 30-day period as an average value not to exceed 45 mg/L for BOD_5 and TSS, an average 7-day value for BOD_5 and TSS of not to exceed 65 mg/L, and a percentage removal of those constituents of not less than 65 percent (30-day average).

- Required that NPDES permit adjustments for "equivalent to secondary treatment" facilities reflect the performance or design capabilities of the facility and ensure that water quality is not adversely affected.

National Municipal Policy (49 FR 3832-3833), published on January 30, 1984

Continually pushing back the deadline for implementation of secondary treatment in POTWs created confusion. The 1972 Amendments had set the original deadline for compliance for l977. For some municipalities, it was extended to 1983 by PL 95-217 and then to 1988 by PL 97-117. The USEPA National Municipal Policy, published in the *Federal Register* on January 30, 1984, was designed to eliminate this confusion and ensure that all POTWs would comply with the statutory requirements and compliance deadlines in the Clean Water Act. It also established that where there were extraordinary circumstances that precluded compliance by the July 1, l988, deadline, POTWs would be put on enforceable schedules designed to achieve timely compliance. The policy described EPA's intentions to focus its efforts on

- POTWs that previously received federal funding assistance and are not in compliance.
- Other POTWs.
- Minor POTWs (less than 1 mgd capacity) that are contributing significantly to impairment of water quality.

This municipal treatment policy has been outstandingly successful, with over 90 percent compliance achieved to date for major POTWs (1 mgd or over).

Secondary Treatment Regulations, published in final on June 3, 1985

The secondary treatment requirement of 85 percent removal of BOD_5 and TSS continued to present problems for POTWs receiving diluted influent wastewater. Whether it was a secondary treatment facility (85 percent removal) or an equivalent of secondary treatment facility (65 percent removal), to stay in compliance a facility had to install advanced technology, even if it consistently met its concentration limits. Recognizing this problem, USEPA on November 16, 1983, published a *Federal Register* notice soliciting public comment on a number of options for amending the percent removal requirements.

Based on the public comments received, the Agency proposed and then finalized a revised Secondary Treatment Regulation. Published in final on June 3, 1985, it authorized USEPA to lower the percent removal requirement, or substitute a mass limit for the percent removal requirement, for certain POTWs. The Agency would make this determination on a case-by-case basis based on the removal capability of the treatment plant, the influent wastewater concentration, and the infiltration and inflow situation.

Treatment plants could apply for a permit adjustment in its percent removal limit only if

- The treatment plant is meeting or will consistently meet its other permit effluent concentration limitations, but its percent removal requirements cannot be met due to less concentrated influent wastewater for separated sewers.

- To meet the percent removal requirement, the treatment works would have to meet significantly more stringent concentration-based limitations.
- The less concentrated influent wastewater to the treatment works was not a result of excessive infiltration and inflow.

The concentration limits in the permit would remain unchanged, and in no case was a permit to be adjusted if the permitting authority determined that adverse water quality impacts would result from a change in permit limits.

Amendment to the Secondary Treatment Regulation, published in final on January 27, 1989 in the *Federal Register*

The Secondary Treatment Regulation published in June 1985 addressed the problem POTWs with separate sewers had in meeting percent reduction standards due to the dilution of influent wastewater by wet weather conditions. The city of New York also had a problem. Its combined sewer system delivered diluted influent to city POTWs, even during dry weather. Consequently, the city petitioned to be eligible for adjustments of percent removal requirements, too, arguing that nonexcessive infiltration can dilute the influent wastewater of treatment works served by combined sewers just as it does for treatment works served by separate sewers. USEPA agreed with this position and published an amendment to the regulation on January 27, 1989, to allow for percent removal adjustments during dry weather periods for POTWs with combined sewers. To obtain this adjustment the treatment works had to satisfy three conditions:

- It must consistently meet its permit effluent concentration limitations, but the percent removal requirements cannot be met due to less concentrated influent wastewater.
- Significantly more stringent effluent concentration than those required by the concentration-based standards must be met to comply with the percent removal requirements.
- The less concentrated influent wastewater must not result from either excessive infiltration or clear water industrial discharges to the system.

Regarding the last condition, the regulation established that if the average dry weather base flow (i.e., the total of the wastewater flow plus infiltration) in a combined sewer system is less than 120 gallons per day per capita (gpcd) threshold value, infiltration is assumed to be nonexcessive. However, sewer systems with average dry weather flows greater than 120 gpcd might also have nonexcessive infiltration if this is demonstrated on a case-by-case basis. An applicant, therefore, has an opportunity to demonstrate that its combined sewer system is not subject to excessive infiltration even if the average total dry weather base flow exceeds the 120 gpcd threshold value.

D. Nationwide Trends in BOD Loading Based on Population and POTW Treatment Design

From 1940 to the present day, the combination of advancing wastewater treatment technology, increased public concern, various state wastewater treatment regulations, and, finally, the 1972 CWA secondary treatment mandate resulted in an increased number of POTWs with at least secondary and, in many cases, greater than secondary levels of treatment. Table 2-2 presents descriptions of the six major types of treatment found at POTWs along with their corresponding design-based BOD_5 removal efficiency[1] (expressed as percent removal).

The total population in the United States grew rapidly in the latter half of the 20th century, increasing from around 140 million people in 1940 to about 270 million in 1996 (see Figure 2-2). This population growth meant POTWs not only had to upgrade their treatment processes to increase pollutant removal efficiency, but they had to accomplish it while dealing with increasing influent wastewater loads. This section examines trends concerning the Nation's expansion and upgrades of POTWs and analyzes how increased use of secondary and greater than secondary treatment after the 1972 CWA affected the rate of effluent BOD loading to the Nation's waterways. Specifically examined are the following:

- The inventory of POTWs in the United States.
- The number of people served by those POTWs and the amount of wastewater flow they generated.
- The rate of BOD entering POTWs (influent loading).
- The rate of BOD discharged by POTWs into receiving waterways (effluent loading).
- BOD removal efficiency of POTWs
- Projections of effluent BOD loading into the 21st century.

The information sources for this study include municipal wastewater inventories published by the U.S. Public Health Service from 1940 through 1968 (USPHS, 1951; NCWQ, 1976; USEPA, 1974) and USEPA's Clean Water Needs Surveys (CWNS) conducted from 1973 through 1996 (USEPA, 1976, 1978, 1980, 1982, 1984, 1986, 1989, 1993, 1997). Many of these sources categorize their information by the six types of wastewater treatment described in Table 2-2. Some sources, however, combine primary and advanced primary data and report it simply as "less than secondary" treatment data. Similarly, data for advanced secondary and advanced wastewater treatment are combined and reported as "greater than secondary" treatment data. To keep the categories consistent, this convention was followed in the analyses presented in this section.

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[1] Designed-based BOD_5 removal efficiencies are minimum requirements typically assigned by NPDES permits according to the treatment process and treatment plant design assumptions (Metcalf and Eddy, 1991). Generally, they represent conservative estimates of BOD_5 removal efficiencies. Many modern POTWs report a higher rate of BOD_5 removal than their permitted rate. This study, however, focuses on designed-based BOD_5 removal efficiencies because it is assumed that these conservative rates would provide a more effective and consistent comparison of BOD_5 removal over the entire historical period of record used in the analysis.

Table 2-2. Six levels of municipal wastewater treatment.

Treatment Type	Design BOD_5 Removal Efficiency	Description
Raw	0%	Wastewater is collected and discharged to surface waters without treatment, or removal, of pollutants from the influent stream.
Primary	35%	Incorporates physical processes of gravitational settling to separate settleable and floatable solids material from the raw wastewater. The removal of settleable solids results in the removal of pollutants associated with solid particles such as organic matter, nutrients, toxic chemicals, heavy metals, and pathogens. Other physical processes such as fine screens and filters can also be used.
Advanced Primary	50%	Enhancement of the primary clarification process using chemical coagulants such as metal salts and organic polyelectrolytes.
Secondary	85%	Biological processes are added to break down organic matter in the primary effluent by oxidation and production of bacterial biomass. Biological waste treatment systems, based on bacterial decomposition of organic matter, can be classified as activated sludge, waste stabilization ponds (suspended bacterial growth), and trickling filters (attached bacterial growth). 84 to 89 percent removal of TSS and 30 mg/L effluent concentration for BOD_5 and TSS.
• Activated sludge		Involves the use of bacteria to decompose suspended solids in the sewage so that they can be settled out. Oxygen to speed the bacteriological process is generated by mechanical aeration or by the infusion of additional oxygen. The solids produced (sludge) by the biological action are settled out and removed, except for a portion of the bacteria-rich sludge that is returned to the head of the secondary treatment process to activate the biological processes to treat sewage. This is the standard method of treatment for medium and large cities.
• Waste stabilization ponds		Pools in which mechanical aeration is used to supply oxygen to the bacteria. In other processes, oxygen is supplied by natural surface aeration or by algae photosynthesis with no mechanical aeration.
• Trickling filters		Employs a bed of highly permeable media such as crushed stone or plastic to which are attached microcosms for treating sewage sprayed on the media by a mechanical arm.
Advanced Secondary	90%	The conventional secondary treatment process incorporates chemically enhanced primary clarification and/or innovative biological treatment processes to increase the removal efficiency of suspended solids, BOD, and total phosphorus. Sludge production is typically increased overall as a result of the chemical enhancement of primary clarification and biological processes. Effluent concentrations of BOD_5 range from 10 to 30 mg/L and processes included to remove ammonia and phosphorus in excess of effluent levels typical for secondary treatment.
Advanced Wastewater Treatment	95%	Advanced wastewater treatment (AWT), or tertiary treatment, facilities are designed to achieve high rates of removal of nutrients (nitrogen or phosphorus), BOD, and suspended solids. Nitrogen removal is achieved by enhancement of the biological processes to incorporate nitrification (ammonia removal) and denitrification (nitrate removal). Phosphorus removal is accomplished by either chemical or biological processes. Addition of high doses of metal salts removes phosphorus while biological processes are dependent on the selection of high-phosphorus microorganisms. Additional removal of nutrients and organic carbon can be accomplished using processes such as high lime, granular activated carbon, and reverse osmosis. Effluent BOD_5 is generally less than 10 mg/L, and total-N removal is more than 50 percent.

Note: Readers desiring more technical details about these processes should review standard engineering reference texts (e.g., Metcalf & Eddy, 1991) or technical reports on wastewater treatment (e.g., NRC, 1993). Effluent removal efficiency and concentrations are from the 1978 USEPA Needs Survey (USEPA, 1978).

Types of BOD Reported in This Trends Analysis

BOD_5 is the most widely used measurement of BOD. In spite of its popularity, there are important limitations of this measurement. The subscript "5" refers to the laboratory incubation period of 5 days at 20 ºC. Many biochemical reactions that determine the ultimate consumption of DO in both wastewater and natural waters are not completed within the 5-day limit, however. Therefore, an estimate of "ultimate" BOD (BOD_u) of a sample requires consideration of all the biochemical processes that consume DO over a longer time scale. Figure 2-7 presents the relationships among the components of BOD_u.

Familiar to most environmental engineers is the oxygen demand associated with the bacterial decomposition of carbonaceous organic matter under aerobic conditions. Through respiration, organic matter is broken down and oxygen is consumed. Parameters in Figure 2-7 relating to carbonaceous BOD are:

- $CBOD_5$—BOD at 5 days that includes only the carbonaceous component of oxygen consumption.
- CBOD—BOD at an unspecified time that includes only the carbonaceous component of oxygen consumption.
- $CBOD_u$—Ultimate BOD of carbonaceous component of oxygen consumption at completion of decomposition process.

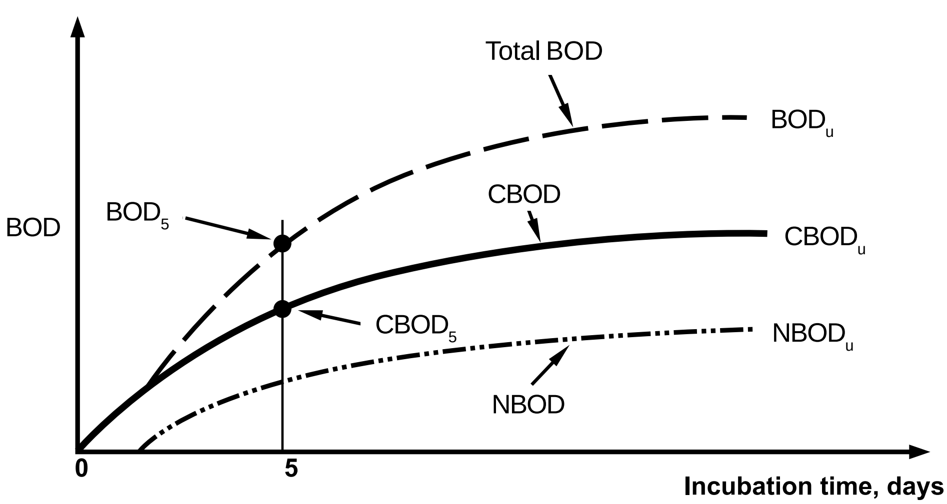
Along with the decomposition of carbonaceous matter is an additional oxygen demand associated with *nitrification*, the process that converts ammonia to nitrate. Nitrogen in wastewater generally appears as organic nitrogen compounds (urea, proteins, etc.) and ammonia. Over time, the nitrogen compounds are hydrolyzed and are converted to ammonia. Autotrophic bacteria of the genus *Nitrosomonas* convert the ammonia to nitrite, using oxygen in the process. Nitrite, in turn, is converted to nitrate by bacteria of the genus *Nitrobacter*, consuming additional oxygen in the process. Parameters in Figure 2-7 relating to nitrogenous BOD are

- NBOD—BOD at an unspecified time that includes only the nitrogenous component of oxygen consumption from nitrification.
- $NBOD_u$—Ultimate BOD of the nitrogenous component of oxygen consumption at completion of nitrification process.

Figure 2-7

Relationship between the carbonaceous, nitrogenous, and total BOD.

Source: Thomann and Mueller, 1987.



In Figure 2-7, carbonaceous and nitrogenous BOD components combine to yield the following parameters:

- BOD_5—BOD at 5 days that includes the carbonaceous and nitrogenous components of oxygen consumption.
- Total BOD—BOD at an unspecified time that includes the carbonaceous and nitrogenous components of oxygen consumption.
- BOD_u—Ultimate BOD of the carbonaceous and nitrogenous components of oxygen consumption at completion of both the carbonaceous decomposition and nitrification processes.

The length of time needed to reach the "ultimate" endpoints of the carbonaceous and nitrogenous components designated in Figure 2-7 ($CBOD_u$ and $NBOD_u$) depends on several factors, including the composition of the wastewater and the corresponding rate of decomposition for its components. For predominately labile fractions of organic carbon that are easy for bacteria to decompose (e.g., mostly sugars, short chain molecules), decomposition can be completed within about 20 to 30 days. In contrast, for refractory organic matter that is strongly resistant to bacterial decomposition (e.g., mostly cellulose, long chain molecules such as pulp and paper waste), complete decomposition might require an incubation period of anywhere from 100 to 200 days. Decomposition rates for a sample of wastewater effluent from a POTW with secondary treatment, consequently, tend to be lower than rates from raw wastewater because the easily decomposed sugars have already been removed by the treatment process.

Timing of the nitrification process is also dependent on several factors. These include the ratio of organic nitrogen compounds to ammonia and the lag time necessary to hydrolyze and convert the compounds to ammonia, the presence of adequate numbers of nitrifying bacteria in the water to begin the nitrification process, alkaline pH levels, and the presence of sufficient oxygen for bacterial respiration. The net effect of these factors is to inhibit nitrification immediately downstream from POTW outfalls (Chapra, 1997). Similarly, in a laboratory sample if a "seed" population is not available for nitrification during the 5-day incubation period, the measured BOD_5 will reflect only the carbonaceous component (i.e., $CBOD_5$). If, however, factors are sufficient for nitrification to occur in the laboratory sample, the measured BOD_5 will reflect both the carbonaceous and nitrogenous components (see Hall and Foxen, 1984).

Is incorporating the nitrogenous component and using BOD_u important enough to eschew the more familiar carbonaceous $CBOD_5$ when presenting BOD information? The answer is *yes*. Chapra (1997) calculates that the oxygen consumed in nitrification is about 30 percent of the oxygen consumed in carbonaceous oxidation of pure organic matter. If this finding was not persuasive enough for the inclusion of nitrification in an analysis of BOD, he also presents evidence that concentrations of NBOD and CBOD are actually nearly equivalent in untreated wastewater. Chapra theorizes that the discrepancy between calculated and the actual concentrations may be attributed to the fact that not all organic matter might be decomposable under the conditions of the BOD test and that nitrogen in wastewater might not all come from organic matter. Fertilizers and other sources likely add to the nitrogen pool, increasing the significance of NBOD in the environment.

In sum, the true measure of the long-term oxygen demand of influent and effluent BOD loading and its effect on water quality in streams and rivers can be determined only if both the carbonaceous and nitrogenous components of BOD are combined and analyzed as BOD_u. Since it is impractical for most monitoring programs and laboratories to extend the incubation period beyond the traditional 5 days associated with the determination of BOD_5, other surrogate methods must be used to determine $CBOD_u$, $NBOD_u$ and BOD_u. Discussed below are the methods used in this study to determine these parameters.

Determination of $CBOD_5$ and $CBOD_u$

BOD loading data for municipal and industrial wastewater dischargers are most often reported in NPDES permit limits and Discharge Monitoring Reports (DMRs) as either BOD_5 or $CBOD_5$. Unfortunately, in analyzing historical loading trends of municipal effluent it is impossible to determine if BOD_5 data compiled by various data sources included the suppression of possible nitrification during the laboratory analysis. In compiling long-term BOD loading trends, therefore, it is frequently assumed that BOD_5 is approximately equal to $CBOD_5$ (see Lung, 1998). This report makes the same assumption. Consequently, for the purposes of this study all BOD_5 data reported to the USEPA are considered to be $CBOD_5$.

Leo et al. (1984) and Thomann and Mueller (1987) point out that conversion ratios for estimating $CBOD_u$ concentrations based on either BOD_5 or $CBOD_5$ concentrations are dependent on the level of wastewater treatment. The proportion of easily degraded (labile) organic matter in the effluent declines as the efficiency of wastewater treatment is improved by upgrading a facility. In an analysis of effluent data from 114 primary to advanced municipal wastewater treatment plants, Leo et al. (1984) determined mean values of 2.47 and 2.84 for the $CBOD_u/BOD_5$ and $CBOD_u/CBOD_5$ ratios, respectively. The differences in the two ratios reflect the oxygen demand from nitrification associated with the BOD_5 data (see Hall and Foxen, 1984).

The assumption in this study that all BOD_5 concentrations reported to USEPA are actually $CBOD_5$ concentrations reduces the focus to only $CBOD_u/CBOD_5$ ratios as they relate to various levels of municipal wastewater treatment. Table 2-3 presents conversion ratios for four wastewater treatment types—raw, less than secondary, secondary, and greater than secondary. The formula for this conversion is:

$$CBOD_u = CBOD_5 \ [CBOD_u/CBOD_5 \ \text{ratio}] \qquad \text{Eq. (2.1)}$$

Table 2-3. $CBOD_u/CBOD_5$ conversion ratios. *Source: Thomann and Mueller, 1987; Leo et al., 1984)*

Municipal Wastewater Treatment Type			
Raw	Less than Secondary[a]	Secondary	Greater than Secondary[b]
1.2	1.6	2.84	2.9

[a] Primary and advanced primary wastewater treatment
[b] Advanced secondary and advanced wastewater treatment

Determination of $NBOD_u$

Recall that nitrogen in wastewater generally appears as organic nitrogen compounds and ammonia and that the organic nitrogen fraction can be remineralized to ammonia and contribute to the oxygen demand in a receiving water. NBOD, therefore, is defined as the oxygen equivalent of the sum of organic nitrogen and ammonia. Conveniently, total Kjeldahl nitrogen (TKN) is defined as the sum of organic nitrogen and ammonia-nitrogen and can be used with the stoichiometric equivalent oxygen:nitrogen ratio (O_2:N). A total of 4.57 g oxygen per 1 g nitrogen consumed in the nitrification process provides the basis for estimating the $NBOD_u$ of a sample. The formula for converting TKN to $NBOD_U$ concentration is:

$$NBOD_U = 4.57\ [TKN] \qquad \text{Eq. (2.2)}$$

Determination of BOD_u

The ultimate biochemical oxygen demand is determined by simply adding the carbonaceous and nitrogenous components.

$$BOD_U = [CBOD_U] + [NBOD_U] \qquad \text{Eq. (2.3)}$$

Trends in POTW Inventory

USPHS municipal wastewater inventories and the USEPA Clean Water Needs Surveys were the primary data sources used to document the inventory of POTWs in the United States before and after the CWA. Table 2-4 presents the national inventory for select years from 1940 to 1996 organized by treatment type. Figure 2-8 is a column chart displaying the POTW inventory data. The “No Discharge” category (data available beginning in 1972) refers to facilities that do not discharge their effluent to surface waters. Most facilities that fall into this category are oxidation/stabilization ponds designed for evaporation and/or infiltration of effluent. Other examples of “No Discharge” facilities include recycling, reuse, and spray irrigation systems.

