# A History of Environmental Engineering in the United States

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Environmental engineering is a relatively new name for a type of engineering that began in the United States in the 1830s. Under different names, it continued to evolve to satisfy environmental challenges posed by urbanization, suburbanization, and the other needs of the nation during the industrial revolution in the late 1800s through the information revolution of the 1990s.

Until 1970, when Earth Day captured the public's attention leading to a concentrated effort to clean up the environment, the profession was practiced by but a few. Yet, the pioneers — Mills, Chesbrough, Sedgwick, Hazen, Metcalf, Eddy, Camp, Fair, Wolman, to name a few — blazed a trail establishing design protocols still in use today. Of necessity, this section is but a brief overview of the rich heritage on which modern environmental engineering is founded.

## The Beginning

Hydraulic engineering best describes environmental engineering at its birth. Early communities were usually located on or adjacent to plentiful sources of fresh water. As these communities grew and people were forced to live farther and farther from the water source, private companies formed to convey water to the outlying areas. By 1800, there were 18 private waterworks in the U.S. (McKinney 1994).

The inability of these private water companies to meet the water needs of rapidly-growing cities forced the larger municipalities such as New York, Boston, and Chicago to consider public water systems. Colonel De Witt Clinton, Jr., an Army engineer and son of the former governor of New York, was retained to examine New York's water supply needs in 1832. He recommended that water be obtained from the Croton River and conveyed to New York City through a 40-mile aqueduct. In 1836, John B. Jervis, a self-educated hydraulic engineer who had learned his engineering on the Erie Canal and the Mohawk and Hudson Railroad, began construction of a dam across the Croton River to provide storage for the aqueduct

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(Jervis 1876). By 1842, fresh water began flowing from the Croton Reservoir to New York City through the aqueduct which carried 95 Mgal/day (4.16 m3/sec) (Hazen 1907).

In Boston, city officials, noting the success of the Croton Aqueduct in New York, retained Jervis and Professor Walter R. Johnson of Philadelphia to find a new water supply for Boston in 1844 (Brandlee 1868). The team identified Lake Cochituate as the best source of water and Jervis designed the Cochituate Aqueduct. At the same time, Ellis S. Chesbrough was retained as Chief Engineer of the West Division of the Boston Water Works (Cain 1991). Under Chesbrough, construction of the Cochituate Aqueduct was completed in 1848 and Boston established its public water system. He became the Commissioner of the Boston Water Works and Boston's first City Engineer.

As City Engineer, Chesbrough was responsible for managing the stormwater sewer system. Boston had taken over the storm sewers in 1823 to ensure that they were properly maintained and that future sewers were built to proper specifications (MSBH 1903). Storm sewers were designed to flow by gravity to the nearest stream and eventually to the ocean. Because Boston prohibited the dumping of human sewage into storm sewers, sanitary sewage was collected in privies and vaults which were pumped out at regular intervals. This septage was carried in special wagons to farms outside the City. But, with the increased water supplies, more water closets and indoor bathtubs increased the flow of wastewaters and quickly filled the sewage storage vaults. A few homeowners solved their problem by building their own sewers and connecting them to the storm sewers without official permission. In addition to domestic sewage pollution of storm water, horse manure from the streets ended up in storm sewers when it rained. While smaller communities typically constructed two sets of sewers, a storm sewer and a sanitary sewer, Boston, like New York and other large cities, combined the sanitary sewers and the storm sewers in one pipe for economic reasons. Under either approach, sewer design required hydraulic engineering.

After serving Boston as its City Engineer for seven years, Chesbrough resigned in 1855 and moved to Chicago. There, he developed its sewerage system, the accomplishment for which he is most remembered. Chesbrough developed an innovative (for the time) plan to employ combined sewers to drain the city's waste into the Chicago River which required raising the elevation of most of the downtown area. The new sewage system contaminated Lake Michigan, the city's water supply. To correct this problem, Chesbrough developed and implemented an intake works offshore which was connected to the city by a 2 mile-long tunnel.

