Readings

(1) pp. 117-118; 163-164; 269-270; 299-308; 331-339; 555-557 in Introduction to Environmental Engineering Science

(2) Attached materials

ENVIRONMENTAL ENGINEERING P.E. EXAMINATION GUIDE & HANDBOOK

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Chapter 1

INTRODUCTION

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This chapter addresses three separate, but important, topics for all environmental engineers and for licensure candidates taking the environmental engineering discipline principles and practice of engineering written examination or, as it is more commonly known, the P.E. examination. In Section 1.1, the rich heritage of environmental engineering, from its beginning in the 1830s to the late 20th century is summarized. The types of credentials available to environmental engineers and their role in the practice of the profession is discussed in Section 1.2. Finally, the development and scope of the environmental engineering P.E. examination is described to inform licensure candidates what the examination covers and why.

1.1 Environmental Engineering History

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

Until 1970, when Earth Day captured the public's attention leading to a concentrated effort to clean up environment, the profession was practiced by but a few.

Yet, the pioneers — Mills, Cheseborough, Sedgewick, Hazen, Metcalf, Eddy, Camp, Fair, Wolman, to name a few — blazed a trail establishing design protocols still in use today. Of necessity, this section is but a brief overview of the rich heritage on which modern environmental engineering is founded.

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

The inability of these private water companies to meet the water needs of rapidly-growing cities forced the larger municipalities such as New York, Boston, and Chicago to consider public water systems. Colonel De Witt Clinton, Jr., an Army engineer and son of the former governor of New York, was retained to examine New York's water supply needs in 1832. He recommended that water be obtained from the Croton River and conveyed to New York City through a 40-mile aqueduct. In 1836, John B. Jervis, a self-educated hydraulic engineer, who had learned his engineering on the Erie Canal and the Mohawk and Hudson Railroad, began construction of a dam across the Croton River to provide storage for the aqueduct (Jervis 1876). By 1842, fresh water began flowing from the Croton Reservoir to New York City through the aqueduct which carried 95 Mgal/day (4.16 m^3/sec) (Hazen 1907).

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

As City Engineer, Cheseborough was responsible for managing the stormwater sewer system. Boston had taken over the storm sewers in 1823 to ensure that they were properly maintained and that future sewers were built to proper specifications (MSBH 1903). Storm sewers were designed to flow by gravity to the nearest stream and eventually to the ocean. Because Boston prohibited the dumping of human sewage into storm sewers, sanitary sewage was collected in privies and vaults which were pumped out at regular intervals. This septage was carried in special wagons to farms outside the City. But, with the increased water supplies, more water closets and indoor bathtubs increased the flow of wastewaters and quickly filled the sewage storage vaults. A few home owners solved their problem by building their

own sewers and connecting them to the storm sewers without official permission. In addition to domestic sewage pollution of storm water, horse manure from the streets ended up in storm sewers when it rained. While smaller communities typically constructed two sets of sewers, a storm sewer and a sanitary sewer, Boston, like New York and other large cities, combined the sanitary sewers and the storm sewers in one pipe for economic reasons. Under either approach, sewer design required hydraulic engineering.

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

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

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

homas M. Brown, Professor of Chemistry was appointed Consulting Chemist
: State Board of Health (McCracken and Sebian 1988).

e beginning, environmental research at the Lawrence Experiment Station re-
ıeavily on British research on intermittent sand filtration. In Britain, Sir Ed-
. Frankland had demonstrated that intermittent sand filtration was a viable
od for treating municipal sewage. Picking up on his work, Allen Hazen, George
:r, and Harry Clark, the staff of the Lawrence Experiment Station, demon-
ed that wastewater treatment was a biochemical process in addition to a physi-
rocess. The station's results, published in two large volumes in 1890 (MSBH
)), were carefully studied across the world and stimulated considerable research
nunicipal wastewater treatment. These reports, *Purification of Sewage and*
-mittent Filtration of Water and *Examination of Water Supplies and Inland Waters*
lassachusetts, contained over 1,500 pages because of Mills' insistence that all
lata collected be shared with others (McCracken and Sebian, 1988). Using the
rence Experiment Station results, the British developed trickling filters. By
), biological wastewater treatment concepts had become well established.

findings by the Lawrence Experiment Station were made possible by the newly-
overed discipline of bacteriology. The discipline rapidly advanced after Dr.
ert Koch, a German physician and self-educated bacteriologist, demonstrated
bacteria could cause diseases (Collard 1976). Koch became a university pro-
or in Berlin and under his leadership, research in the fledgling field moved
:kly from growing bacteria on potato slices to gelatin and agar during the 1880s.
s development enabled Professor Sedgewick and Edwin O. Jordan, a recent
duate of Sedgwick's, to conduct research on sewage bacteriology.

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

ofessor Sedgwick's studies also included algae and protozoa found in surface
aters. Sedgwick developed a quantitative method for counting these large micro-
ganisms that was modified by George W. Rafter. The *Sedgwick-Rafter Concen-*
ator and Counting Cell became standard equipment for evaluating algae and

protozoa in water supplies. The work at M.I.T. and the Lawrence Experiment Station established Water Microbiology as a major area for environmental engineering.