Key observations from Table 2-4 and Figure 2-8 include the following:

- The total number of POTWs in the Nation increased by about 36 percent between 1950 and 1996.
- POTWs providing only raw and less than secondary treatment decreased in proportion to facilities providing secondary and greater than secondary treatment during the 1950-1996 time period. In 1950, only 30 percent of POTWs nationwide (3,529 of 11,784 facilities) provided secondary treatment. In 1968, 4 years before the CWA, 72 percent of the POTWs (10,052 of 14,051 facilities) had secondary treatment or greater. By 1996, 24 years after the 1972 CWA, 99 percent of the Nation’s 16,024 POTWs were providing either secondary treatment or greater or were no discharge facilities.
- In 1968, 72 percent of the Nation’s POTWs were providing secondary treatment and less than 1 percent were providing greater than secondary treatment. By 1996, 59 percent of POTWs were providing secondary treatment and 27 percent had greater than secondary treatment.

Table 2-4. Inventory of POTWs by wastewater treatment type, 1940 - 1996. *Source: U.S. Public Health Service Municipal Wastewater Inventories and USEPA Clean Water Needs Surveys.*

Inventory of POTWs		TREATMENT TYPE				
	Total	Raw	Less than Secondary	Secondary	Greater than Secondary	No Discharge
1940	NA	NA	2,938	2,630	0	NA
1950	11,784	5,156	3,099	3,529	0	NA
1962	11,698	2,262	2,717	6,719	0	NA
1968	14,051	1,564	2,435	10,042	10	NA
1972	19,355	2,265	2,594	9,426[a]	461	142
1978	14,850	91	4,278	6,608	2,888	985
1982	15,662	237	3,119	7,946	2,760	1,600
1988	15,708	117	1,789	8,536	3,412	1,854
1992	15,613	0	868	9,086	3,678	1,981
1996	16,024	0	176	9,388	4,428	2,032

[a] This total excludes 4,467 oxidation ponds and 142 land application facilities classified as secondary treatment facilities in EPA's 1972 inventory of municipal wastewater facilities (USEPA, 1972). They were excluded because (1) EPA did not categorize oxidation ponds as secondary treatment facilities in any other year covered in this analysis and (2) land application facilities are classified as "no discharge" facilities in subsequent years and therefore (to be consistent) they were included in the no discharge facilities category for 1972.

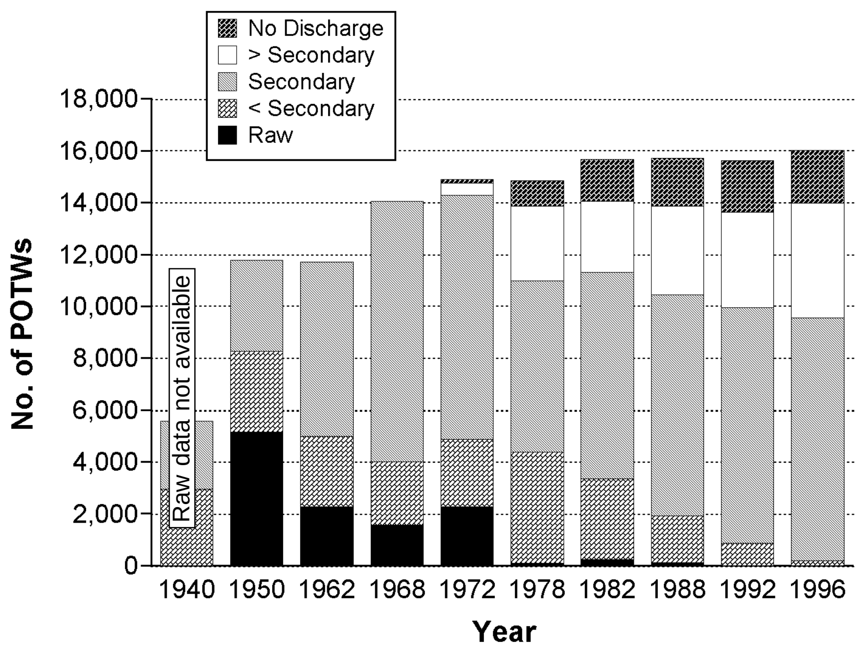


Figure 2-8

Number of POTWs nationwide for select years between 1940 and 1996 organized by wastewater treatment type.

Source: U.S. Public Health Service Municipal Wastewater Inventories and USEPA Clean Water Needs Surveys.

Trends in Population and Influent Wastewater Flow to POTWs

USPHS municipal wastewater inventories and the USEPA Clean Water Needs Surveys were the primary data sources used to document the population served by POTWs and the rate of influent wastewater flow to them between 1940 and 1996. Actual influent wastewater flow data were available from reports prepared for 1978, 1980, 1982, 1984, and 1986. For the years in which these data were not available, influent wastewater flow data were estimated based on the population served and an assumed constant normalized flow rate of 165 gallons per capita per day (gpcd). The influent wastewater flow rate of 165 gpcd is based on the mean of the total population served and wastewater flow data compiled in the USEPA Clean Water Needs Surveys for the five years for which actual wastewater flow data were reported (data ranged from 160 to 173 gpcd).

Influent wastewater includes residential (55 percent), commercial and industrial (20 percent), stormwater (4 percent), and infiltration and inflow (20 percent) sources of wastewater flow (AMSA, 1997). The constant per capita flow rate of 165 gpcd used in this study is identical to the typical U.S. average within the wide range (65 to 290 gpcd) of municipal water use that accounts for residential, commercial and industrial, and public water uses in the United States (Metcalf and Eddy, 1991).

Table 2-5 presents the population served by POTWs and the rate of influent wastewater flow to POTWs nationally for select years from 1940 to 1996. Figure 2-9 is a column chart displaying the population data.

Key observations from Table 2-5 and Figure 2-9 include the following:

- The population served by POTWs in the Nation increased significantly, from about 91.8 million people in 1950 to about 140.1 million in 1968 (four years before the 1972 CWA). By 1996, 189.7 million people were connected to POTWs, a 35 percent increase from 1968.
- The number of people relying on POTWs with less than secondary treatment dropped rapidly after passage of the 1972 CWA. In 1968 (4 years before the CWA), about 39 percent of the 140.1 million people were served by POTWs providing only raw or less than secondary wastewater treatment. By 1996 (24 years after the 1972 CWA), this percentage was reduced to about 9 percent; only 17.2 million people of the 189.7 million served by POTWs received less than secondary wastewater treatment.

  Stated another way, the U.S. population served by POTWs with secondary or greater treatment almost doubled between 1968 and 1996 from 85.9 million people in 1968 to 164.8 million people in 1996! (It is noted that 5.1 million of the 17.2 million people served by less than secondary facilities in 1996 were connected to 45 POTW facilities granted CWA Section 301(h) waivers (9 pending final waiver decision as of November 1998), which allow the discharge of primary or advanced primary effluent to deep, well-mixed ocean waters.)
- Although the number of people served by POTWs with secondary treatment remained fairly constant between 1968 and 1996 (a slight decrease of 3.7 million people or about 4 percent of the population), the number of people provided with greater than secondary treatment increased significantly (from 0.3 million people in 1968 to 82.9 million people in 1996). This is consistent with the trend since 1968 in increasing numbers of POTWs providing greater than secondary treatment, as shown in Table 2-4.

Table 2-5. Population served by and influent wastewater flow to POTWs by wastewater treatment type, 1940 - 1996.

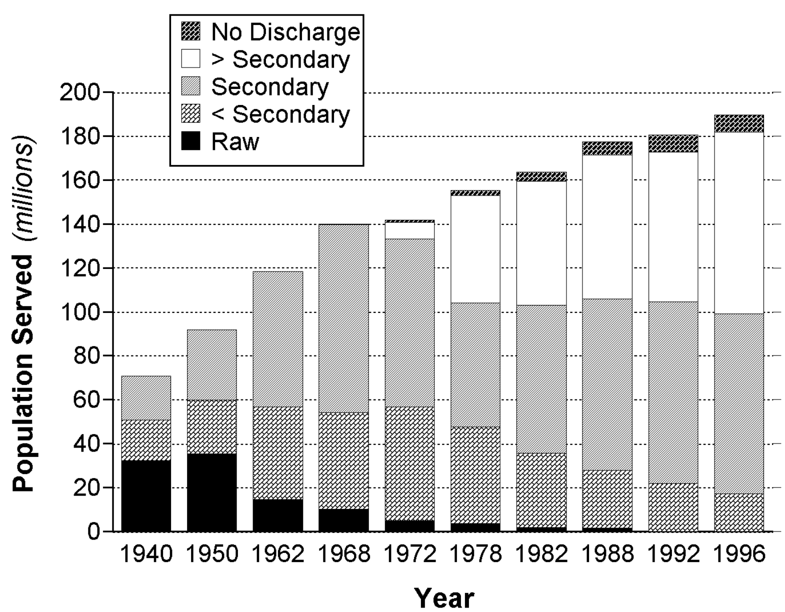
Population Served by POTWs (millions)		TREATMENT TYPE				
	Total	Raw	Less than Secondary	Secondary	Greater than Secondary	No Discharge
1940	70.5	32.1	18.4	20.0	0.0	NA
1950	91.8	35.3	24.6	31.9	0.0	NA
1962	118.3	14.7	42.2	61.5	0.0	NA
1968	140.1	10.1	44.1	85.6	0.3	NA
1972	141.7	4.9	51.9	76.3	7.8	0.8
1978	155.2	3.6	44.1	56.3	49.1	2.2
1982	163.5	1.9	33.6	67.6	56.3	4.2
1988	177.5	1.4	26.5	78.0	65.7	6.1
1992	180.6	0.0	21.7	82.9	68.2	7.8
1996	189.7	0.0	17.2	81.9	82.9	7.7

Influent Wastewater Flow to POTWs (mgd)						
Year	Total	Raw	Less than Secondary	Secondary	Greater than Secondary	No Discharge
1940	11,682	5,313	3,053	3,317	0	NA
1950	15,141	5,819	4,059	5,263	0	NA
1962	19,520	2,409	6,963	10,148	0	NA
1968	23,117	1,667	7,277	14,124	50	NA
1972	23,384	815	8,560	12,585	1,288	136
1978	26,800	601	7,152	10,139	8,545	363
1982	27,203	310	5,301	11,010	10,092	491
1988	29,294	226	4,370	12,863	10,832	1,003
1992	29,801	0	3,583	13,680	11,258	1,281
1996	31,302	0	2,834	13,521	13,683	1,264

Figure 2-9

Population served by POTWs nationwide for select years between 1940 and 1996 organized by wastewater treatment type.

Source: U.S. Public Health Service Municipal Wastewater Inventories and USEPA Clean Water Needs Surveys.



Trends in Influent BOD Loading to POTWs

Table 2-6 presents nationwide influent loading of $CBOD_5$, $CBOD_u$, $NBOD_u$, and BOD_u organized by wastewater treatment type for select years from 1940 to 1996.

Data Sources and Calculations

The USEPA Clean Water Needs Surveys were the primary data source used to estimate the nationwide rate of influent $CBOD_5$ loading to POTWs. Actual influent $CBOD_5$ loading data were reported for 1978, 1980, 1982, 1984, and 1986. For the years for which data were not available, per capita influent loading was assumed to be 0.296 lb $CBOD_5$ per person per day. This rate was based on an estimated constant normalized flow rate of 165 gallons per capita per day and an influent $CBOD_5$ concentration of 215 mg/L. The use of 215 mg/L as the influent $CBOD_5$ concentration is consistent with several other estimates of raw wastewater strength (e.g., AMSA, 1997; Tetra Tech, 1999; Metcalf and Eddy, 1991). It also is the mean nationally aggregated ratio of the total influent $CBOD_5$ loading rate normalized to total wastewater flow reported in the USEPA Clean Water Needs Surveys for the 5 years that actual wastewater flow data were reported (range from 209 to 229 mg/L). Sources of influent BOD include residential, commercial and industrial, and infiltration and inflow contributions.

Some readers might note that an influent loading rate of 0.296 lb $CBOD_5$ per person per day is almost twice the typical "textbook" value of 0.17 lb $CBOD_5$ per person per day, sometimes referred to as the "population equivalent" (PE) rate. Textbook values, however, usually account for only the average per capita residential load contributed by combined stormwater and domestic wastewater. The industrial and commercial components are excluded (see Fair et al., 1971). To provide a more complete characterization of influent BOD loading inclusive of all sources, the higher figure was used in this study.

$CBOD_u$ data were determined using $CBOD_5$ data and Equation 2.1 as follows:

$$CBOD_u = CBOD_5\,[1.2] \qquad \text{Eq. (2.4)}$$

where: $1.2 = CBOD_u/CBOD_5$ ratio associated with raw wastewater

The USEPA Clean Water Needs Surveys were the primary data source used to estimate the nationwide rate of influent $NBOD_u$ loading to POTWs. Actual influent TKN loading data were reported for 1978, 1980, 1982, 1984, and 1986. For the years for which wastewater flow data were not available, per capita influent loading was assumed to be 0.191 lb NBOD per person per day. This rate was based on an estimated constant normalized flow rate of 165 gallons per capita per day and an influent TKN concentration of 30.3 mg/L, a level derived from an analysis of about 100 wastewater facilities (AMSA, 1997). Influent $NBOD_u$ loading was determined using influent TKN data and Equation 2.2.

Trends in Influent $CBOD_5$ and BOD_u Loading to POTWs

Figure 2-10 is a column chart that compares total influent $CBOD_5$ and BOD_u loading from 1940 to 1996. Figures 2-11(a) and (b) display influent $CBOD_5$ and BOD_u loading data, respectively, organized by wastewater treatment type.

Table 2-6. Influent BOD loading to POTWs by wastewater treatment type, 1940 - 1996.

Influent $CBOD_5$ Loading (metric tons per day)

		TREATMENT TYPE				
Year	Total	Raw	Less than Secondary	Secondary	Greater than Secondary	On-Site
1940	9,508	4,324	2,484	2,699	0	NA
1950	12,323	4,736	3,303	4,283	0	NA
1962	15,886	1,961	5,667	8,259	0	NA
1968	18,814	1,356	5,922	11,495	40	NA
1972	19,032	663	6,967	10,242	1,049	111
1978	21,253	489	5,721	8,222	6,526	295
1982	21,170	252	4,280	8,623	7,616	400
1988	23,841	184	3,557	10,468	8,816	816
1992	24,254	0	2,916	11,134	9,162	1,043
1996	25,476	0	2,307	11,004	11,136	1,029

Influent $CBOD_u$ Loading (metric tons per day)

Year	Total	Raw	Less than Secondary	Secondary	Greater than Secondary	On-Site
1940	11,409	5,189	2,981	3,239	0	NA
1950	14,787	5,683	3,964	5,140	0	NA
1962	19,063	2,353	6,800	9,910	0	NA
1968	22,576	1,628	7,107	13,794	48	NA
1972	22,838	796	8,360	12,291	1,258	133
1978	25,503	587	6,865	9,866	7,831	354
1982	25,405	302	5,136	10,348	9,139	479
1988	28,609	220	4,268	12,562	10,579	980
1992	29,105	0	3,499	13,360	10,995	1,251
1996	30,571	0	2,768	13,205	13,363	1,235

Influent $NBOD_u$ Loading (metric tons per day)

Year	Total	Raw	Less than Secondary	Secondary	Greater than Secondary	On-Site
1940	6,123	2,785	1,600	1,738	0	NA
1950	7,936	3,050	2,128	2,758	0	NA
1962	10,232	1,263	3,650	5,319	0	NA
1968	12,117	874	3,814	7,403	26	NA
1972	12,257	427	4,487	6,597	675	71
1978	14,047	315	3,749	5,314	4,479	190
1982	14,259	162	2,778	5,771	5,290	257
1988	15,355	118	2,291	6,742	5,678	526
1992	15,621	0	1,878	7,171	5,901	672
1996	16,408	0	1,486	7,087	7,172	663

Influent BOD_u Loading (metric tons per day)

Year	Total	Raw	Less than Secondary	Secondary	Greater than Secondary	On-Site
1940	17,532	7,974	4,581	4,977	0	NA
1950	22,723	8,734	6,092	7,898	0	NA
1962	29,295	3,615	10,450	15,229	0	NA
1968	34,693	2,501	10,921	21,197	74	NA
1972	35,095	1,223	12,847	18,887	1,933	204
1978	39,551	901	10,614	15,181	12,310	544
1982	39,663	465	7,914	16,118	14,429	737
1988	43,964	339	6,558	19,304	16,257	1,506
1992	44,726	0	5,377	20,531	16,896	1,923
1996	46,979	0	4,254	20,292	20,536	1,897

Figure 2-10

Total influent BOD_u and $CBOD_5$ loading, 1940 to 1996.

Source: U.S. Public Health Service Municipal Wastewater Inventories and USEPA Clean Water Needs Surveys.

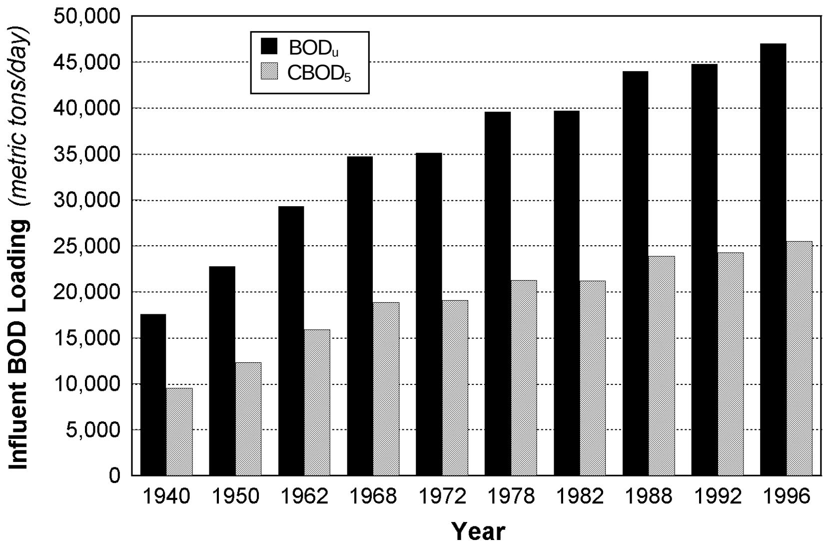
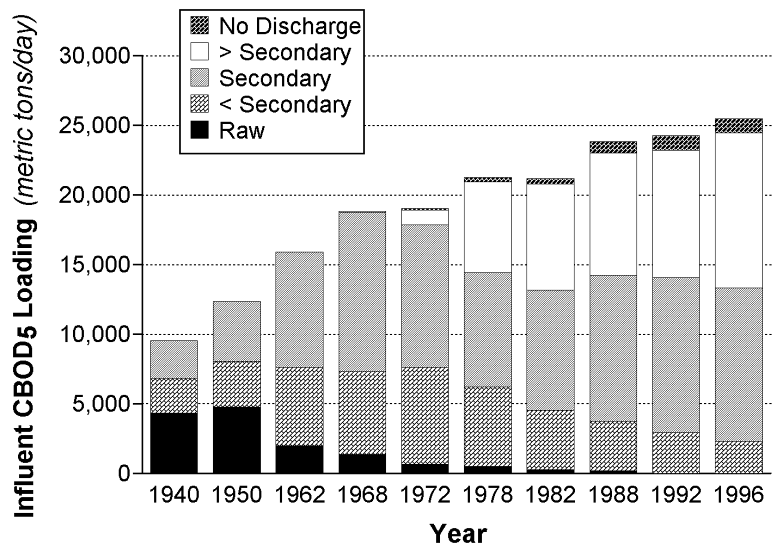


Figure 2-11

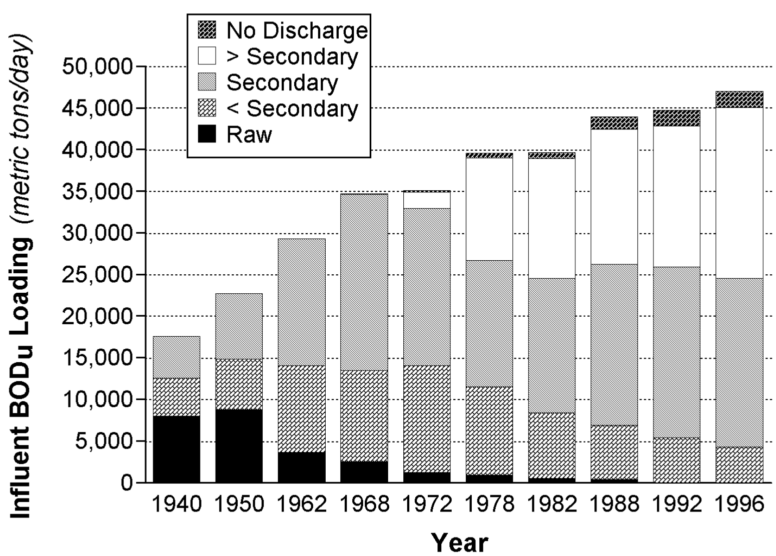
Influent loading of (a) $CBOD_5$ and (b) BOD_u to POTWs nationwide for select years between 1940 and 1996 organized by wastewater treatment type.