**A Discipline Takes Shape**

As the fruits of hydraulic engineering water systems serving the public became more common, and concerns about the quality of the water used for public water supplies grew, Sanitary Chemistry emerged as a new facet of environmental engineering. In 1873, the Massachusetts State Board of Health asked Professor William Ripley Nichols, who was in charge of Chemistry at the then infant Massachusetts Institute of Technology (M.I.T.), to analyze the water quality of the major rivers used for public water supplies in Massachusetts (MSBH 1874). Nichols agreed and set up the first Sanitary Chemistry Laboratory in 1874 to perform water analyses. Ellen Richards, then Ellen Swallow, the first coed at M.I.T., had just graduated with her BS degree in Chemistry from M.I.T. She was named Professor Nichols' assistant and did most of the analyses at the new Sanitary Chemistry Laboratory. She went on to become one of the foremost sanitary chemists in the United States.

Water pollution problems also increased as populations rose and industrial and water system development advanced. Research by the Sanitary Chemistry Laboratory at M.I.T. into the chemical quality of Massachusetts' river water showed that pollution was becoming significant and needed to be reduced before wastewaters contaminated public water supplies. Because there was no viable system for treating sewage, in 1887 the Massachusetts State Board of Health established the Lawrence Experiment Station, the first of its kind, to do the necessary research. Hiram F. Mills, a hydraulic engineer from Lawrence, Massachusetts, who also was a member of the Board of Health, was chosen as the station's first director. Mills recognized that research on wastewater treatment required not only engineers, but also chemists and biologists. As a member of the M.I.T. Board of Trustees, Mills did not hesitate to draw upon M.I.T. to supplement the staff at the experiment station. Professor William T. Sedgwick was appointed as Consulting Biologist and Dr. Thomas M. Brown, Professor of Chemistry, was appointed Consulting Chemist to the State Board of Health (McCracken and Sebian 1988).

In the beginning, environmental research at the Lawrence Experiment Station relied heavily on British research on intermittent sand filtration. In Britain, Sir Edward Frankland had demonstrated that intermittent sand filtration was a viable method for treating municipal sewage. Picking up on his work, Allen Hazen, George Fuller, and Harry Clark, the staff of the Lawrence Experiment Station, demonstrated that wastewater treatment was a biochemical process in addition to a physical process. The station's results, published in two large volumes in 1890 (MSBH 1890), were carefully studied across the world and stimulated considerable research on municipal wastewater treatment. These reports, Purification of Sewage and Intermittent Filtration of Water and Examination of Water Supplies and Inland Waters of Massachusetts, contained over 1,500 pages because of Mills' insistence that all the data collected be shared with others (McCracken and Sebian 1988). Using the Lawrence Experiment Station results, the British developed trickling filters. By 1900, biological wastewater treatment concepts were well established.

The findings by the Lawrence Experiment Station were made possible by the newly-discovered discipline of bacteriology. The discipline rapidly advanced after Dr. Robert Koch, a German physician and self-educated bacteriologist, demonstrated that bacteria could cause diseases (Collard 1976). Koch became a university professor in Berlin and under his leadership, research in the fledgling field moved quickly from growing bacteria on potato slices to gelatin and agar during the 1880s. This development enabled Professor Sedgwick and Edwon O. Jordan, a recent graduate student of Sedgwick's, to conduct research on sewage bacteriology.

Their efforts focused on isolating and identifying different bacteria in pure cultures. They discovered that bacteria isolated from intermittent sand filters used to treat municipal sewage were non-pathogenic. However, isolating pathogenic bacteria was difficult, even from contaminated wastewaters. Professor Sedgwick, Jordan, and Ellen Richards demonstrated that nitrification was a biological process that could be caused by bacteria, but they were unable to isolate the nitrifying bacteria in pure culture. Nitrate formation was the primary indicator for the stability of wastewaters after filtration. Allen Hazen, the first Chemist-in-Charge at the Lawrence Experiment Station, suggested using a liquid medium containing only inorganic materials rather than using gelatin. After several attempts, Jordan developed a nitrifying culture in an organic-free medium. At the same time, in Russia, Serge Winogradsky, a soil microbiologist, successfully applied the same approach. Winogradsky was able to isolate nitrifying bacteria on silica gel media.

