FIFTY YEARS OF PROGRESS
AND CHALLENGES FOR THE NEXT CENTURY

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It is fitting, on the occasion of the 50th Annual Environmental Engineering Conference, the last Environmental Engineering Conference of the 20th century, to take a glance back at the accomplishments of environmental engineering and science over the past 50 years and to consider the challenges environmental engineers and scientists face at the dawn of the 21st century -- challenges not met, or not fully met, during the past 50 years, as well as challenges just now emerging or reemerging. To put the accomplishments of the past 50 years in proper perspective, the challenges and accomplishments of environmental engineering and science prior to 1950 will first be considered, in condensed form, before examining the past 50 years on a decade-by-decade basis.

CHALLENGES AND ACCOMPLISHMENTS PRIOR TO 1950

Ancient Civilizations

Ancient civilizations faced some of the same environmental problems facing modern society and ancient "environmental engineers and scientists" developed a number of solutions to these problems that are still in use today. For example:

- Municipal sewers were built in Sumeria (c. 3700 BC), Tell Asmar (c. 2600 BC), Baghdad (c. 2500 BC), Nineveh, and Babylon. (By way of comparison, the U.S. had only 10 sewered communities in 1860 AD).
- Many ancient civilizations constructed chimneys to remove smoke from living and working areas.
- Sanskrit writings (c. 2000 BC) recommended that water be kept in copper vessels, exposed to sunlight, and filtered through charcoal, and that impure water be boiled, heated by the sun, or filtered through sand and course gravel (Baker, 1948).
- Before 1500 BC, the palace of Minos at Knossus, Crete, had facilities (fresh running water, baths, and sewers) comparable to those of a modern hotel.
- In about 1500 BC, Egyptians were using alum to clarify water.
- Mosaic law (c. 1300 BC) required waste disposal outside of the camp and isolation (quarantine) of lepers and diseased persons.
- The Cloaca Maxima (Great Sewer) was built in the 6th century BC to drain sewage and stormwater from the forum and other low-lying parts of the city of Rome. It is still in service today, more than 2,500 years later; and its longevity and "return on investment" present a challenge that few modern public works projects can hope to rise to (especially since it is now much more difficult to obtain permission to drain a swamp).

- Hippocrates (460-354 BC), known as the "Father of Medicine," said that "water contributes much to health" and recommended that polluted water be boiled or filtered before being consumed.
- The ancient Greeks recognized both endemic disease (native to a particular population or region) and the occurrence of infrequent epidemics (outbreaks of communicable disease) which they considered to result from natural processes rather than "evil spirits." Plato and Aristotle, during the Golden Age, provided "accurate and apparently eyewitness accounts of deforestation and soil erosion in the fourth century B.C." and "the ancient Greeks were responsible for the deforestation and erosion that have reduced much of Greece to a barren, stony -- if picturesque -- wasteland" (Runnels, 1995).
- The Romans built numerous aqueducts, some still in use today, to provide cities with an adequate supply of fresh water. They also recognized the hazardous nature of asbestos and mercury.
- In ancient Jerusalem, solid waste was disposed of by dumping it over a wall into the valley below (Gehenna, later translated as "hell"), where it was consumed by continuously burning fires in an open landfill.

Thus, more than 2000 years ago, civilized societies began to recognize, and in some cases to effectively address, environmental problems associated with air quality, water supply and treatment, wastewater disposal, stormwater, solid waste disposal, hazardous chemicals, erosion, and deforestation. These problems and closely related problems remain the central focus of environmental engineering and science today; but they have intensified as the world's population has increased, and new problems have emerged.

The United States and Europe Prior to 1842

With the fall of the Roman Empire, Europe plunged into the "Dark Ages" (500 to 1500 AD). Sanitation declined, as people crowd together behind city walls for protection. Many wells, cisterns, and transmission lines were constructed; but the water generally received no treatment other than plain sedimentation to remove silt. Wastes were commonly dumped into rivers and transported downstream. Some municipalities instituted street cleaning and garbage disposal practices; but improper disposal of wastes in many towns and cities, e.g., discharge of fecal material and garbage directly into the streets, led to epidemics, e.g., leprosy (c. 600 to 700 AD) and "black death" (c. 1300 to 1400 AD), which were treated by quarantine.

Upon emerging from the Dark Ages, Europe entered a period known as the Renaissance (or "rebirth," c. 1500 to 1750 AD), marked by a flowering of the arts and literature, the beginnings of modern science, and increased emphasis on education, including medical education. Scavengers were employed by cities to collect garbage and sanitary waste, but cities were generally unhealthy and unsanitary compared to rural areas. Burning of soft coal began to foul the air, especially in larger cities in England, but not nearly as much as it would during the "Industrial Revolution" of the late 1800s. In the U.S., cities grew rapidly following the Revolutionary War; and communicable diseases were a serious problem, especially in port cities such as New York, Boston, and Philadelphia, from which they spread to other places.

As exemplified in Table 1, these historical periods were marked by an increased incidence and awareness of disease; by the beginnings of modern science (which would eventually establish the scientific basis for controlling disease and pollution); and by the development of water filtration processes that would later prove to be remarkably effective in controlling waterborne disease. The view in Table 1 and in subsequent sections of this manuscript is purposefully Eurocentric, reflecting the fact that the roots of environmental engineering and science in the U.S. and Europe are strongly intertwined; and this is not intended as a slight to the knowledge, practices, and contributions of other cultures.

The Great Sanitary Awakening

During the 1800s, the industrial revolution caused a massive influx of workers (seeking employment) into cities. Enormous water supply and sewerage problems arose; air pollution worsened due to increased burning of coal and wood; and the urban poor lived in extremely unsanitary conditions in some of the worst slums in history. The water was impure, and open sewers ran down the centers of the streets. There were no trees or parks in working class neighborhoods. Poor worker health led to low productivity, hindering economic development and reducing profits. Edwin Chadwick was appointed to investigate these problems in England and in 1842 wrote the report for which he is so well known: "Report from the Poor Law Commissioners on an Inquiry into the Sanitary Conditions of the Labouring Population of Britain." Disease was found to be related to an unsanitary environment, the government was given the power to regulate sanitary conditions, and public health protection began to shift into the realm of engineering. Chadwick's report marked the beginning of what would later come to be called the "Great Sanitary Awakening" and is widely considered to mark the birth of sanitary engineering. More than 100 years would pass before other concerns besides public health protection grew strong enough to cause the name of the field to shift from "sanitary engineering" to "environmental engineering."

On the other side of the Atlantic, the Great Sanitary Awakening can be considered to have begun with the celebration, in 1842, of the delivery of water from the Croton River to New York City (Okun, 1996). Despite the higher cost of this supply relative to other available sources, it was selected in the hope of avoiding another cholera epidemic like the one that had killed approximately 3,500 people in 1832.

In 1849, a major cholera epidemic struck both Europe and the U.S. Dr. John Snow, physician to Queen Victoria, hypothesized that cholera was waterborne, contrary to the popular miasmatic or "atmospheric" theory of the day that held that epidemics arise from poisons in the air emanating from the "bowels of the earth" (Okun, 1996). Plotting cholera deaths on a map, he found that "upwards of 500 fatal attacks of cholera occurred in 10 days" within 250 yards of the Broad Street well (located in the parish of St. James in London and later found to be contaminated with human waste from a nearby cesspool). He convinced the owners of the well to remove the pump handle, but by then the epidemic had already begun to subside.

In the U.S., Lemuel Shattuck, a Boston bookseller and chair of the Massachusetts Sanitary Commission, wrote a report in 1850 recommending the establishment of a State Health Department. The report established the basis for modern health departments, but no immediate

Table 1
Selected Historical Notes: The United States and Europe Prior to 1842

1200s	Roger Bacon (c. 1214 - 1294), a Franciscan monk known as the "Father of Modern Science," postulates that disease is produced by invisible living creatures and states that "clarifying water tends to improve health." Believing that a rational God created an orderly and rational universe (governed by laws), he develops the "scientific method" based on reproducible experiments.
1300s	Edward II (1307-1327) prohibits coal burning while Parliament is in session.
1349	The "Black Death" kills one-third of the English population.
1550s	The Germans practice "sewage farming" (land application of wastewater).
1563	A general outbreak of the Black Plague occurs in Europe.
1567	Paracelsus, the "Father of Toxicology," states that "the dose makes the poison."
1665	A Bubonic Plague epidemic occurs in Europe. Robert Hooke sees cork cells and establishes the "cell theory" (living organisms are comprised of tiny cells).
1675	Anton van Leeuwenhoek (1632-1723) discovers small living creatures in rain water. He later provides the first accurate descriptions and drawings of protozoa and other microorganisms observed with his handmade microscopes.
1685	Luc Antonio Porzio designs a staged filter for use in Army camps.
1756	Dr. Francis Home of Scotland reports on his studies of water softening.
1762	Chemical precipitation of wastewater, to remove nutrients, is tried in England.
1780s	The Lancashire slow sand filter is designed to purify drinking water.
1791	James Peacock patents a filter featuring graded media and upward flow.
1793	A cholera epidemic kills 4044 in Philadelphia.
1798	In New York City, 2086 die of cholera and 1600 of yellow fever. Jenner develops the smallpox vaccine.
1800	There are 18 privately operated waterworks in the U.S.
1801	Philadelphia constructs the first steam-powered waterworks.
1804	John Gibb builds the first modern municipal water filtration plant in Scotland. New York City appoints its first health inspector; other U.S. cities soon follow.
1805	The first large sewer is constructed in New York City.
1829	Slow sand filters are used to treat London's water supply.
1832	A cholera epidemic kills 3,500 in New York City.
1841	Thomas Clark patents a lime softening process.

action was taken. Louisiana established the first State Health Department in the U.S. in 1855, but it was ineffective. The Massachusetts State Board of Health, the first major, effective state board of health, was established in 1869, and an engineering division was created in 1886 (Okun, 1996).

Although Dr. Snow is best known in connection with the Broad Street well, it was his epidemiological study of the 1854 cholera outbreak in London, in which he demonstrated that waters withdrawn upstream of the city led to a much lower fatality rate, that more firmly established the link between cholera and water contamination (Okun, 1996). Numerous later studies in both Europe and the U.S. confirmed his findings.

Waste disposal practices also caused severe air pollution problems at this time. Haskins (1951) describes conditions in London as follows:

> The years 1858-59 were known as the period of the "great stink" in London because of the stench arising from the Thames River, the great open sewer of the city. Boat traffic nearly disappeared. Bridge traffic was almost nil. Parliament could meet only with windows hung with sacks of chlorinated lime, and even then with great discomfort.

The United States and Europe in the Late 1800s

As exemplified by the historical notes in Table 2, the latter half of the 19th century witnessed a rapid growth in scientific understanding of disease and water purification processes, the establishment of public health departments, the development of new technologies for water treatment and waste disposal, the establishment of environmental engineering and science as an academic discipline, the discovery of radioactivity, and the first known concerns about global warming. However, communicable disease remained widespread, air pollution worsened, and governmental bodies were slow to support measures to protect human health or the environment.

Kansas Near the Last Turn of the Century

The early history of environmental engineering in Kansas is closely linked with that of the Department of Civil Engineering at the University of Kansas (KU), which has been well described by Haines *et al.* (1989). The central figures in this story are Professor Frank O. Marvin and Dr. Samuel J. Crumbine.

Frank O. Marvin received a B.A. in science from Allegheny College in 1871 and moved to Lawrence in 1874 with his father, James Marvin, KU's newly appointed Chancellor. He was not academically trained as an engineer, but learned engineering from his uncle, a railroad engineer who later served as the city engineer for Kansas City, MO, and through self study. He was appointed in 1878 as an assistant professor of mathematics, physics, and civil engineering; promoted to full professor and chair of Civil Engineering in 1882 (positions he held until 1913); and elected as the first Dean of the School of Engineering (1893-1913). Marvin Hall was named in his honor.

Table 2
Selected Historical Notes: The United States and Europe in the Latter Half of the 19th Century

1854	French chemistry professor Louis Pasteur links fermentation to microbes. A cholera epidemic kills 5.5% of the population of Chicago.
1860s	Mouras experiments with anaerobic digestion of wastewater solids.
1861	In England, sewage treatment is required prior to disposal; land treatment is proposed by the Royal Commission.
1864	Pasteur develops the "pasteurization" process to rid beer and wine of undesirable strains of bacteria.
1865	Gregor Mendel, an Augustinian monk, elucidates the principles of genetics.
1867	Traube, a German chemist, experiments with artificially prepared membranes.
1868	Sir Edward Frankland conducts the first scientific study of intermittent sand filtration of sewage. The application proves unsuccessful, but later efforts result in development of the "trickling filter."
1869	James P. Kirkwood writes the first book on filtration of municipal water supplies. He recommends filtration for St. Louis, but the idea is rejected.
1872	The American Public Health Association is formed and recommends creation of a federal health department; but lawmakers are unsure whether it should be under the Army, Navy, or Marines, and a majority of people believe that public health should be addressed locally. Slow sand filters are installed in Poughkeepsie, NY, about 100 years after they were first used in Europe.
1874	MIT establishes the first Sanitary Chemistry Laboratory, under the supervision of Professor William Ripley Nichols, to analyze water quality samples for the Massachusetts State Board of Health (established in 1869).
1876	The first septic tanks are built in the U.S. Robert Koch isolates anthrax bacilli and proves they cause anthrax in cattle. The first good incinerator is designed at Manchester, and the British feel that incineration should be used to generate steam for electric power. By 1900, 112 cities in England have incinerators.
1880s	Pasteur develops the germ theory of disease, demonstrates the principle of vaccination, and develops a rabies vaccine. Combustion of soft coal creates serious air pollution problems in England.
1880	Rudolf Hering studies European sewerage practices and concludes that large cities should use combined sewers while small cities should use separate sewers.
1881	The American Water Works Association is formed. Septic tanks are employed in France.

Table 2 (continued)	
1882	Rapid sand filtration is introduced at Somerville, NJ. The earliest known experiments on aeration of sewage are conducted in England. Koch identifies the bacterium responsible for tuberculosis.
1884	Robert Koch proves *Vibrio comma* causes cholera. Ellen Swallow Richards, the "first woman environmental engineer" (Vesilind and Murcott, 1996), is appointed "Instructor of Sanitary Chemistry" at MIT. She is credited with developing the "sanitary survey"; is instrumental in establishing standard methods for analysis of water and wastewater and the first water quality standards; and explicitly recognizes the importance of ecology and proper use of resources.
1885	An outbreak in Chicago, which discharges its sewage directly into lake Michigan (its source of drinking water), kills about 90,000 people, an eighth of the city's population, leading to formation of the Chicago Sanitary District (1889), construction of the Chicago Sanitary and Ship canal, and diversion of the city's wastes to the Mississippi River. The first incinerator is built in the U.S.; 208 more are built in the next 23 years.
1886	H.A. Fleischman of Vienna develops a garbage reduction process to recover grease and fertilizer; but it proves to be impractical.
1887	Dibdin indicates that bacteria are needed for sewage purification. The Massachusetts State Health Department establishes the Lawrence Experiment Station, under Hiram Mills, to study water and sewage treatment. William T. Sedgewick (an MIT professor to whom the academic lineage of a large percentage of environmental engineering professors can be traced) and Edwin O. Jordan demonstrate that the destruction of organic matter is related to bacterial metabolism. Research on plain aeration is not very successful.
1888	Professor Sedgewick of MIT is appointed as Consulting Biologist for the Massachusetts State Board of Health.
1889	Hiram Mills and Professor Sedgewick convince MIT to establish the first degree program in Sanitary Engineering.
1890s	New York City sets up a reclamation plant for refuse. Non-reclaimables are sent to an incinerator and incinerator ash is landfilled. Garbage is fed to pigs until health problems stop the practice in the 1940s. Garbage collection and disposal eventually become "involved with politics" and deteriorate.
1891	Sludge digestion lagoons are built in Germany.
1892	A cholera epidemic hits Altona and Hamburg, sister cities on the Elbe River in Germany, killing more than 1% of the people of Hamburg, which has an unfiltered upstream water supply. The death rate in Altona, which withdraws its water downstream from both cities but filters it, is 85% lower than in Hamburg. Rudolf Diesel patents the internal combustion engine.