Source: U.S. Public Health Service Municipal Wastewater Inventories and USEPA Clean Water Needs Surveys.

(a)



(b)



Key observations from Table 2-6 and Figures 2-10 and 2-11 include the following:

- Influent BOD loading to the Nation's POTWs more than doubled from 1940 to 1996, reflecting population growth, increases in the number of facilities, and expanding service areas.
- Influent $CBOD_5$ loading increased from 9,508 metric tons per day in 1940 to 18,814 metric tons per day in 1968. By 1996, influent $CBOD_5$ loading stood at 25,476 metric tons per day, a 35 percent increase from 1968.
- Influent BOD_u loading increased from 17,532 metric tons per day in 1940 to 34,693 metric tons per day in 1968. By 1996, influent BOD_u loading stood at 46,979 metric tons per day, a 35 percent increase from 1968.
- In 1940, 72 percent of influent BOD_u loading nationwide was being treated by facilities with less than secondary treatment (12,555 of 17,532 metric tons per day of BOD_u). By 1968, 39 percent of influent BOD_u loading nationwide was being treated by facilities with less than secondary treatment (13,422 of 34,693 metric tons per day of BOD_u). Twenty-four years after the 1972 CWA, only 9 percent of influent BOD_u loading was being treated by facilities with less than secondary treatment (4,254 of 46,979 metric tons per day of BOD_u).

Trends in Effluent BOD Loading from POTWs

Table 2-7 presents nationwide effluent loading of $CBOD_5$, $CBOD_u$, $NBOD_u$, and BOD_u organized by wastewater treatment type for select years from 1940 to 1996.

Data Sources and Calculations

Effluent $CBOD_5$ loading rates were estimated based on influent $CBOD_5$ loading rates and $CBOD_5$ removal efficiencies (expressed as a percentage) associated with each type of municipal wastewater treatment (see Table 2-2). In keeping with the convention of combining primary and advanced primary treatment and designating the result as "less than secondary" treatment, $CBOD_5$ removal efficiencies for these two categories were averaged to derive a "less than secondary" treatment removal efficiency of 42.5 percent. Likewise, $CBOD_5$ removal efficiencies assigned to advanced secondary treatment (90 percent) and advanced wastewater treatment (95 percent) were averaged to derive a "greater than secondary" treatment removal efficiency of 92.5 percent. Table 2-8 presents $CBOD_5$ removal efficiencies by municipal wastewater treatment type and corresponding effluent $CBOD_5$ concentrations.

Recall that the $CBOD_5$ removal efficiencies used in this study are percentages typically assigned to NPDES permits according to the treatment process and POTW design assumptions (USEPA, 1978; Metcalf and Eddy, 1991). Use of "design-based" removal efficiencies may, in some cases, result in a conservative (i.e., high) estimate of effluent $CBOD_5$ loading. USEPA's Clean Water Needs Surveys for the years 1976, 1978 and 1982, for example, report 41 and 64 percent

Table 2-7. Effluent BOD loading from POTWs by wastewater treatment type, 1940 - 1996.

|---------- TREATMENT TYPE ----------|

Effluent $CBOD_5$ Loading (metric tons per day)

Year	Total	Raw	Less than Secondary	Secondary	Greater than Secondary	On-Site
1940	6,344	4,324	1,615	405	0	NA
1950	7,526	4,736	2,147	642	0	NA
1962	6,883	1,961	3,684	1,239	0	NA
1968	6,932	1,356	3,849	1,724	2	NA
1972	6,768	663	4,501	1,536	68	0
1978	5,510	489	2,654	1,596	771	0
1982	4,380	252	1,975	1,539	614	0
1988	4,460	184	2,045	1,570	661	0
1992	4,034	0	1,677	1,670	687	0
1996	3,812	0	1,326	1,651	835	0

Effluent $CBOD_u$ Loading (metric tons per day)

Year	Total	Raw	Less than Secondary	Secondary	Greater than Secondary	On-Site
1940	8,922	5,189	2,584	1,150	0	NA
1950	10,943	5,683	3,436	1,825	0	NA
1962	11,765	2,353	5,894	3,518	0	NA
1968	12,689	1,628	6,159	4,897	6	NA
1972	12,558	796	7,201	4,363	198	0
1978	11,621	587	4,246	4,533	2,255	0
1982	9,582	302	3,160	4,371	1,749	0
1988	9,869	220	3,272	4,460	1,918	0
1992	9,418	0	2,683	4,743	1,993	0
1996	9,232	0	2,122	4,688	2,422	0

Effluent $NBOD_u$ Loading (metric tons per day)

Year	Total	Raw	Less than Secondary	Secondary	Greater than Secondary	On-Site
1940	5,146	2,785	1,248	1,113	0	NA
1950	6,475	3,050	1,660	1,765	0	NA
1962	7,514	1,263	2,847	3,404	0	NA
1968	8,591	874	2,975	4,738	4	NA
1972	8,273	427	3,500	4,222	125	0
1978	7,526	315	2,924	3,401	886	0
1982	7,168	162	2,167	3,693	1,145	0
1988	7,327	118	1,787	4,315	1,107	0
1992	7,205	0	1,465	4,589	1,151	0
1996	7,093	0	1,159	4,536	1,399	0

Effluent BOD_u Loading (metric tons per day)

Year	Total	Raw	Less than Secondary	Secondary	Greater than Secondary	On-Site
1940	14,068	7,974	3,832	2,262	0	NA
1950	17,419	8,734	5,095	3,590	0	NA
1962	19,278	3,615	8,740	6,922	0	NA
1968	21,281	2,501	9,134	9,635	11	NA
1972	20,831	1,223	10,701	8,585	322	0
1978	19,147	901	7,171	7,934	3,141	0
1982	16,750	465	5,327	8,064	2,894	0
1988	17,196	339	5,059	8,774	3,025	0
1992	16,623	0	4,147	9,332	3,144	0
1996	16,325	0	3,281	9,224	3,821	0

Table 2-8. $CBOD_5$ removal efficiencies by municipal wastewater treatment type and corresponding effluent $CBOD_5$ concentrations.

	Municipal Wastewater Treatment Type			
	Raw	Less than Secondary[a]	Secondary	Greater than Secondary[b]
$CBOD_5$ removal efficiency (%)	0.0	42.5	85.0	92.5
$CBOD_5$ conc. in effluent (mg/L)	215[c]	123.6	32.3	16.1

[a] Primary and advanced primary wastewater treatment.
[b] Advanced secondary and advanced wastewater treatment.
[c] Equivalent to $CBOD_5$ conc. in (untreated) influent

$CBOD_5$ removal efficiency for primary and advanced primary facilities, respectively. These same reports present removal efficiencies for secondary (82 to 86 percent), advanced secondary (89-92 percent), and advanced wastewater treatment (87 to 94 percent) either in the range or very near to the range of design-based removal efficiencies. The design-based $CBOD_5$ removal efficiencies were chosen for use in this study over actual reported efficiencies because it was assumed that a conservative approach would provide a more effective and consistent comparison of trends for POTW BOD removal over the entire period of record analyzed.

Effluent $CBOD_u$ loading rates were estimated for each category of wastewater treatment from effluent $CBOD_5$ loading rates and the corresponding $CBOD_u/CBOD_5$ ratio (see Table 2-3) using Equation 2.1. $CBOD_u$ removal efficiencies for each treatment category were then computed from the influent (I) and effluent (E) loading as:

$$\text{Percent Removal Efficiency} = \frac{(I - E)}{I} \times 100 \qquad \text{Eq. (2.5)}$$

Table 2-9 presents the calculated $CBOD_u$ removal efficiencies by municipal wastewater treatment type and corresponding effluent $CBOD_u$ concentrations.

Effluent $NBOD_u$ loading rates were estimated based on influent $NBOD_u$ and $NBOD_u$ removal efficiencies reported for TKN (expressed as a percentage)

Table 2-9. $CBOD_u$ removal efficiencies by municipal wastewater treatment type and corresponding effluent $CBOD_u$ concentrations.

	Municipal Wastewater Treatment Type			
	Raw	Less than Secondary[a]	Secondary	Greater than Secondary[b]
$CBOD_u$ removal efficiency (%)	0.0	23.3	64.5	81.9
$CBOD_u$ conc. in effluent (mg/L)	258[c]	197.8	91.6	46.8

[a] Primary and advanced primary wastewater treatment.
[b] Advanced secondary and advanced wastewater treatment.
[c] Equivalent to $CBOD_u$ conc. in (untreated) influent

Table 2-10. TKN and $NBOD_u$ removal efficiencies by municipal wastewater treatment type and corresponding effluent TKN and $NBOD_u$ concentrations.

	Municipal Wastewater Treatment Type			
	Raw	Less than Secondary[a]	Secondary	Greater than Secondary[b]
TKN & $NBOD_u$ removal efficiency (%)	0.0	22.0	36.0	80.5
TKN conc. in effluent (mg/L)	30.3	23.6	19.4	5.9
$NBOD_u$ conc. in effluent (mg/L)	138.5[c]	108.0	88.6	27.0

[a] Primary and advanced primary wastewater treatment.
[b] Advanced secondary and advanced wastewater treatment.
[c] Equivalent to $NBOD_u$ conc. in (untreated) influent

Table 2-11. BOD_u removal efficiencies by municipal wastewater treatment type and corresponding effluent BOD_u concentrations.

	Municipal Wastewater Treatment Type			
	Raw	Less than Secondary[a]	Secondary	Greater than Secondary[b]
BOD_u removal efficiency (%)	0.0	22.9	54.5	81.4
BOD_u conc. in effluent (mg/L)	396.5[c]	305.8	180.2	73.8

[a] Primary and advanced primary wastewater treatment.
[b] Advanced secondary and advanced wastewater treatment.
[c] Equivalent to BOD_u conc. in (untreated) influent.

associated with each category of wastewater treatment. Removal efficiencies for TKN were based on data compiled in Gunnerson et. al (1982) for primary facilities, AMSA (1997) for secondary facilities, and AMSA (1997) and MWCOG (1989) for advanced wastewater treatment facilities. Since $NBOD_u$ is estimated from TKN and the constant stoichiometric ratio of 4.57 g O_2 $(gN)^{-1}$, removal efficiencies for TKN and $NBOD_u$ have the same value for the various categories of wastewater treatment. Table 2-10 presents TKN removal efficiencies and effluent concentrations as TKN and $NBOD_u$.

The effluent BOD_u loading rates were determined by adding the calculated $CBOD_u$ and $NBOD_u$ loading rates. BOD_u removal efficiencies for each treatment category were then computed from the influent (I) and effluent (E) BOD_u loading rates according to Equation 2.4. Table 2-11 presents the calculated BOD_u removal efficiencies by municipal wastewater treatment type and corresponding effluent BOD_u concentrations.

Trends in Effluent $CBOD_5$ and BOD_u Loading From POTWs

Figure 2-12 is a chart that compares effluent $CBOD_5$ and BOD_u loading over the same time period. Figures 2-13(a) and 2-13(b) display effluent $CBOD_5$ and BOD_u loading data organized by wastewater treatment type.

Figure 2-12

Total effluent BOD_u and $CBOD_5$ loading, 1940 to 1996.

Source: U.S. Public Health Service Municipal Wastewater Inventories and USEPA Clean Water Needs Surveys.

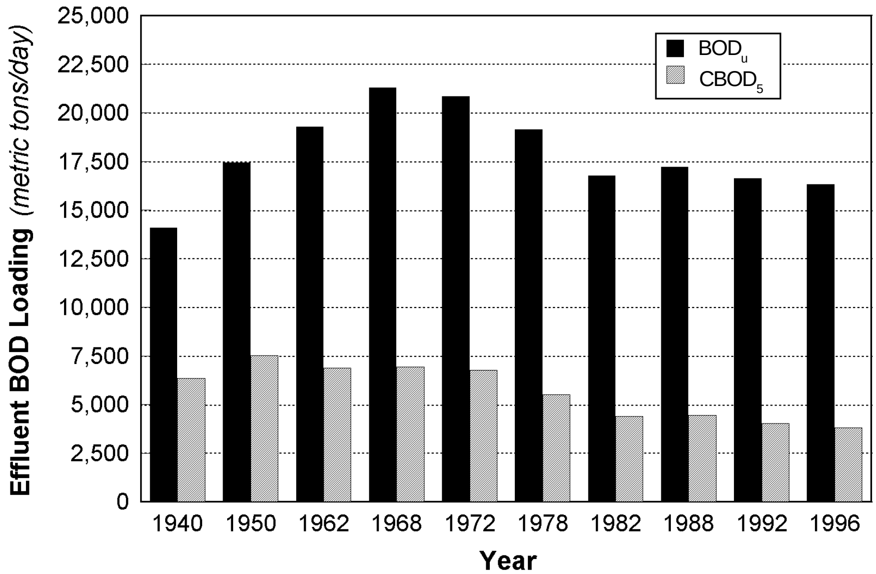
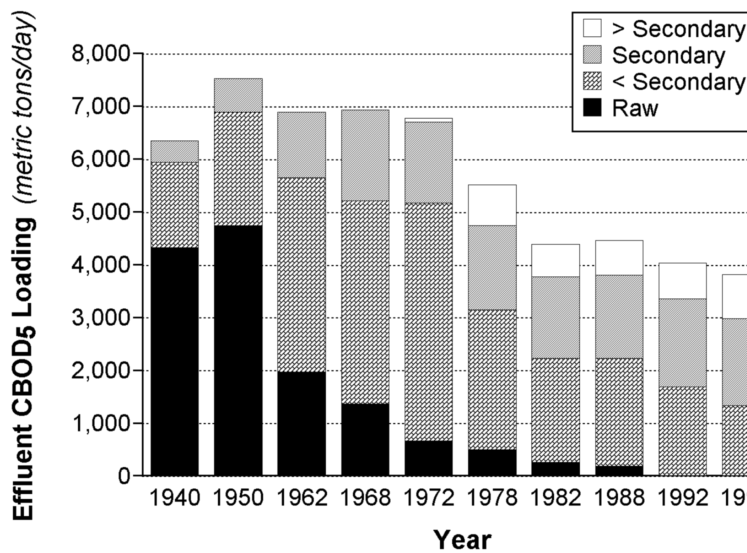


Figure 2-13

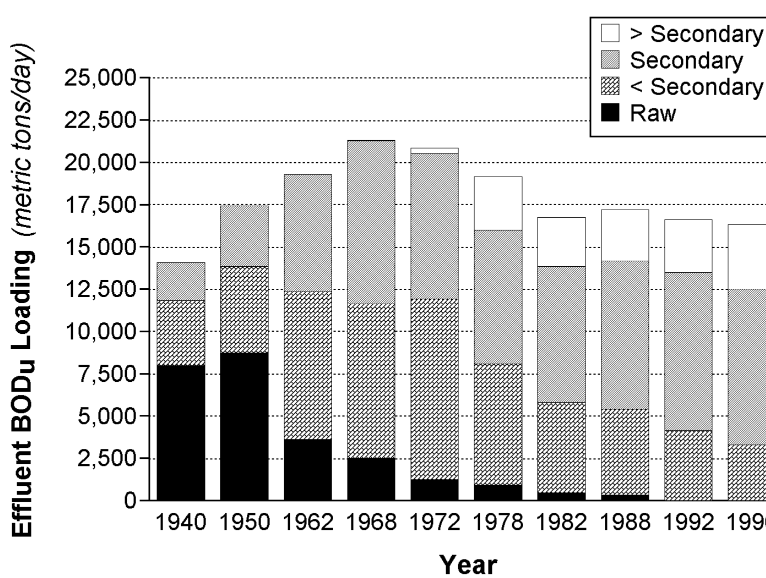
Effluent loading of (a) $CBOD_5$ and (b) BOD_u from POTWs nationwide for select years between 1940 and 1996 organized by wastewater treatment type.

Source: U.S. Public Health Service Municipal Wastewater Inventories and USEPA Clean Water Needs Surveys.

(a)



(b)



Key observations from Table 2-7 and Figures 2-12 and 2-13 include the following:

- Effluent BOD loading by POTWs was significantly reduced between 1968 and 1996. In 1968, 4 years before the 1972 CWA, effluent $CBOD_5$ and BOD_u loadings were 6,932 and 21,281 metric tons per day, respectively. By 1996 $CBOD_5$ and BOD_u loadings were reduced to 3,812 and 16,325 metric tons per day, respectively. This represents a 45 percent decline in $CBOD_5$ and a 23 percent decline in BOD_u between 1968 and 1996. Notably, these declines were achieved even though influent $CBOD_5$ and BOD_u loading to POTWs each increased by 35 percent during the same time period!
- The proportion of effluent $CBOD_5$ loading attributable to raw and less than secondary wastewater treatment was reduced from about 94 percent in 1940 to 35 percent in 1996 (see Figure 2-13(a)). The proportion of effluent BOD_u loading attributable to raw and less than secondary wastewater treatment was reduced from about 84 percent in 1940 to 20 percent in 1996 (see Figure 2-13(b)).

Trends in BOD Removal Efficiency

The rate of effluent BOD loading from a POTW is determined by two main factors, the rate of influent BOD loading and the BOD removal efficiency of the facility. Influent BOD loading, in turn, is determined by the number of people connected to the system and the rate at which they generate and export BOD in their wastewater flow. The analysis above indicates that tremendous progress was achieved between 1968 and 1996 in reducing effluent BOD loading from POTWs into the Nation's waterways. Notably, this reduction occurred at the same time the number of people served by POTWs was increasing rapidly. Figures 2-14 and 2-15 present influent and effluent loadings and removal efficiencies for $CBOD_5$ and BOD_u, respectively.

Key observations from Figures 2-14 and 2-15 include the following:

- BOD removal efficiency nationwide significantly increased between 1940 and 1996. In 1940 the aggregate national removal efficiency stood at about 33 percent for $CBOD_5$ and 20 percent for BOD_u. By 1968 removal efficiencies had increased to 63 percent for $CBOD_5$ and 39 percent for BOD_u. By 1996 they had further increased to nearly 85 percent for $CBOD_5$ and 65 percent for BOD_u!
- The BOD removal efficiency increased substantially between 1972 and 1978, the 6-year period after the passage of the CWA (from 64 to 74 percent for $CBOD_5$ and from 41 to 52 percent for BOD_u). Between 1978 and 1996 removal efficiency increased an additional 11 percent for $CBOD_5$ and 13 percent for BOD_u. Those larger increases in BOD_u removal efficiency reflect the ever-increasing role of greater-than-secondary POTWs over this time period.

Figure 2-14

Total POTW influent and effluent $CBOD_5$ loading and corresponding $CBOD_5$ removal efficiency for select years between 1940 and 1996.

Source: U.S. Public Health Service Municipal Wastewater Inventories and USEPA Clean Water Needs Surveys.