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

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

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

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

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

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

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

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

A discipline is born when the development of knowledge and its application evolves from individual experimentation into a formal course of study. In 1889, M.I.T. established the first program in Sanitary Engineering (Wylie 1975). It was designated Course XI and incorporated courses in sanitary chemistry and sanitary biology into the Civil Engineering Department. The new department was named Civil and Sanitary Engineering and degrees were offered at the undergraduate level in Civil Engineering and in Sanitary Engineering. By 1893, when engineering faculty from across the country gathered at the Columbian Exposition in Chicago to organize a professional society to represent engineering educators, the only other school that had a degree program in Sanitary Engineering was the University of Illinois, which offered a degree in Municipal and Sanitary Engineering. A survey of engineering education in 1899 by Ira O. Baker, President of the Society for the Promotion of Engineering Education (SPEE) (Baker 1900), indicated that there were 110 engineering schools, but only 89 were active and only two schools offered degrees in Sanitary Engineering. There were 9,679 students enrolled in engineering, with 19 in Sanitary Engineering. Of the 1,413 engineering degrees awarded in 1898-1899, only one was in Sanitary Engineering (McKinney 1994).

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

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

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

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

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

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

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

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

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

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

- a strategic selection of rivers to understand the properties of their differences (1914);
- the initiation of a comprehensive survey of stream pollution (1915);
- support for the growth and improved capacity of the states to participate in efforts to control stream pollution (1920);
- public education efforts focusing on the importance of water pollution control measures as an aspect of comprehensive water resources development (1936); and
- increased technical assistance to states through the creation of a separate PHS Office of Stream Sanitation (1932) (Dworsky, 1990).

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

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

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

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

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

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

- a PHS and US Bureau of Mines study of silicosis (1910).
- PHS organizes a Division of Industrial Hygiene (1912).
- studies of air in industrial workshops were well underway, e.g., carbon monoxide from the use of gas- heated equipment (1916); and

- industrial hygiene activities of the PHS included studies of municipal dust, the radium dial painting industry, and a comparative study of air pollution in fourteen of the largest cities (1931) (Dworsky 1990).

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

- "This study is the opening move in what may develop into a major field of operation in improving the nation's health.
- We have realized, during our growing impatience with the annoyance of smoke, that pollution from gases, fumes and microscopic particles was also a factor to be reckoned with.
- The Donora report has completely confirmed two beliefs we held at the outset of the investigation:

  1. how little fundamental knowledge exists regarding the effects of atmospheric pollution on health, and
  2. how long range and complex is the job of overcoming air pollution."

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

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

As the next millennium approaches, environmental engineers practice in a world of increasing complexity as they attempt to work in harmony with a most complex system - nature - and a rapidly expanding knowledge base made possible by the "information age". Yet, it is meaningful to reflect upon the profession's history and to take note that what environmental engineers do today and tomorrow is grounded on fundamental principles developed and perfected 50, 100, and 150 years ago. These principles remain those which today's environmental engineers *must* know to be deemed minimally competent and, therefore, entitled to a license to practice the profession.

1.2 Engineering Credentials

1.2.1 Definitions There are 4 terms that need definition to provide the foundation for discussing credentialling of engineers - licensing, registration, certification, and accreditation.

Licensing — A license is authorization granted by a government to an individual or entity to perform a function or service, e.g., driver's license, engineer's license, etc. The root of licensing lies in the police powers embodied in governments to protect the health, safety, and welfare of its constituents.

Registration — Registration is listing with and by some body. It can be a governmental or a non-governmental entity that does the registration. Properly applied, registration is the listing of an individual, e.g., registering with Selective Service. It grants no authority nor does it address qualifications.

Certification — A voluntary act which, in some organized fashion, measures an individual's qualifications to perform a specialized function. Because it is voluntary, it conveys no authority or privilege, i.e., one does not need to possess the certificate to perform a function or service, albeit custom or market forces may require it. Certification exists in many professions and trades.

Accreditation — It is like certification, except that it applies to institutions and programs, not individuals. A familiar example is the accreditation of college curricula.

Confusion in credentialling is rampant because these four words are seldom correctly applied in society. Engineers are familiar with the word "registration" which is often used when the correct term that should be used is "license." Yet, engineers have no lock on the misapplication of these four words. Throughout American society the misapplication of these terms abound. And, their misapplication has been institutionalized by encoding them in laws and regulations. Many states continue to call their engineering licensing programs *engineering registration*, a misnomer. In 1995, National Council of Examiners for Engineering and Surveying (NCEES) adopted a policy requesting all licensing boards to use the term "licensing" instead of "registration."

1.2.2 Licenses The first law governing the practice of engineering in the United States was passed by Wyoming in 1907. This law was created because many non-professionals were practicing engineering and surveying. By 1920 there were 13 states that required engineers and surveyors to be licensed to practice. That same year, Iowa called a meeting and representatives from seven of the thirteen states met in Chicago, Illinois. They founded what is today the National Council of Examiners for Engineering and Surveying (NCEES). It currently consists of licensing boards from all fifty states and five jurisdictions (District of Columbia, Puerto Rico, Virgin Islands, Guam, and Northern Mariana Islands) that license engineers.

NCEES provides an organization through which state boards act and counsel together to better discharge their responsibilities in regulating the practice of engineering and land surveying to protect the welfare of the public by safeguarding life, health, and property. During the early years of the Council, its activities focused on the education and experience requirements for licensing as well as the development of a model law which could be used by states as they enacted legislation requiring licensing and/or modifying existing legislation.