Professor Sedgwick's studies also included algae and protozoa found in surface waters. Sedgwick developed a quantitative method for counting thee large microorganisms that was modified by George W. Rafter. The Sedgwick-Rafter Concentrator and Counting Cell became standard equipment for evaluating algae and protozoa in water supplies. The work at M.I.T. and the Lawrence Experiment Station established Water Microbiology as a major area for environmental engineering.

The concept that bacteria cause disease was not readily accepted in 1890, despite its wide acceptance in the scientific community. Even the isolation of several disease-producing bacteria in pure cultures was not considered adequate proof. A typhoid fever epidemic in Lowell and Lawrence, Massachusetts, in December 1890 and early 1891 provided the impetus for a concerted research effort.

By using engineering techniques and scientific logic, Sedgwick developed a form to collect data on a house-to-house basis to determine the source of infections. Together with George V. McLauthlin, Sedgwick began collecting data from every house reporting cases of typhoid fever and those in the immediate vicinity. Each house with a reported death was marked on a map of Lowell along with the houses with reported typhoid cases. This mapping showed that some areas of the city were affected more severely than others. This data, when compared with a map of Lowell's five different water systems, clearly demonstrated that the areas that obtained drinking water from the Merrimack River were most affected by the typhoid fever epidemic. Applying their methodology in Lawrence, Sedgwick and McLauthlin found that people who used Merrimack River water were most affected. The documentation of these epidemics of typhoid fever, together with several other smaller epidemics transmitted by water, milk, and direct contact, provided irrefutable proof that typhoid fever could be spread by polluted water.

Formal engineering design evolved slowly as engineers learned the best design concepts, but it eventually became the backbone for environmental engineering. Early design efforts were focused on water distribution and sewers. After the Civil War, there was a decades-long debate between proponents of "separate" versus "combined" sewers. Some engineers favored building separate sewers for stormwater and sanitary wastewater. Others favored combining stormwater and wastewater into a single sewer. George E. Waring was among the proponents of separate sewers. Waring, a self-educated engineer, became interested in sewerage systems in the 1870s. He was retained by the city of Memphis, Tennessee, as a consulting engineer after epidemics broke out there in 1878 and 1879. Waring recommended that the city construct separate sewers, using small-diameter pipes with automatic flush tanks (Odell 1880). After the Memphis project, Waring worked on the Buffalo, New York, trunk sewer and was also appointed to the National Board of Health. In 1895, he was named Commissioner of Sanitation in New York City. In three short years, Waring improved the city's solid waste collection and processing which had been one of the worst of the major cities.

James P. Kirkwood was one of the first American engineers to design a slow sand filter for water treatment based on data collected in Europe as part of a study of water treatment for St. Louis, Mo., published in 1869 (Baker 1948). Yet, Kirkwood's initial design of slow sand filters for St. Louis was ignored. It was not until 1871 that Poughkeepskie, New York, constructed a slow sand filter based on his design.

In response to the typhoid epidemics of 1890 and 1891, Hiram Mills designed an intermittent sand filter to treat Merrimack River water in Lawrence. The sand filter was placed into operation in 1893 and removed 98 percent of the bacteria from the polluted river water (MSBH 1894). Deaths from typhoid fever took a dramatic drop, clearly demonstrating the value of sand filtration for purifying polluted water. With slow sand filters proven, considerable effort was directed toward developing mechanical, rapid sand filters. However, the interest in patenting such devices slowed their development.

Rudolph Hering made perhaps the most significant early contributions to the development of engineering design for water supply and sewage treatment. Hering was born in Philadelphia and educated in Germany. He returned to the United States as an engineer, eventually becoming the Assistant City Engineer of Philadelphia in 1873. In 1880, Hering was commissioned by the National Board of Health to go to Europe and study the latest methods for sewage treatment. He presented a report on his findings to the American Society of Civil Engineers in 1881 (Hering 1881). In 1889, he was appointed by President Harrison to make plans for sewerage and drainage in Washington, D.C. Over the years, Hering prepared water supply and treatment studies for 150 cities. It is not surprising that he became known as the "Dean of Sanitary Engineering" (ASCE 1972).