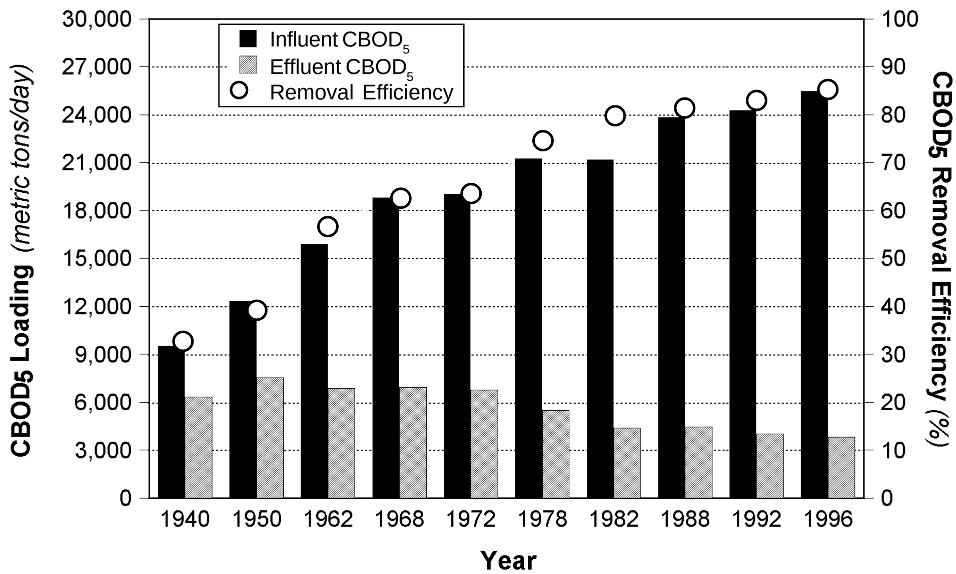


Figure 2-15

Total POTW influent and effluent BOD_u loading and corresponding BOD_u removal efficiency for select years between 1940 and 1996.

Source: U.S. Public Health Service Municipal Wastewater Inventories and USEPA Clean Water Needs Surveys.

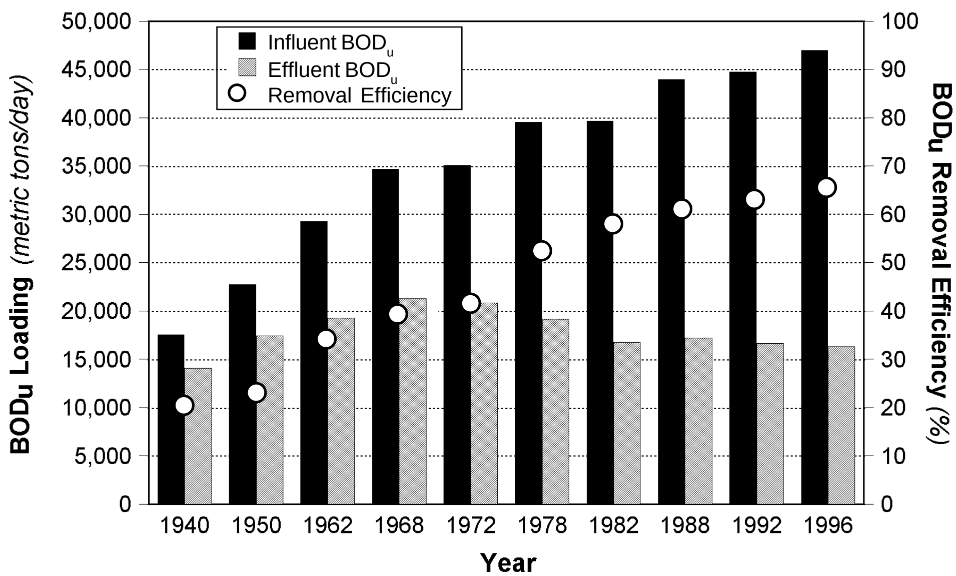


Figure 2-16, a three-dimensional graph of the population data presented earlier in Table 2-5 and Figure 2-9, is useful for visualizing the trends in population served by POTW treatment type. The population served by secondary treatment facilities declined sharply between 1968 (85.6 million) and 1978 (56.3 million) and then leveled off at about 82 million in the 1990s. In contrast, the number of people served by greater than secondary treatment surged between 1968 and 1978 (0.3 to 49.1 million) and then increased steadily to about 82.9 million in 1996. Unlike secondary treatment, advanced wastewater treatment enhances biological processes to incorporate nitrification (ammonia removal) and denitrification (nitrate removal), thus reducing the NBOD fraction of effluent BOD_u loading.

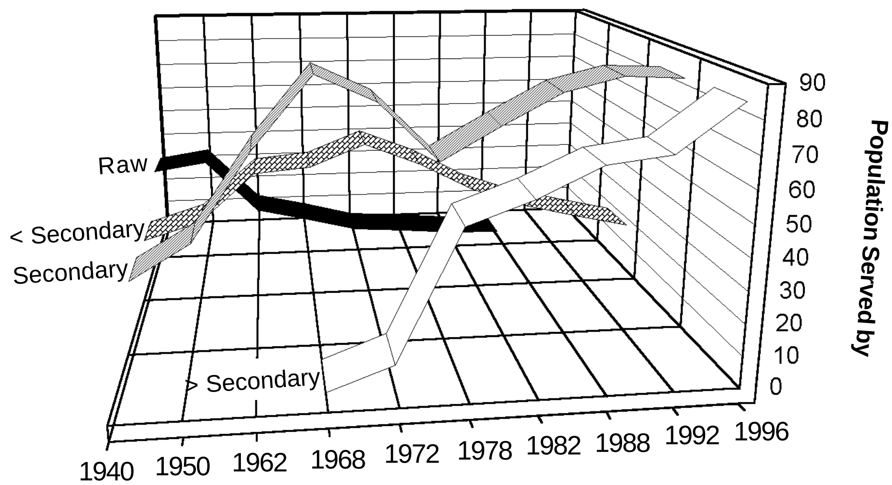


Figure 2-16

Population served by POTWs nationwide for select years between 1940 and 1996 organized by wastewater treatment type.

Source: U.S. Public Health Service Municipal Wastewater Inventories and USEPA Clean Water Needs Surveys.

Future Trends in BOD Effluent Loading

The data presented in the previous sections indicate that the increase in BOD removal efficiency between 1940 and 1996 resulted in significant reductions in BOD effluent loading to the Nation's waterways even though the number of people served by POTWs greatly increased. *Given that the population served by POTWs is projected to continue to increase well into the 21st century, will the trend of effluent BOD loading reductions also continue into the future?* A preliminary examination of estimated influent and effluent BOD loadings based on USEPA projections of facility inventory and population served for the year 2016 indicates that the answer might be "no."

Table 2-12 presents a summary of the population served, wastewater flow, influent and effluent BOD loading rates, and BOD removal efficiencies for 1996 and corresponding projections for 2016 and 2025. Figure 2-17 is a column chart that extends the influent and effluent BOD_u loading totals and POTW removal efficiencies originally presented in Figure 2-15 into the 21st century by adding columns for the years 2016 and 2025 to the chart. These projections are based on the following assumptions:

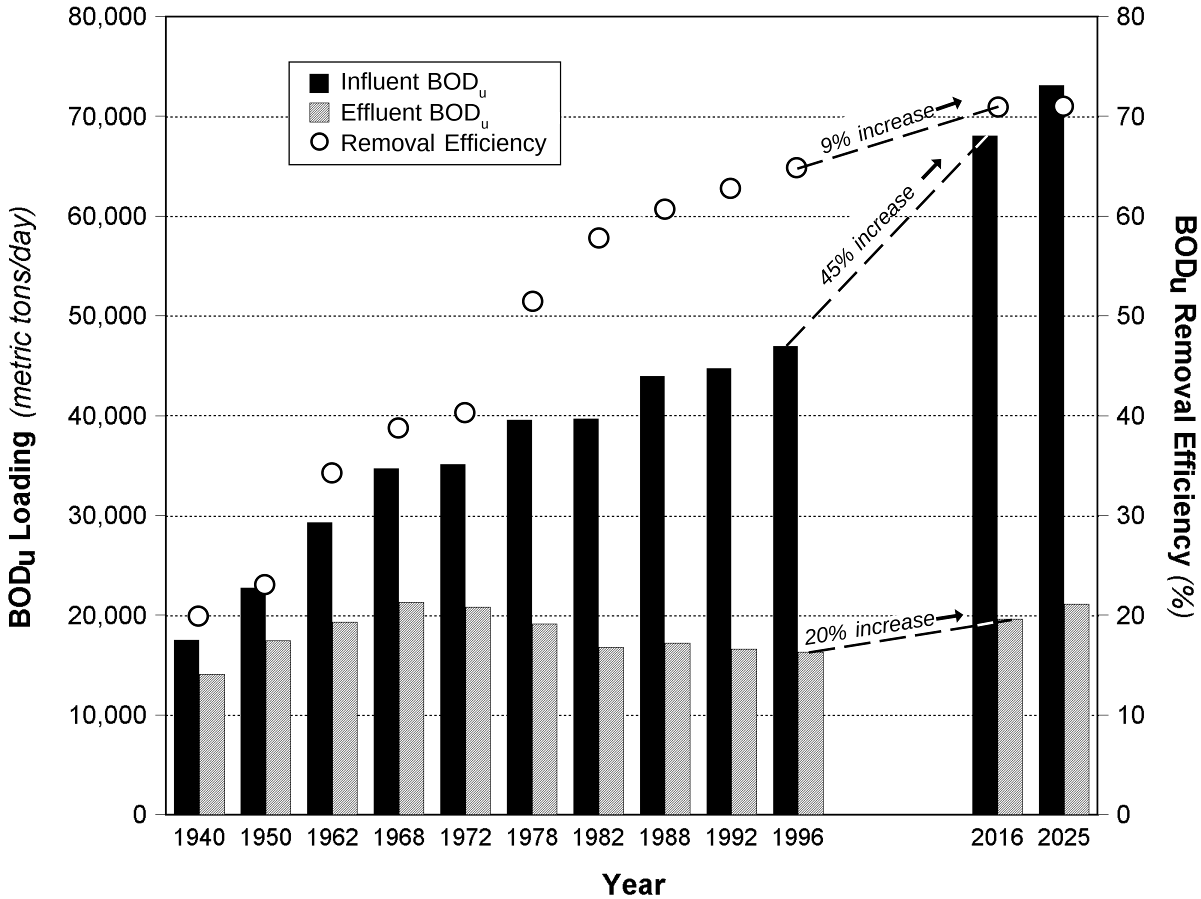
- USEPA Clean Water Needs Survey (USEPA, 1997) estimates that 275 million people will be served by POTWs in the year 2016. This figure is based on middle-level population projections from the Census Bureau (USBC, 1996) and the assumption that 88 percent of the population will be served by POTWs in 2016. Assuming that 88 percent of the population projected for 2025 is also served by POTWs, about 295 million people will be served by POTWs.
- Design-based BOD_u removal efficiency will increase from a nationwide average of 65 percent in 1996 to 71 percent by 2016 based on projections of population served by the different categories of POTWs. This removal efficiency is assumed to remain at that level through 2025.
- Influent wastewater flow will remain a constant 165 gpcd and influent BOD_u concentration will remain a constant 396.5 mg/L for the projection period from 1996 to 2025.

Table 2-12. 1996 estimates and 2016 and 2025 projections of POTW infrastructure and influent and effluent BOD loading.

		TREATMENT TYPE				
1996	**Total**	**Raw**	**Less than Secondary**	**Secondary**	**Greater than Secondary**	**On-Site**
Inventory of POTWs	16,024	0	176	9,388	4,428	2,032
Population of U.S. *(millions)*	263.4	-	-	-	-	-
Population served *(millions)*	189.7	0	17.2	81.9	82.9	7.7
Percent of population served	72%	-	-	-	-	-
Influent wastewater flow *(mgd)*	31,302	0	2,834	13,521	13,683	1,264
Unit flow *(gallons/person/day)*	165	-	-	-	-	-
Influent $CBOD_5$ loading *(metric tons/day)*	25,476	0	2,307	11,004	11,136	1,029
Influent $CBOD_u$ loading *(metric tons/day)*	30,571	0	2,768	13,205	13,363	1,235
Influent $NBOD_u$ loading *(metric tons/day)*	16,408	0	1,486	7,087	7,172	663
Influent BOD_u loading *(metric tons/day)*	46,978	0	4,254	20,292	20,536	1,897
Effluent $CBOD_5$ loading *(metric tons/day)*	3,812	0	1,326	1,651	835	-
Effluent $CBOD_u$ loading *(metric tons/day)*	9,232	0	2,122	4,688	2,422	-
Effluent $NBOD_u$ loading *(metric tons/day)*	7,093	0	1,159	4,536	1,399	-
Effluent BOD_u loading *(metric tons/day)*	16,325	0	3,281	9,224	3,821	-
$CBOD_5$ percent removal	85%	-	42%	85%	92%	-
$CBOD_u$ percent removal	70%	-	23%	64%	82%	-
$NBOD_u$ percent removal	57%	-	22%	36%	80%	-
BOD_u percent removal	65%	-	23%	54%	81%	-
2016	**Total**					
Inventory of POTWs	18,303	0	61	9,738	6,135	2,369
Population of U.S. *(millions)*	311.5	-	-	-	-	-
Population served *(millions)*	274.7	0	5.5	102.3	152.7	14.2
Percent of population served	88%	-	-	-	-	-
Influent wastewater flow *(mgd)*	45,329	0	910	16,883	25,200	2,337
Unit flow *(gallons/person/day)*	165	-	-	-	-	-
Influent $CBOD_5$ loading *(metric tons/day)*	36,892	0	740	13,740	20,509	1,902
Influent $CBOD_u$ loading *(metric tons/day)*	44,270	0	888	16,489	24,611	2,282
Influent $NBOD_u$ loading *(metric tons/day)*	23,760	0	477	8,850	13,209	1,225
Influent BOD_u loading *(metric tons/day)*	68,030	0	1,365	25,338	37,819	3,507
Effluent $CBOD_5$ loading *(metric tons/day)*	4,025	0	426	2,061	1,538	-
Effluent $CBOD_u$ loading *(metric tons/day)*	10,995	0	681	5,853	4,461	-
Effluent $NBOD_u$ loading *(metric tons/day)*	8,611	0	372	5,664	2,576	-
Effluent BOD_u loading *(metric tons/day)*	19,607	0	1,053	11,517	7,036	-
$CBOD_5$ percent removal	89%	-	42%	85%	92%	-
$CBOD_u$ percent removal	75%	-	23%	64%	82%	-
$NBOD_u$ percent removal	64%	-	22%	36%	80%	-
BOD_u percent removal	71%	-	23%	54%	81%	-

2025 ***Totals Only***	**Total**		**Total**
Inventory of POTWs	-		
Population of U.S. *(millions)*	335.1	Effluent $CBOD_5$ loading *(metric tons/day)*	4,330
Population served *(millions)*	295.5	Effluent $CBOD_u$ loading *(metric tons/day)*	11,827
Percent of populaton served	88.2%	Effluent $NBOD_u$ loading *(metric tons/day)*	9,263
Influent wastewater flow *(mgd)*	48,760	Effluent BOD_u loading *(metric tons/day)*	21,090
Unit flow *(gallons/person/day)*	165		
Influent $CBOD_5$ loading *(metric tons/day)*	39,684	$CBOD_5$ percent removal	89%
Influent $CBOD_u$ loading *(metric tons/day)*	47,620	$CBOD_u$ percent removal	75%
Influent $NBOD_u$ loading *(metric tons/day)*	25,558	$NBOD_u$ percent removal	64%
Influent BOD_u loading *(metric tons/day)*	73,179	BOD_u percent removal	71%

Figure 2-17. POTW influent and effluent BOD_u loading and removal efficiency for select years between 1940 and 1996 and 2016 and 2025. *Source: U.S. Public Health Service Municipal Wastewater Inventories, USEPA Clean Water Needs Surveys and U.S. Census Population Projections.*



Key observations from Figure 2-17 include the following:

- Population growth from 1996 to 2016 will increase influent BOD_u loading nationwide to 68,030 metric tons per day, an increase of 45 percent. By 2025 influent loading will be about 73,057 metric tons per day, a 56 percent increase from 1996.
- In spite of a projected national increase in BOD_u removal efficiency from 65 to 71 percent by 2016 (a 9 percent increase), it is estimated that the trend of decreasing effluent BOD_u loadings experienced in the 24 year period from 1968 to 1996 will be reversed. It is predicted that effluent BOD_u loadings will increase from 16,325 metric tons per day in 1996 to 19,606 metric tons per day in 2016, an increase of 20 percent. The effluent BOD_u loading rate estimated for 2016 is about equal to effluent loading rates that existed in the mid-1970s, only a few years after the CWA was enacted!
- By 2025 the projected effluent BOD_u loading will be 21,090 metric tons per day, an increase of 29 percent from 1996. This rate is about equal to effluent loading rates experienced in 1968 (21,280 metric tons per day), the year when the discharge of oxygen-demanding material from POTWs had reached its historical peak!

- By 2016, when the projected needs for wastewater treatment are expected to be met (USEPA, 1997), the overall BOD_u removal efficiency of 71 percent and increases in population will result in a 20 percent increase of effluent loads relative to the 1996 loading rate. To maintain an effluent BOD_u loading rate comparable to 1996 conditions through 2016 (i.e., "running in place"), the national aggregate removal efficiency would have to be increased from 71 to 76 percent. This would need to be accomplished by shifting the projected population served from secondary to advanced secondary and advanced wastewater treatment facilities.

The estimated projections of increasing effluent loading rates of BOD_u over the next quarter-century underscore the importance of continually investing in improvements to wastewater treatment infrastructure to maintain and improve pollutant removal efficiencies. Without these improvements many of the environmental successes of the water pollution control efforts over the past three decades may be overwhelmed by the future demand from population growth. The very real risk of losing the environmental gains achieved by federal (Construction Grants Program), state, and local water pollution control efforts under the technology and water quality-based effluent limit regulations of the 1972 CWA is also documented by Jobin (1998) and the Water Infrastructure Network (WIN, 2000).

E. Comparison of Contemporary BOD_5 Loadings From POTWs and Other Point and Nonpoint Sources Based on Estimates of Actual Loadings

The primary purpose of Chapter 2 is to examine whether there was a significant reduction in effluent BOD loading to the Nation's waterways after the technology-based and water quality-based treatment provisions of the CWA were implemented. To fully address this subject, however, it is important to recognize the following:

- Effluent BOD loading comes from several point and nonpoint sources in addition to POTWs.
- BOD is only one of several contaminants that have the potential to affect aquatic resources and the lives and livelihoods of water resource users. Table 2-13 presents some of the concerns and conditions associated with several types of water pollutants.

This section is divided into two subsections. The first subsection briefly describes non-POTW sources of BOD loading, including industrial wastewater treatment facilities, combined sewer overflows (CSOs), urban stormwater runoff, and rural nonpoint sources[1] of pollution. For the purposes of this comparison,

[1] Nonpoint source (NPS) pollution sources are sources of pollution not defined by statute as point sources. NPS pollution results from the transport of pollutants into receiving waters via overland flow runoff in a drainage basin. Because NPS pollution is diffuse, its specific sources can be difficult to identify.

Table 2-13. Pollutant groups and related water resource issues.

Pollutant Group	Water Quality Conditions and Concerns	
Nutrients (nitrogen and phosphorus)	Eutrophication Ammonia toxicity Anoxia/ hypoxia; oxygen depletion Water clarity/transparency Reduced diversity/trophic structure	Nuisance algal blooms Toxic algal blooms Fish kills Shellfish bed closure/loss Loss of seagrass beds/habitat
Metals and Toxics	Fish body burden Shellfish body burden Mammals body burden	Birds body burden Sediment contamination Drinking water supply
Organic Matter	Anoxia/hypoxia; oxygen depletion Adsorption/desorption of toxic chemicals	Fish kills
Pathogens	Shellfish bed closure Recreational beach closure	Drinking water supply
Sediment	Anoxic sediments Damage to benthic biota	Habitat destruction/fish spawning Water clarity/ transparency
Hazardous materials	Oil spills Chemical spills	Fish kills

urban stormwater runoff includes areas both outside (termed "nonpoint source") and within (meeting the legal definition of a point source in section 502(14) of the CWA) the NPDES stormwater permit program.

The second subsection introduces the National Water Pollution Control Assessment Model (NWPCAM) (Bondelid et al., 1999), a tool that can be used to estimate the water quality impact of current (ca. 1995) BOD_5 effluent loadings from point and nonpoint sources nationwide. The primary purpose of this exercise is to compare BOD_5 effluent loadings from POTWs with BOD_5 effluent loadings from other point and nonpoint sources.