The requirements for licensing in all states and jurisdictions include education, experience, and examination. The NCEES started developing uniform examinations with the offering of the Fundamentals of Engineering (FE) examination for the first time in 1965. The Principles and Practice (P.E.) examinations were first offered in 1966. Since then, use of the uniform national examinations by the Member Boards has steadily increased. By 1984, all 55 states and jurisdictions were using these examinations. Further, uniformity is achieved by all states using the same passing point developed and recommended by the Council.

The FE examination tests those basic engineering science knowledges which are normally acquired through a bachelors engineering degree. Successful completion of the FE examination is a preresquite to take the P.E. examination. For licensing as a professional engineer, most states require four years experience and passing of the P.E. examination. Currently the P.E. examination is offered in sixteen disciplines: chemical, civil, electrical, mechanical, and special structural examinations offered twice a year in April and October; and aeronautical/aerospace, agricultural, control systems, fire protection, industrial, manufacturing, metallurgical, mining/mineral, nuclear, and petroleum offered once a year in October.

1.2.3 Specialty Certification Specialty certification is certification of a particular specialty of a discipline. Generically, every profession becomes more and more specialized as its technology advances and the understanding of the forces at play increases. Specialization requires specialists. At some point in time either a general license or certification is no longer sufficient. Specialty licensing and specialty certification is a mechanism used to identify those with special capabilities,

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that effects created by every self-aggrandizing individual will never intersect and intermesh in such a way as to lead to dysfunctional and negative consequences.[1] So, many believe, the total results will work out for the good if everybody acts in his own interest. It is this view, coupled with a lack of thought on what is the ultimate benefit of man, that has led to harmful applications of technologies.

But what can be done to show a man that his individual gain may be at the ultimate cost of others? The gain in his driving an auto built without pollution controls (and thus more powerful) will result in some deterioration of the environment. Furthermore, if many take the individualistic view, then air pollution is bound to rise significantly. And yet why should one individual find it to his interest *not* to use a resource—in this case the air? For the resource is infinite, in his view, even though all the drivers in Los Angeles contribute enough air pollution to show that fresh air in the Los Angeles basin is indeed not infinite, but actually very limited indeed.

CONCEPT OF THE COMMONS

The *commons* consists of all those attributes of the earth which humans use jointly.[5] There is no exclusive ownership right, but rather some form of common-usage rights. One example of common usage can be seen in the case of the oceans. Another form of commons is the atmosphere. These common sources of goods have been seen as free to human use in the past.

In the following articles Professor Hardin and Professor Crowe discuss what is called the *tragedy of the commons*, which occurs when each man is locked into a system that compels him to increase his well-being, often at the expense of his fellow citizens of the commons. For example, worn-out tires discarded in the oil fields of Texas in 1939 are shown in Figure 10–1. In this case the commons may be our common atmosphere, land, energy resources—whatever. The steelmaker or auto driver finds that his share of the cost of the wastes he discharges into the commons is less than the cost of purifying his wastes before releasing them. Since this is true for all on the commons, how do we avoid polluting our commons? Hardin and Crowe here discuss legislative, technological and administrative paths to the solution of the problems of the tragedy of the commons.

The Tragedy of the Commons*

Garrett Hardin

At the end of a thoughtful article on the future of nuclear war, Wiesner and York concluded that: "Both sides in the arms race are . . . confronted by the dilemma of steadily increasing military power and steadily decreasing national security. *It is our considered professional judgment that this dilemma has no technical solution.* If the great powers

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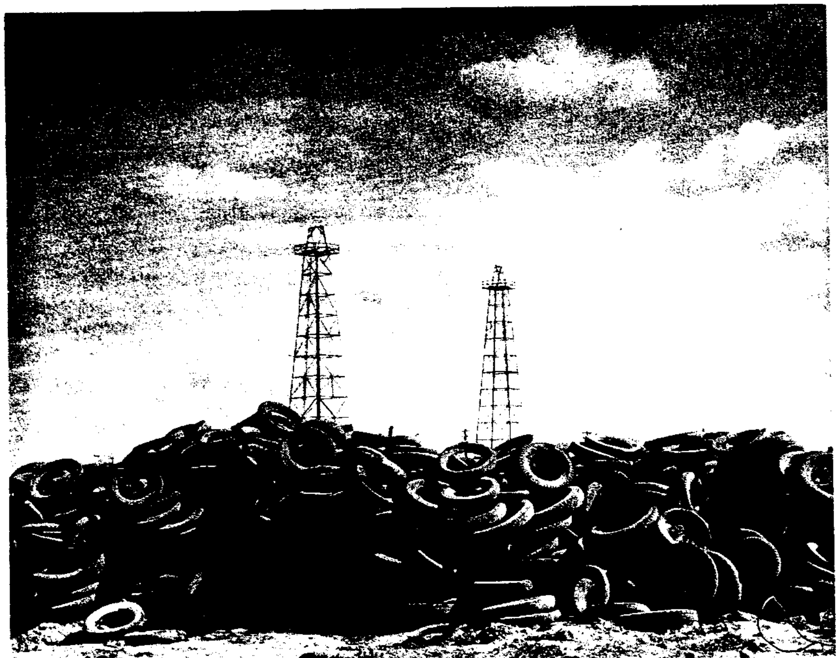

FIGURE 10–1 Worn-out tires deposited in oil fields in Texas, 1939. Courtesy of the Library of Congress.

continue to look for solutions in the area of science and technology only, the result will be to worsen the situation."