While working at the Lawrence Experiment Station, Allen Hazen had examined chemical precipitation and the sedimentation processes. Because of this expertise, Hazen was invited to Chicago in 1893 to operate the wastewater treatment plant constructed for the Columbian Exposition, a showcase for modern technology. A sewerage system connected each of the exposition's major buildings to the wastewater treatment plant enclosed in a separate building. Because of the flat terrain, each building was equipped with an ejector to lift the sewage into the sewers and convey it to the treatment plant. Unfortunately, the multitude of ejectors and their random operation created a number of problems such as periodic sewer ruptures caused by system pressures exceeding pipe capacity and peak flows disrupting the settling characteristics in the 30 foot high Dortmund settling tanks. Coping with the Columbian Exposition wastewater treatment plant operations showed Hazen that there was a major difference between operating pilot plants at the Lawrence Experiment Station and actual full-scale plants. When the Columbian Exposition closed, Hazen returned to Boston to become a consulting civil engineer, eventually locating his practice in New York City. His paper, "On Sedimentation", was presented before the American Society of Civil Engineers in 1904 and became one of the classic papers on sedimentation theory and design (Hazen 1904). In 1907, he summarized water treatment plant design in his book, Clean Water and How to Get It (Hazen 1907). Hazen became one of the most successful and respected water treatment plant design engineers in the early 1900s.

As Hazen had demonstrated, design engineering grew out of need and experience rather than from theory. This was true for both sewage treatment plants and water treatment plants, although there was more interest in water treatment plants. Most design engineers depended on information published in the latest engineering magazines. In the United States, engineers quickly adopted trickling filter designs and activated sludge technology from the British and Imhoff tanks from the Germans. As each new plant was constructed, design engineers learned what worked and what did not. Leonard Metcalf and Harrison P. Eddy, consulting engineers in Boston, brought the best of American wastewater technology together for all engineers in 1915 with the publication of American Sewerage Practice (Metcalf and Eddy 1915). They set a standard for professionalism while demonstrating their knowledge for future customers. They also provided texts for teaching future generations of design engineers.

A discipline is born when the development of knowledge and its application evolves from individual experimentation into a formal course of study. In 1889, M.I.T. established the first program in Sanitary Engineering (Wylie 1975). It was designated Course XI and incorporated courses in sanitary chemistry and sanitary biology into the Civil Engineering Department. The new department was named Civil and Sanitary Engineering, and degrees were offered at the undergraduate level in Civil Engineering and in Sanitary Engineering. By 1893, when engineering faculty from across the country gathered at the Columbian Exposition in Chicago to organize a professional society to represent engineering educators, the only other school that has a degree program in Sanitary Engineering was the University of Illinois, which offered a degree in Municipal and Sanitary Engineering. A survey of engineering education in

1899 by Ira O. Baker, President of the Society for the Promotion of Engineering Education (SPEE) (Baker 1900), indicated that there were 110 engineering schools, but only 89 were active and only two schools offered degrees in Sanitary Engineering. There were 9,679 students enrolled in engineering, with 19 in Sanitary Engineering. Of the 1,413 engineering degrees awarded in 1898-1899, only one was in Sanitary Engineering (McKinney 1994).

**The 20th Century Before World War II**

Environmental engineers entered the 20th century with hope and aspiration of the opportunities that lay ahead. M.I.T.'s Sedgwick was confident that Sanitary Engineers had a special place in the future of technology, even though most Course XI graduates at M.I.T. were still concentrating on hydraulic engineering. Environmental engineering was water-oriented. The need for safe water supplies for a dynamic, growing nation occupied many. Additionally, with connection between safe drinking water and polluted waters firmly established, substantial effort was focused on the abatement of water pollution. Interestingly, even air pollution, a post World War II focus, attracted some interest.

While these various facets of environmental engineering are interconnected, technology development and applications were pursued separately. Any interchanges between the specialties existed primarily at universities teaching sanitary engineering, the Public Health Service, and associated state departments of health.

George C. Whipple, who had been a biologist at the Boston Water Works for eight years after graduating and a member of Hazen, Whipple and Fuller, water and wastewater consultants in New York City since 1903, was appointed Professor of Sanitary Engineering at Harvard University in 1911. After his appointment, he joined forces with his professor Sedgwick at M.I.T. and in 1913 the M.I.T.-Harvard School of Public Health was established with Sedgwick as the Program Head and Whipple as Secretary. This association enabled the Harvard Sanitary Engineering program to maintain a focus on Public Health Engineering in addition to customary civil engineering.