Pollutant Loading From Sources Other Than POTWs

Industrial Wastewater Treatment Facilities

Many industrial facilities discharge treated wastewater directly to surface waters. Similar to municipal wastewater treatment, industrial wastewater treatment consists of a sequence of physical, biological, and chemical processes designed to remove pollutants that are specific to an industrial facility's manufacturing operations. USEPA's effluent guidelines, prepared for specific categories of industrial groups, prescribe effluent limits in terms of the industry's output production rate (e.g., *n* kilograms of pollutant discharged per 1,000 kilograms of factory production). Table 2-14 presents median effluent concentrations for conventional and nonconventional pollutants for the industrial categories that account for the largest contributions to effluent loading rates for BOD_5.

Table 2-14. Effluent characteristics for select major industry groups. Source*: Tetra Tech, 1999; NOAA, 1994.*

Parameter (mg/L)	Inorganic Chemical Products	Organic Chemical Products	Feedlots	Food and Beverages	Iron and Steel	Petroleum Refining	Pulp and Paper
BOD_5	6.5	6.3	6.0	11.8	6.0	8.8	24.5
TOC	9.4	11.2	N/A	N/A	N/A	12.0	N/A
NH_3-N	1.3	1.2	0.7	0.6	1.0	2.0	1.2
Total-N	1.9[a]	33.4[a]	28.5[a]	17.9[a]	2.9[a]	N/A	1.4[a]
Total-P	0.4	N/A	1.4	6.7[a]	N/A	N/A	0.6
TSS	10.6	11.8	13.1	12.0	9.9	12.9	29.4
DO	N/A	N/A	7.7	N/A	6.6	N/A	5.8
No. of Facilities	273	232	32	62	186	203	309
Average Median Design Flow (mgd)							
Major Facilities	2.9	2.3	N/A	0.3	3.9	3.0	5.0
Minor Facilities	0.2	1.7	0.3	0.1	0.2	0.3	0.8

Note: The table presents the median value of effluent data extracted from PCS for the period 1991 to 1998 except where indicated by [a], which indicates that Typical Pollutant Concentration (TPC) effluent data compiled by NOAA (1994) are used.

In contrast to direct industrial dischargers, industrial facilities can also discharge wastewater to sanitary sewer systems, where it mixes with domestic sources of wastewater (indirect industrial dischargers). This wastewater often contains a variety of metals, organic chemicals, and oily wastes that are not common to domestic sources of wastewater. Because of the high degree of variability, most municipal treatment systems are not designed to treat a vast array of industrial wastes. Consequently, these wastes can interfere with the operation of treatment plants, contaminate receiving waterbodies, threaten worker health and safety, and increase the cost and risks of sludge treatment and disposal. Using proven pollution control technologies and practices that promote the reuse and recycling of material, however, industrial facilities can provide "pretreatment" by removing pollutants from their wastewater before discharging to the municipal wastewater system. In addition to the categorical standards for pretreatment established as part of the industrial effluent guideline process, local pretreatment limits are enforced by various municipal facilities to protect treatment processes, worker health and safety, and equipment. USEPA's National Pretreatment Program, a cooperative effort of federal, state, and local officials, is fostering this practice nationwide.

Combined Sewer Overflows

In many older cities of the United States, urban sewer systems were originally designed to convey both raw sewage and storm water runoff collected during rainstorms. These combined sewer overflow systems were also explicitly designed to discharge (overflow) the mixture of raw sewage and storm water into the river if a heavy rainstorm exceeded the hydraulic capacity of the combined sewer system. As a vestige of public works practices from approximately 1850 to 1900, about 880 cities mostly in the central and northeastern states have combined sewer systems that continue to function in this manner (USEPA, 1997). Table 2-15 presents characteristic discharge concentrations of conventional and nonconventional pollutants in combined sewer overflows (CSOs).

In addition to raw sewage, a CSO system can discharge pretreated industrial waste and street debris washed off during a storm. Although pollutant loading from CSO systems is intermittent, occurring only under heavy rainstorm conditions, the high loading rates of sewage from CSO outlets frequently result in the closure of recreational beaches and shellfish beds to protect public health. Discharges from CSOs also are associated with depressed oxygen levels in poorly flushed waterbodies, accumulation of organics in sediments, and generally noxious conditions and odors.

National assessments show that the relative significance of annual loading of BOD_5 from CSO systems is about the same as the effluent loading from second-

Table 2-15. Effluent characteristics of urban runoff and CSOs.

Parameter	Urban Runoff *Range*[a,b]	CSO *Range*[c,d]	CSO *(event mean)*
BOD_5 (mg/L)	10-13	60-200	(115)
$CBOD_u/BOD_5$	ND	ND	(1.4)[e]
TSS (mg/L)	141-224	100-1100	(370)
TKN (mg/L)	1.68-2.12	ND	(6.5)
NH_3-N (mg-N/L)	ND	ND	(1.9)
NO_2-N +NO_3-N (mg-N/L)	0.76-0.96	ND	(1.0)
Total N (mg-N/L)	3-10	3-24	(7.5)
Total P (mg-P/L)	0.37-0.47	1-11	(10)
Total Lead (mg/L)	161-204	ND	(370)
Total Coliforms (MPN/100 m/L)	10^3-10^8	10^5-10^7	(ND)

NOTES: ND = No data

[a] Range of urban runoff concentrations reflects variability of coefficient of variation of event mean concentrations for median urban sites. Data from USEPA (1983) presented in Novotny and Olem (1994) (Table 1.3, p.36).

[b] Range of urban runoff concentrations for total N and total coliforms from Novotny and Olem (1994) (Table 1.3, p. 36).

[c] Range of CSO concentrations for BOD_5, TSS, total N and total coliforms from Novotny and Olem (1994) (Table 1.3, p36).

[d] Mean CSO concentrations of BOD_5, TSS, and total lead from USEPA (1978) presented in Novotny and Olem (1994); median CSO concentrations of nitrogen constituents from Driscoll (1986); mean CSO concentration of total phosphorus from Ellis (1986).

[e] $CBOD_u/BOD_5$ ratio from Thomann and Mueller, 1987.

ary wastewater treatment facilities in the same urban area. In contrast to BOD_5, annual loading of suspended solids and lead is about 15 times greater from CSO systems than from secondary wastewater treatment facilities. Annual loading rates of total nitrogen and phosphorus from CSOs, however, are only about one-fourth (total N) and one-seventh (total P) of the annual loads contributed by secondary facilities (Novotny and Olem, 1994).

Urban and Rural Nonpoint Sources

Organic and inorganic materials, both naturally occurring and related to human activities, are transported to waterbodies within a drainage basin by surface runoff over the land as nonpoint, or diffuse, sources of pollutants. The magnitude and the timing of nonpoint pollutant loads are dependent on many complex, and interacting, processes within a drainage basin. In contrast to the relatively continuous input of pollutants from point sources, the timing of loading from diffuse sources is highly variable with intermittent loading related primarily to meteorological events (storms and snowmelt). The magnitude of pollutant loads is dependent on the area of the drainage basin, the characteristics of land uses, including ground cover, and distribution of the volume of precipitation between infiltration into shallow aquifers and surface runoff into streams and rivers.

Within a watershed undisturbed by human activities, naturally occurring biogeochemical processes account for the continual cycles of organic and inorganic materials (as uncontrollable nonpoint source loads) transported from the land to rivers, lakes, and estuaries, with eventual discharge of these materials to the coastal ocean. Since it is the uses of the land and the associated activities that occur on the land within a drainage basin that contribute anthropogenic organic and inorganic materials to surface waters, nonpoint source loading rates have been related to the type of land use (Table 2-16). The most critical factor, however, in understanding the management of nonpoint source loading is characterizing the transition from one land use to another (e.g., forest to agriculture, agriculture to suburban/urban).

Table 2-16. Nonpoint source runoff export coefficients for general land uses

Parameter	Urban	Agriculture	Forest
BOD5[a,b]	34-90	26	5
TSS [a,b]	3,360-672	1,600	256
Total N [b,c]	7.8-11.2	16.5	2.9
Total P [b,c]	1.6-3.4	1.1	0.2

Units are kg/hectare-year

[a] Export coefficients for BOD_5 and TSS for agriculture and forest categories from Thomann and Mueller (1987).

[b] Range of export coefficients for urban land use categories I, II, and III from PLUARG studies (Marsalek, 1978) presented by Novotny and Olem (1994) (Table 8.2, p. 449).

[c] Mean export coefficients for total N and total P for mixed agricultural and forest land uses from Reckhow et al. (1980).

Beginning with the four natural land classifications (arid lands, prairie, wetland, and woodland), the transformation of a watershed's land uses progresses over many years through several intermediate stages of development to a fully developed urban-industrial watershed (Novotny and Olem, 1994). With the irreversible transformation to the endpoint of urban-industrial land uses of a watershed, the emphasis in water quality management needs to incorporate strategies for control of both nonpoint sources of runoff and the point source discharges within the "urban-industrial" water cycle. In contrast to the control strategy for point sources (build a wastewater treatment facility) as the most effective technology for removal of pollutants from a point source waste discharge, the reduction of nonpoint source loading of pollutants is focused on the design and implementation of "best management practices" to control, and manage, land use activities and surface runoff. As with urban runoff control measures, the technical aspects of the numerous practices available for controlling nonpoint source runoff from forest, agricultural, and other rural land uses are presented in detail by Novotny and Olem (1994).

As part of its public works infrastructure, practically every town and city in the nation has an urban stormwater sewer system designed to collect and convey water runoff from rainstorms and snowmelt. Depending on the development characteristics of an urban area, stormwater runoff can result in significant intermittent loading of pollutants to surface waterbodies. Based on findings from the National Urban Runoff Project (NURP) conducted by USEPA from 1978 to 1983, USEPA (1983) concluded that urban runoff accounted for significant wet weather loading to the Nation's surface waters of pathogens, heavy metals, toxic chemicals, and sediments. The origins of the diffuse discharges of these pollutants include contaminants contained in wet and dry atmospheric deposition, erosion of pervious lands, accumulation of debris on streets, traffic emissions, and washoff of contaminants from impervious land surfaces. Table 2-15 presents typical discharges of conventional and nonconventional pollutants in urban runoff.

Estimates of Contemporary (ca. 1995) BOD_5 Loading Using the National Water Pollution Control Assessment Model (NWPCAM)

The NWPCAM is a national-scale water quality model designed to link point and nonpoint source loadings and resultant calculated in-stream concentrations of $CBOD_5$, $CBOD_u$, DO, TKN, total suspended solids, and fecal coliform bacteria with a "water quality ladder" of beneficial uses (Carson and Mitchell, 1983). The framework for the model is EPA's Reach File Version 1 (RF1) national database of streams, rivers, lakes, and estuaries and uses mean summer streamflow data to characterize the steady-state loading, transport, and fate of water quality constituents. Presented for comparison purposes is current (ca. 1995) BOD_5 loading information derived using available NWPCAM national data for municipal and industrial discharges, CSOs, and urban[1] and rural nonpoint sources.

[1] For purposes of this comparison, urban stormwater runoff includes areas both outside (termed "nonpoint sources") and within (meeting the legal definition of a point source in section 502(14) of the CWA) the NPDES stormwater permit program.

BOD_5 Loading from Municipal and Industrial Sources

The input data used to estimate municipal and industrial effluent loading of BOD_5 within the NWPCAM come from USEPA's Permit Compliance System (PCS), the Clean Water Needs Survey (CWNS) databases, and default assumptions derived from the literature. The PCS database contains discharge monitoring data for major POTWs and industrial dischargers (facilities with a discharge greater than 1 mgd). The CWNS database provides a more comprehensive database of all POTWs and generally reliable population, flow, and treatment level information. Less confidence is placed on the effluent concentration data reported in the CWNS database. Therefore, when actual discharge data were available from PCS, those data were used. PCS data were also used to develop default effluent concentrations to apply when a facility's actual concentration was not available or was outside normal ranges expected for a given level of treatment.

Municipal

Table 2-17 presents a compilation of characteristic effluent concentrations of conventional and nonconventional pollutants used in NWPCAM for different types of municipal POTWs. The data sets extracted from USEPA's PCS and CWNS databases are supplemented by influent and effluent data taken from the literature (e.g., AMSA, 1997; Metcalf and Eddy, 1991; Clark et al., 1977; Leo et al.; 1984; Thomann and Mueller, 1987).

A total of 1,632 of the 2,111 hydrologic catalog units in the contiguous United States are subject to municipal effluent loading. Figure 2-18 presents distributions of municipal BOD_5 loading by percentile of catalog units with nonzero municipal loads according to (a) loading rate and (b) fraction of total municipal loading. Figure 2-19 presents a map showing the magnitude of municipal effluent loading of BOD_5 aggregated for the 1,632 catalog units with nonzero municipal loads. Figure 2-20 displays the proportion of the total nonpoint and point sources load contributed by municipal waste loads.

Key observations from Figures 2-18 through 2-20 include the following:

- Less than 1 percent of the 1,632 catalog units subject to municipal loading receive effluent BOD_5 loading at a rate greater than 25 metric tons/day (Figure 2-18a). About 20 percent of the catalog units account for about 90 percent of the total municipal BOD_5 loading to the Nation's waterways (Figure 2-18b).
- Relatively low municipal BOD_5 loading rates (less than 0.5 metric ton/day) characterize many of the catalog units within the western and central portions of the contiguous 48 states.
- Higher rates of municipal loading (0.5 to 5 metric tons/day) are characteristic of the Mississippi River valley and the Northeast, Midwest, and Southeast. The highest loading rates (> 25 metric tons/day) are for major urban centers, including New York, Boston, Los Angeles, San Diego, Dallas-Ft. Worth, Detroit, and San Francisco.

Table 2-17. Effluent characteristics for POTWs.

Parameter (mg/L)	(Influent) Raw	Primary	Advanced Primary	Secondary	Advanced Secondary	Advanced Wastewater Treatment
BOD_5						
Mean	205.0	143.5	102.5	16.4	6.2	4.1
% Removal	0	30	50	92	97	98
Reference/Notes	*a, j*	*b*	*c*	*a*	*a, d*	*a, d*
$CBOD_u/CBOD_5$						
Mean	1.2	1.6	1.6	2.84	2.84	3.0
Reference/Notes	*e*	*f*	*f*	*f*	*f*	*f*
TSS (mg/L)						
Mean	215	107.5	64.5	17.2	6.5	4.3
% Removal	0	50	70	92	97	98
Reference/Notes	*a, j*	*b*	*c*	*a*	*a,d*	*a,d*
NH_3-N (mg-N/L)						
Mean	18.0	14.4	14.4	12.2	3.4	2.0
% Removal	0	20	20	32	81	89
Reference/Notes	*a*	*b*	*b*	*a*	*a,d*	*a,d*
TKN (mg-N/L)						
Mean	30.0	23.4	23.4	16.5	12.9	3.6
% Removal	0	22	22	45	57	88
Reference/Notes	*a*	*b*	*b*	*a*	*a,d*	*a,d*
Total N (mg-N/L)						
Mean	30.0	23.4	23.4	18.3	18.4	14.4
% Removal	0	22	22	39	39	52
Reference/Notes	*g*	*h*	*h*	*a*	*a,d*	*a,d*
Total P (mg-P/L)						
Mean	6	5.2	5.2	2.5	0.4	0.4
% Removal	0	13	13	58	94	94
Reference/Notes	*a*	*b*	*b*	*a*	*a,d*	*a,d*
DO (mg/L)						
Mean	4.1	4.3	4.3	6.6	6.6	7.1
Reference/Notes	*i*	*j*	*j*	*j*	*j*	*j*
Total Organic Carbon (mg/L)						
Mean	148.6	107.5	76.8	21.8	8.2	5.8
% Removal	0	28	48	85	94	96
Reference/Notes	*g*	*b, k*	*k*	*b,k*	*k*	*k*

References/Notes

a. AMSA, 1997. Influent concentration, percent removal, and TKN:TN, NH_3:TKN, and PO_4:TP ratios for secondary, advanced secondary, and advanced wastewater treatment. ***b.*** Gunnerson et al., 1982. ***c.*** NRC, 1993. Percent removal for advanced primary with "low dose chemical addition." ***d.*** MWCOG, 1989. Percent removal and TKN:TN, NH_3:TKN, and PO_4:TP ratios for advanced secondary, and advanced wastewater treatment. ***e.*** Thomann and Mueller, 1987. ***f.*** Leo et al., 1984. ***g.*** Metcalf and Eddy, 1991. TKN:TN, NH_3:TKN, and PO_4:TP ratios of influent concentration for "medium" strength wastewater, raw TOC influent concentration based on BOD_5, $CBOD_u$:BOD_5, oxygen:carbon, and ratios of C:DW. ***h.*** ICPRB, 1991. TKN:TN, NH_3:TKN, and PO_4:TP ratios of effluent concentration for primary, advanced primary, and secondary treatment. ***i.*** Assume 50 percent saturation at 25 °C and 50 mg/L chlorides at sea level. ***j.*** Tetra Tech, 1999. Mean effluent oxygen concentrations based on PCS database for primary, secondary, and advanced treatment. Mean influent concentrations for BOD_5 (207 mg/L) and TSS (209 mg/L) from CWNS database consistent with influent data from AMSA (1997). ***k.*** Effluent TOC concentration computed from effluent BOD_5, $CBOD_u$:BOD_5, oxygen:carbon ratio and assumption that 80 percent of organic carbon is accounted for by BOD_5 measurement. Removal efficiencies computed for primary and secondary treatment are consistent with data from Gunnerson et al., 1982.

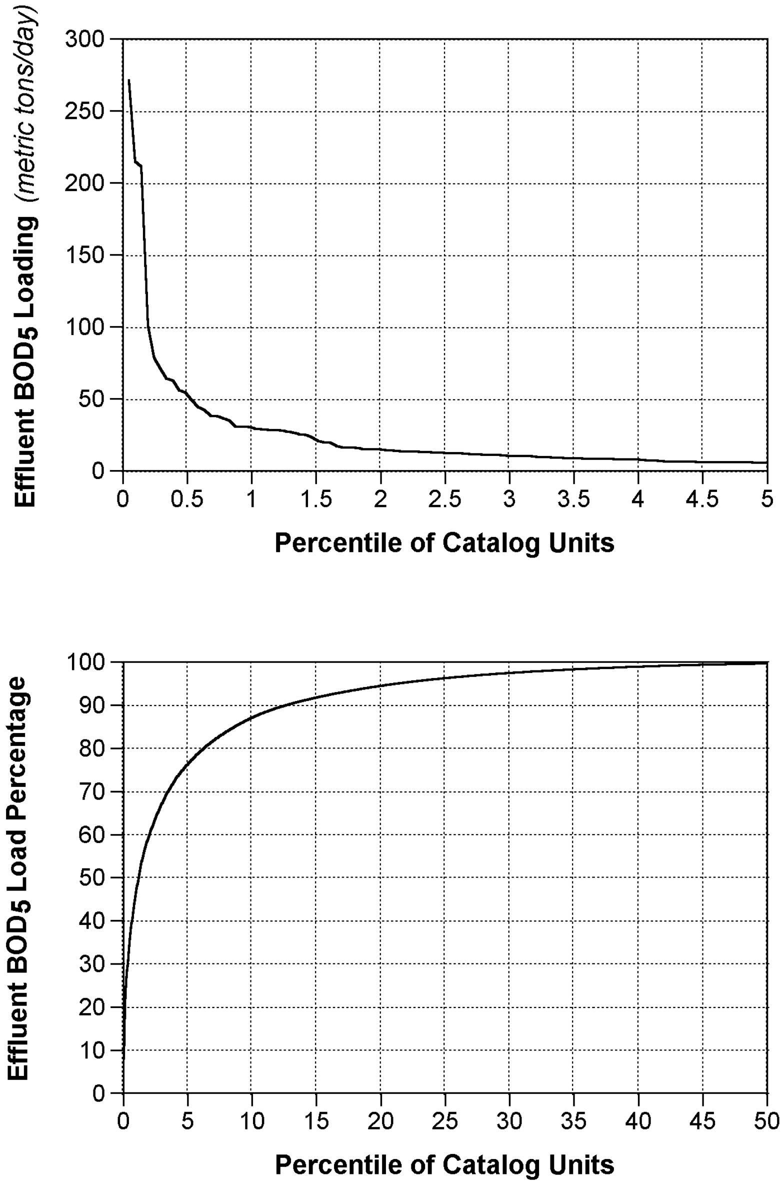
Figure 2-18

Distribution of municipal BOD_5 loading by percentile of catalog units subject to municipal loading (N=1,632) as (a) metric tons/day and (b) fraction of total municipal loading rate.