Table 2 (continued)

1893	The U.S. Congress passes the Interstate Quarantine Act. J. Corbett develops the first trickling filter. The London County Council examines hand sorting of refuse but condemns it as impractical. Ozone is used at Oudshoorn, The Netherlands, to purify filtered Rhine River water.
1895	Hazen publishes a treatise on filtration. He and his successor, George Fuller, prove the effectiveness of filtration, especially when combined with coagulation, as a water treatment technique. Slow sand filtration is found to reduce the death rate from cholera by 79%.
1896	Arrhenius, a Swedish chemist, links increased CO_2 to global warming.
1896	Adding bleaching powder (chlorine) to drinking water stops a typhoid epidemic in Yugoslavia.
1897	The first municipal softening plant in No. America is installed at Winnepeg.
1898	Marie and Pierre Curie discover radium.

Professor Marvin took a keen interest in public health and sanitary engineering. Typhoid was endemic in Kansas at that time, and sanitation was generally poor to nonexistent. He appealed through the Kansas State Board of Health (KSBH, which had been established in 1885) to the Kansas legislature for support of efforts to control typhoid and improve sanitation; but the legislature, lacking understanding of the problems, failed to provide the necessary resources. In 1895, Professor Marvin established a hydraulic and sanitary engineering option within civil engineering; and in 1896 he established a course in bacteriology. In 1898 he was elected to KSBH; organized a state sanitary convention to stimulate interest in sanitary problems; and continued to appeal to the state legislature for state control of water supplies and sewerage, since KSBH's role at that time was largely limited to education and data gathering. Between 1895 and 1904 there were 2,929 deaths due to typhoid fever in Kansas, deaths that were preventable.

In 1904, Professor Marvin gained a strong new ally in the person of Dr. Samuel J. Crumbine, a Dodge City physician who was appointed executive secretary of KSBH. Together, they forged a cooperative effort between the KU and the U.S. Geological Survey to study the pollution of the major rivers in Kansas and eventually brought sufficient pressure to bear on the state legislature, resulting in the passage of the Water and Sewage Law of 1907. This law established the position of State Sanitary Engineer, who was to be a faculty member at KU. Professor William C. Hoad of KU, a KU alumnus who had received special training in sanitary engineering at MIT, was appointed as the first State Sanitary Engineer; and Dean Marvin was elected sanitary advisor. Together, they led the effort to design and construct water and wastewater treatment facilities, control waste discharges into the state's waters, and establish appropriate sanitary practices. Many water quality studies were conducted, with the necessary analyses being performed in university laboratories. Haskins (1950) described sewage treatment practices in Kansas in 1907 as follows:

> At that time practically all of the sewage treatment plants in Kansas consisted of septic tanks and intermittent sand filters or septic tanks and contact beds, but almost immediately Imhoff tanks began to appear in plans for new improvements, following very quickly by the trickling filters in place of contact beds.

Dr. Crumbine's efforts were not limited to water and wastewater treatment. He and his agency (KSBH) were also very active in efforts to protect the purity of food and drugs and to protect public health in various other ways. Dr. Crumbine became well known as a strong advocate of simple, effective public health measures. His efforts led to the development of the first flyswatter; a ban on the use of common cups in Kansas (1909) and the subsequent development of the single-use paper product industry; the practice of changing bed sheets daily in motels and hotels; and campaigns to educate the public on the need to kill flies and rats, to avoid spitting on the sidewalk, and to reduce their exposure to typhoid by screening their houses and outhouses, protecting their wells, and cleaning up their yards. By the time he left office in 1923, Kansans were living an average of five years longer than people in any other state (Carpenter, 1996).

The United States and Europe in the Early 1900s

The most significant developments In the earliest years of the 20th century (Table 3) were the development of effective processes (chlorination and ozonation) for disinfecting drinking water; the development of the activated sludge process, which greatly facilitated treatment of the wastewater effluents produced by large cities and industries; and the small but growing involvement of the federal government in pollution control and other areas previously considered to be under state and local jurisdiction. The 10th Amendment to the U.S. Constitution states that "powers not delegated to the United States [federal government] by the Constitution ... are reserved to the States respectively, or to the people." However, federal involvement in pollution control was justified first on the basis of the "commerce clause" and later on the basis of the "general welfare" clause, both of which are found in Article I, Section 8, of the U.S. Constitution, which states that "The Congress shall have power to ... provide for ... the general welfare of the United States ... [and] to regulate commerce ... among the several states, and with the Indian tribes."

During the 1920s and 30s, numerous water and wastewater treatment facilities were built, many with assistance from the Work Projects Administration; and the death rate attributable to waterborne disease plummeted. As the incidence of disease decreased, the states became less interested in pollution control, which eventually (after World War II) led to increasing public pressure on the federal government to control pollution. Although many municipal treatment facilities were built, environmental problems not directly linked to communicable disease received scant attention. There were important gains in scientific knowledge (e.g., an understanding of the chemistry of chlorination and chloramination) and pollution control technology; but World War I, World War II, and the Great Depression caused public attention and most available resources to be largely focused elsewhere.

Table 3
Selected Historical Notes:
The United States and Europe from 1900 to 1950

1900	The child mortality rate is 4,350 per 100,000, versus 43.6 in 1992.
1902	A chlorine disinfection system is installed in Middlekerke, Belgium.
1904	The Imhoff tank is patented in Germany by Karl Imhoff.
1905	The first edition of *Standard Methods of Water Analysis* is published by APHA.
1906	Ozone is used for disinfection at Nice, France. The U.S. passes the Food and Drug Act (modeled after a similar act in Kansas in 1901).
1908	Jersey City becomes the first large U.S. municipality to receive chlorinated drinking water. Chlorination is also employed at the Bubbly Creek filters of the Chicago stockyards. Harriet Chick formulates the "laws of disinfection."
1911	The first Imhoff tanks are built in the U.S. (Patent proceeds, impounded during WWI, are eventually used to support for the fledgling Federation of Sewage Works Associations, later renamed the Water Environment Federation).
1912	The U.S. passes the Public Health Service Act, establishing the U.S. Public Health Service (USPHS, under the Treasury Department) and the Streams Investigations Station in Cincinnati and authorizing surveys and studies of water pollution, particularly as it affects human health.
1913	Dr. Fowler, who had pioneered sewage treatment in India, returns home to England by way of the Lawrence Experiment Station, where aeration of sewage is being studied. He stimulates two of his students, Ardern and Lockett, to do research on sewage aeration; and they develop the activated sludge process at Manchester, England. The U.S. Congress authorizes collection of an income tax (with proponents contending that "it is inconceivable that it will ever be necessary to levy and collect more than 5% of the annual income of any entity, either personal or corporate"), enabling the role of the federal government to dramatically expand, eventually leading to massive federal involvement in pollution control. George C. Whipple, a former student of Sedgewick's who had been appointed Professor of Sanitary Engineering at Harvard University in 1913, and Professor Sedgewick establish the MIT-Harvard School of Public Health, which became separate programs in 1917 due to a ruling by the Massachusetts Supreme Court (McKinney, 1995)
1914	In January, Jones and Attwood patent a process similar to the modern activated sludge process. In May, Ardern and Lockett present a paper describing the results of their experiments, including accumulation of solids by recycling, energy conservation, sludge handling, and the sensitivity of nitrifying organisms to pH and temperature. The USPHS sets the first federal drinking water standard (on coliforms) and bans the use of the "common cup" on interstate carriers.

Table 3 (continued)

1915	Leslie Frank obtains an American patent for the activated sludge process. Patent litigation during the next 20 years greatly slows employment of the process and encourages the use of trickling filters.
1916	The first activated sludge plant in the U.S. is built at San Marcos, Texas. Houston and Milwaukee soon follow. The first school nurse is hired, in Dodge City, Kansas.
1924	Baylis tests powered activated carbon for taste and odor control. The U.S. passes the Oil Pollution Control Act to reduce damage and fire hazards to ships and harbors. Dissolved air flotation is patented in U.S.
1925	The U.S. drinking water standards are revised to require a protected, pollution-free source; limits are set on lead, copper, and zinc; and recommended limits are set on a number of other constituents.
1928	The Water Environment Federation (as it is presently named) is formed. Alexander Fleming discovers penicillin.
1933	Canned beer is introduced; and litter problems increase.
1940s	Conversion from coal to gas helps alleviate England's air pollution problems. Nonbiodegradable detergents are replaced with biodegradable detergents in England and the U.S. Los Angeles' severe air pollution problems become a public issue. The first water desalination plants are built on land. Water fluoridation is introduced (and becomes common by the 1950s). The "chemical explosion" (i.e., manufacturing of numerous new synthetic chemicals in large quantities) and the "nuclear age" begin.
1946	Water utilities are made responsible for sanitary defects "to the tap."
1948	A severe air pollution episode in Donora, PA, brings attention to the need for air pollution research and control. The Federal Water Pollution Control Act (FWPCA) directs the Surgeon General to investigate the water quality and the nature of industrial wastewater discharges; authorizes loans for construction of sewage treatment plants (but none are made, since both Truman and Eisenhower did not consider it appropriate for the federal government to be making loans to local agencies); authorizes the attorney general to sue polluters of interstate waters, with the consent of the states involved (but there was never a single case filed); and provides technical assistance to the states.

The Status Quo in 1950

By 1950 most mid- to large-sized cities, as well as many smaller ones, had both water and wastewater treatment facilities, although many coastal cities were still discharging raw wastewater or primary effluent into the ocean. Many industries had begun treating their wastewater discharges, but many were either untreated or inadequately treated. Prior to 1950, the primary basis of design for most sewage treatment plants was either hydraulic residence time or, in the case of the newer plants, volumetric loading rate (lbs BOD_5 per 1000 ft^3 per day); and designs that worked reasonably well for treating municipal wastewater often failed miserably when used to treat industrial wastewater without a fundamental understanding of the differences involved.

On other fronts, progress was partial to nonexistent. Most municipal solid wastes were being disposed of in sanitary landfills, but landfills were rarely designed to prevent groundwater contamination. Many industrial solid wastes were not being properly disposed of. Air pollution was of growing concern, but was virtually uncontrolled. Nutrients were being discharged to the aquatic environment at a rapidly growing rate, from both point and nonpoint sources; and eutrophication of lakes and estuaries was a rapidly growing problem. Knowledge of radiation had "mushroomed" but nuclear weapons tests were discharging large amounts of radioactive substances into the atmosphere and increasing radioactive "fallout." Environmental engineers and scientists had a handful of good tools at their disposal; but they did not yet recognize a number of problems, were unsure of the nature or magnitude of other problems (or even how to measure them), and were just beginning to tackle some of the more complex problems that had been identified.

However, by 1950 environmental engineers and scientists in the U.S. and Europe had already accomplished one of the most significant feats in human history -- a dramatic decrease in the death rate associated with waterborne disease. For example, the typhoid death rate in the U.S. was reduced from 36 per 100,000 in 1900 to 0.1 in 1950; and the incidence of other waterborne diseases had been similarly reduced. This achievement has not been equaled in the past 50 years (although the eradication of smallpox and the control of polio are worthy of honorable mention) and it is not likely to be equaled again anytime soon. In fact, keeping waterborne disease under control in the U.S. and other developed countries and bringing it under control in other parts of the world are major challenges facing environmental engineers and scientists as they enter the next century.

FIFTY YEARS OF PROGRESS -- A DECADE-BY-DECADE SUMMARY

The 1950s

It is appropriate, given the audience for which this manuscript is written, to begin the discussion of the 1950s with a brief history of the Environmental Engineering Conference and to explicitly note its contributions, and those of similar programs, to the progress of the past 50 years.

The first Environmental Engineering Conference was organized by Dwight F. Metzler, who had received a B.S. degree in Civil Engineering from KU in 1940 and an M.S. from Harvard's School of Public Health. In 1948 he returned to KU as an assistant professor and was appointed Chief Sanitary Engineer for KSBH, positions which he held until 1966. The conference was organized to meet the "need for postgraduate short courses for sanitary engineers, as expressed by the Kansas Contractors Association and municipal and consulting engineers at their annual meeting at Arlington, Kansas in June, 1950." The first conference focused on sewage treatment "because of the emphasis being placed on sewage treatment in Kansas, and the relatively recent real advances in the theory and practice of sewage treatment." Metzler (personal communication, 1999) recently indicated that there were, at that time in Kansas, only three cities in Kansas (including Kansas City) with engineering firms able to properly design an activated sludge plant.

The first conference was cosponsored by the KU Department of Civil Engineering and KSBH and was held on January 11, 1951. The first presentation was given by Charles A. Haskins, a KU alum who had taken a course on sewage disposal under Professor Hoad and later joined him as an assistant, at a salary of $900 per year, following the passage of the Kansas Water and Sewage Law in 1907. As he later recalled it (Haskins, 1951), he had not been particularly interested in sewage treatment as an undergraduate, but thought it might be a bit easier for him to learn than reinforced concrete or structural design. He also noted that "in those 43 years [1907 to 1950] practically all of the development of the modern processes of sewage treatment [had] occurred and those years cover practically one-half of the development of 'Modern Sanitation'."

Metzler had initially envisioned only a series of short courses rather than an annual conference; but the success of the first conference encouraged the organizers to publish a proceedings and to plan additional conferences in subsequent years. Since old habits are hard to break, especially for bureaucracies, the conference has continued to this day. The format of the conference has undergone relatively little change over the years. The range of topics has been expanded by adding concurrent afternoon sessions; and recent conferences have included presentations on air quality, solid and hazardous waste management, and other topics besides water and wastewater treatment. However, the conferences have consistently focused on the educational and informational needs of environmental engineers in Kansas. Some conferences or conference sessions have focused on design, while others have focused on science, broader societal issues, emerging or reemerging problems, new technologies, regulations, current research, or various ancillary topics.

A cursory inspection of the presentations given at the first five conferences (Table 4) reveals that most of the topics addressed are quite familiar to today's audience. This underscores the fact that environmental engineering has greatly expanded over the years rather than moving along in linear fashion, i.e., many of the technologies used in the past are still in use today, but the number of problems being addressed and the technologies available to address them have both greatly increased in number. This has led to increased specialization, and to a need for conferences that foster interaction and the exchange of ideas among those in various areas of specialization.

In the broader historical context of environmental engineering, it is not at all surprising that the Environmental Engineering Conference was founded in the early 1950s. There had, for decades, been a growing recognition of the need to train engineers, scientists, and operators to effectively address environmental problems; but the need increased sharply following World War II and the "Korean conflict." Public attention now turned to tasks that had been pushed aside by the war effort; veterans returned home in large numbers, married, and began raising families (creating the "baby boom"); and, with little competition from other industrialized countries (which had sustained far more damage than the U.S. during the war), the economy began a strong expansion that would continue largely unchecked for more than 50 years and that would greatly increase the mass of pollutants being discharged to the environment. University enrollments rose rapidly, especially in the sciences and engineering; state operator certification programs were initiated; and universities began to offer conferences designed to meet the needs of practicing engineers. Examples include the Purdue Industrial Waste Conference (1945 to the present) and the water supply conferences offered by the University of Illinois (1959 to 1983).