I would like to focus your attention not on the subject of the article (national security in a nuclear world) but on the kind of conclusion they reached, namely that there is no technical solution to the problem. An implicit and almost universal assumption of discussions published in professional and semipopular scientific journals is that the problem under discussion has a technical solution. A technical solution may be defined as one that requires a change only in the techniques of the natural sciences, demanding little or nothing in the way of change in human values or ideas of morality.

In our day (though not in earlier times) technical solutions are always welcome. Because of previous failures in prophecy, it takes courage to assert that a desired technical solution is not possible. Wiesner and York exhibited this courage; publishing in a science journal, they insisted that the solution to the problem was not to be found in the natural sciences. They cautiously qualified their statement with the phrase, "It is our considered professional judgment. . . . " Whether they were right or not is not the concern of the present article. Rather, the concern here is with the important concept of a class of human problems which can be called "no technical solution problems," and, more specifically, with the identification and discussion of one of these.

It is easy to show that the class is not a null class. Recall the game of tick-tack-toe.

Consider the problem, "How can I win the game of tick-tack-toe?" It is well known that I cannot, if I assume (in keeping with the conventions of game theory) that my opponent understands the game perfectly. Put another way, there is no "technical solution" to the problem. I can win only by giving a radical meaning to the word "win." I can hit my opponent over the head; or I can drug him; or I can falsify the records. Every way in which I "win" involves, in some sense, an abandonment of the game, as we intuitively understand it. (I can also, of course, openly abandon the game—refuse to play it. This is what most adults do.)

The class of "No technical solution problems" has members. My thesis is that the "population problem," as conventionally conceived, is a member of this class. How it is conventionally conceived needs some comment. It is fair to say that most people who anguish over the population problem are trying to find a way to avoid the evils of overpopulation without relinquishing any of the privileges they now enjoy. They think that farming the seas or developing new strains of wheat will solve the problem —technologically. I try to show here that the solution they seek cannot be found. The population problem cannot be solved in a technical way, any more than can the problem of winning the game of tick-tack-toe.

What Shall We Maximize?

Population, as Malthus said, naturally tends t grow "geometrically," or, as we would now say, exponentially. In a finite world this means that the per capita share of the world's goods must steadily decrease. Is ours a finite world?

A fair defense can be put forward for the view that the world is infinite; or that we do not know that it is not. But, in terms of the practical problems that we must face in the next few generations with the foreseeable technology, it is clear that we will greatly increase human misery if we do not, during the immediate future, assume that the world available to the terrestrial human population is finite. "Space" is no escape.

A finite world can support only a finite population; therefore, population growth must eventually equal zero. (The case of perpetual wide fluctuations above and below zero is a trivial variant that need not be discussed.) When this condition is met, what will be the situation of mankind? Specifically, can Bentham's goal of "the greatest good for the greatest number" be realized?

No—for two reasons, each sufficient by itself. The first is a theoretical one. It is not mathematically possible to maximize for two (or more) variables at the same time. This was clearly stated by von Neumann and Morgenstern, but the principle is implicit in the theory of partial differential equations, dating back at least to D'Alembert (1717–1783).

The second reason springs directly from biological facts. To live, any organism must have a source of energy (for example, food). This energy is utilized for two purposes: mere maintenance and work. For man, maintenance of life requires about 1600 kilocalories a day ("maintenance calories"). Anything that he does over and above merely staying alive will be defined as work, and is supported by "work calories" which he takes in. Work calories are used not only for what we call work in common speech; they are also required for all forms of enjoyment, from swimming and automobile racing to playing music and writing poetry. If our goal is to maximize population it is obvious what we must do: We must make the work calories per person approach as close to zero as possible. No gourmet meals, no vacations, no sports, no music, no literature, no art. . . . I think that everyone will grant, without argument or proof, that maximizing population does not maximize goods. Bentham's goal is impossible.

In reaching this conclusion I have made the usual assumption that it is the acquisition of energy that is the problem. The appearance of atomic energy has led some to question this assumption. However, given an infinite source of energy, population growth still produces an inescapable problem. The problem of the acquisition of energy is replaced by the problem of its dissipation, as J. H. Fremlin has so wittily shown. The arithmetic signs in the analysis are, as it were, reversed; but Bentham's goal is still unobtainable.

The optimum population is, then, less than the maximum. The difficulty of defining the optimum is enormous; so far as I know, no one has seriously tackled this problem. Reaching an acceptable and stable solution will surely require more than one generation of hard analytical work—and much persuasion.

We want the maximum good per person; but what is good? To one person it is wilderness, to another it is ski lodges for thousands. To one it is estuaries to nourish ducks for hunters to shoot; to another it is factory land. Comparing one good with another is, we usually say, impossible because goods are incommensurable. Incommensurables cannot be compared.

Theoretically this may be true; but in real life incommensurables *are* commensurable. Only a criterion of judgment and a system of weighting are needed. In nature the criterion is survival. Is it better for a species to be small and hideable, or large and powerful? Natural selection commensurates the incommensurables. The compromise achieved depends on a natural weighting of the values of the variables.

Man must imitate this process. There is no doubt that in fact he already does, but unconsciously. It is when the hidden decisions are made explicit that the arguments begin. The problem for the years ahead is to work out an acceptable theory of weighting. Synergistic effects, nonlinear variation, and difficulties in discounting the future make the intellectual problem difficult, but not (in principle) insoluble.

Has any cultural group solved this practical problem at the present time, even on an intuitive level? One simple fact proves that none has: there is no prosperous population in the world today that has, and has had for some time, a growth rate of zero. Any people that has intuitively identified its optimum point will soon reach it, after which its growth rate becomes and remains zero.