Source: Bondelid et al., 1999.

(a)

(b)



- The municipal wastewater component of total point and nonpoint source load of BOD_5 tracks closely with the results of the loading magnitude calculation. The municipal wastewater component is highest around major urban centers and lowest in the western and central portions of the contiguous 48 states.

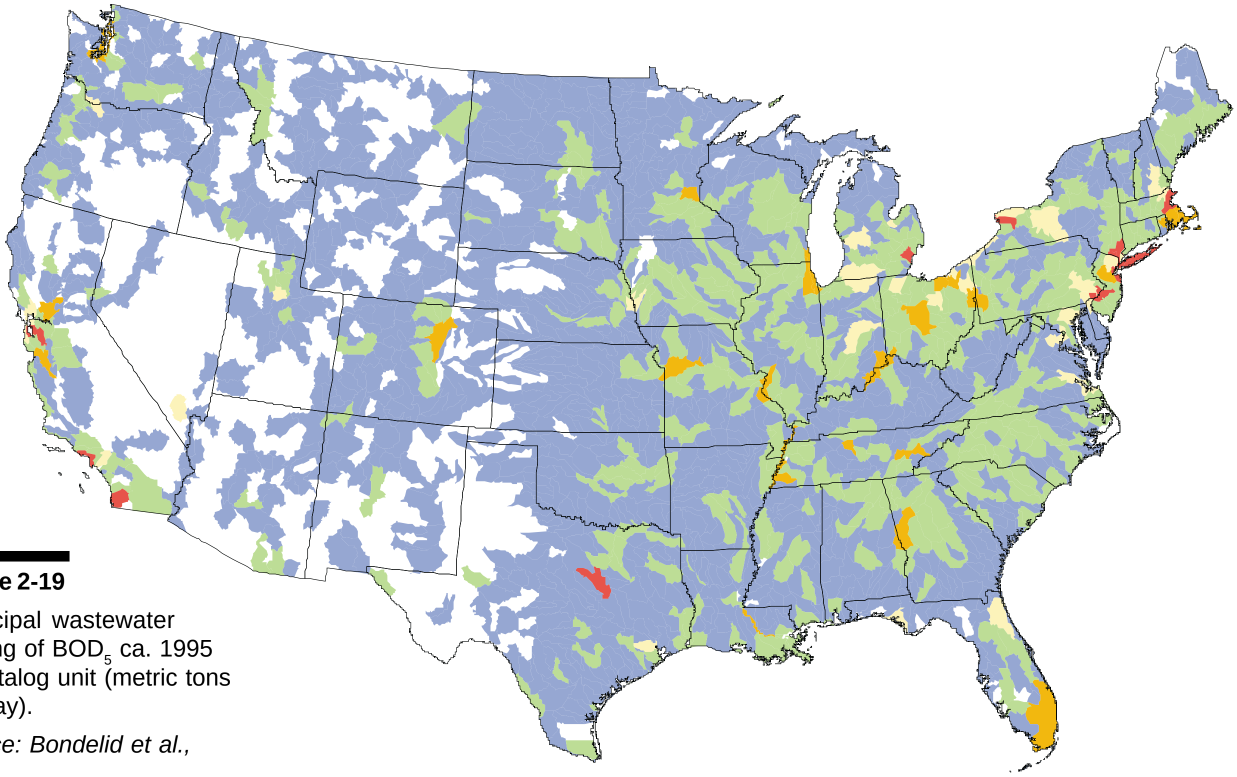


Figure 2-19

Municipal wastewater loading of BOD_5 ca. 1995 by catalog unit (metric tons per day).

Source: Bondelid et al., 1999.

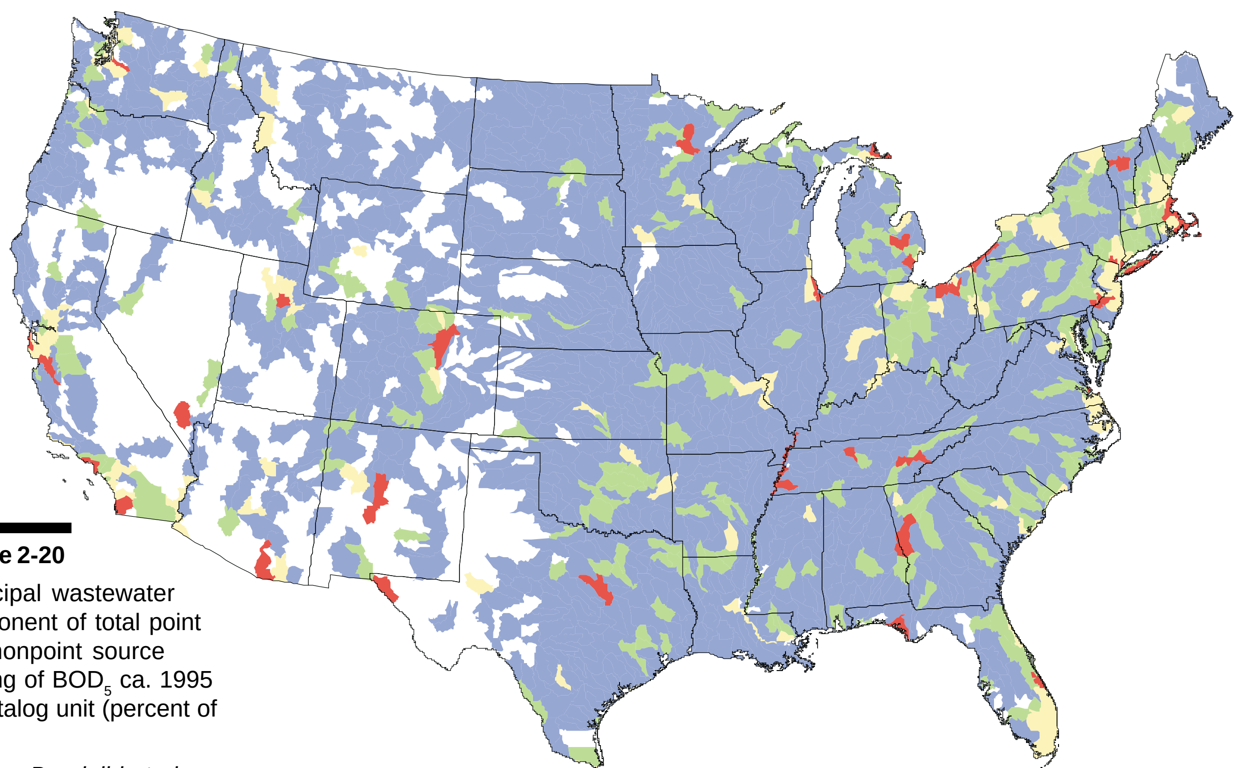


Figure 2-20

Municipal wastewater component of total point and nonpoint source loading of BOD_5 ca. 1995 by catalog unit (percent of total).

Source: Bondelid et al., 1999.

Industrial

Similar to the two municipal maps, Figure 2-21 presents the magnitude of the industrial effluent loading of BOD_5 aggregated for a total of 1,504 catalog units with nonzero industrial loads. Figure 2-22 displays the proportion of the total nonpoint and point sources load accounted for by industrial waste loads.

Key observations include the following:

- Relatively low industrial BOD_5 loading rates (< 0.5 metric ton/day) characterize many of the catalog units in the western and central portions of the 48 states.
- Higher rates of industrial loading (0.5 to 5 metric tons/day) are characteristic of the Mississippi River valley, the Northeast, Midwest, and Southeast. The highest loading rates (> 25 metric tons/day) are indicated for major urban industrial watersheds including Austin-Oyster in Texas, East-Central in Louisiana, Buffalo-San Jacinto and Galveston Bay, and the Locust River, Upper Black Warrior, and Middle Coosa basins in Alabama.
- Industrial loads are the dominant component (>75 percent) of the total point and nonpoint source load in many catalog units associated with major urban-industrial areas, particularly in the Southeast. Although not shown, the frequency distributions of industrial BOD_5 loads (as a percentile of catalog units with nonzero industrial loads) are very similar to those presented for municipal BOD_5 loads.

BOD_5 Loading From CSOs

Effluent loadings for CSOs were based on an analysis performed in support of the 1992 Clean Water Needs Survey (CWNS) (Tetra Tech, 1993) and subsequently adopted for the NWPCAM. During this 1992 CWNS, it was estimated that there were approximately 1,300 CSO facilities in the United States (USEPA, 1993). The number of facilities was substantially reduced to 880 during the 1996 CWNS.

The effluent loading for CSOs used in the NWPCAM is based on computing a pulse load based on the runoff volume and pollutant load associated with a 5-year, 6-hour storm event. Runoff was computed as a function of the combined sewer system's population, service area, and imperviousness. For the purposes of the NWPCAM, the pollutant loading used in the model was estimated to yield a national BOD_5 loading of 15 metric tons/day (Bondelid et al., 1999). As expected, most of the CSO loading is accounted for by older cities in the New England, Middle Atlantic, Great Lakes, Ohio River, and Upper Mississippi basins.

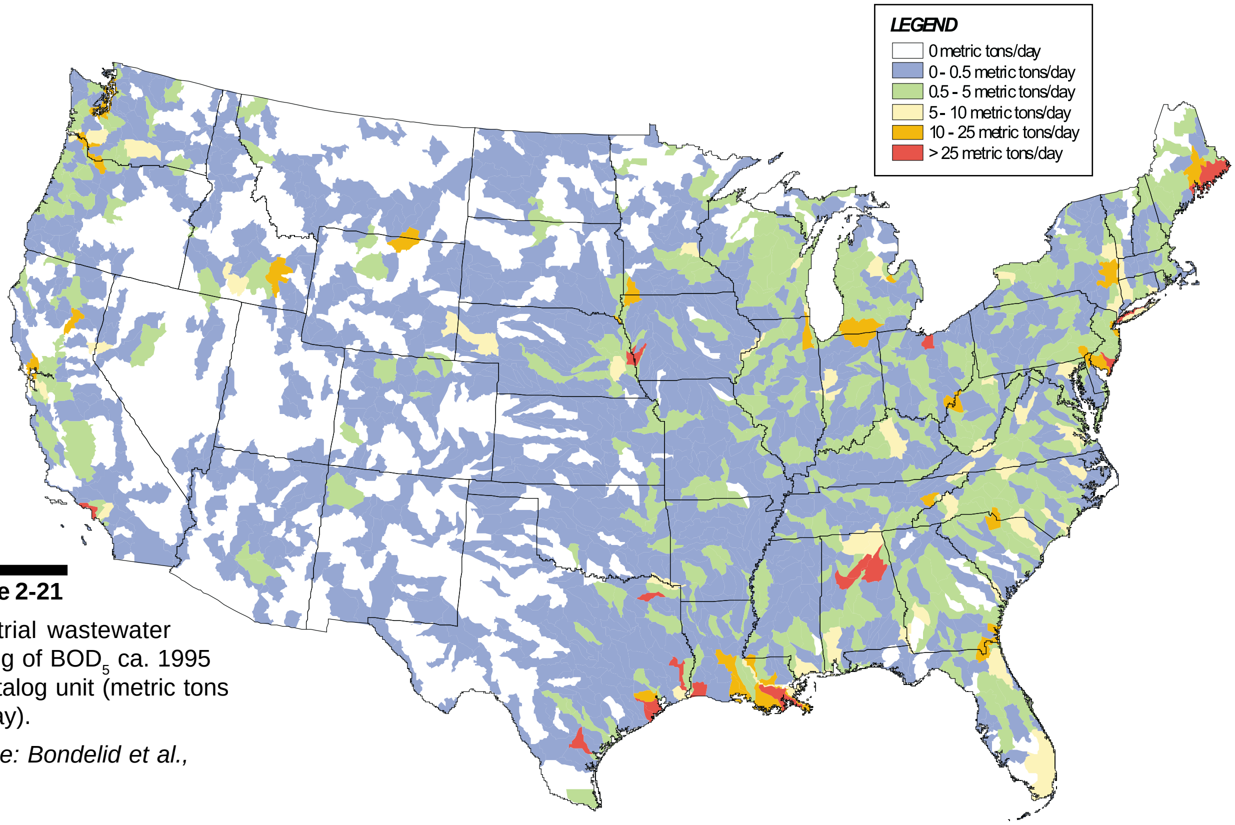


Figure 2-21

Industrial wastewater loading of BOD_5 ca. 1995 by catalog unit (metric tons per day).

Source: Bondelid et al., 1999.

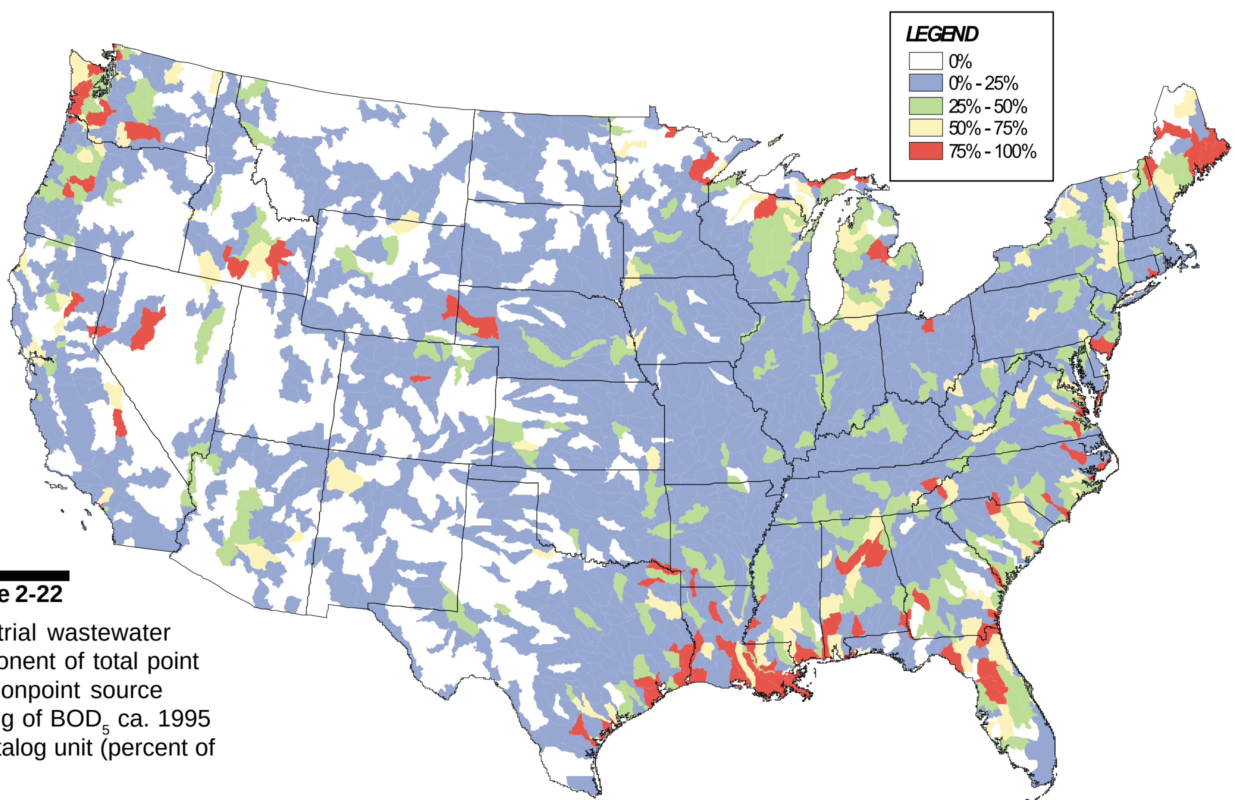


Figure 2-22

Industrial wastewater component of total point and nonpoint source loading of BOD_5 ca. 1995 by catalog unit (percent of total).

Source: Bondelid et al., 1999.

BOD_5 Loading From Urban Stormwater Runoff and Rural Nonpoint Sources

Nonpoint source BOD_5 loading data were developed on a county-level basis by Lovejoy (1989) and Lovejoy and Dunkelberg (1990), with urban stormwater runoff[1] and rural runoff loadings reported separately. These values were converted into loadings allocated to each catalog unit in the contiguous 48 states based on the proportion of a county's area in a given catalog unit. For the NWPCAM, the rural loadings were disaggregated based on stream length in a given county while urban loadings were disaggregated based on stream length and population associated with a given stream.

Using the loading data compiled for the NWPCAM, the national catalog unit-based distributions of urban stormwater and rural BOD_5 loading are presented in Figures 2-23 and 2-24 (urban) and Figures 2-25 and 2-26 (rural). The map sets present both the magnitude of the loading rate (as metric tons per day) and the percentage of the total point and nonpoint source load accounted for by the urban and rural runoff contributions, respectively.

Key observations include the following:

- With the exception of urban areas on the west coast and in the Midwest and Northeast, low loading rates (< 0.5 metric tons/day) characterize most of the Nation's watersheds for urban runoff loads.
- In urban areas, loading rates are typically less than 5 metric tons/day, accounting for about 25 to 75 percent of the total point and nonpoint source BOD_5 load discharged to a catalog unit.
- Rural loading rates of BOD_5 are characterized by a distinctly different geographic distribution, with the highest rates (> 25 metric tons/day) estimated for the upper Missouri basin. Intermediate loading rates of 5 to 25 metric tons/day of BOD_5 characterize rural runoff in the Missouri, Upper Mississippi, and Ohio river basins. The lowest rates (< 0.5 metric tons/day) are estimated for the coastal watersheds of the east coast and Gulf of Mexico and the arid areas of the western states.
- Rural nonpoint source loads of BOD_5 are the dominant component (> 75 percent) of total point and nonpoint source loads in vast areas of the Nation, principally west of the Mississippi River and in the Ohio River Basin.
- The geographic distribution of relatively low contributions of rural runoff (< 25 percent) is consistent with the locations of large urban-industrial areas (e.g., New York, Boston, Miami, New Orleans, Chicago, Seattle, San Francisco, Los Angeles).

[1] For purposes of this comparison, urban stormwater runoff includes areas both outside (termed "nonpoint sources") and within (meeting the legal definition of a point source in section 502(14) of the CWA) the NPDES stormwater permit program.

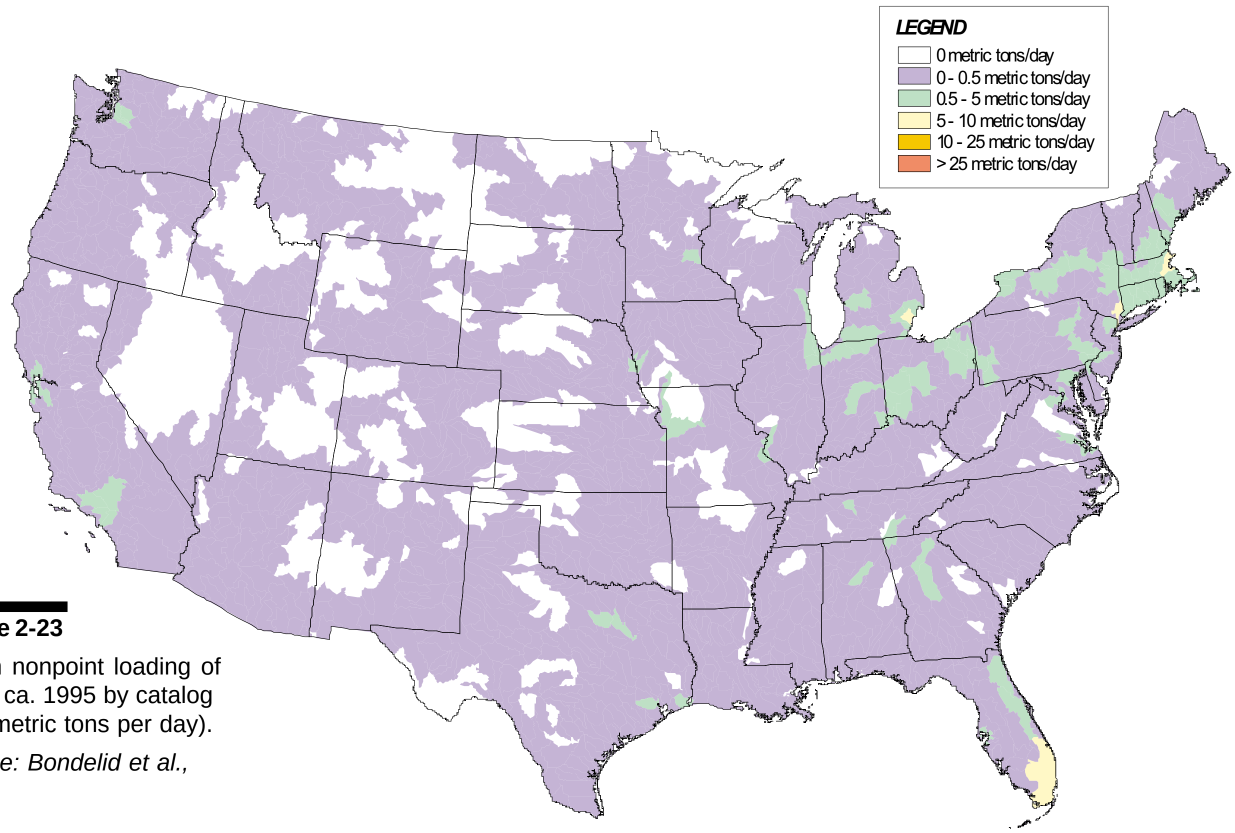


Figure 2-23

Urban nonpoint loading of BOD_5 ca. 1995 by catalog unit (metric tons per day).