Table 4
Papers Included in the Proceedings of the First
Five Environmental Engineering Conferences

1951	"The Theory of Sewage Treatment," Charles A. Haskins, Consulting Engineer "Sedimentation Theory and Practice," Roger D. Lee, District Engineer, KSBH "The Design of Trickling Filters," F. M. Veatch, Black & Veatch
1952	"Water Resources in Kansas," Russell L. Culp, KSBH "The Effect of the 1952-1954 Drought on the Design of Water Supply Impounding Reservoirs," Thomas B. Robinson, Black & Veatch "Biological Oxidation of Organic Wastes," W. Wesley Eckenfelder, Jr., Asst. Prof., Manhattan College, and Partner, Weston Eckenfelder and Hood, Consultants "Critical Evaluation of Recent Trends and New Developments in Accelerated Sludge Digestion," Harry E. Schlenz, President, Pacific Flush Tank Co.
1953	"Profitable Garbage Disposal by Composting," Eric Eweson, Consulting Engineer, Frazer Products, Inc. "Solids Contact Basins in the Treatment of Ground and Surface Waters," H. O. Hartung, Superintendent of Production, St. Louis County Water Co. "Impact of Air Conditioning on Water Works Design and Operation," Melvin P. Hatcher, Director, Water Department, Kansas City, MO "Water Quality Objectives," Glen Hopkins, USPHS "State Policies for the Review of Plan and Specifications for Sewage Works," Paul Bolton, Iowa State Dept. of Public Health "Financing and Rallying Support for Sewage Treatment," C. Madison Williams, Street Commissioner, Topeka, KS "Sportman's Viewpoint of Stream Pollution," H. F. Lutz, Kansas Fish and Game Commission
1954	"Sewage Lagoons Provide Lost-Cost Treatment in North Dakota," W. Van Heuvelen and Jerome H. Svore, North Dakota State Department of Health "Plastic Pipe in Public Water Supply Systems," Walter D. Tiedeman, National Sanitation Foundation Testing Laboratory, University of Michigan "Aeration of Water," Paul D. Haney, Sanitary Engineer Director, USPHS, Cincinnati, OH "The Legal and Financial Problems of Growing Cities," Albert B. Martin, Director of Research, League of Kansas Municipalities
1955	"Progress in the Design of Rapid Sand Filters," John R. Baylis, Engineer of Water Purification, Chicago, IL "The Use of Activated Silica Sols in Raw and Waste Water Treatment," A. B. Middleton, Philadelphia Quartz Co. "Conservation of Wastes Within Industries," Hayse H. Black, USPHS "Sewer System Problems Caused by Rapid Municipal Growth," R. E. Lawrence, Black & Veatch; Lester T. Hagadorn, Wilson & Co.; L. K. White, Wichita, KS; H. F. Harper, Salina, KS; W. E. Briscoe, Topeka, KS

The 1950s (Table 5) were marked by increased federal support for research and training in the areas of air and water quality and wastewater treatment; by the beginning of the federal construction grants program; and by a greatly increased emphasis on science education (due in large part to the contribution of the Manhattan Project to U.S. success in World War II and, especially after the Soviet Union's successful launch of Sputnik, to "Cold War" concerns that failure to keep up technologically would lead to future military defeat). Universities began to place a very strong emphasis on research, to establish new doctoral programs, and to produce Ph.D.s in record numbers. Engineering schools, which had previously used success in engineering practice as the primary criterion in most hiring and promotion decisions, began hiring "green" Ph.D.s in large numbers to obtain a bigger share of the "research pie"; and the previously close ties between practice and academia began to weaken.

Table 5
Environmental Progress and Related Events in the 1950s

1950	Inclined plate settlers are developed in Sweden.
1950s	Extended aeration systems are developed and used for treatment of industrial wastewater.
1953	The American Academy of Sanitary Engineers (renamed the American Academy of Environmental Engineers in 1966) is formed.
1954	Demineralization by electrodialysis becomes commercially available.
	Enders, Robbins, and Weller are awarded a Nobel Prize in 1954 for culturing poliomyelitis virus on monkey kidney cells, laying the foundation for the development of effective polio vaccines. (Polio is suspected of being waterborne, but its pattern of infection differs from that typically exhibited by waterborne diseases.)
1955	In the aftermath of the Donora, PA episode, Congress authorizes federal funding for research, training, and support of local air pollution control agencies for five years. The American Sanitary Engineering Intersociety Board is formed.
1956	President Dwight Eisenhower proposes the interstate highway system.
	The Federal Water Pollution Control Act Amendments authorize grants to state and local governments for up to 30% of the cost of sewage treatment plant construction, with a ceiling of $250,000; authorize funds for research and training; and direct the Surgeon General to identify pollution problems affecting waters involved in interstate commerce and to attempt to get action in a cumbersome conference-hearing procedure requiring state consent.
1957	The Soviet Union launches Sputnik, taking the lead in the "space race."

During the 1950s, those in the field of environmental engineering were actively engaged in debating and resolving a number of questions: what the field should encompass; whether it should be called "public health engineering" or "sanitary engineering" (Babbitt, 1952); whether postgraduate training should be mandatory (as in other professions such as law and medicine); what topics should be included in the curriculum; whether graduate programs should be accredited; who should certify or license sanitary engineers; and whether a new professional society was needed to adequately represent those in the field. Some of these questions had arisen in earlier decades, and many would continue to be debated for decades to come, including the present one.

The situation in Kansas in the 1950s mirrored that at the national level; but there was also a very significant change in the relationship between KU and KSBH in 1957. As related by Haines *et al.* (1989):

> Federal support for education, especially engineering education, and university research increased rapidly. KU took advantage of the new emphasis ... The sanitary engineering division of [KSBH] used KU to obtain federal funds for a new environmental health research laboratory. Unfortunately, the Division of Sanitation was moved from the KU campus to Topeka in 1957, making it difficult to maintain the close relationship that had developed between the Civil Engineering Department and the division of sanitation. The loss of the division of sanitation left the department with no full-time research personnel in sanitary engineering and resulted in a smaller federal grant than originally sought.

The 1960s

At KU, the 1960s began very auspiciously. Professor Ross E. McKinney was recruited from MIT and placed in charge of the environmental health research laboratory that would be constructed in 1961. Since state funds were lacking, the new building provided only space and not equipment, so he and his students began by constructing a lab bench and salvaging others discarded by the chemistry department. He subsequently obtained federal funds to more fully furnish and equip the laboratory and to support graduate students; and he established a new graduate program in environmental health engineering and science, one of the first such programs to bear the name "environmental" rather than "sanitary." At this time, there was very strong interest in improving biological wastewater treatment for both municipal and industrial applications, and Professor McKinney and his students were pioneers in the development of fundamentally sound, scientific approaches to biological wastewater treatment. They were also very active in other areas, including solid waste management and sludge digestion.

Milestones of Professor McKinney's career and the program he developed at KU are presented in Table 6. KU's graduate program in environmental engineering and science, as it has been named since 1994, has approximately 400 alumni, most of whom sat under Professor McKinney's tutelage. He also taught numerous other students: students who earned a B.S. or M.S. degree in Civil Engineering, rather than an "environmental" degree; both graduate and undergraduate students in other engineering and science disciplines; students around the nation and the world who used his classic textbook *Microbiology for Sanitary Engineers*; and the many

Table 6
Selected Milestones in the Career of Professor Ross E. McKinney

1948	Receives B.S. degree in Civil Engineering and B.A. in Mathematics from SMU
1949	Receives S.M. (sic) in Sanitary Engineering from MIT
1951	Receives Sc.D. in Sanitary Engineering from MIT; appointed Acting Chairman, Dept. of Sanitary Science, Southwest Foundation for Research and Education, San Antonio, TX
1953	Appointed Assistant Professor at MIT
1954	Vice-President of Rolf Eliassen Associates (through 1960)
1958	Appointed Associate Professor at MIT
1960	Appointed Professor at KU
1962	Establishes KU's M.S. degree program in Environmental Health Engineering; receives Harrison P. Eddy Medal from Water Pollution Control Federation
1963	Appointed chair of KU's Civil Engineering Department
1964	Receives Rudolf Hering Medal from the American Society of Civil Engineers
1966	Named Parker Distinguished Professor of Civil Engineering (and therefore forced to resign as chair)
1967	Establishes KU's Ph.D. degree program in Environmental Health Engineering
1968	Establishes KU's M.S. degree program in Environmental Health Science
1972	Establish KU's Ph.D. program in Environmental Health Science
1975	Construction of the new Environmental Health Research Laboratory in Learned Hall completed
1976	Appointed N.T. Veatch Professor of Environmental Engineering
1977	Elected to the National Academy of Engineering
1979	Designated as a U.S./People's Republic of China Exchange Scholar
1982	Receives Thomas R. Camp Medal from the Water Pollution Control Federation
1991	Receives Gordon Maskew Fair award from WPCF for contributions to environmental engineering education
1992	Receives Chancellors Club Career Teaching Award from KU
1993	Retires from KU, having supervised the research of more than 160 M.S. and Ph.D. students
1997	Appointed Adjunct Prof. of Civil and Environ. Engrg. at Duke University
1999	Cited by Engineering News Record as one of top 125 engineers of past 125 years

practitioners who took courses or short courses from him without pursuing a degree. An even greater number of students have been taught by professors whose graduate work was supervised by Professor McKinney (at least 14 in number) or by their descendants.

By the time he retired from KU in 1993, Professor McKinney had supervised the research of more than 160 graduate students, published more than 200 technical papers, written 60 research reports and 370 consulting reports, and received numerous awards for his efforts as an educator, researcher, and engineer. His strong, positive impact on the field of environmental engineering was felt and recognized both nationally and internationally, as evidenced by his election to the National Academy of Engineering and his being named by ENR as one of the top 125 people in the field in the past 125 years.

The 1960s can, in retrospect, be considered as a time of preparation for the tremendous environmental protection efforts that would be unleashed in the 1970s. As noted by Thomas Camp at the first Conference on Graduate Education of Sanitary Engineers in 1960, fewer than 100 doctoral degrees in sanitary engineering had been awarded prior to 1954 and between 1947 and 1956 there had been an average of only about 300 sanitary engineering graduates per year (including B.S., M.S., and Ph.D.) in the U.S.; but the USPHS had estimated a need for about 22,000 sanitary engineers by 1970 (Hendricks and Baumann, 1990). This need was met in part by rapidly increasing the size and number of graduate programs in sanitary engineering and by expanding the training grants program, which provided tuition and stipends for students pursuing degrees in sanitary engineering.

On the technological front, research blossomed in the 1960s. There was great optimism that new technologies would be developed to effectively and inexpensively control pollution, e.g., that activated carbon adsorption or similar processes would be used to remove toxic organic chemicals; that "advanced waste treatment" processes would replace or treat the effluents from conventional treatment plants that were rapidly becoming overloaded; and that removing nutrients from municipal wastewater discharges would solve the growing eutrophication problems. The economy was strong, the nation was experiencing unprecedented prosperity, and it was believed that the "Great Society" that had emerged victorious from two world wars could readily solve more mundane problems, either by spending money (e.g., the War on Poverty) or through legislation (the Civil Rights Act). This optimism and enthusiasm would eventually lead to the very ambitious environmental legislation of the 1970s.

On the legislative front, there was a growing involvement of the federal government in pollution control efforts (Table 7). Congress was somewhat reluctant to trample "states rights" in this area, and began by "encouraging" the states to establish criteria and standards for air and water quality and by providing grants and technical assistance to support and enhance state programs. However, Congress threatened to expand the role of the federal government to protect the environment if the states failed to do so. This threat was carried out beginning in the 1970s, when federal environmental legislation routinely encouraged states to assume "primacy" for major environmental programs (i.e., to exercise their right and responsibility to control pollution) but also authorized the federal government to assume primacy when a state program failed to meet minimum federal requirements.

Table 7
Environmental Progress and Related Events in the 1960s

1960	The First Conference on Graduate Education of Sanitary Engineers is held in Cambridge, MA, with Thomas Camp serving as chair.
1960s	Major advances are made in membrane technology, including development of spiral-wound membranes, and RO membranes become commercially available.
1961	The FWPCA Amendments eliminate state consent, extend coverage to all navigable waters, increase the construction grant ceiling, establish seven regional laboratories, and authorize $5 million per year for research.
1962	Rachel Carson's *Silent Spring* catalyzes public concern for the environment. The USPHS sets many new drinking water standards, including recommended minima and maxima for fluoride, and systems are required to be under the responsible charge of qualified personnel.
1963	The American Association of Professors in Sanitary Engineering (renamed the Association of Environmental Engineering Professors in 1972) is formed. The Clean Air Act authorizes the secretary of HEW to publish air quality criteria, establishes a conference-hearing procedure for interstate air pollution, and authorizes federal funds for state air pollution control agencies.
1965	The Water Quality Improvement Act creates the Federal Water Pollution Control Administration; transfers pollution control from USPHS to the Dept. of Interior (Health, Education, and Welfare); requires states to establish water quality criteria and set ambient water quality standards, threatening federal pre-emption if the states fail to act; and increases construction grants. The Clean Air Act Amendments authorize HEW to promulgate and enforce federal emission standards for new motor vehicles, resulting in the requirement for positive crankcase ventilation (PCV) for new autos beginning in 1968. The Solid Waste Disposal Act targets municipal solid waste, especially open burning in dumps, and authorizes grants for state programs and research.
1966	The Clean Water Restoration Act increases construction grants, extends the 1924 Oil Pollution Control Act to all waters, and authorizes funds for research, river basin planning, and state assistance.
1967	The Air Quality Act requires states to promulgate ambient standards and to develop state implementation plans to meet them; but, by July 1970, only 10 state plans have been approved, causing Congress to consider enforceable federal emission standards.
1968	A study finds not a single fish in the Cuyahoga River between Akron and Cleveland, OH.
1969	The Cuyahoga River catches fire.

One administrative change made during the 1960s appeared to some to be simply another attempt at government reorganization; but it was both highly symbolic and substantive. The creation of the Federal Water Pollution Control Administration (FWPCA) and its transfer from USPHS to the Department of Interior was more than just a minor reorganization effort. This change was made because many believed that the natural environment would not be adequately protected so long as the responsibility for doing so rested within an agency that was charged primarily with protecting human health. Though this change had the unfortunate effect of distancing environmental engineering from others involved in public health protection, it had the positive effect of broadening the scope of the field. Within a few years, the term "environmental engineering" had largely replaced "sanitary engineering" and efforts to protect "the environment" gain equal footing with efforts to protect human health.

Numerous references to specific legislative acts are made in this discussion of "progress." This is not intended to suggest that legislation is synonymous with progress. However, the various pieces of legislation cited herein do reflect, perhaps imperfectly: 1) societal consensus as to how certain environmental problems should be addressed; 2) societal recognition or belief that certain technologies or management practices are reasonably effective and affordable; and 3) societal willingness to devote resources to environmental protection.

The 1960s were also a time of growing social unrest in the U.S., and the environment became one of the major focal points of this unrest. Rachel Carson's *Silent Spring* raised serious concerns regarding the long-term consequences of the use of chemicals, especially pesticides, on both human health and the environment, sparking an enormous growth in public interest in environment issues. Her concerns were magnified by the state of the environment at that time (e.g., dirty smokestacks, fish kills, severe smog, rivers catching fire, acid mine drainage, etc.), which contributed to the undermining of public confidence in the willingness and ability of public institutions to protect human health and the environment. Public confidence in government, industry, science, and academia was also eroding for other reasons:

- Federal government policies and military decisions during the Vietnam War, which reached its height in the 1960s, were increasingly questioned or opposed.

- Federal support of the civil rights movement caused opponents to oppose further expansion of federal power, while advocates began doing battle with the many state and local governments that were unwilling to change the *status quo*.

- Some state and local governments were seen as corrupt (e.g., due to ties to organized crime) and many as beholden to private interests, as evidenced by their failure to address the pollution problems caused by local industries.

- Industry was obviously profiting at the expense of the environment, and the public began increasingly to realize that business was primarily concerned with the "bottom line" and had no inherent incentive to protect the environment and would not do so without effective government intervention.