Of course, a positive growth rate might be taken as evidence that a population is below its optimum. However, by any reasonable standards, the most rapidly growing populations on earth today are (in general) the most miserable. This association (which need not be invariable) casts doubt on the optimistic assumption that the positive growth rate of a population is evidence that it has yet to reach its optimum.

We can make little progress in working toward optimum poulation size until we explicitly exorcize the spirit of Adam Smith in the field of practical demography. In economic affairs, *The Wealth of Nations* (1776) popularized the "invisible hand," the idea that an individual who "intends only his own gain," is, as it were, "led by an invisible hand to promote . . . the public interest". Adam Smith did not assert that this was invariably true, and perhaps neither did any of his followers. But he contributed to a dominant tendency of thought that has ever since interfered with positive action based on rational analysis, namely, the tendency to assume that decisions reached individually will, in fact, be the best decisions for an entire society. If this assumption is correct it justifies the continuance of our present policy of laissez-faire in reproduction. If it is correct we can assume that men will control their individual fecundity so as to produce the optimum population. If the assumption is not correct, we need to reexamine our individual freedoms to see which ones are defensible.

Tragedy of Freedom in a Commons

The rebuttal to the invisible hand in population control is to be found in a scenario first sketched in a little-known pamphlet in 1833 by a mathematical amateur named William Forster Lloyd (1794–1852). We may well call it "the tragedy of the commons," using the word "tragedy" as the philosopher Whitehead used it.: "The essence of dramatic tragedy is not unhappiness. It resides in the solemnity of the remorseless working of things." He then goes on to say, "This inevitableness of destiny can only be illustrated in terms of human life by incidents which in fact involve unhappiness. For it is only by them that the futility of escape can be made evident in the drama."

The tragedy of the commons develops in this way. Picture a pasture open to all. It is to be expected that each herdsman will try to keep as many cattle as possible on the commons. Such an arrangement may work reasonably satisfactorily for centuries because tribal wars, poaching, and disease keep the numbers of both man and beast well below the carrying capacity of the land. Finally, however, comes the day of reckoning, that is, the day when the long-desired goal of social stability becomes a reality. At this point, the inherent logic of the commons remorselessly generates tragedy.

As a rational being, each herdsman seeks to maximize his gain. Explicitly or implicitly, more or less consciously, he asks, "What is the utility *to me* of adding one more animal to my herd?" This utility has one negative and one positive component.

1) The positive component is a function of the increment of one animal. Since the herdsman receives all the proceeds from the sale of the additional animal, the positive utility is nearly +1.

2) The negative component is a function of the additional overgrazing created by one more animal. Since, however, the effects of overgrazing are shared by all the herdsmen, the negative utility for any particular decision-making herdsman is only a fraction of −1.

Adding together the component partial utilities, the rational herdsman concludes that the only sensible course for him to pursue is to add another animal to his herd. And another; and another. . . . But this is the conclusion reached by each and every rational herdsman sharing a commons. Therein is the tragedy. Each man is locked into a system that compels him to increase his herd without limit—in a world that is limited. Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all.

Some would say that this is a platitude. Would that it were! In a sense, it was learned thousands of years ago, but natural selection favors the forces of psychological denial. The individual benefits as an individual from his ability to deny the truth even though society as a whole, of which he is a part, suffers. Education can counteract the natural tendency to do the wrong thing, but the inexorable succession of generations requires that the basis for this knowledge be constantly refreshed.

A simple incident that occurred a few years ago in Leominster, Massachusetts, shows how perishable the knowledge is. During the Christmas shopping season the parking meters downtown were covered with plastic bags that bore tags reading: "Do not open until after Christmas. Free parking courtesy of the mayor and city council." In other words, facing the prospect of an increased demand for already scarce space, the city fathers reinstituted the system of the commons. (Cynically, we suspect that they gained more votes than they lost by this retrogressive act.)

In an approximate way, the logic of the commons has been understood for a long time, perhaps since the discovery of agriculture or the invention of private property in real estate. But it is understood mostly only in special cases which are not sufficiently generalized. Even at this late date, cattlemen leasing national land on the western ranges demonstrate no more than an ambivalent understanding, in constantly pressuring federal authorities to increase the head count to the point where overgrazing produces erosion and weed-dominance. Likewise, the oceans of the world continue to suffer from the survival of the philosophy of the commons. Maritime nations still respond automatically to the shibboleth of the "freedom of the seas." Professing to believe in the "inexhaustible resources of the oceans," they bring species after species of fish and whales closer to extinction.

The National Parks present another instance of the working out of the tragedy of the commons. At present, they are open to all, without limit. The parks themselves are limited in extent—there is only one Yosemite Valley—whereas population seems to grow without limit. The values that visitors seek in the parks are steadily eroded. Plainly, we must soon cease to treat the parks as commons or they will be of no value to anyone.

What shall we do? We have several options. We might sell them off as private property. We might keep them as public property, but allocate the right to enter them. The allocation might be on the basis of wealth, by the use of an auction system. It might be on the basis of merit, as defined by some agreed-upon standards. It might be by lottery. Or it might be on a first-come, first-served basis, administered to long queues. These, I think, are all the reasonable possibilities. They are all objectionable. But we must choose—or acquiesce in the destruction of the commons that we call our National Parks.