Source: Bondelid et al., 1999.

Note: Urban stormwater runoff includes areas both outside and within the NPDES stormwater permit program.

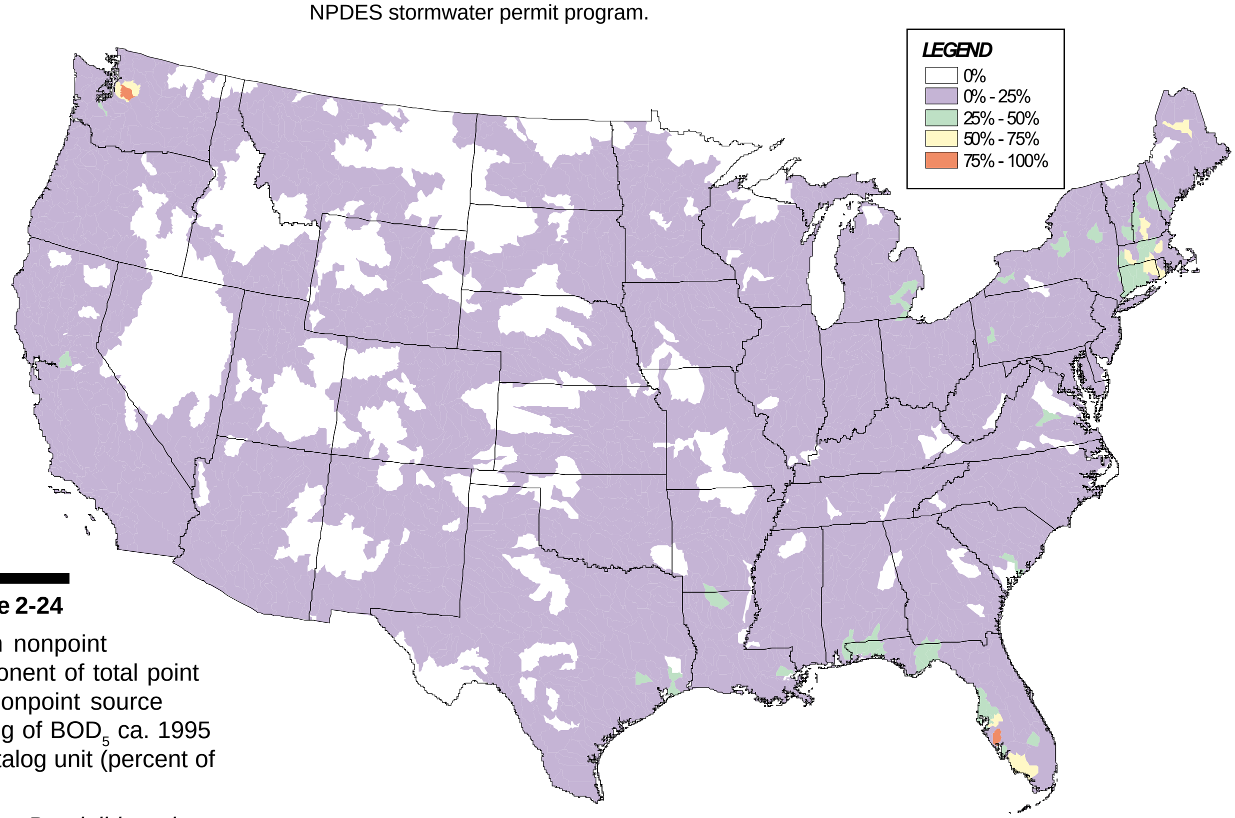


Figure 2-24

Urban nonpoint component of total point and nonpoint source loading of BOD_5 ca. 1995 by catalog unit (percent of total).

Source: Bondelid et al., 1999.

Note: Urban stormwater runoff includes areas both outside and within the NPDES stormwater permit program.

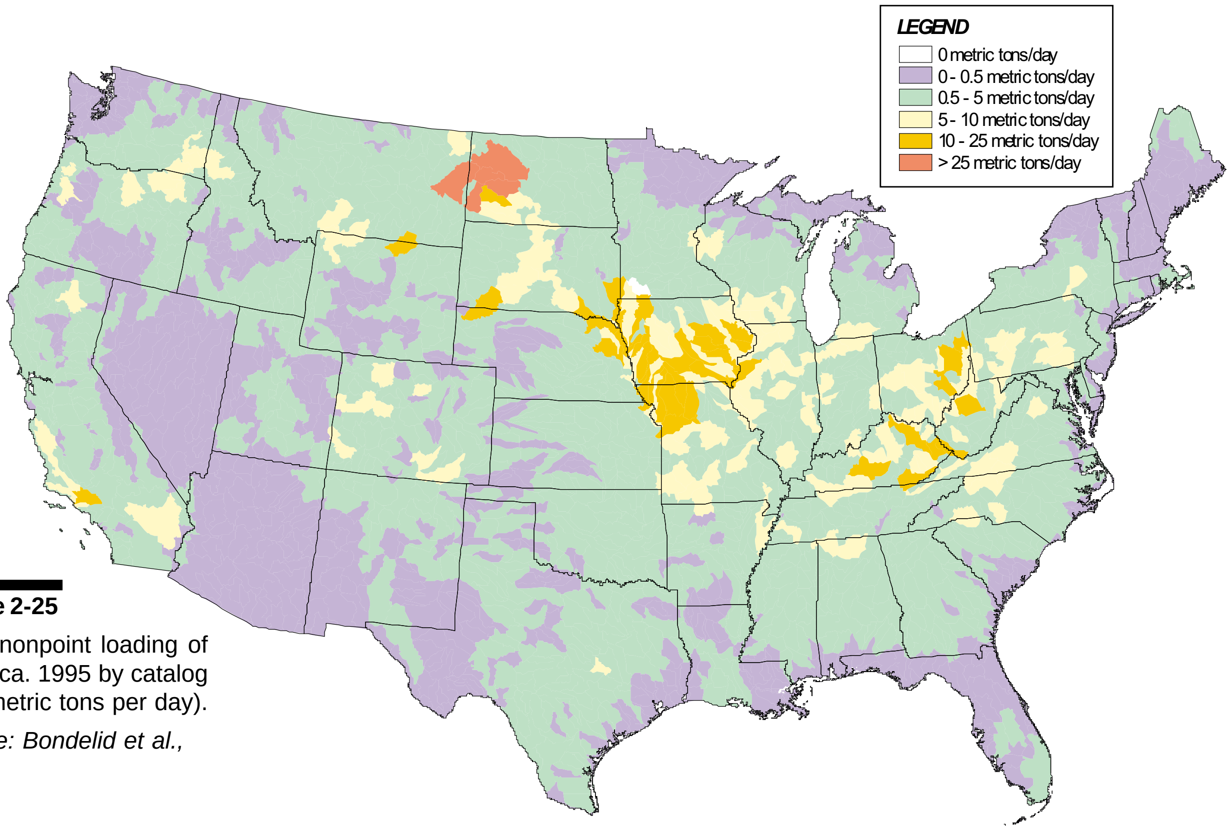


Figure 2-25

Rural nonpoint loading of BOD_5 ca. 1995 by catalog unit (metric tons per day).

Source: Bondelid et al., 1999.

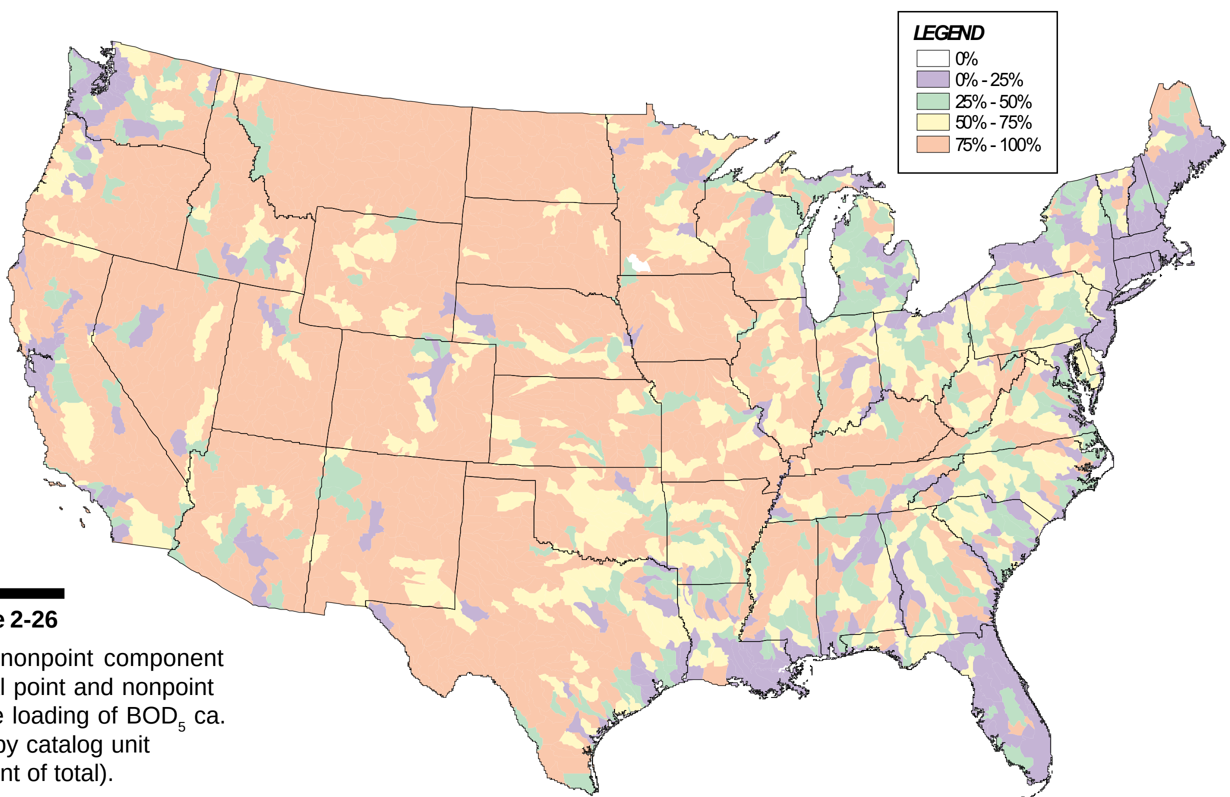


Figure 2-26

Rural nonpoint component of total point and nonpoint source loading of BOD_5 ca. 1995 by catalog unit (percent of total).

Source: Bondelid et al., 1999.

Comparison of Point and Nonpoint Sources of BOD_5 at the National Level

From a national perspective, BOD_5 loading from municipal facilities currently (ca. 1995) accounts for only about 38 percent of total point source loadings and only 21 percent of total loadings (point and nonpoint). Industrial facilities (major and minor) account for about 62 percent of total point source BOD_5 loadings and 34 percent of total BOD_5 loadings. Rural nonpoint source loads account for about 40 percent of the total BOD_5 loading rate. Urban stormwater runoff and CSOs, although significant in most urban waterways, account for a small share (5 percent) of the total nationwide load (Bondelid et al., 1999).

Based on this analysis of contemporary sources of loading of BOD_5, continued maintenance and improvement of water quality conditions of the Nation's surface waters will clearly require an integrated, watershed-based strategy, such as that presented in the USEPA's (1998) *Clean Water Action Plan*, including the appropriate management of point and nonpoint sources of BOD_5 and other pollutants (e.g., nutrients, suspended solids, toxic chemicals, pathogens).

F. Investment Costs for Water Pollution Control Infrastructure

The analysis presented in Section D indicates that nationwide effluent BOD_u loadings from POTWs were reduced by 23 percent between 1968 and 1996. Examination of historical trends in industrial wastewater loads also suggests substantial declines in BOD loads from industrial point sources have been achieved since the early 1970s (see Luken et al., 1976). Declines can be credited to industrial pretreatment programs, upgrades of industrial wastewater treatment as required by the NPDES permit program, abandonment of obsolete manufacturing facilities in the Midwest and Northeast "rustbelt" (Kahn, 1997), and improved efficiency in industrial water use (Solley et al., 1998). The purpose of this section is to provide an overview of the costs of implementing public and private water pollution control programs.

The Construction Grants Program

The Water Pollution Control Act of 1956 was significant because it both established and funded a grant program for the construction of POTWs for the purpose of ensuring the implementation of adequate levels of municipal waste treatment as a national policy for water pollution control. Following the 1956 Amendments, however, federal funding ($5.1 billion allotted from 1957 to 1972) accounted for only a small portion of the total construction costs for municipal facilities (FWPCA, 1970). The CWA made it a national policy to provide federal grants to assist in the upgrade and construction of municipal wastewater facilities. The 1972 act authorized $5.0 billion in federal spending for fiscal year 1973, $6.0 billion for fiscal year 1974, and $7.0 billion for fiscal year 1975. Under the revamped Construction Grants Program, the federal share was 75 percent of cost from fiscal years l973 to l983, and 55 percent thereafter.

USEPA's Grants Information and Control System (GICS) database is the central repository of Construction Grants Program data. For the following financial analysis, grant awards in the GICS database were indexed to constant 1995 dollars using the *Chemical Engineering* Plant Cost Index (CE, 1995) for the purpose of providing a suitable indicator of the inflation of wastewater treatment facility construction costs.

National Summary

During the 25-year period from 1970 to 1999, the Construction Grants Program distributed a total of $61.1 billion in federal contributions ($96.5 billion as constant 1995 dollars) to municipalities for new construction and upgrades of POTWs to secondary and greater levels of wastewater treatment (Figure 2-27). An additional $16.1 billion (capitalization) in federal contributions was also distributed to the states through the Clean Water State Revolving Fund (CWSRF) Program from 1988 through 1999 (Figure 2-27). Additional state match, state-leveraged bonds, loan repayments, and fund earnings increased CWSRF assets by $18.4 billion. Since 1988, therefore, the CWSRF loan program assets have grown to over $30 billion, and they are funding about $3 billion in water quality projects each year.

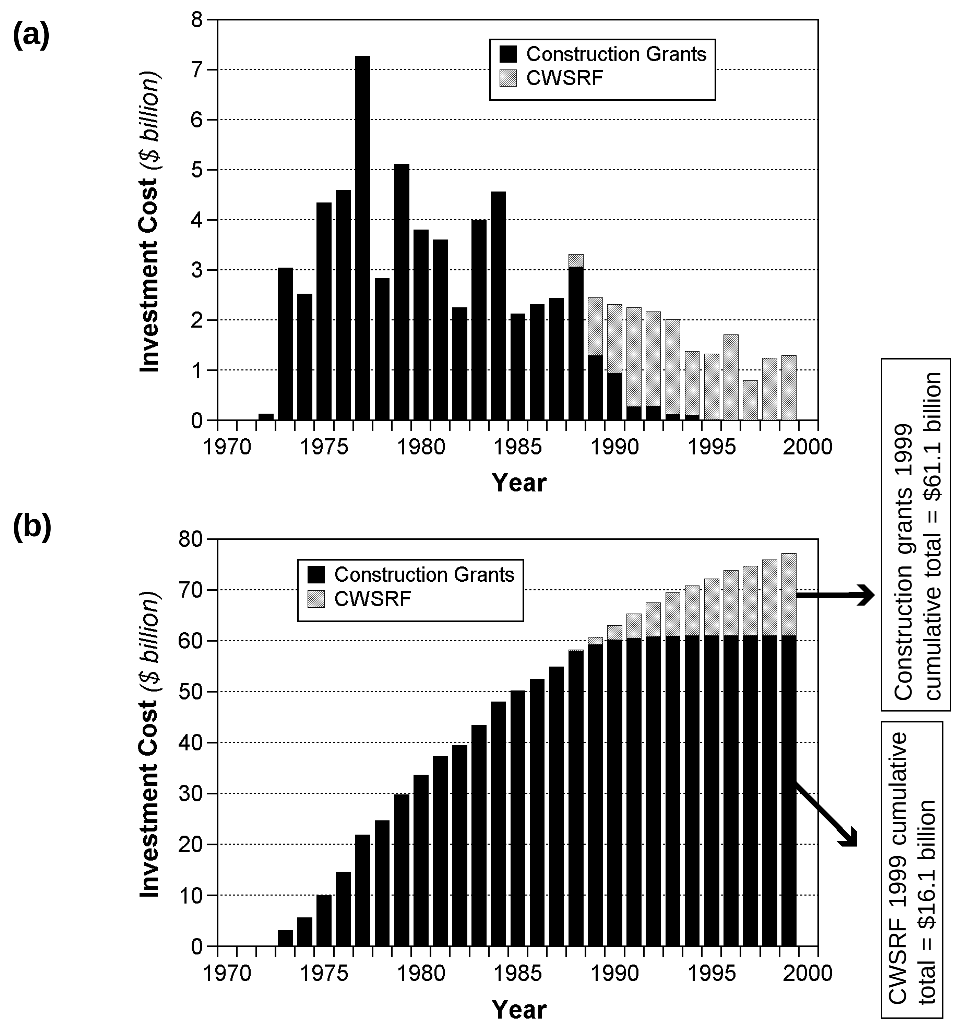


Figure 2-27

Annual funding provided by USEPA's Construction Grants and CWSRF programs to local municipalities for improvements in water pollution control infrastructure as (a) annual allotments for each program and (b) cumulative funding from both programs from 1970 to 1999.

Source: USEPA GICS database and CWSRF Program.

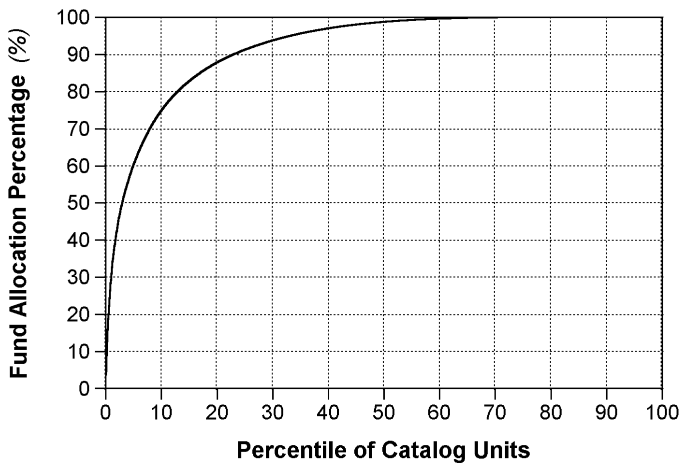


Figure 2-28

Cumulative funding of Construction Grants Program awards as a percentile of 2,111 catalog units.

Source: USEPA GICS and reach file Version 1 (RF1) databases.

Summaries by Catalog Unit

Awards data extracted from the GICS database were assigned to each of the 2,111 catalog units of the 48 contiguous states by matching city names and counties with corresponding catalog units. Of the total amount of funding awards in the GICS database ($61.1 billion), only a small fraction (less than 1 percent) of the awards could not be assigned to a specific catalog unit. In addition, approximately 2 percent of the GICS funding was awarded to watersheds located outside the 48 contiguous states. (This accounts for the discrepancy between a total national investment of $61.1 billion and the investment of $59.2 billion that was allocated to the 48 contiguous states.)

Figure 2-28 presents the cumulative distribution of the GICS funding awards (total $59.2 billion) as a percentile of the 2,111 catalog units within the contiguous 48 states. Twenty percent of the catalog units account for about 88 percent of the funding. There is also a relationship between the municipal BOD_5 loading rate (ca. 1995) and the Construction Grants award allocated to each catalog unit. Increased municipal loading rates related to larger facilities resulted in increased grant awards from the Construction Grants Program (Figure 2-29).