- Scientists had been expected to usher in a nuclear age that would provide cheap and abundant power for all; but after 20 years of research what the public had received in exchange for their massive investment was a massive arms race, global insecurity, radioactive fallout, increasingly expensive nuclear power, and rapidly growing piles of nuclear waste having no agreed upon means of disposal. The public began to recognize that science and technology not only solved problems but could also create them.

- Students began to question whether they were being educated or simply trained to play roles in "the system"; and student protests over the Vietnam War, civil rights, and other issues sometimes erupted in violence (as exemplified by the riot at the 1968 National Democratic Convention), leading to even greater mistrust of public officials.

Nevertheless, as described by Christman (1991):

> There was a palpable power in the times of the 1960s, and a passion for change was upon us. It was a glorious time for politics, and the disenchantment of the people with a polluted environment was quickly transformed into sweeping legislation forbidding pollution. Public interest groups with adequate legal advice found that they could exert effective pressure on government agencies and on Congress by invoking the possibility that contaminants posed serious threats to human health (largely cancer).

The public's growing interest and involvement in environmental issues during the 1960s would also lead, in the 1970s, not only to a flood of new legislation but also to an unprecedented opening up of political, regulatory, and administrative processes to public scrutiny, oversight, and involvement. This would be rather traumatic for many environmental engineers and public works officials, who had historically carried out most of their duties largely unnoticed and behind closed doors, and who considered lack of public attention as a sign they were doing their jobs well.

The 1970s

On the first day of the decade, January 1, 1970, President Richard Nixon signed into law the National Environmental Policy Act (NEPA, passed by Congress in 1969). Its stated purposes were: "1) to declare a national policy which will encourage productive and enjoyable harmony between man and his environment; 2) to promote efforts which will reduce or eliminate damage to the biosphere and stimulate the health and welfare of man; and 3) to enrich our understanding of the ecological systems and natural resources important to the nation." The act required federal agencies to produce environmental impact statements, identifying the potential environmental impacts of their proposed actions (e.g., funding a project, issuing a permit, etc.), so that the public and various decision makers would have the necessary information to make informed decisions on matters affecting the environment. The act also called for the formation of a Council on Environmental Quality (CEQ) to advise the president on environmental matters and to review environmental impact statements.

The National Environmental Policy Act ushered in the "decade of the environment" as it would soon come to be called in the U.S. (although the term would later be applied to the 1990s in a global context). Public support for stronger environmental protection had gained considerable momentum during the 1960s, but it was not until the 1970s that most of the "real action" began. Major pieces of legislation (Table 8) were passed to address air quality, water quality, ocean dumping, resource conservation and recovery, drinking water quality, energy use, protection of endangered species, solid and hazardous waste management, and control of pesticides and toxic substances. These legislative acts, with their later amendments, form the core of environmental protection efforts in the U.S. today and have served as models for many other nations. These acts also led to an unprecedented allocation of resources to environmental protection. Literally tens of billions of public dollars and even greater sums of private dollars were used to design, construct, and operate treatment facilities; to purchase and install pollution control devices; to design and implement effective management systems; to train scientists, engineers, and operating personnel; to conduct research; to monitor treatment effectiveness and environmental quality; and to enforce the new regulations.

Other notable events besides the signing of NEPA took place during the watershed year of 1970. In 1970, President Nixon created the U.S. Environmental Protection Agency (EPA) by executive order, combining the environmental control functions of 13 different agencies into a single agency having ten regional offices. Its mission was to establish and enforce environmental protection standards; to conduct environmental research; to provide assistance to others combating environmental pollution, especially state and local governments; and to assist the CEQ in developing and recommending to the president new policies and legislation for environmental protection. The new agency quickly sprang into action, and a major piece of legislation, the Clean Air Act, was pushed through Congress the same year. Also in 1970, the first Earth Day, in essence a nationwide protest and "teach in" organized largely by students, was observed on April 22, i.e., Arbor Day, which had been established in the 1800s in response to widespread deforestation in many parts of the U.S.

In 1971, President Nixon declared a "war on cancer" in his State-of-the-Union address, and Congress soon passed the National Cancer Act as well as a resolution calling for a cancer cure by 1976. Though publicly popular, this initiative would later be referred to by its critics as a "medical Vietnam" and would contribute to the growing public misperception that the nation was experiencing a cancer epidemic. Several factors led to this misperception: 1) the testimony of scientists before Congress that most cancers were "environmentally" caused, by which the scientists meant not that pollutants cause cancer but that most cancers are not of genetic origin; 2) fear, as voiced in *Silent Spring*, that toxic chemicals released into the environment might cause a cancer epidemic (a reasonable concern given what was then known, but one that would later prove to be largely unfounded); and 3) the obvious increase in recent decades in the total number of people dying of cancer, even within family lineages.

Table 8
Environmental Progress and Related Events in the 1970s

1970	The National Environmental Policy Act, passed by Congress in 1969 and signed by President Nixon on January 1, 1970, establishes environmental protection as a national priority, requires federal agencies to produce environmental impact statements, and calls for establishment of a Council on Environmental Quality.
1970	The U.S. Environmental Protection Agency is created by Presidential Order.
1970	The first Earth Day is observed on April 22.
1970	The Clean Air Act Amendments require EPA to establish national ambient air quality criteria and standards, national emission standards for new light-duty motor vehicles, national emission standards for new stationary sources, and national emission standards for hazardous air pollutants. States must develop implementation plans to meet air quality standards. State primacy is encouraged; but EPA will preempt states not meeting minimum federal guidelines. Private citizens may sue states or the EPA to prevent lax enforcement.
1970	The Resource Recovery Act provides funds for planning, research, and demonstration grants to promote recovery of resources from solid wastes.
1970	The Water Quality Improvement Act holds spillers of oil absolutely liable for damages and extends oil pollution legislation to offshore facilities.
1971	President Nixon declares a "war on cancer" in his State of the Union Address. Congress passes the National Cancer Act and calls for a cure for cancer by 1976.
1972	PL92-500 (the Federal Water Pollution Control Act Amendments) establishes a national objective (to restore and maintain "the chemical, physical, and biological integrity of the nation's waters") and national goals, including "fishable, swimmable waters" by 1983 and "zero discharge of pollutants" by 1985. The act requires secondary treatment for all publicly owned treatment works (POTWs) by 1977; sets national discharge standards for POTWs on BOD, SS, and pH; directs EPA to establish regulations for pretreatment of industrial wastes and to promulgate discharge standards for toxic chemicals; allocates $25 billion for municipal construction grants; requires non-POTWs (industrial dischargers) to achieve Best Practicable Treatment (BPT) by 1977 and Best Available Treatment (BAT) economically achievable by 1983; requires EPA to establish New Source Performance Standards for newly constructed facilities; establishes the National Pollutant Discharge Elimination System (NPDES), a permit system serving as the enforcement mechanism; requires comprehensive planning at three levels: basin, area, and facility; provides for citizen suits against EPA or polluters; and makes public participation in certain pollution control and policy decisions mandatory. States are required to set water quality standards appropriate for the designated uses of waters within their jurisdiction. States are encouraged to assume primacy in the setting and enforcement of standards, but EPA is required to approve state programs and to take action if a state program is found lacking.

Table 8 (continued)

1972	The Marine Protection, Research, and Sanctuaries Act declares "that it is the policy of the United States to regulate the dumping of all types of materials into ocean waters and to prevent or strictly limit the dumping into ocean waters of any material which would adversely affect human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities." The act prohibits, except by permit, transportation of wastes for dumping and dumping of wastes into U.S. territorial seas or contiguous zones; authorizes EPA to issue permits for dumping of non-dredged materials that will not "unreasonably degrade" public health or the marine environment; authorizes the Corps of Engineers to issue permits for dumping dredged material that will not "unreasonably degrade" human health or the marine environment; and instructs the Coast Guard to conduct surveillance and other enforcement activities to prevent unlawful transportation of material for dumping or unlawful dumping.
1972	The Federal Insecticide, Fungicide, and Rodenticide Act regulates the manufacture, application, and disposal of pesticides. (It is amended in 1988 to accelerate the re-registration process, authorize the collection of fees for re-registration, and increase criminal penalties for violators.)
1973	The Endangered Species Act requires federal agencies and their permittees and licensees to ensure that their actions are not likely to jeopardize the existence of an endangered or threatened species or result in destruction or adverse modifications of critical habitats of endangered or threatened species.
1974	Johannes Rook reports his discovery of trihalomethanes in drinking water.
1974	The Safe Drinking Water Act extends federal drinking water regulations to all public water supplies (not just those serving interstate carriers); requires EPA to promulgate primary and secondary drinking water regulations; provides special protection for "sole-source" aquifers; allocates funds for research and to subsidize state programs; encourages state primacy, but authorizes federal intervention, if necessary, to enforce the primary regulations; and requires public notification of consumers whenever the primary standards are violated.
1975	The Energy Policy and Conservation Act requires each car maker's fleet to achieve an average of 27.5 mile per gallon by 1985 and also requires that cars made in the U.S. have at least 75 percent domestic content.
1976	The Resource Conservation and Recovery Act (RCRA) authorizes EPA to set guidelines for the design, operation, and performance of sanitary landfills; provides technical and financial assistance to develop plans and facilities for the recovery of energy and other resources from discarded materials; prohibits disposal of certain hazardous wastes in unsecured sanitary landfills; authorizes EPA to establish criteria to define wastes as hazardous and to regulate hazardous waste generators, transporters, and processors; establishes a manifest system (tracking system) providing "cradle to grave" control of hazardous wastes; and encourages state primacy.

Table 8 (continued)	
1976	The Toxic Substances Control Act gives EPA broad regulatory authority to control trans-media pollution, without limiting the effort to a single medium, and to regulate the manufacture, distribution, processing, use, and disposal of toxic substances (e.g., asbestos, PCBs, pesticide wastes, etc.). Substantial testing is required for permitting of new chemicals and of new uses of existing chemicals. The criteria used to determine toxicity include adverse environmental effects, persistence, and toxicity to aquatic organisms (and not just human health).
1977	The Clean Air Act Amendments relax deadlines established in 1970 (to help alleviate the effects of the energy crisis, a high rate of inflation, and growing unemployment, especially in the auto industry); authorize EPA to designate those areas not meeting the standards as "non-attainment areas," in which new emissions must be offset or more than offset by reductions in existing emissions; and give EPA authority to prevent significant deterioration of the air quality in designated areas (e.g., national parks).
1977	The Clean Water Act relaxes the deadlines and requirements for meeting BPT and BAT standards; permits discharges of industrial pollutants to a POTW if they can be removed without interfering with sludge disposal; requires EPA to set standards for sludge quality for various disposal options and to set industrial pretreatment standards to prevent deterioration of sludge quality; directs EPA to set BAT standards for 129 "priority pollutants" (toxic chemicals) for 21 industrial categories and to promulgate Best Management Practices to control runoff, spills, and accidental releases of toxic substances into the environment from industrial sites; increases construction grants for innovative or alternative treatment systems; allocates another $25 billion for municipal construction grants; permits relaxation of water quality standards when it can be shown that there is no reasonable relationship between costs and benefits; allows EPA to relax secondary treatment requirements for POTWs discharging to ocean outfalls; allows EPA to modify limits on thermal pollution when no harm will result; and requires anyone conducting activities not specifically exempted and involving the discharge of "dredged or fill material" into "waters of the United States" to obtain a permit, thus establishing one of the two major pillars of the federal wetlands protection program (the other being the "swampbuster" provisions of the 1985 Food Security Act (farm bill).
1977	The Marine Protection, Research, and Sanctuaries Act is amended to ban ocean dumping of sewage sludge if such dumping may "unreasonably degrade or endanger human health, welfare, amenities, or the marine environment, ecological systems, or economic potentialities."

The public's observation of a significant increase in the overall rate of cancer, even within specific family lineages, was indeed accurate; but their interpretation of this increase -- that there was a cancer epidemic -- was inaccurate. What the public failed to realize was that cancer rates are enormously dependent on age, increasing approximately with age to the fourth power. Thus, the near doubling of the average life span achieved by improved sanitation in earlier decades of the 20th century had led to a great increase in the overall incidence of cancer, as did the growth in the total population of the nation. However, on an age-adjusted basis, the rate of cancer has not increased during the past 60 years, although some forms of cancer have increased (e.g., skin and lung cancer, due to increased smoking and sunbathing, respectively), while others have decreased (e.g., stomach cancer). In essence there has been an "epidemic of longer life." Public misperceptions regarding cancer resulted in more emphasis being placed on control of possible carcinogens than on control of other pollutants that may eventually prove to pose a greater threat to human health or to the environment. Public fear of cancer has been exploited by lobbyists, by opponents of various actions or activities (e.g., building an incinerator for waste disposal), and by environmental extremist groups seeking donations to their cause.

Another major public misconception arose during the 1970s as a result of the unfortunate choice of words, "zero discharge of pollutants," used to express one of the national goals of what is now referred to as the water quality act. The intent of Congress and its advisors was not to prohibit all discharges (zero flow) or to set all discharge standards to zero (zero concentration); but to limit discharges to the assimilative capacity of the stream, such that no pollution, i.e., no adverse effects, would occur. Misinformed and uninformed individuals, as well as various extremist groups, have repeatedly misrepresented the goal of "zero discharge of pollutants" to the public and to various decision-making bodies. As a result, pressure is often brought to bear on dischargers to forego the use of natural assimilative capacity and to expend resources and energy to treat "pollutants" present in concentrations too low to harm the environment. Although such efforts are generally well intentioned, their end result can be increased environmental damage resulting from the unnecessary use of natural resources.

In the mid to late 1970s, dreams of rapidly reestablishing a pristine environment came face-to-face with harsh reality due to the "energy crisis," a deep recession, and a growing recognition that the task was far more immense and socially complex than had at first been imagined. The "energy crisis," sparked by a cartel of oil-producing nations, led to a shortage of gasoline (and very long lines at service stations around the country), steep increases in energy costs, and sharp increases in the cost of energy intensive pollution control processes, such as the activated sludge process and aerobic digestion. On the positive side, the energy crisis forced the public to confront its wasteful use of energy, to recognize that fossil fuels are nonrenewable sources of energy that are being rapidly depleted, and to support efforts to develop renewable energy sources. Also, due in part to reduced combustion of fossil fuels and reduced factory outputs, and in part to pollution control efforts, the quality of air and water began to improve.

In 1975, Congress, in an effort to reduce U.S. reliance on imported oil and to conserve fossil fuels, passed the Energy Policy and Conservation Act, which required each car manufacturer's fleet to achieve 27.5 mpg by 1985. With the intent of protecting the jobs of U.S. workers, the act also required that U.S.-made cars contain at least 75 percent domestic content. Thus, U.S. auto makers were required to nearly double the fuel milage of their fleets, and to do so at a time when they were also being required to drastically reduce emissions, when the U.S. was entering a recession, and when foreign car makers were far ahead of the U.S. in producing small, fuel-efficient cars. As a result, sales of U.S. autos fell nearly 50 percent, thousands of workers lost their jobs, and it would be more than 20 years before the industry recovered its market share. Furthermore, a study of 11 General Motors cars found that fatality rates increased in 10 of them after smaller models of the cars were produced.

Prior to the energy crisis, many citizens viewed pollution as something caused primarily by industry and believed that most of the cost of environmental protection would be borne by wealthy capitalists and corporations rather than by the public. Congress contributed to this misperception by subsidizing state programs and providing construction grants, such that increases in state and local taxes could be avoided or minimized. The energy crisis and the new federal emission standards for automobiles were helpful in educating the public in this regard. Their cars were now smaller, less powerful, less safe, and more expensive; the price of gasoline had risen sharply; and many auto workers were unemployed. Although this caused some backlash against the "environmental movement," it helped consumers to understand that individual consumers also contribute to pollution, that at least part of the cost of pollution control is borne by the public, and that effective pollution control and conservation of energy may require lifestyle changes.