The Harvard Sanitary Engineering faculty was joined in 1918 by one of its recent graduates, Gordon Maskew Fair, an immigrant from South Africa via Germany. This inauspicious beginning launched a career that would have a profound impact on the profession. A survey taken in 1949 showed that about half of all American doctorate degrees in Sanitary Engineering up to that time had been earned at Harvard, and over half of the State Sanitary Engineers had received advanced degrees under Fair's direction (Anderson 1986).

When Fair began work, the technology of most processes and practices for environmental control were characterized by a high degree of empiricism. The remedies prescribed for freeing air and water of pollutants were derived from workaday experience rather that from scientific observation and analysis. His research in environmental science was motivated by the belief that a set of theoretical principles governed a wide range of artificial and natural purification processes — and that these could be specified in mathematical language so that engineers could use an orderly process of calculation in designing treatment works for water and air. His success in developing the theory of purification kinetics was embodied in widely read books and papers including his well-known textbook, Water Supply and Waste Water Disposal (with J.C. Geyer). He provided additional contributions in limnology, the broad application of the principles of physical chemistry to complex processes of water purification, to specific problems of quantitative measurement of tastes and odors, and mechanisms of biodegradation of certain organic compounds in streams. Perhaps his greatest achievements stemmed from his ability as a theorist to deploy the methods of science and the techniques of mathematical analysis, a precursor of today's emphasis of mathematical modeling and the key to computerization, to a discipline that had evolved for many centuries as a practical art. Fair's grasp of environmental engineering was visionary and prophetic. Years ago he understood that environmental control is a multi-media challenge.

The impact of sewage on water quality and the need for safe drinking water identified in the Massachusetts and other major urban centers in the U.S. gave impetus for the creation of a sanitary engineering component within the US Public Health Service (PHS) in 1890. At the start of the new century, this predecessor of EPA came to be a dominating force. In 1901, Congress authorized the construction of a PHS Hygienic Laboratory, "for the investigation of infectious and contagious diseases."

This was followed by commissions in 1908-1909 to study water pollution and protect water supplies in Lake Michigan and Lake Erie. A major reorganization in 1912 gave the PHS a broad mandate to study the diseases of man and conditions influencing their propagation.

In 1913, a group of medical officers, engineers, and scientists took over the laboratories at an abandoned Marine Hospital in Cincinnati, Ohio, with a mission to control water pollution. This center produced much of the fundamental research on which the control of water pollution is founded, including:

- definition of the Oxygen Sag Equation by Streeter and Phelps;
- confirmation of the rate of oxygenation of polluted waters by Theriault;
- confirmation of the rate of atmospheric reaeration by Streeter;
- definition of the elements of bacterial pollution by Hoskins;
- development of major elements of stream biology by Purdy; and
- initiation of studies on industrial wastes (Dworsky 1990).

For nearly thirty years, between 1913-1938, many of the Cincinnati group, augmented by a second, but still small, wave of engineers and scientists, structured and implemented plans which carried the nation rationally toward its goal of water pollution control. Some of these include:

- a strategic selection of rivers to understand the properties of their differences (1914);
- the initiation of a comprehensive survey of stream pollution (1915);

- support for the growth and improved capacity of the states to participate in efforts to control stream pollution (1920);
- public education efforts focusing on the importance of water pollution control measures as an aspect of comprehensive water resources development (1936); and
- increased technical assistance to states through the creation of a separate PHS Office of Stream Sanitation (1932) (Dworsky 1990).

Their efforts culminated in Public Law 845, enacted by the 80th Congress on June 30, 1948, the nation's first comprehensive Water Pollution Control Act.