Pollution

In a reverse way, the tragedy of the commons reappears in problems of pollution. Here it is not a question of taking something out of the commons, but of putting something in—sewage, or chemical, radioactive, and heat wastes into water; noxious and dangerous fumes into the air; and distracting and unpleasant advertising signs into the line of sight. The calculations of utility are much the same as before. The rational man finds that his share of the cost of the wastes he discharges into the commons is less than the cost of purifying his wastes before releasing them. Since this is true for everyone, we are locked into a system of "fouling our own nest," so long as we behave only as independent, rational, free-enterprisers.

The tragedy of the commons as a food basket is averted by private property, or something formally like it. But the air and waters surrounding us cannot readily be fenced, and so the tragedy of the commons as a cesspool must be prevented by different means, by coercive laws or taxing devices that make it cheaper for the polluter to treat his pollutants than to discharge them untreated. We have not progressed as far with the solution of this problem as we have with the first. Indeed, our particular concept of private property, which deters us from exhausting the positive resources of the earth, favors pollution. The owner of a factory on the bank of a stream—whose property extends to the middle of the stream—often has difficulty seeing why it is not his natural right to muddy the waters flowing past his door. The law, always behind the times, requires elaborate stitching and fitting to adapt it to this newly perceived aspect of the commons.

The pollution problem is a consequence of population. It did not much matter how a lonely American frontiersman disposed of his waste. "Flowing water purifies itself every 10 miles," my grandfather used to say, and the myth was near enough to the truth when he was a boy, for there were not too many people. But as population became denser, the natural chemical and biological recycling processes became overloaded, calling for a redefinition of property rights.

How To Legislate Temperance?

Analysis of the pollution problem as a function of population density uncovers a not generally recognized principle of morality, namely: *The morality of an act is a function of the state of the system at the time it is performed.* Using the commons as a cesspool does not harm the general public under frontier conditions, because there is no public; the same behavior in a metropolis is unbearable. A hundred and fifty years ago a plainsman could kill an American bison, cut out only the tongue for his dinner, and discard the rest of the animal. He was not in any important sense being wasteful. Today, with only a few thousand bison left, we would be appalled at such behavior.

In passing, it is worth noting that the morality of an act cannot be determined from a photograph. One does not know whether a man killing an elephant or setting fire to the grassland is harming others until one knows the total system in which his act appears. "One picture is worth a thousand words," said an ancient Chinese; but it may take 10,000 words to validate it. It is as tempting to ecologists as it is to reformers in general to try to persuade others by way of the photographic shortcut. But the essense of an argument cannot be photographed: it must be presented rationally—in words.

That morality is system-sensitive escaped the attention of most codifiers of ethics in the past. "Thou shalt not . . . " is the form of traditional ethical directives which make no allowance for particular circumstances. The laws of our society follow the pattern of ancient ethics, and therefore are poorly suited to governing a complex, crowded, changeable world. Our epicyclic solution is to augment statutory law with administrative law. Since it is practically impossible to spell out all the conditions under which it is safe to burn trash in the back yard or to run an automobile without smog-control, by law we delegate the details to bureaus. The result is administrative law, which is rightly feared for an ancient reason—*Quis custodiet ipsos custodes?*—"Who shall watch the watchers themselves?" John Adams said that we must have "a government of laws and not men." Bureau administrators, trying to evaluate the morality of acts in the total system, are singularly liable to corruption, producing a government by men, not laws.

Prohibition is easy to legislate (though not necessarily to enforce); but how do we legislate temperance? Experience indicates that it can be accomplished best through the mediation of administrative law. We limit possibilities unnecessarily if we suppose that the sentiment of *Quis custodiet* denies us the use of administrative law. We should rather retain the phrase as a perpetual reminder of fearful dangers we cannot avoid. The great challenge facing us now is to invent the corrective feedbacks that are needed to keep custodians honest. We must find ways to legitimate the needed authority of both the custodians and the corrective feedbacks.

. . .

Pathogenic Effects of Conscience

The long-term disadvantage of an appeal to conscience should be enough to condemn it; but has serious short-term disadvantages as well. If we ask a man who is exploiting a commons to desist "in the name of conscience," what are we saying to him? What does he hear?—not only at the moment but also in the wee small hours of the night when, half asleep, he remembers not merely the words we used but also the nonverbal communication cues we gave him unawares? Sooner or later, consciously or subconsciously, he senses that he has received two communications, and that they are contradictory: (i) (intended communication) "If you don't do as we ask, we will openly condemn you for not acting like a responsible citizen"; (ii) (the unintended communication) "If you *do* behave as we ask, we will secretly condemn you for a simpleton who can be shamed into standing aside while the rest of us exploit the commons."

Everyman then is caught in what Bateson has called a "double bind." Bateson and his co-workers have made a plausible case for viewing the double bind as an important causative factor in the genesis of schizophrenia. The double bind may not always be so damaging, but it always endangers the mental health of anyone to whom it is applied. "A bad conscience," said Nietzsche, "is a kind of illness."

To conjure up a conscience in others is tempting to anyone who wishes to extend his control beyond the legal limits. Leaders at the highest level succumb to this temptation. Has any President during the past generation failed to call on labor unions to moderate voluntarily their demands for higher wages, or to steel companies to honor voluntary guidelines on prices? I can recall none. The rhetoric used on such occasions is designed to produce feelings of guilt in noncooperators.

For centuries it was assumed without proof that guilt was a valuable, perhaps even an indispensable, ingredient of the civilized life. Now, in this post-Freudian world, we doubt it.