The energy crisis led to a strong economic recession, growing unemployment, inflation, and very high interest rates. By the late 1970s, public attention had shifted from environmental protection to the economy, especially employment. To reduce the size of bond issues or to comply with limitations on their indebtedness, municipalities began to delay or to reduce the size of various public works projects, including pollution abatement projects. It was now obvious that the goals that had been established for environmental protection would take longer to achieve and would require a much greater financial commitment than had been envisioned in the 1960s and early 1970s. There was also growing recognition of the need to properly balance the costs and benefits of environmental protection; and various deadlines and requirements of the Clean Air Act and Clean Water Act were relaxed for this reason, as well as to give industry a reasonable amount of time to comply. These developments were viewed by the more radical elements of the environmental movement as a "sell out" by Congress to corporate interests.

During the 1970s, several new concerns arose or received widespread public attention for the first time. These included: acid rain and its suspected adverse impacts on aquatic and terrestrial ecosystems; damage to the ozone layer by a proposed fleet of supersonic airplanes or by chlorofluorohydrocarbons (CFCs); the importance of nonpoint source pollution relative to the point sources that were the focus of most control efforts; contamination of ground water with synthetic chemicals, especially volatile organic chemicals; and hazardous wastes that had been improperly disposed of prior to the passage of RCRA. In 1974, Molina and Rowland presented calculations showing that CFCs could potentially diffuse into the stratosphere, decompose into more active forms of chlorine, and catalytically decompose ozone. Based on model predictions, there was general agreement that continued use of CFCs would probably lead to a gradual but limited decrease in stratospheric ozone, and all "nonessential" uses of CFCs were soon banned. Public fear of a "new ice age," fueled by scientists studying historical climate patterns and by environmental groups concerned about particulate matter in the atmosphere, was reinforced by several cold winters and by rising energy costs.

The 1980s

In the 1979 presidential campaign the single most important issue was not the environment but inflation. Ronald Reagan promised to beat inflation, reduce interest rates, restore the economy, eliminate the federal budget deficit, reduce taxes, and reduce the size and role of the federal government. He also promised to reduce the regulatory burden on industry so that our nation would be more competitive in the world marketplace (and he later appointed Vice-President George Bush to lead a task force to accomplish this goal). It was reasonable to assume that these promises implied a reduced commitment to environmental protection, and Reagan's detractors accused him loudly and often, before and after the election, of being opposed to environmental protection. Nevertheless, he was elected president in a landslide by a nation concerned primarily with the economy.

During the eight years of the Reagan administration, nearly every major piece of environmental legislation passed in the 1970s was reauthorized, and major new legislation was passed (Table 9). RCRA was reauthorized and strengthened in 1984, increasing the cost of compliance from $2 billion per year to $20 billion per year. The 1985 Food Security Act ("farm bill"), largely ignored by the media, was considered by some to be the most significant piece of conservation legislation since the 1930s. The "Superfund" act was reauthorized in 1986 and the size of the fund increased from $1.6 billion to $8.5 billion. The Safe Drinking Water Act Amendments of 1986 drastically increased the number of contaminants regulated in drinking water. The 1987 amendments to the Clean Water Act made sweeping new changes. Although credit for developing these bills belongs to Congress, which in some cases passed legislation out of frustration with the slow pace at which EPA was moving ahead in some area, President Reagan did sign most of them into law. As a result, the overall cost of compliance with environmental regulations increased dramatically, reaching an estimated $115 billion per year by 1990.

President Reagan did oppose several pieces of legislation. He vetoed the 1981 Construction Grants bill (and was overridden by Congress) because he wanted to shift the cost of constructing wastewater treatment facilities from the federal government back to state and local governments; and Congress eventually compromised with him in 1987 when funds were allocated to initiate state revolving loan programs. He argued against passage of a new Clean Air Act, citing an inadequate scientific basis for controlling "acid rain"; but he signed a bill in 1980 authorizing $500 million dollars for research on acid rain so that future decisions could be based on sound science. He was also heavily criticized for failing to adequately protect the environment on publicly owned lands and for appointing James Watt as Secretary of the Interior. Many of Watt's actions, such as opening up certain federal lands for oil and gas exploration, were viewed as an assault on the environment, but increasing energy reserves and decreasing U.S. dependence on foreign oil were major national goals at the time; and Watt's efforts to add to federal land reserves were largely ignored by the press.

Table 9
Environmental Progress and Related Events in the 1980s

1980	The Energy Security Act authorizes $500 million for the National Acid Precipitation Assessment Program (NAPAP).
1980	The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, better known as "Superfund") authorizes EPA to respond to actual or threatened releases of hazardous wastes and toxic substances; authorizes compensation to the government or private parties for cleanup costs; allows responsible parties to be held liable for damages resulting from release or clean up of hazardous wastes and toxic chemicals and for resource restoration costs; and establishes a $1.6 billion fund, financed jointly by the federal government and industry, for cases involving unknown polluters or in which damages cannot be recovered, for investigations and enforcement activities, and for research.
1980	The Low-Level Radioactive Waste Policy Act makes each state responsible for disposal of low-level radioactive waste generated within its borders, but allows multi-state disposal sites (compacts).
1981	The Municipal Wastewater Treatment Construction Grant Amendments allocate another $20 billion for construction grants and allow oxidation ponds, lagoons, and trickling filters to be considered equivalent to secondary treatment where water quality is not adversely affected.
1983	In an EPA-sponsored study, researchers model the earth and predict that it will warm 2°C by the year 2040 and 5°C by the year 2100, with noticeable regional changes in weather patterns being seen by 1990. However, their model does not include clouds.
1984	The Hazardous and Solid Waste Act (amending RCRA) extends RCRA to small quantity generators; requires generators to minimize waste; authorizes EPA to regulate underground storage tanks to prevent ground water contamination; bans landfilling of bulk or non-containerized liquids; bans certain wastes from landfills unless demonstrated not harmful to human health or the environment; establishes 72 deadlines, 58 requiring action within less than three years, and "hammer" provisions to take effect automatically if EPA fails to act; requires surface impoundments of hazardous wastes to be retrofitted with double liners and with groundwater monitoring and leachate collection systems; and requires EPA to report to Congress on hazardous wastes discharged to municipal sewers.
1984	EPA issues a national "Policy for the Development of Water-Quality-Based Permit Limitations for Toxic Pollutants," indicating its intention to put site-specific toxicological assessments and controls on a par with chemical-specific and technology-specific limits included in NPDES permits. The objective is to directly address the toxicity of effluents, especially complex industrial effluents, which though treated to remove specific pollutants or using BAT might still pose a threat to human health or the environment.

Table 9 (continued)

1985	Farman and his colleagues report the discovery of the "ozone hole," which leads to efforts to phase out the use of CFCs and other ozone depleting chemicals.
1985	The Food Security Act ("farm bill") allows farmers to contract with the federal government (Conservation Reserve program) to switch highly erodible cropland to grass or trees with the government paying 50% of the cost of establishing permanent cover; and disqualifies farmers for certain USDA benefits for failing to use conservation methods on highly erodible cropland, for "sodbusting" (growing crops on highly erodible land not in production during at least one of the past five years), and for "swampbusting" (converting a wetland by draining, dredging, filling, leveling, or any other means, or planting an agricultural commodity on a wetland converted after 1985).
1986	The Safe Drinking Water Act Amendments require EPA to regulate 9 contaminants within one year, another 40 within two years, and another 34 within three years; to set at least 25 more primary standards by 1991; to specify criteria for filtration of surface water supplies and disinfection of groundwater supplies; to establish demonstration programs for protection of sole-source aquifers and "well-head protection"; to issue rules regarding waste injection below drinking water sources; to treat Indian tribes as states, allowing them to assume primacy and receive grants; and, with the Indian Health Service, to survey drinking water quality on Indian reservations. The amendments also increase the ceiling on civil and criminal penalties; require large public water systems to monitor unregulated contaminants to be listed by EPA; and prohibit the use of lead solder, flux, and pipe in new installations and for repairs.
1986	The Superfund Amendment and Reauthorization Act (SARA) increases the size of the superfund to $8.6 billion, plus an additional $0.5 billion for abandoned leaking underground storage tanks; requires "cost-effective" remedial actions, with preference given to actions which will permanently and significantly reduce the volume, toxicity, or mobility of hazardous wastes (rather than simply moving them from one place to another); adds a series of provisions to facilitate settlement of CERCLA litigation and hasten cleanup; adds a statute of limitations for cost recovery actions; and authorizes $20 million annually for five years to develop and demonstrate new technologies to destroy, immobilize, or reduce the volume of hazardous wastes.
1986	The Emergency Planning and Community Right-to-Know Act (actually Title III of SARA) requires each state to appoint a State Emergency Response Commission which is to divide the state into Emergency Planning Districts, each having a Local Emergency Planning Committee.
1987	The Montreal Protocol on Substances That Deplete the Ozone layer is developed and is soon ratified by many CFC-producing nations.

Table 9 (continued)

1987	The Clean Water Act Amendments allocate another $6.0 billion for municipal construction grants, plus an additional $8.4 billion to capitalize state revolving funds to be used to make loans to municipalities; legally establish EPA's "antidegradation policy" (existing uses of water should be maintained and protected); under some circumstances and with public approval water quality may be allowed to deteriorate down to the level required to maintain fishing and swimming uses; and waters designated as Outstanding Natural Resource Waters may not be degraded); authorize $50 million per year to help states prepare assessments of, and plans to control, nonpoint-source runoff; set a tight time schedule for states to control point sources of toxic chemicals causing impairment; require states to promulgate specific numerical water quality criteria and to adopt standards for specific toxic chemicals; prohibit the discharge of "substances in concentrations or combinations toxic to humans or aquatic life"; require EPA to finish setting discharge standards for certain industrial categories; give legislative authority to EPA's "anti-backsliding policy" (a broad prohibition against relaxing effluent limits); require EPA to establish NPDES permit application requirements for stormwater discharges associated with industrial activity and discharges from large and medium municipal storm water systems; and prohibit EPA from requiring NPDES permits for various other classes of stormwater discharges.
1988	The appearance of medical waste (e.g., syringes) in various locations, including swimming beaches, following the onset of the AIDS epidemic leads Congress to pass the Medical Waste Tracking Act (amending RCRA). The act directs EPA to implement a two-year demonstration program to track regulated medical waste from the point of generation to the point of disposal and to establish requirements for its segregation, handling, and labeling. The purpose is to provide Congress with the information needed to develop future laws regulating medical waste.
1988	The Ocean Dumping Ban Act prohibits all dumping of municipal sewage sludge and industrial waste into the ocean after Dec. 31, 1991; prohibits marine dumping of medical wastes effective six months after enactment; and forbids transportation of municipal or commercial waste within coastal waters by a vessel not having a permit issued by the Department of Transportation.
1988	EPA promulgates stringent regulations for underground storage tanks; and all systems must be in full compliance by December 22, 1998.
1989	EPA promulgates the Surface Water Treatment Rule, specifying minimum requirements for filtration and disinfection of drinking water obtained from surface sources.

During the 1980s the U.S. brought inflation under control, reduced interest rates, lowered taxes, and reduced unemployment to an acceptable level. However, contrary to President Reagan's campaign promises, the federal budget was not balanced and the federal deficit grew at an unprecedented rate. What this means, in simple terms, is that the U.S. "borrowed" (and continues to borrow) money for various activities, including pollution control. Some consider this practice to be intergenerational theft. Others consider it appropriate. Some arguing that future generations will benefit from today's expenditures (e.g., by inheriting a cleaner environment, better roads, etc.), which is reasonable if the benefits to future generations equal or exceed the costs that are passed along to them. Others argue that if the economy continues to expand the debt can be repaid in future dollars that are worth less than current dollars.

During the mid-1980s, the "infrastructure crisis" was brought to the attention of the American public by municipalities, engineers, and contractors. In 1985, the Association of General Contractors estimated that $3.03 trillion in repairs and renovations were needed by municipalities, including $510 billion for wastewater treatment and $140 billion for water supply. There were calls in some quarters for a massive federal program to provide assistance to local and state governments whose roads, bridges, storm drains, and treatment facilities would otherwise rapidly collapse; but cooler heads prevailed. The problem was in essence a local financing problem. Between 1960 and 1990, spending for capital improvements decreased from 3% of the GNP to less than 1% of the GNP. The Organization for Economic Cooperation and Development estimated (c. 1993), that the U.S. was investing only 0.3% of its gross domestic product in infrastructure versus Germany's 3.7% and Japan's 5.7%. The problem was that many state and local governments had greatly increased spending for social programs without increasing taxes, thereby "borrowing" money from their capital improvements and public works budgets. Well managed utilities, both public and private, did not experience such problems.

In 1985, scientists announced the discovery of an "ozone hole" over Antarctica; and subsequent research in the 1980s suggested that the ozone layer was thinning outside of the Antarctic region and that an ozone hole might develop in the Arctic as well. Representatives from many nations gathered together in 1985 in Vienna and in 1987 in Montreal to discuss protection of the earth's ozone layer; and in 1987 they developed the Montreal Protocol on Substances That Deplete the Ozone Layer (referred to as the "Montreal Protocol"). The protocol, which was ratified by many nations and became effective in 1989, was an agreement by CFC producing nations to first freeze CFC production and to then reduce production by 50% by 1998. In 1989, representatives of 80 countries met in Helsinki to review new research findings; and they unanimously approved the "Helsinki declaration" supporting a complete phase-out of CFCs by 2000, as well as a phase out of halons and certain other ozone depleting chemicals as soon as feasible. The led to strengthening of the Montreal Protocol in 1990 and 1992; and the U.S. incorporated its commitment to the protocol into the 1990 Clean Air Act.

In 1983, researchers conducting a study sponsored by the EPA predicted that the earth would warm 2 °C by the year 2040 and 5 °C by the year 2100, with noticeable regional changes in weather patterns being seen by 1990. Their report was widely publicized and raised public awareness of the "global warming" issue; but it met with considerable skepticism, especially among scientists, who realized that the predictions were based on a one-dimensional model of a cloudless planet.

However, several of the later years during the 1980s were among the warmest on record, making dire predictions of global warming much more credible. Although many aspects of global warming are still being researched and debated, there is a growing consensus among scientists that the earth is actually warming and that human activity is at least partly responsible for the increase. Considerable attention is now being devoted to possible ways to minimize the impact of human activity on climate, with the primary focus being on reducing the use of fossil fuels and sequestering the carbon released when they are burned for energy.

The "garbage crisis" arose during the late 1980s and extended through the early 1990s. It was symbolized by a barge loaded with municipal solid waste (MSW) that traveled from port to port, growing ever more putrid, without finding a place to unload. Although environmental activists led the public to believe that the nation had finally run out of landfill space and would eventually be covered with refuse if drastic measures were not imposed, the crisis was a natural consequence of the Resource Conservation and Recovery Act (RCRA). In 1981, there were about 16,000 MSW landfills in the U.S. Between 1976, when RCRA was passed, and 1987, the number of MSW landfills decreased by about 50%. Between 1988 and 1995, the number of solid waste landfills dropped by about 55%, from 8,000 to 3,558. Although there was no shortage of space for landfills in most areas of the country, the construction of new landfills meeting the requirements of RCRA was slowed or brought to a standstill by nearby residents, by regulatory agencies, and by the protests of "environmentalists." Stringent regulations on air emissions closed down many incinerators, and local opposition prevented siting of new incinerators. Due to the created shortage of disposal facilities, the cost of disposal skyrocketed in many locations, sometimes increasing more than 100% in one year.