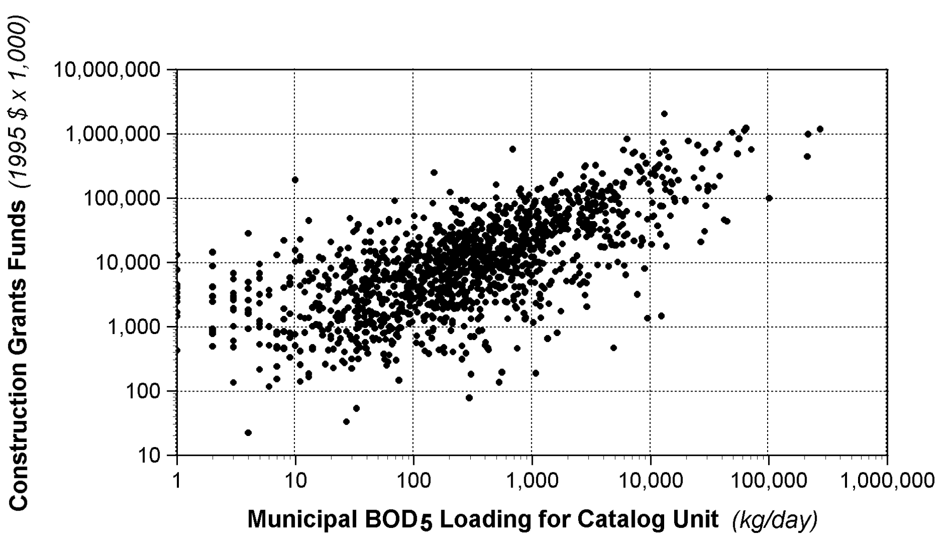


Figure 2-29

Relationship of municipal BOD_5 loading rate ca. 1995 and EPA Construction Grants Program awards by catalog unit.

Source: USEPA GICS database and Bondelid et al., 1999.

Other Investment Costs for Water Pollution Control Infrastructure

In addition to the federal expenditures through the Construction Grants Program, state and local governments and private industries have made significant investments to comply with the water pollution control requirements of the CWA and other state and local environmental legislation. On a nationwide basis, actual expenditure data compiled by the U.S. Department of Commerce, Bureau of Economic Analysis in the annual *Pollution Abatement Cost Expenditures* (Vogan, 1966) document a cumulative public and private sector capital expenditure of approximately $200.6 billion and an additional $210.1 billion as operating expenditures (capital and operation and maintenance costs as current year dollars) for water pollution control activities during the period from 1972 through 1994 (Figure 2-30).

As shown in Table 2-18, current year dollars compiled in the annual survey have been indexed to constant 1995 dollars using the *Chemical Engineering* Plant Cost Index for capital costs and the consumer-based Gross Domestic Product for operating costs as appropriate indices. The Construction Grants Program provided federal grant support to local municipalities that amounted to almost one-half of the public sector costs and about one-third of the total public and private sector capital investment for water pollution control.

Figure 2-30

Annual water pollution control expenditures (as current year dollars) by the public and private sectors for capital and operations and maintenance costs from 1972 through 1994. *Source: Vogan (1996).*

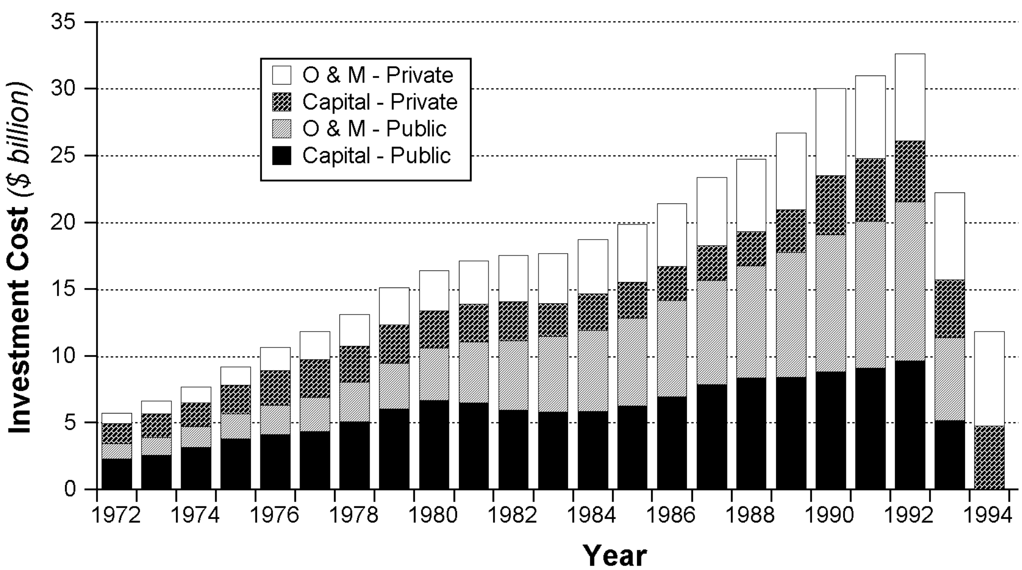


Table 2-18. National public and private sector investment in water pollution control infrastructure, 1956-1994.

	EPA Construction Grants (1956-1972)	EPA Construction Grants (1970-1995)	EPA CWSRF (1988-1999)	Public Sector (1972-1994)	Private Sector (1972-1994)	Public + Private Sectors (1972-1994)
Current Year Dollars						
Capital	$5.1	$61.1	$16.2	$132.4	$68.2	$200.6
O & M	n/a	n/a	n/a	$121.2	$88.9	$210.1
Totals	**$5.1**	**$61.1**	**$16.2**	**$253.6**	**$157.1**	**$410.7**
Equivalent as Constant 1995 Dollars						
Capital	$14.3	$96.5	n/a	$178.9	$93.5	$272.4
O & M	n/a	n/a	n/a	$175.5	$128.1	$303.6
Totals	**$14.3**	**$96.5**	**n/a**	**$354.4**	**$211.6**	**$576.0**

Sources:

1. EPA Construction Grants Program (1956-1972): data obtained from EPA-OWM files compiled by R.K. Bastian, March 1992.
2. EPA Construction Grants Program (1970-1995): data obtained from EPA GICS database, August 1995.
3. EPA Clean Water State Revolving Fund (CWSRF) (1988-1999): data from EPA-OWM files by R.K. Bastian, April 2000.
4. Public and private sector (1972-1994): Data from Vogan (1996). Data obtained from T. Gilliss, EPA-OPPE, 1997.
5. Current year dollars adjusted to equivalent constant 1995 dollars. Plant Cost Index obtained from *Chemical Engineering* (CE, 1995) for capital expenditures. Gross Domestic Product for O&M costs obtained from Council of Economic Advisors (1997).

Future Infrastructure Needs

USEPA (1997) estimates that by 2016 approximately 2,400 new facilities with secondary or greater than secondary levels of treatment will be needed to service an additional 85 million people (a 45 percent increase of total population). Further, during that time period the Agency estimates that 115 of the approximately 176 POTWs currently providing less than secondary treatment will upgrade their facilities to meet the minimum technology requirements of secondary treatment under the CWA. USEPA estimates the costs for POTW construction and upgrades to be $75.9 billion (indexed to constant 1996 dollars).

Further, USEPA plans to put more emphasis on “wet weather” sources of pollution, including CSOs and storm water drainage from agricultural, silvicultural, city, and suburban lands. USEPA (1997) has estimated these associated federal costs to include the following:

- $44.7 billion (indexed to constant 1996 dollars) to meet infrastructure needs associated with CSOs.
- $7.4 billion (indexed to 1996 dollars) to meet the Clean Water State Revolving Fund (CWSRF)-eligible portion of the costs that the municipal separate storm sewer systems are expected to incur for the development and implementation of a stormwater management program in response to the Phase I NPDES stormwater program regulations.

- $3.8 billion (indexed to 1996 dollars) to meet the CWSRF-eligible projects related to cropland, pastureland, and rangeland.
- $2.1 billion (indexed to 1996 dollars) to meet the CWSRF-eligible projects related to confined animal facilities with fewer than 1,000 animal units.
- $3.5 billion (indexed to 1996 dollars) to meet the CWSRF-eligible projects related to silviculture.

G. Summary, Conclusions, and Future Trends

The purpose of this chapter is to address the first leg of the three-legged stool approach for answering the question posed in Chapter 1—*Has the Clean Water Act's regulation of wastewater treatment processes at POTWs been a success?* Recall that the basic goal of this first leg is to examine the extent to which the Nation's investment in building and upgrading POTWs to secondary and greater than secondary wastewater treatment resulted in a decrease in effluent BOD loading to the Nation's waterways. If evidence showed that these investments achieved significant reductions in the discharge of oxygen-demanding organic wasteload to the Nation's waterways, the first leg of the investigation could add cumulative support for the conclusion that the CWA's mandates were successful.

This section summarizes the key points presented in *Sections A* through *F* of Chapter 2, discusses conclusions, and addresses future trends in wastewater infrastructure requirements.

Key Points of the Background Sections

Specifically discussed in *Sections A* and *B* is the significance of water supply and wastewater treatment in the urban water cycle, the invention of secondary treatment, and the use of biochemical oxygen demand (BOD) as a measure of the pollutional strength of organic wasteloads. *Section C* focuses on the roles the federal government and the CWA played in establishing, and funding, secondary and greater than secondary treatment in the Nation's POTWs.

Key points made in *Sections A* through *C* include the following:

- All components of the urban water cycle must be in place and functioning properly to satisfy the needs of both water supply and water resource users.
- In the "Great Sanitary Awakening" in the late 19th and early 20th centuries, public infrastructure investment was focused primarily on the water supply side of the urban water cycle and sewage collection systems for the control of waterborne diseases and protection of public health.
- Increasing urban populations in the first half of the 20th century exacerbated water quality problems associated with the discharge of inadequately treated sewage in urban waterways.

- Secondary treatment proved to be a breakthrough discovery in treating wastewater; by 1930 several cities, especially in the Northeast, Midwest, and far West, had incorporated the technology into their wastewater treatment systems.
- Before 1972 and the passage of the CWA, municipal and industrial wastewater discharges were regulated by individual states based on state ambient water quality standards. The federal government's authority for water pollution control was restricted to interstate waterways under the Commerce clause of the U.S. Constitution.
- The passage of the CWA resulted in the federal government's assuming a greater role in directing and defining water pollution control programs in the Nation. The states' water quality-based approach for regulating wastewater discharges was replaced by the CWA's two-pronged approach—a mandatory technology-based approach supplemented by a water quality-based approach on an as-needed basis—and enforced under the National Pollutant Discharge Elimination System permit program.
- Section 301 of the CWA required POTWs to achieve effluent limitations based on secondary treatment as the minimum level of technology.

Key Points of the BOD Loading Analysis Sections

Establishing a national policy requiring secondary treatment of municipal wastewater as the minimum acceptable technology supplemented by more stringent water quality-based effluent controls on a site-specific, as-needed basis was a key provision of the 1972 CWA. This mandate, coupled with an increase in funding assistance to municipalities through the Construction Grants Program, led to a dramatic increase in the number of POTWs with secondary and greater than secondary treatment capabilities.

Section D examines several national POTW trends, including the population they serve, influent and effluent BOD loadings, and BOD removal efficiencies. Key findings include the following:

- *The U.S. population served by POTWs with secondary or greater treatment almost doubled between 1968 and 1996 from 85.9 million people in 1968 to 164.8 million people in 1996!*
- *BOD_u loading to POTWs (influent loading) increased significantly*. In 1968 influent BOD_u loading was 34,693 metric tons per day. By 1996 influent BOD_u loading stood at 46,979 metric tons per day, a 35 percent increase from 1968! The same trend was seen for influent BOD_5 loading to POTWs.
- *Effluent BOD_u loading discharged by POTWs was significantly reduced*. In 1968 effluent BOD_u loading was 21,281 metric tons per day. By 1996 effluent BOD_u loading stood at 16,325 metric tons per day, a 23 percent decrease from 1968! Effluent BOD_5 loading was also significantly reduced (by 45 percent) over the same time period.

- *BOD removal efficiency increased significantly.* In 1940 the aggregate national removal efficiency stood at about 33 percent for BOD_5 and 20 percent for BOD_u. By 1968 removal efficiencies had increased to 63 percent for BOD_5 and 39 percent for BOD_u. By 1996 these had increased to nearly 85 percent for BOD_5 and 65 percent for BOD_u!
- *Increasing numbers of people served by POTWs in the 21st century will likely reverse the trend established between 1968 and 1996 of decreasing effluent BOD loading to the Nation's waterways*. Assuming that national aggregate design-based BOD_u removal efficiency will increase to 71 percent, influent wastewater flow will remain a constant 165 gpcd, and influent BOD_u concentrations will remain a constant 396.5 mg/L, population projections indicate that by 2016 effluent BOD_u loading will increase by 20 percent to 19,606 metric tons per day, equivalent to the rate in the mid-1970s. It is projected that by 2025 the effluent BOD_u loading will be 21,280 metric tons per day, a rate approximately equal to that observed in 1968 when the discharge of oxygen-demanding material from POTWs reached its historical peak!
- *By 2016, when the projected needs for wastewater treatment are expected to be met (USEPA, 1997), the overall BOD_u removal efficiency of 71 percent and increases in population will result in a 20 percent increase of effluent loads relative to the 1996 loading rate.* To maintain an effluent BOD_u loading rate comparable to 1996 conditions through 2016 (i.e., "running in place"), the national aggregate removal efficiency would have to be increased from 71 to 76 percent. This would need to be accomplished by shifting the projected population served from secondary to advanced secondary and advanced wastewater treatment facilities.

Section E presents a national "snapshot" comparison of contemporary (ca. 1995) BOD_5 loadings from POTWs and other point and nonpoint sources based on available data from PCS and the Clean Water Needs Survey. Using the NWPCAM (Bondelid et al., 1999), BOD_5 loadings were estimated for municipal (POTW) and industrial point sources (major and minor), CSOs, and rural and urban[1] nonpoint sources. Loading data for each category were aggregated by catalog units and major river basins. The inclusion of other loading sources in this modeling exercise helps put the municipal loading component in perspective with total nationwide BOD_5 loading from all sources. Key findings include the following:

- *Of the 2,111 catalog units in the contiguous United States, 1,632 receive municipal discharges*.
- *Twenty percent of catalog units account for 90 percent of the total municipal BOD_5 loading*. Highest rates of municipal loading of BOD_5 occurred in the Mississippi River Valley and the Northeast and Midwest.

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[1] For purposes of this comparison, urban stormwater runoff includes areas both outside (termed "nonpoint sources") and within (meeting the legal definition of a point source in section 502(14) of the CWA) the NPDES stormwater permit program.

- *Municipalities (POTWs) are the dominant source of the BOD_5 component in catalog units associated with major urban areas.* Several urban areas had rates greater than 25 metric tons per day.
- *Municipal BOD_5 loadings account for about 38 percent of total point source loadings and 21 percent of total loadings (point and nonpoint).*
- *Industrial (major and minor) BOD_5 loadings account for about 62 percent of total point source loadings and 34 percent of total loadings (point and nonpoint).*
- *Urban stormwater and CSOs account for about 5 percent of total nonpoint source loadings and 2 percent of total loadings (point and nonpoint).*
- *Rural nonpoint source BOD_5 loadings account for about 95 percent of total nonpoint source loadings and 43 percent of total loadings.*

Clearly, continued improvement in water quality conditions of the Nation's waterways will require an integrated strategy to address all pollutant sources, including both point and nonpoint sources.

Key Points of the Investment Costs Section

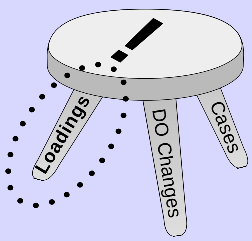
Section F focuses on investment costs associated with water pollution control. It includes a discussion of the Construction Grants Program and provides summaries of program spending for new construction and upgrades of POTWs. Also included in this section are summaries of public and private investment totals in point source water pollution control. Key findings include the following:

- *From 1970 to 1995 the Construction Grants Program has distributed $61.1 billion (as current year dollars) to municipalities for POTW building and upgrades.* The federal share was 75 percent of total costs from fiscal years l973 to l983, and 55 percent thereafter.
- *From 1988 to 1999 an additional $16.1 billion (capitalization) in federal contributions was also distributed to the states through the Clean Water State Revolving Fund.*
- *From 1972 to 1994 approximately $200.6 billion in capital costs and $210.1 billion in operation and maintenance costs (as current year dollars) were spent by the public and private sectors for point source water pollution control.* Based on these figures, the Construction Grants Program has contributed almost one-half of the public sector costs and about one-third of the total public and private sector capital investment for point source water pollution control.
- *Excluding combined sewer systems and urban stormwater controls, EPA estimates $75.9 billion (1996 dollars) will be required to meet traditional wastewater treatment plant (and sewer) needs through the year 2016 (USEPA, 1997).*

Conclusions and Future Trends

Based on the results of the analyses presented in this chapter, the study authors propose the following conclusion regarding the first leg of the three-legged stool approach concerning the Nation's investment in building and upgrading POTWs to achieve at least secondary treatment: *The CWA's mandated POTW upgrades to at least secondary treatment, combined with financial assistance from the Construction Grants Program and Clean Water State Revolving Fund, resulted in a dramatic decrease in effluent BOD loading from POTWs to the Nation's waterways.* This decrease was realized in spite of significant increases in influent BOD loading that occurred due to increases in the population served by POTWs.

Conclusion of the first leg of the stool



There was a dramatic nationwide decrease in effluent BOD loading from POTWs after the 1972 CWA despite a significant increase in population served!

Based on needs data submitted by the states, EPA projects that by the year 2016, 18,303 POTWs in the United States will be serving a population of 274.7 million (USEPA, 1997). Excluding combined sewer systems and storm water controls, the Agency estimates that $75.9 billion (1996 dollars) will be required to meet traditional wastewater treatment plant and sewer needs at this projected level of service. Based on these projections, influent BOD_u loading in 2016 is estimated to be about 68,030 metric tons per day, a 45 percent increase in influent BOD_u loading from 1996 (see *Section D*). Assuming a BOD_u removal efficiency of 71 percent based on the effluent loads contributed by different categories of POTWs (USEPA, 1997), effluent BOD_u loading in 2016 would be about 19,606 metric tons per day.

The projected effluent BOD_u loading of 19,606 metric tons per day in 2016 is a concern. Directly and indirectly due to the implementation of the CWA, there was a downward trend of effluent BOD_u loading rates beginning in the early 1970s through at least 1996 (the endpoint year of this study). The highest effluent BOD_u loading rate, 21,281 metric tons per day, was estimated to have occurred in 1968, four years before the passage of the CWA, and the lowest, 16,325 metric tons per day, in 1996. The 2016 effluent BOD_u loading estimate reverses the downward trend, with a 20 percent *increase* in effluent loading over the 20-year period from 1996 to 2016. This level of loading is equivalent to the effluent BOD_u loading rates in the mid-1970s. Further, effluent loading rates projected to 2025 reveal that the Nation may experience loading rates similar to those occurring in 1968, a time when the symptoms of water pollution were especially acute.

These findings underscore the importance of incorporating pollutant loading estimates and corresponding water quality improvements into POTW needs surveys. Projected large increases in service population have the potential to overwhelm the gains made to date in effluent BOD loading reductions due to the CWA. To continue the downward trend in effluent BOD loading to the Nation's waterways, further improvements need to be made in technologies and actions that decrease influent BOD loading to POTWs (through conservation methods) and increase BOD removal efficiency in the Nation's POTWs (through more advanced wastewater treatment methods).

In the 25 years since the passage of the CWA, a majority of the national water pollution control efforts have focused on controlling pollutants from POTWs and other point sources. National standards ensure that every discharger meets or beats the performance of the best technology available. Continuing the success achieved to date in reducing BOD and other pollutants, however, will require additional investment as older facilities wear out and increasing population pressures demand that existing facilities expand and new facilities be constructed. If these investments are not made and treatment services do not keep pace with growth, many of the gains achieved by the effluent loading reductions that have occurred in the years after the CWA will be lost (WIN, 2000). If this occurs, the wastewater treatment component of the urban water cycle will again assume "weak link" status, with corresponding detrimental consequences to water resource users.

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