Paul Goodman speaks from the modern point of view when he says: "No good has ever come from feeling guilty, neither intelligence, policy, nor compassion. The guilty do not pay attention to the object but only to themselves, and not even to their own interests, which might make sense, but to their anxieties".

One does not have to be a professional psychiatrist to see the consequences of anxiety. We in the Western world are just emerging from a dreadful two-centuries-long Dark Ages of Eros that was sustained partly by prohibition laws, but perhaps more effectively by the anxiety-generating mechanisms of education. Alex Comfort has told the story well in *The Anxiety Makers*; it is not a pretty one.

Since proof is difficult, we may even concede that the results of anxiety may sometimes, from certain points of view, be desirable. The larger question we should ask is whether, as a matter of policy, we should ever encourage the use of a technique the tendency (if not the intention) of which is psychologically pathogenic. We hear much talk these days of responsible parenthood; the coupled words are incorporated into the titles of some organizations devoted to birth control. Some people have proposed massive propaganda campaigns to instill responsibility into the nation's (or the world's) breeders. But what is the meaning of the word responsibility in this context? Is it not merely a synonym for the word conscience? When we use the word responsibility in the absence of substantial sanctions are we not trying to browbeat a free man in a commons into acting against his own interest? Responsibility is a verbal counterfeit for a substantial *quid pro quo*. It is an attempt to get something for nothing.

If the word responsibility is to be used at all, I suggest that it be in the sense Charles Frankel uses it. "Responsibility," says this philosopher, "Is the product of definite social arrangements." Notice that Frankel calls for social arrangements—not propaganda.

Mutual Coercion Mutually Agreed upon

The social arrangements that produce responsibility are arrangements that create coercion, of some sort. Consider bank-robbing. The man who takes money from a bank acts as if the bank were a commons. How do we prevent such action? Certainly not by trying to control his behavior solely by a verbal appeal to his sense of responsibility. Rather than rely on propaganda we follow Frankel's lead and insist that a bank is not a commons; we seek the definite social arrangements that will keep it from becoming a commons. That we thereby infringe on the freedom of would-be robbers we neither deny nor regret.

The morality of bank-robbing is particularly easy to understand because we accept complete prohibition of this activity. We are willing to saay "Thou shalt not rob banks," without providing for exceptions. But temperance also can be created by coercion. Taxing is a good coercive device. To keep downtown shoppers temperate in their use of parking space we introduce parking meters for short periods, and traffic fines for longer ones. We need not actually forbid a citizen to park as long as he wants to; we need merely make it increasingly expensive for him to do so. Not prohibition, but carefully biased options are what we offer him. A Madison Avenue man might call this persuasion; I prefer the greater candor of the word coercion.

Coercion is a dirty word to most liberals now, but it need not forever be so. As with the four-letter words, it dirtiness can be cleansed away by exposure to the light, by saying it over and over without apology or embarrassment. To many, the word coercion implies arbitrary decisions of distant and irresponsible bureaucrats; but this is not a necessary part of its meaning. The only kind of coercion I recommend is mutual coercion, mutually agreed upon by the majority of the people affected.

To say that we mutually agree to coercion is not to say that we are required to enjoy it, or even to pretend we enjoy it. Who enjoys taxes? We all grumble about them. But we accept compulsory taxes because we recognize that voluntary taxes would favor the conscienceless. We institute and (grumblingly) support taxes and other coercive devices to escape the horror of the commons.

An alternative to the commons need not be perfectly just to be preferable. With real estate and other material goods, the alternative we have chosen is the institution of private property coupled with legal inheritance. Is this system perfectly just? As a genetically trained biologist I deny that it is. It seems to me that, if there are to be differences in individual inheritance, legal possession should be perfectly correlated with biological inheritance—that those who are biologically more fit to be the custodians of property and power should legally inherit more. But genetic recombination continually makes a mockery of the doctrine of "like father, like son" implicit in our laws of legal inheritance. An idiot can inherit millions, and a trust fund can keep his estate intact. We must admit that our legal system of private property plus inheritance is unjust—but we put up with it because we are not convinced, at the moment, that anyone has invented a better system. The alternative of the commons is too horrifying to contemplate. Injustice is preferable to total ruin.

It is one of the peculiarities of the warfare between reform and the status quo that it is thoughtlessly governed by a double standard. Whenever a reform measure is proposed it is often defeated when its opponents triumphantly discover a flaw in it. As Kingsley Davis has pointed out, worshippers of the status quo sometimes imply that no reform is possible without unanimous agreement, an implication contrary to historical fact. As nearly as I can make out, automatic rejection of proposed reforms is based on one of two unconscious assumptions: (i) that the status quo is perfect; or (ii) that the choice we face is between reform and no action; if the proposed reform is imperfect, we presumably should take no action at all, while we wait for a perfect proposal.

But we can never do nothing. That which we have done for thousands of years is also action. It also produces evils. Once we are aware that the status quo is action, we can then pare its discoverable advantages and disadvantages with the predicted advantages and dvantages of the proposed reform, discounting as best we can for our lack of rience. On the basis of such a comparison, we can make a rational decision which will involve the unworkable assumption that only perfect systems are tolerable.

gnition of Necessity

Perhaps the simplest summary of this analysis of man's population problems is this: commons, if justifiable at all, is justifiable only under conditions of low-population ity. As the human population has increased, the commons has had to be abandoned ne aspect after another.