The "garbage crisis" ended as new and better landfills and incinerators opened for business. In fact, some had trouble attracting enough business to pay off the bond issues or loans that financed their construction. One positive aspect of the crisis was that it focused public attention on solid waste management, especially reuse and recycling. During this time many municipalities took steps to implement recycling programs, to build composting facilities for grass clippings and leaves, and to educate the public regarding proper disposal of household hazardous wastes; and many states levied fees to implement disposal programs for such things as tires and batteries and to support recycling and household hazardous waste management programs. Unfortunately, many of these programs were adopted without an intelligent assessment of the costs and benefits involved and some may do more harm than good, i.e., the resources expended may exceed the resources conserved or the indirect damages to the environment may exceed the damages avoided.

During the 1980s, the Superfund program grew much more rapidly than most other environmental programs; and by 1990 it accounted for about 50% of EPA's resources and about 33% of its personnel. The nation had busied itself with the task of cleaning up the improperly disposed wastes of the past, leading to the removal and disposal of 9.4 million cubic yards of contaminated soil and waste, treatment of 3.8 billion gallons of contaminated groundwater, removal of a billion gallons of liquid waste from treated soil, treatment of 104 million gallons of surface water, and receipt of over one billion dollars from responsible or potentially responsible parties (*Chemical Engineering*, Jan., 1991). However, few sites had actually been cleaned up, an estimated 40% of the funds had been spent in trial litigation and for administrative oversight, few (if any) lives had been saved, and few of the sites on the national priority list were associated with significant potential for human exposure or risk levels significantly higher than those targeted following cleanup. Consequently, this program is expected to slowly decline in the future as resources are devoted to more pressing problems.

The 1990s

The most significant legislative act of the decade was the passage of the Clean Air Act Amendments of 1990, the major provisions of which are described in Table 10. Other majors environmental issues had been addressed during the 1980s, but action on acid rain and related air quality issues had been delayed while Congress awaited the final NAPAP report. In the interim, concern grew over destruction of the ozone layer and emissions of toxic chemicals into the atmosphere. Although both President George Bush and Congress were anxious to strengthen the Clean Air Act, the desired changes were complex and costly; and it took several years of negotiating to work out the details. It is interesting to note that the amendments were signed into law before the results of the 10-year NAPAP study were released. This was the result of strong lobbying by environmental groups, which had argued for strict control of sulfur oxides (the major component of acid rain) and feared (correctly) that the NAPAP report would not scientifically support their position. Eight months before the bill was signed, the Director of NAPAP, Dr. Mahoney, had noted that "there is currently no widespread forest or crop damage in the United States related to [acid deposition]." Other significant developments during the 1990s included the following:

- Global environmental issues, including ozone depletion, global warming, declining fisheries, damage to coral reefs, the possible effects of "endocrine system disruptors," and exportation of hazardous wastes, received growing international attention (to the extent that the 1990s are being referred to in some circles as the "Decade of the Environment").

- State and local governments began to strongly voice opposition to the growing list of "unfunded federal mandates" (as discussed below).

- The largest recorded outbreak of waterborne disease in U.S. history, in Milwaukee, WI, in 1993, attributed to *Cryptosporidium*, lead to a "sanitary reawakening" in the U.S. and to further strengthening of the surface water treatment rule.

- Public attention was drawn to the issue of "endocrine system disruptors" (also referred to as "environmental estrogens"), which began to rival cancer as a driving issue in public policy debates.

- The fall of the "Iron Curtain" allowed the world to observe the devastating pollution in Eastern Europe.

- An increasing emphasis was placed on "pollution prevention" (which contrary to the claims of several parties, including EPA, to have discovered the idea had been commonly practiced by industry and environmental engineers for over a century).

Table 10
Environmental Progress and Related Events in the 1990s

1990	The Oil Pollution Act enhances EPA's ability to prevent and respond to catastrophic oil spills; creates a trust fund financed by a tax on oil to clean up spills when the responsible party is unwilling or unable to do so; requires oil storage facilities and large vessels to develop spill response plans; and requires development of area contingency plans to handle large spills on a regional scale.
1990	The Montreal Protocol is strengthened.
1990	The Pollution Prevention Act promotes source reduction of pollutants through changes in production, operation, and selection of raw materials; promotes efficient use of energy, water, and other natural resources; and promotes recycling and sustainable agriculture.
1990	Sweeping amendments are made to the Clean Air Act.
	Title I sets deadlines for "non-attainment" areas to comply with ambient air quality standards and establishes penalties for those failing to comply.
	Title II establishes stricter vehicle emissions standards; requires reductions in fuel volatility and in the sulfur content of diesel fuel; requires cleaner "reformulated" gasolines in the nine cities with the worst ozone problems; requires oxygenated fuels to be produced and sold in 41 areas where the federal CO standard is exceeded during winter months; establishes a clean-car pilot program in California; delays the diesel particulate standard for urban buses from 1991 to 1993; requires EPA to regulate air toxics, including benzene and formaldehyde, from mobile sources; requires 26 areas with the poorest air quality to limit emissions from centrally fueled fleets of 10 or more vehicles; and bans the use of lead in motor vehicle fuels by 1996.
	Title III lists 189 toxic air pollutants for which emissions must be reduced; establishes a Chemical Safety Board to investigate accidental releases of extremely hazardous chemicals; requires each industrial plant to have comprehensive plans for preventing and managing accidental releases of toxic pollutants; and requires EPA to issue Maximum Achievable Control Technology (MACT) standards for 40 source categories within two years, to implement controls for the remaining source categories over a ten-year period, to determine whether additional controls are necessary to reduce risk to an acceptable level, and to regulate air emissions from municipal, hospital, commercial, and industrial incinerators.
	Title IV establishes an innovative market-based systems for SO_2 control that caps annual utility emissions of SO_2 at about 8.9 million tons by the year 2000, and requires EPA to set more stringent performance standards for NOx emissions from utilities.

(continued)

Table 10 (continued)	
1990	(The Clean Air Act, continued:) Title V requires states to develop air permit programs similar to the NPDES permit program for water. Title VI requires EPA to list ozone depleting substances, their ozone depleting potential, their global warming potential, and their atmospheric lifetimes; requires a phase-out of ozone depleting chemicals similar to that agreed upon in the Montreal Protocol, but with more stringent interim reductions; requires EPA to publish lists of safe and unsafe substitutes and to ban the use of unsafe substitutes; and bans the use of certain classes of chemicals, with exemptions for flammability and safety. Title VII upgrades criminal violations from misdemeanors to felonies; adds new criminal sanctions for endangerment and negligent endangerment in connection with air toxics; and increases penalties for violators. Title VIII requires sources within 25 miles of shore to meet the same standards that apply on shore; establishes programs to monitor and improve air quality along the Mexican Border; and provides $8 million for studies on visibility impairment. Title IX authorizes research on monitoring and modeling techniques, health effects, ecosystem effects, accidental releases, pollution prevention, emissions control, acid precipitation, alternative fuels, foreign control technologies, and the effects of acid deposition on waters in the Adirondacks. Title X provides support for disadvantaged business concerns. Title XI allocates $50 million per year for five years to provide additional unemployment benefits to workers dislocated by implementation of the acid rain title.
1990	The Superfund program is extended to 1994 and the ceiling on the Superfund is raised to $11.97 billion.
1991	Under the authority of the Clean Air Act, EPA proposes new standards requiring large landfills to install gas collection systems; and, under the authority of RCRA, EPA issues new rules requiring nearly all landfills to monitor for leaks.
1993	An outbreak of waterborne disease in Milwaukee, attributed to *Cryptosporidium*, leads to an estimated 400,000 cases of illness and 40 deaths.
1996	The book *Our Stolen Future* (Colburn *et al.*) raises public awareness of the threats posed by endocrine system disruptors ("environmental estrogens," or synthetic chemicals that mimic hormones) to human health and the environment.

Table 10
Environmental Progress and Related Events in the 1990s

1996	Amendments to the Safe Drinking Water Act require EPA to strengthen the surface water treatment rule and regulations on disinfection by-products; to limit the maximum concentration of disinfectant residuals; and to develop a screening program for estrogenic substances (endocrine system disruptors). They also require states to develop programs to insure the technical, managerial, and financial capacity of public water supply systems to comply with the act; require utilities to annually report to consumers the levels of regulated contaminants in the water; provide relief from analysis of contaminants that have never been found and are unlikely to occur; and provide funds for research on arsenic, radon, and *Cryptosporidium*.
1996	The Food Quality Protection Act amends both the Federal Insecticide, Fungicide, and Rodenticide Act and the Federal Food, Drug, and Cosmetic Act, deleting the Delaney clause of the latter (which had banned the use of any food additive shown to cause cancer in humans or animals, without regard to the actual or estimated level of risk or the potential benefits) and establishing a new safety standard for use of chemicals on foods and crops ("reasonable certainty that no harm will result from aggregate exposures to the pesticide chemical residue"), to be based on risk assessment, with special recognition of the greater sensitivity of infants and children to pesticide exposure.

Concern over "unfunded federal mandates" had arisen in earlier decades, but it began to intensify with the passage of the 1986 Safe Drinking Water Act Amendments. Throughout the 1970s, federal environmental legislation requiring state action had heavily subsidized state programs (and in some cases local governments and municipalities), thereby eliminating or reducing the need for state and local tax increases. However, in the late 1970s and early 1980s, Congress came under increasing pressure to balance the federal budget and to avoid further increases in taxes. When Congress passed the 1986 SDWA Amendments, it failed to provide funds for state programs to enforce the host of new drinking water standards that were mandated. State programs were expected to cost an average of about $500 million. Some states lacked the necessary resources; some believed it would be difficult or impossible to raise taxes to cover these expenses (the infamous "Proposition 13," aimed at reducing state spending, had just passed in California); and other states were not convinced that this would be the best way to spend their money, i.e., they had higher priorities both in regard to public health and in regard to other matters.

After the passage of the 1986 SDWA Amendments, a number of states seriously considered giving up primacy, thinking that the federal governments would not have the resources to single-handedly impose stringent new standards on all of the states, while others entertained the notion of "split primacy," in which they would choose which standards they would enforce and leave the rest up to the federal government. EPA's response was simple and direct: split primacy was not permitted under the law and EPA would be happy to impose a tax sufficient to cover the cost of implementing the regulations in any state that failed to do so. This temporarily quelled the rebellion, as the states were quite certain they could do the job at a far lower cost than the federal government. However, Congress' new approach did not stop with the SDWA.

By the early 1990s, state and local officials began to recognize that they were facing a financial crisis due to the growing list of unfunded federal mandates (i.e., federal laws requiring state action but providing no funds), many of which addressed environmental issues. Not only would state and local governments have to raise taxes to pay the cost associated with the new federal requirements (a very risky decision for officials facing reelection, given the strong opposition to tax increases at that time); but the aggregate cost of the suite of new regulations was staggering and the benefits sometimes appeared small or negligible. For example:

1) The city of Columbus, Ohio found that federal regulations would require a fourfold increase in the city budget by the year 2000. EPA had estimated that the city would have to spend about $77,000 to comply with EPA's new (1990) stormwater rule, but the actual cost was $1.5 million. The city expected to pay $15 million in capital costs and $2.4 million in annual operating costs to remove atrazine from its water supply, but compliance was expected to have a negligible impact on human health (*Mainstream*, April, 1992).

2) A study of environmental regulations indicated that Anchorage Alaska's 240,000 residents would have to pay $430 million during the 1990s to comply with existing regulations, or $5,000 per household by the year 2000 (*Jour. Amer. Water Works Assn.*, Nov. 1992).

3) Despite scientific evidence that providing full secondary treatment for San Diego's wastewater would be a waste of money, "EPA spent millions in court to require the city to spend billions on a system that nobody accepted as necessary," according to the director of the city's clean water program (*Civil Engrg.*, July, 1994).

4) The town of Lancaster, NH was collecting $1.4 million in revenues each year, but would have to spend $2 million just to comply with the Safe Drinking Water Act alone (*Science*, Nov. 19, 1993).

This problem has not gone away; but Congress decided to require, before passing future laws, an assessment of the costs of compliance and identification of the funding sources.

Perhaps the most encouraging environmental accomplishment of the 1990s was the successful implementation of the Montreal Protocol (CFC control) and the subsequent strengthening of its provisions. The goals of the U.S. and other countries were achieved ahead of schedule; and recent studies indicate that the levels of chlorine and bromine in the stratosphere have already peaked and will gradually decline over the next century, provided that production of CFCs continues to decline. That so many nations could agree on the need for action, and actually take action so quickly, bodes very well for the future.

Summary

As noted in the preceding paragraphs, which describe the progress of the past 50 years largely in terms of laws, regulations, and state and federal programs, an extensive statutory, regulatory, and bureaucratic framework has been developed to address numerous environmental issues. However, progress has also been made in other ways. Effective control systems are in place for many, perhaps even most, major sources of pollution; there is unprecedented public awareness of environmental issues and strong public support for environmental protection; and an army of environmental scientists, engineers, managers, and operators has been recruited, trained, equipped with a large arsenal of weapons, and sent forth to do battle on a number of fronts, including many that did not exist 50 years ago.

However, since "the proof is in the pudding," it is important to consider not only laws, programs, and activities, but the actual progress that has been made in terms of human health and the quality of the environment. It is difficult, in looking at the past 50 years, to find any single accomplishment in the U.S. that rivals the increase in life expectancy associated with the efforts of sanitary engineers during the first half of this century. Nevertheless, it is abundantly clear that enormous progress has been made. For example:

- The citizens of virtually every city and town in the U.S. now receive basic sanitary services, i.e., safe drinking water and a reasonably appropriate means of disposal of domestic wastewater and municipal solid waste.

- Air quality has improved dramatically, especially in major cities such as Los Angeles, where photochemical smog has been reduced by more than 80%. Emissions of sulfur oxides and particulate matter have been cut by more than 50%, and lead levels in the air and in the blood of urban children have been drastically lowered.

- The fuel milage of the average automobile in the U.S. has nearly doubled, while emissions of carbon monoxide, hydrocarbons, and nitrogen oxides have been reduced by more than 90%.

- Water quality has greatly improved, as evidenced by the reduced frequency of algal blooms and fish kills in many water bodies that previously experienced them on a regular basis. Municipal and industrial wastewater discharges no longer flow untreated into the nation's streams and lakes; and pools of oil and piles of foam are much less commonly observed.

- Today's landfills are designed not only to protect the public from disease but also to protect ground water and nearby surface water sources. Open burning in dumps no longer fouls the air, and approximately two-thirds of aluminum cans are now recycled.

- Modern incinerators do not spew large quantities of ash, acids, and toxic chemicals into the atmosphere.

- Industrial waste discharges to the ocean decreased 94% between 1972 and 1987 and have since been essentially eliminated, as has ocean disposal of solid waste and the residuals from municipal wastewater treatment plants (formerly known as sludge and more recently referred to as "biosolids").

- The quantity of hazardous wastes produced has been greatly reduced, as has the amount being placed in landfills; most hazardous wastes currently being generated are being properly managed; and an enormous effort has been made to clean up the improperly disposed wastes of the past.

- In many arenas, the question "How much is enough?" is heard more and more frequently, indicating that at least some parties believe they are approaching the point where further action may be counterproductive.

- The Cuyahoga now meets all applicable state water quality standards and, more importantly, it is no longer flammable and actually contains fish!

Despite these and the many other accomplishments of the past 50 years not specifically mentioned earlier, it is also abundantly clear, especially to environmental engineers and scientists, that much more remains to be accomplished. Although much progress has been made in addressing the more obvious problems, such as cholera outbreaks, dirty smokestacks, and massive fish kills, many less obvious and more complex problems have not been adequately addressed, the size and cost of the tasks the nation set out to accomplish in the 1970s turned out to be far greater than expected, and the national goal of living in harmony with the environment is far from being fulfilled.