While educators and government officials labored to understand the science of water pollution control in the first half of the century, wastewater was being treated in urban areas of all sizes. Technology developments continued to flow back and forth across the Atlantic. The studies at Lawrence Experiment Station fueled the creation of the trickling filter in England and the Imhoff Tank in Germany. These developments were applied in many U.S. communities; Chicago used Imhoff tanks to treat over 500 million gallons per day by the mid 1920's. In 1914, the activated sludge method of wastewater treatment, today's most commonly-used wastewater treatment technology, was developed in Manchester, England. Shortly thereafter, in 1918, Houston, Texas, placed the first large-scale activated sludge plant in the U.S. in operation.

The work at the Lawrence Experiment Station fostered not only wastewater treatment, but water treatment as well. The station's research proved the efficacy and value of sand filtration to protect human health. First with slow sand filters and then into the 20th century with rapid sand filters, water filtration became the preferred treatment technology for all but those with a pure, upland, source of supply.

The Interstate Quarantine Act in 1893 laid the foundation for the control of communicable disease and the regulation of its carriers, such as water. A regulation pursuant to this act compelled trains and other interstate carriers to use waters of known quality which had been certified by the local health authority. The nation's first drinking water standards were adopted in 1914 as an aid to the enforcement of the Quarantine Act. These were implemented by state agencies with support from the PHS.

Arguably, the most significant development in water treatment in the first half of the 20th century occurred in 1923. That was the year Abel Wolman, who had recently been appointed Chief Engineer of the Maryland Department of Health, developed and perfected techniques for controlled chlorination of water. These techniques made possible the prescription of chlorine feed rates for water leaving the treatment plant sufficient to provide for effective and reliable disinfection of the water supplied. With filtration and/or reliable disinfection, the major public health threat of water-borne disease ceased to exist in the U.S. by World War II.

Clearly, water-related issues occupied the first half of the 1900s. However, air quality concerns began to receive attention shortly after the turn of the century. The major atmospheric concern stemmed from the presence of smoke. Up to the late 1940s, most American urban centers had smoke abatement agencies. The transfer of interest from solely smoke abatement to more comprehensive air quality issues came about as a result of developments in the field of industrial hygiene. Early atmospheric pollution studies were an extension of the science of industrial hygiene and included:

- a PHS and US Bureau of Mine study of silicosis (1910)
- organization of a Division of Industrial Hygiene by the PHS (1912).
- studies of air in industrial workshops, e.g., carbon monoxide from the use of gas-heated equipment (1916); and
- studies by the PHS of municipal dust, the radium dial painting industry, and a comparative study of air pollution in fourteen of the largest cities (1913) (Dworsky 1990).

Not withstanding the foregoing, the seminal event in the speciality of air pollution control was triggered by an air pollution episode in Donora, Pennsylvania, in 1944; twenty persons died and 5,910 became ill. It triggered the first major comprehensive study of air pollution by the PHS. The resulting Surgeon General's Report noted:

- "This study is the opening move in what may develop into a major field of operation in improving the nation's health.
- We have realized, during our growing impatience with the annoyance of smoke, that pollution from gases, fumes and microscopic particles was also a factor to be reckoned with.
- The Donora report had completely confirmed beliefs we held at the outset of the investigation:
  1. how little fundamental knowledge exists regarding the effects of atmospheric pollution on health, and
  2. how long range and complex is the job of overcoming air pollution."

## Post World War II

The industrial explosion that accompanied World War II had two significant impacts in environmental engineering. On the one hand, the richness and diversity of technological exploitation resulted in a plethora of chemical and other industrial wastes discharged to the water and air and deposited on the land. At the time, these were of little concern to a public tired from war and anxious to enjoy the fruits of peace. They systematically ignored the concerns and warnings from environmental engineers of the day. But the day-by-day, year-in-year-out callous disregard of wasteful production sowed the seeds for an environmental revolution triggered by Rachel Carlson's 1964 book, Silent Spring, and which culminated with Earth Day 1970. These events unleashed a torrent of regulations which has dominated the profession ever since.

The immediate post World War II period was also marked by a significant increase in environmental engineering research, made possible by significant federal grants to universities. A pattern was established and continues to this day that has significantly increased the knowledge of the science underlying environmental engineering. These grants also produced increasing numbers of environmental engineers with masters and doctorate degrees and spawned a new class of environmental engineer – the academic-researcher – which replaced, for the most part, the academic-practitioner who was the norm before the