CHALLENGES FOR THE NEXT CENTURY

Environmental engineers and scientists will face many new challenges in the coming century. There are several reasons why this is so. First, scientific knowledge increased dramatically during the last century, especially in the past 50 years; and although this knowledge has helped in addressing many important environmental problems, it has also revealed, and will continue to reveal, new problems and the more complex nature of previously recognized problems. (The more one knows about a particular topic, the more one realizes how much more one does not know.) Second, it is reasonable to expect that new technologies will continue to create unforeseen environmental problems, as CFC refrigerants did in the 20th century. Lastly, the continuing growth of the earth's population is placing an increasing burden on its limited resources, to the point where the earth's landscape and evidently even its climate are being significantly altered.

Environmental engineers and scientists will also face many of the same challenges they already face, in some cases because the challenges are ongoing ones and in other cases because the job has not yet been completed. Although it is not possible to recognize all of the challenges environmental engineers and scientists will face in the next century, the following challenges are already evident:

Sustaining Past Accomplishments

This challenge may seem mundane; but it is a very critical one. The Milwaukee outbreak in 1993 provided a "wake-up call" reminding water utilities in the U.S. that disinfection must not be compromised as efforts are made to address other, less important, problems. As Okun (1996) has stated: "Our concerns have become similar to those which troubled our forebears 150 years ago, ... protection against infectious waterborne disease." Such concerns are not limited to the U.S. An analysis of the factors contributing to a cholera outbreak in Peru in 1991, which subsequently spread to several other countries, identified deteriorating sanitation as a key factor (Craun *et al.*, 1991); and a recent report by the American Academy of Microbiology (Ford and Colwell, 1996) indicates that this is a growing, global problem.

The need to sustain past accomplishments is not limited to sanitation. For example, although CFC levels in the stratosphere are beginning to decrease, only 36 countries had ratified the Montreal Protocol as of 1989; and the ground that has been gained could readily be lost if production of CFCs rises in countries not participating in the effort. Although the U.S. and Europe have greatly reduced sulfur dioxide emissions, other countries (notably China) are increasing their emissions as they seek to match the standard of living enjoyed by "developed" countries. Although controls on vehicle emissions have significantly improved air quality in urban areas in the U.S. and Europe, the number of vehicles on the road continues to increase, such that further action will be needed to prevent a reversal in air quality trends.

Educational efforts must also be sustained. Following the discovery of trihalomethanes (THMs) in drinking water, the mayor of a small town in Illinois, upon hearing that THMs were suspected carcinogens, ordered the chlorinator shut off at the local water treatment plant. When challenged by the Illinois EPA, he replied that there was no need to chlorinate the water because the town had not experienced an outbreak of waterborne disease in more than 50 years. A recent study conducted in a major airport in the U.S. revealed that only a small percentage of those using the restrooms actually washed their hands afterwards. Deteriorating sanitation is evidently not limited to "third-world" countries; and improved public education appears to be urgently needed so that society can learn from the lessons of the past rather than repeating them.

Controlling Emerging and Reemerging Pathogens

Success in the "war" against infectious diseases, waterborne and otherwise, will require not only sustaining past accomplishments but also continued vigilance and preparation to address microbial threats as they emerge. A number of emerging pathogens threaten the nation's water supplies (AWWA, 1999a&b); and the potential for serious problems is exemplified by the rapid emergence of *Cryptosporidium* following its first diagnosis in humans in 1976. There is growing concern over the ability of pathogens to migrate from animals into the human population, as the AIDS virus (which appears closely related to various simian viruses) is thought to have done; and some believe that such incidences will increase as humans increasingly come into contact with exotic ecosystems, such as the Amazonian forest. Migration of pathogens from domestic animals to wild animals poses a threat to biodiversity (Daszak *et al.*, 2000). Antibiotic-resistant strains of tuberculosis have already initiated the reemergence of TB as an important public health issue in the

U.S.; and resistant strains of these and other pathogens are expected to emerge due to the increasingly widespread and careless use of antibiotics and to the possibility that genes coding for antibiotic resistance will be transferred from one group of microorganisms to another.

Developing Better Technologies for Pollution Control and Environmental Protection

Engineers typically place a high priority on developing new technologies and improving existing ones, so this challenge can be expected to receive much attention, but hopefully not so much that other challenges are neglected. Many new technologies currently under development or already being deployed, e.g., membrane processes, will undergo further development and to flourish in the coming century; and, given the rapid increase in scientific knowledge in recent years, it is reasonable to anticipate that a host of new technologies will appear on the scene during the next century. One aspect of this challenge for environmental engineers and scientists will be to maintain open lines of communications with other disciplines to facilitate incorporation of new discoveries and innovations (e.g., molecular biology and remote sensing) into practice.

New and improved technologies are needed to reduce the amounts of pollutants produced by human activities (e.g., manufacturing and energy production), to remove pollutants more effectively, and to replace existing technologies with others that consume less energy, consume fewer materials (e.g., chemicals), and produce smaller quantities of residuals. Environmental engineers and scientists already have many "tools" in their tool boxes, but they will need to add new and better tools to their collections to effectively address the challenges before them.

"Plugging the Holes" in Existing Barriers

Most of the more obvious environmental problems have been at least partly addressed. Continued progress will require that smaller and less obvious sources of pollution and more subtle forms of environmental damage be addressed; and some pollutants now circumventing existing barriers will need to be cost effectively controlled. Examples include small systems that still receive inadequate treatment; stormwater discharges that carry toxic chemicals, sediment, and nutrients into waterways from areas disturbed by human activity; nutrient discharges from wastewater treatment plants that adversely impact downstream ecosystems or degrade estuarial or marine ecosystems; chemicals from human activity or human waste (e.g., estrogens) that adversely influence the development and reproduction of fish and wildlife; overflows that cannot be handled by existing sewers and wastewater treatment systems; and fugitive emissions of toxic air pollutants. The key to meeting this challenge will be to identify and effectively address the things that truly matter and to avoid wasting valuable resources on those that do not.

Assessing, Communicating, and Managing Risks

Given the number of chemicals in use, the ability of chemists to analyze them at ever lower levels, and the propensity of humans to worry, it is a certainty that questions about the adverse effects of chemicals will continue to be raised during the next century, much in the same way that Rachel Carson (1962) raised questions about the possible adverse effects of pesticides and Colburn *et al.* (1996) raised questions about "endocrine system disruptors." In fact, new questions are currently being raised concerning the possible effects of pharmaceutical chemicals and their by-products in the environment; and there are ongoing investigations regarding the effects of mixtures of pollutants, especially on children and sensitive populations, and regarding the possible effects of algal toxins, ozone, small airborne particles, and many other substances on human health and the environment. Environmental scientists will continue to be called upon to address these questions, i.e., to accurately characterize the risks involved. One challenge is to develop better frameworks for characterizing various types of risks, so that greater efficiency can be achieved. Another challenge is to develop better ways to characterize the risks associated with mixtures of contaminants, since current methods typically focus on single chemicals or groups of like chemicals, whereas most exposures involve complex mixtures of chemicals.

Both engineers and scientists need to develop better ways to manage environmental risks and to effectively communicate to the public the nature of the risks involved and the options (including costs) to reduce or eliminate those risks that are deemed significant. Communicating with the public is something neither scientists nor engineers have done particularly well in the past 50 years; and the difficulty of doing so appears to be increasing, due in part to the continued national decline in the quality of science education, the growing tendency of special interest groups to misinform the public, continued public mistrust of the government and its representatives, and the media's penchant for sensationalizing risks and "balancing" the views of professionals working in the public interest with those of "fringe groups."

Helping Society to Establish Appropriate Priorities

Since there are numerous environmental risks that vary in their significance, as well as numerous issues besides environmental issues that society must address, society must give priority to some issues and set others aside, at least temporarily. Although scientists and engineers should not attempt to dictate society's choices, they have an obligation to accurately inform the public regarding the scientific aspects of important issues, so that society can base its decisions on sound science; and they must also take the broader public agenda into account in prioritizing their own activities. Unfortunately, some avoid doing so because they dislike "politics," wish to avoid politicizing their activities, or are disinterested in policy issues, while others prefer to narrowly focus only on the scientific or technological aspects of complex problems, such as global warming, that also have significant social and economic implications. This can lead to the misallocation or inefficient use of public resources, or to public policies not adequately supported by science. For example:

1) The NAPAP ("acid rain") study was applauded for the high quality of its scientific research, but was heavily criticized for failing to adequately address key public policy questions. The sponsors of the research (Congress) felt that the scientific basis for their subsequent decisions was not as strong as it could have been. (This situation might have been avoided had there been better communication between politicians and scientists.)

2) As noted earlier, miscommunication between cancer scientists and the public fueled public fears of a cancer epidemic caused by environmental pollution, leading to an overemphasis on cancer, relative to other risks and to costs, in numerous public policy decisions.

3) In the late 1980s, an internal assessment by EPA revealed that agency priorities were aligned much more closely with public opinion than with either scientific estimates of risk or the agency's statutory authorities.

4) Many community recycling programs have been funded without even a superficial analysis of their costs and benefits. Some of these programs may benefit the environment; but others may provide no net benefit to the environment, or may even do more harm than good.

5) Great progress has been made in improving air quality, and "maximum achievable control technology" is being used to reduce emissions of small amounts of "toxic air pollutants"; but carbon dioxide, which could potentially alter the climate of the entire planet, is not even classified as an air pollutant. (Perhaps this is akin to "swatting flies while being trampled by elephants.")

As society begins to address less obvious and more complex environmental issues, and as emissions of pollutants are reduced to lower and lower levels, it is critically important for environmental scientists and engineers to help the public to distinguish between important and insignificant issues, to prioritize the important issues, and to develop strategies (including, but not limited to legislative strategies) for addressing them.

Conserving and Reusing Water

This can be viewed as an ongoing challenge, with much progress having been made in the past, especially in the last 30 years, or as a cyclical challenge that receives significant attention only during periods of drought. However, if the population or the economy of the U.S. (or the world) continues to grow, increasing competition for limited water resources will push the need for water conservation and reuse to unprecedented levels. Many "western" states have experienced drought, water shortages, and battles over water rights at various times in the past; but because there is no major crisis at the present time, many believe that the problems have been solved. This is not the case.

Consider the situation in Kansas. An historical review by Metzler (1980) found that droughts struck Kansas in 1859-1868 (causing 40,000 settlers in eastern Kansas to leave); in 1881 (causing banks and businesses to fail); in 1893-94; in 1910-1917; in 1933-1938 (during which water had to be pumped from pools in rivers, creeks, and ponds to save livestock); in 1952-1957 (during which 258 out of 426 public water systems experienced shortages, some of them severe, and two, Lyndon and Chanute, supplemented their supplies with reclaimed sewage); in 1963-1967 (with 136 of 514 systems experiencing shortages); in 1971-1974 (with 45 systems experiencing shortages); in 1976-1977; and in 1980 (with 52 systems experiencing shortages).

The many federal reservoirs constructed in eastern Kansas during the past 40 years will help alleviate future shortages, but are unlikely to be sufficient. The surface waters of Kansas, except those of the Missouri River, are now fully allocated at normal flow; the flow in every river in Kansas except the Missouri River and the Kansas River has dropped to zero on at least one occasion; the population is much greater than it was during the most severe droughts of the past and is still increasing; and some of the water stored in reservoirs will be needed to protect fish and aquatic organisms (i.e., to meet minimum in-stream flow needs) or to maintain navigation in downstream waterways (at the discretion of the U.S. Army Corps of Engineers). The next major drought in Kansas can be expected to have devastating consequences.

The situation is similar throughout most of the west. Aqueducts were built to help supply the water needs of states such as California and Arizona; but the water they carry, once considered excess water in many cases, will not be sufficient to meet future needs if the demand continues to increase or if a major drought occurs. Eastern systems have also begun to experience shortages, as was the case in New Jersey during a recent drought; and water is now in limited supply in locations where shortages were once unimaginable, e.g., in various locations in Florida and Georgia. In most locations, the challenge of adequately preparing for the next drought will almost certainly go unmet because it is politically difficult to devote resources to a problem that is not presently occurring. Politicians prefer the historic approach, i.e., appointing a task force to temporarily solve the problem after it becomes critical. Environmental engineers and scientists must encourage politicians to be more proactive in this area.

Engineers and scientists will be called on to develop new and innovative water management strategies, such as the plan being implemented in Wichita, KS to capture excess flow, and to design many more (and better) water reclamation facilities than have been built in the past. Some of these facilities are likely to be "engineered ecosystems" that provide not only treatment but also wildlife habitats and that utilize "natural" processes and minimize energy consumption. Utilities will be increasingly under pressure to reuse water, for both potable and nonpotable purposes. The sometimes acrimonious debates over potable reuse can be expected to grow more frequent and more intense in the next century, with environmental engineers and scientists often caught in the middle, arguing the technical and nontechnical issues from both sides of the aisle.

Although the public is aware of its vulnerability to a drought, support for water conservation efforts is often unenthusiastic due in large part to general dissatisfaction with the performance of low-flow toilets and shower heads, which many people assume will be the first step in any new water conservation plan. Although the public supports water reuse in principle, many people are uncomfortable with the idea that they, their food sources, or the environment should come into contact with reclaimed sewage, regardless of the degree to which it has been treated. Environmental engineers and scientists will need to adequately address these and other concerns, both technical and social, to move forward in conserving and reusing water in the next century. Progress will in all likelihood be proportional to the incidence of drought.

Developing and Enforcing Appropriate Air Quality and Water Quality Standards

To some it may seem that this effort has already been underway for over a century; and indeed it has. However, much more remains to be accomplished to meet the goals set by Congress in the 1970s. Ambient air and water quality standards are not being met in numerous locations, and they may not be stringent enough to adequately protect the environment in some locations where they are being met. In areas where the water quality standards are not being met, the Clean Water

Act specifies that "total maximum daily loads" (TMDLs) are to be calculated and allocated among the various dischargers; but this provision was largely ignored until recently and efforts to enforce it, for a limited number of pollutants, are being slowed both by litigation and by uncertainty over how to include and regulate nonpoint sources of pollutants.

To satisfactorily accomplish the objectives of the Clean Air Act and the Clean Water Act, it will be necessary to strengthen air and water quality criteria; to review existing standards and, if necessary, to revise them so that they are truly protective of the environment; and to develop strategies to effectively manage airsheds and watersheds. One of the significant difficulties commonly encountered today is pollutant levels in the air or water upstream of a particular discharger may exceed ambient standards, such that no assimilative capacity remains. In some cases, for example, a wastewater treatment plant would have to produce an effluent having a higher quality than that of the drinking water treatment plant serving the same city in order to meet local water quality criteria. Wisdom, good science, and innovation will be needed to solve these types of problems.

Developing Sustainable Systems

It is evident that today's society is rapidly depleting the earth's fossil fuels and minerals. In many locations the land is being used in such a way that, due to the loss or contamination of soil or the consumption of water, it will eventually cease to be productive. On a global scale, human activities are significantly altering the landscape and are evidently changing the earth's climate and causing the extinction of numerous species. The situation is growing worse as the earth's population increases. Most people realize that such behavior represents irresponsible stewardship and ultimately cannot be sustained; and many are calling for sustainable development, defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." (Brundtland, 1987). This broad-based challenge includes the following more narrowly defined challenges:

- Reducing energy use and developing renewable and less polluting sources of energy

  The last major energy crisis spawned extensive efforts to develop alternative energy sources, including coal gasification (which does not reduce reliance on fossil fuels but does stretch petroleum and gas reserves), solar energy, and wind power. None of the alternatives pursued has replaced a significant fraction of the nation's (or world's) fossil fuel use. Nuclear power, the leading alternative in the 1960s and early 1970s, has lost most of its public support; and the problem of disposing of high-level radioactive waste has not been satisfactorily resolved. There are more cars than ever on the highway, and the average fuel mileage achieved by U.S. cars has stopped increasing. Thus, it may appear to some that little progress has been made.

  In fact, significant advances have been made on many fronts. The efficiency of photovoltaic cells has improved by an order of magnitude and further increases are expected. Some utilities are seriously considering building "wind farms" and a few have actually done so. Fuel-cell technology has improved to the point that many believe there will soon be an explosion of practical applications on the market; and energy companies have invested large sums of money to develop hydrogen power, which some feel is the ultimate long-term solution given the abundance of hydrogen (in water) and the fact that its only by-product is water. Automobile manufacturers are developing a host of new vehicles that pollute less (low emission and zero emission vehicles), get better mileage, contain more recyclable components, run on alternate fuels (including electricity, fuel cells, hydrogen, and liquefied gas), run on combinations of fuel (hybrids), or generate some of their own power from braking action. Cities are increasingly using refuse- derived fuel to generate electricity, which can be a sustainable technology if the waste being combusted is derived entirely from renewable resources.

Widespread change is unlikely to occur until the next energy crisis occurs; but this may be sooner than most people realize. Although American consumers have been lulled into a false sense of security by stable fuel prices for the past 20 years (prices much lower than those typically found elsewhere around the world), there is a delicate balance between supply and demand, as evidenced by the recent sharp rise in gasoline prices (and the price of crude oil) after a small cut-back in oil production by the oil-producing nations. Experts in economics and geology agree that a major and permanent shortage of fossil fuels will occur during the next century; they only disagree on the date.

- Developing "green" engineering and manufacturing practices

Pollution prevention has received considerable emphasis for the past decade; but sustainable development will require a quantum leap in this effort. Environmental engineers and scientists will be called upon to assist manufacturers, as well engineers and scientists from other disciplines, in producing energy-efficient and environmentally benign products using renewable resources. Life-cycle analyses, including arrays of indirect impacts, will need to be routinely incorporated into such efforts. "Take-back" laws, requiring manufacturers to service and dispose of their products, perhaps through a lease arrangement, appear to be an attractive option for forcing manufacturers to focus on the environmental and energy impacts of their products; but environmental engineers will need to help society to carefully assess this option and, if it proves worthwhile, to implement it in an efficient and effective manner.

- Managing the earth's fisheries in a sustainable manner

Fifty years ago, the ocean appeared to be a nearly unlimited resource. During the past 50 years it became evident that the ocean does not have an infinite assimilative capacity. Great progress has been made, in the U.S. and elsewhere, in controlling marine pollution, and this effort needs to continue. However, it has also become evident that the ocean is not an unlimited source of food and that current harvesting practices (and perhaps other factors associated with human activity) are leading to sharp declines in the abundance of many species, including commercially important fish species. The same is true of various bodies of fresh water. Environmental engineers and scientists must work with others to determine what must be done to protect and manage these valuable resources.

- Designing sustainable water reservoirs

  The numerous reservoirs built in the past century are providing a multitude of benefits to society, including water supply, flood protection, recreation, wildlife habitat, and food production. However, these reservoirs, as presently designed and operated, are only temporary; they are filling in with sediment at a rate this is quite rapid on a geological scale, with many having a design life of 100 years or less. These too represent unsustainable development. As noted by deNoyelles *et al.* (1999), existing reservoirs have been built in the best available locations, such that equally good sites are not available for constructing new reservoirs; and once existing reservoirs fill with sediment, the amount of material that will need to be moved (e.g., by dredging) to restore their capacity will typically exceed the amount originally moved by more than an order of magnitude. Environmental engineers and scientists need to develop economical ways to sustain reservoirs and maintain their associated benefits.

- Sustaining and restoring ecosystems and building sustainable ecosystems

  Human activity has altered or damaged some habitats to the extent that human intervention (e.g., pollutant removal, dam removal, water-level maintenance, etc.) is required to sustain or restore them. Others, such as wetlands, have been greatly reduced in number or size by human activity; and it is conceivable that the damage can be partially offset by constructing new ecosystems. In the case of wetlands, it remains to be seen whether environmental engineers and scientists can build sustainable wetlands ecosystems rivaling in quality the natural wetlands that have been destroyed.

- Developing sustainable farming practices

  Present day farming practices are clearly not sustainable. Fossil fuels are used to produce fertilizers (primarily nitrogen and phosphorus) and transport them long distances to farms, where a portion of the fertilizer runs off into various water bodies, a portion is incorporated into various foodstuffs, including feed grains, and a portion is lost. The feed grains are then transported, using more fossil fuel, to a feedlot, where a portion of the fertilizer is incorporated into the animals and the rest is typically discharged to the environment or to a waste lagoon. In the latter case, most of the nitrogen is lost to the atmosphere though some, along with other pollutants, seeps into the ground. The animals are then transported long distances, again using fossil fuels, to various locations where they are consumed, and most of their nutrient value is discharged to sewers and ultimately into the environment. Only a small fraction of the nutrients is ever recycled back into crop production. Developing better systems is not a simple matter and will require the active participation not only of farmers and agricultural engineers but also environmental engineers and scientists, as well as individuals in many other disciplines.

- Creating sustainable urban ecosystems

  The population of many large cities is growing rapidly as people flock to them seeking employment and other opportunities. These "urban ecosystems" pose a great challenge to environmental engineers and scientists, not only in terms of public health and sanitation, but also in terms of their impacts on the environment, the quality of the environment, and the quality of life within them. On the other hand, large cities offer significant environmental opportunities. Due to their economy of scale, they offer opportunities to test or implement technologies and management practices that may not yet be economical elsewhere, e.g., fleets of electric vehicles, mass transportation systems, "intelligent highways," and cost-effective recycling programs. Furthermore, if urban ecosystems can be engineered so that they are attractive to live in and less polluting, perhaps the burden of human activity on the environment in rural and more pristine areas can be reduced.

- Effectively addressing the global warming issue

  The global warming issue is fundamentally a sustainability issue. It is reasonable to believe that significant warming of the planet would have many dire consequences. Thus, if greenhouse gases do in fact cause significant warming, current emission rates and the activities associated with them are not sustainable.

Since many of the challenges described above fall outside the traditional domain of environmental engineering, some environmental engineers believe that developing sustainable systems is not their responsibility but that of other groups, such as power companies, manufacturers, farmers, and fishermen. Two points are worth noting in this regard:

1) Environmental engineers are at least partly responsible for the current state of the environment, in that certain technologies and practices they have recommended to the public have polluted the environment (e.g., using streams for waste conveyance) or are clearly not "sustainable."

2) The public and various other parties involved are looking to environmental engineers and scientists for leadership in this area. They should not avoid a leadership role because the problems are complex, but should assume a leadership role precisely because they have been trained to work with those in other disciplines to address complex environmental problems. No other group is better prepared to do so; but others will rise to the occassion if environmental engineers and scientists fail to do so.

Defining and Organizing Environmental Engineering

As Professor John Ferguson (1999) wrote, after reviewing the content of the journal *Water Environment Research* and the program for the Water Environmental Federation's annual conference and finding that most of the papers addressed wastewater treatment: "What is our profession after all? It certainly is no longer sanitary engineering, but we have much further to go before we finally earn the use of the other term [i.e., environmental engineering]." Although environmental engineers have broadened out beyond sanitation, they have not embraced all aspects of environmental engineering, especially some related to developing sustainable systems.

There is debate over what areas are or are not part of environmental engineering and over who speaks for environmental engineers. The American Society of Civil Engineers (ASCE) considers environmental engineering as a subdiscipline of civil engineering; but many of today's environmental engineers and nearly all of the scientists they interact with are not civil engineers, nor do they look to ASCE for leadership in this field. In fact, even those interested in water supply and sewage treatment in the early days of the profession were forced to organize outside of ASCE, since they were concerned with more than the engineering aspects of these topics. The American Academy of Environmental Engineers also claims to speak for the profession; but it has relatively few members, since few meet the qualifications for membership and many who do meet the qualifications have failed to join. Environmental engineers must define what the field embraces so that those in the profession can organize themselves along appropriate lines and interact more effectively with other groups, other disciplines, and the public.

Defining the Role of Engineers in Society

Historical accounts of the field of environmental engineering, when it was still known as sanitary engineering, clearly show that many of our professional forebears were leaders in society. Some were able to envision grand solutions to important environmental problems (such as bringing water to New York City from the Croton River) and to win public support for them; some were able to organize large task forces to implement these solutions at a time when the problems appeared just as complex as do the challenges facing society today; and some advised political leaders and governmental bodies. Even those who were not leaders conducted themselves in such a manner that they earned the trust and respect of the public. Today, however, engineers (including environmental engineers) are increasingly being viewed as skilled technicians, their firms are increasingly being viewed as commodities, and public trust in the recommendations of engineers is eroding. Engineers must decide whether they are comfortable with these changes, whether these changes are in the best interest of society and, if not, what needs to be done to remedy the situation.

Educating the Environmental Engineers of the Future

Prior to 1920, most engineering professors in the U.S. were practicing engineers; engineering curricula, which emphasized "how" at the expense of "why," were intended to develop practical engineers; and engineering students spent a great deal of their time in labs and shops. During the 1920s and 1930s, Americans began to recognize the value of research and the superior ability of engineers trained in Europe (where a greater emphasis was placed on scientific fundamentals) to develop innovative designs and solve new or difficult problems. As a result, engineering curricula in the U.S. began to place a strong emphasis on science, as they still do today; and engineering professors began to involve themselves more heavily in research.

After World War II, the emphasis of many engineering programs shifted much more heavily toward research. This was due in part to the success of the Manhattan Project and to the Cold War, but also to the start of a massive infusion of federal funds into university research programs. As a result, new faculty members began to be hired primarily on the basis of their potential to attract research dollars rather than their engineering experience; and engineering programs began to emphasize theory and research at the expense of practice.

Most engineers realize that a good engineering education requires an appropriate mix of theory and practice, but many believe the pendulum has swung too far toward theory. Although employers are generally satisfied with the quality of the new engineers they hire, they believe there is room for improvement. To help students obtain practical experience, many employers have created internship programs, which currently appear to be on the rise. However, some engineering firms have begun to use overseas "job shops" where low-paid engineers perform many of the more routine calculations. This practice may erode the availability of internships and reduce opportunities for student engineers to obtain experience; but it may also cause more students to go abroad and to gain the international experience that many employers covet.

Other issues confronting engineering education besides the "theory versus practice" issue include the issue of "breadth versus depth" at the undergraduate level (i.e., the extent to which undergraduate students should be allowed to specialize) and the appropriateness and quality of "distance learning" (i.e., taking courses for academic credit from a remote location by means of video tapes, satellite downlinks, or web-based courses). The debate over the latter issue grew as the number of "nontraditional" and part-time students rose over the years; risen; but it took a quantum leap with the advent of web-based courses, and opinion is sharply divided. Although the web did not exist in Einstein's day, his opinions on both specialization and personal contact with professors are worth noting:

> It is not enough to teach a man a specialty. Through it he may become a kind of useful machine, but not a harmoniously developed personality. It is essential that the student acquire an understanding of and a lively feeling for values. He must acquire a vivid sense of the beautiful and of the morally good. Otherwise, he -- with his specialized knowledge -- more closely resembles a trained dog than a harmoniously developed person. He must learn to understand the motives of human beings, their illusions, and their sufferings in order to acquire a proper relationship to individual fellow men and to the community.
>
> These precious things are conveyed to the younger generation through personal contact with those who teach, not -- or at least in the main -- through textbooks. It is this that primarily constitutes and preserves culture. This is what I have in mind when I recommend the "humanities" as important, not just dry specialized knowledge in the fields of history and philosophy.
>
> Overemphasis on the competitive system and premature specialization on the ground of immediate usefulness kill the spirit on which all cultural life depends, specialized knowledge included.
>
> Albert Einstein, *The New York Times*, October 5, 1952

Einstein's comments are also relevant to the question, raised earlier, as to whether engineers wish to be highly trained technicians or leaders.

Two other educational issues are of particular concern to environmental engineers: 1) whether an undergraduate specialization in environmental engineering is appropriate; and 2) whether the B.S. or M.S. degree should be considered as the "entry-level" degree for environmental engineers. There is currently much disagreement in regard to both of these issues. ASCE recently passed a resolution calling for the designation of the M.S. degree as the entry-level degree for civil engineers; but fewer than half of civil engineers currently earn an advanced degree. Many environmental engineering programs have recently created B.S. degree programs; but some are having second thoughts, some are finding it difficult to find employment opportunities for their graduates, and relatively few graduate are choosing to become registered as environmental engineers (perhaps because this would limit their opportunities to practice civil engineering, which already includes environmental engineering).

Managing Information

The "information explosion" of the past 50 years appears destined to continue well into the next century. It is increasingly difficult to keep current even in a narrow field of specialization, while in highly interdisciplinary fields such as environmental engineering it is virtually impossible except for those having an encyclopedic memory or a great deal of time on their hands. To take advantage of the wealth of information available, and to effectively bring it to bear on environmental problems, environmental engineers and scientists must familiarize themselves with available sources of information and the tools (information technologies) that have been developed to access and utilize it.

Working and Competing in a Global Marketplace

The world is changing. Most large engineering firms now compete for clients on a global basis; consulting firms, water utilities, and power utilities are being bought and sold like commodities; and a number of major municipalities have signed, or are considering signing, long-term agreements with private entities to operate their facilities (contract operations). Utilities and various services are being consolidated in much the same way that grocery stores provide postal, floral, and video rental services. The best known example of this phenomenon in the U.S. is U.S. Filter, which after buying up more than a dozen different companies over an eight-year period, some of them costing hundreds of millions of dollars, was itself sold for $6.2 billion to Vivendi, a multinational company, and combined with Generale des Eaux, a major French company specializing in water services. Environmental engineering is big business (with the U.S. alone spending more than $125 billion per year for environmental compliance); and it is a global and competitive business.

These changes are expected to benefit society by providing access to certain economies of scale, as well as managerial and operational efficiencies; but individual engineers, consulting firms, and utilities will not necessarily benefit from the changes that are occurring. For example, some individuals may be laid off when their employer is "downsized"; and others may be forced to move to a less desirable location or position. This is a classic equity problem in that what may be best for society will not necessarily be best for each member of society, nor will the costs and benefits be equally shared. However, the hope is that the benefits will be great enough to "trickle down" through the economy so that everyone is ultimately better off than they were. Each person and organization will need to determine how to take advantage of the potential savings while protecting their own interests and the environment.

Developing Solutions to Complex Multinational and Global Environmental Problems

A number of complex environmental issues facing society today are either global (e.g., global warming, protection of the ozone layer, and declining marine fisheries) or involve more than one nation (e.g., management of water quality in the Rhine River or along the border between the U.S. and Mexico). Some problems involve the sharing and management of limited resources, especially water; and some involve balancing humanitarian needs against environmental concerns or the goal of developing sustainable systems, e.g., providing food for starving refugees in overpopulated countries. Environmental engineers and scientists must develop a better understanding of various complex environmental systems, develop any technological solutions that may be needed, help society to understand the issues involved, and help governments to develop politically acceptable solutions. The successful effort to date to control emissions of ozone depleting substances provides much hope, and perhaps a good model, for future global or multinational efforts to protect the environment. Developed nations, such as the U.S., will need to provide leadership and may at times need to subsidize the efforts of their less wealthy neighbors.

Concluding Remarks

There are certainly other challenges on the horizon that could not be included in this already lengthy discourse, and the reader may be aware of challenges that others have not yet recognized. One of the great strengths of the field of environmental engineering and science is that it is, and has always been, highly diverse in terms of the background, experience, and interests of those engaged in it. This has been of great value to the field in recognizing and addressing new challenges, and this will continue to be the case in the coming century. Most of those who attended the 50th Annual Environmental Engineering Conference have contributed in some truly important way (even if it never receives specific mention in a history book) to the environmental progress of the past 50 years. Hopefully, every attendee will contribute to meeting the challenges of the next century and progressing far beyond what has been accomplished thus far.

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