First we abandoned the commons in food gathering, enclosing farm land and icting pastures and hunting and fishing areas. These restrictions are still not complete ughout the world.

Somewhat later we saw that the commons as a place for waste disposal would also to be abandoned. Restrictions on the disposal of domestic sewage are widely pted in the Western world; we are still struggling to close the commons to pollution by mobiles, factories, insecticide sprayers, fertilizing operations, and atomic energy llations.

In a still more embryonic state is our recognition of the evils of the commons in ers of pleasure. There is almost no restriction on the propagation of sound waves in public medium. The shopping public is assaulted with mindless music, without its ent. Our government is paying out billions of dollars to create supersonic transport h will disturb 50,000 people for every one person who is whisked from coast to coast 3 s faster. Advertisers muddy the airwaves of radio and television and pollute the view avelers. We are a long way from outlawing the commons in matters of pleasure. Is this use our Puritan inheritance makes us view pleasure as something of a sin, and pain is, the pollution of advertising) as the sign of virtue?

Every new enclosure of the commons involves the infringement of somebody's onal liberty. Infringements made in the distant past are accepted because no emporary complains of a loss. It is the newly proposed infringements that we ously oppose; cries of "rights" and "freedom" fill the air. But what does "freedom" n? When men mutually agreed to pass laws against robbing, mankind became more not less so. Individuals locked into the logic of the commons are free only to bring on ersal ruin; once they see the necessity of mutual coercion, they become free to pursue goals. I believe it was Hegel who said, "Freedom is the recognition of necessity."

The most important aspect of necessity that we must now recognize, is the necessity bandoning the commons in breeding. No technical solution can rescue us from the ry of overpopulation. Freedom to breed will bring ruin to all. At the moment, to avoid decisions many of us are tempted to propagandize for conscience and responsible nthood. The temptation must be resisted, because an appeal to independently acting ciences selects for the disappearance of all conscience in the long run, and an increase xiety in the short.

The only way we can preserve and nurture other and more precious freedoms is by quishing the freedom to breed, and that very soon. "Freedom is the recognition of ssity"—and it is the role of education to reveal to all the necessity of abandoning the lom to breed. Only so, can we put an end to this aspect of the tragedy of the nons.

Environmental Engineering

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Environmental regulations have existed for centuries. Because of poor air quality near his palace in about A.D. 1300, King Edward II of England reportedly ordered any person burning coal to be hanged. However, no major environmental legislation in any country existed until the second half of the twentieth century. The first significant laws in this area were federal statutes passed in the United States in the 1970s dealing with air and surface water quality and hazardous waste.

Those laws are still in effect in much of their original form. However, they are still in a period of transition. What is legal or accepted practice today may be illegal in a few years. When today's average college student was born, the first significant environmental laws had been passed, but their requirements were just beginning to become effective. You have been witness to the most sweeping environmental regulations in history.

This chapter introduces the process that brings about changes in environmental law, and briefly describes major federal environmental laws. More detailed discussions of each area of legislation will appear where appropriate in later chapters.

ENT OF ENVIRONMENTAL REGULATIONS

The U.S. Congress writes environmental laws. For such legislation to be enacted, lawmakers must perceive that environmental regulation benefits society. Only after legislators see the public interest in and the public's desire for such laws will they be passed. In the United States a law can be passed by a simple majority of the Houe of Representatives and the Senate if the bill is signed by the president. However, if the president vetoes the bill, a two-thirds majority of both houses is required to override. Several important pieces of environmental legislation have been passed over presidential vetoes during the past twenty-five years.*

When Congress passes environmental legislation, it directs the appropriate federal agency to develop and publish regulations to implement it. Before 1970 the U.S. Public Health Service was the agency most concerned about environmental matters. In 1970 Congress created the U.S. Environmental Protection Agency. Since then the EPA has been responsible for enforcing applicable federal laws. In many cases the laws allow the states to adopt and enforce the federal laws.

There are laws, for example, to protect people from the toxic effects of copper and lead in drinking water. These require the EPA to determine

*The Clean Water Act of 1972 (PL 92-500) was passed over President Nixon's veto. The Resource Conservation and Recovery Act and the reauthorization of the Clean Water Act in 1987 were passed over President Reagan's vetoes.

acceptable levels of the contaminants and what must be done to bring excessively high levels into compliance. In this case the EPA set maximum contaminant levels for metals, and public utilities are now required to test their drinking water for actual amounts. If a public water supply has levels in excess of the limits, responsible officials must initiate a treatment plan to reduce the contamination. Individual states may adopt the federal regulations and obtain EPA permission to enforce them.

Why Are Environmental Laws Passed?

Hindsight tells us that the United States should have passed hazardous waste laws in about 1940. Regulations would then have been in place as the petrochemical industry developed. However, in the 1940s the world did not envision a petrochemical industry—or the hazardous wastes it was later to generate.

Hazardous wastes became more and more of an issue during the 1970s. Although many toxic compounds existed before the 1940s, during that decade synthetic organic chemistry was born, and with it came catalytic synthesis of gasolines from heavier crude oils. That infant enterprise bloomed into the massive petrochemical industry of today. Many synthetic organic chemicals are carcinogenic, but carcinogens often have latency periods of 10 to 20 years. Thus, it took decades for scientists, engineers, and physicians to recognize the link, which is tenuous even today, between particular chemicals in the environment and adverse health effects. One initial missing element was the ability to detect chemicals at extremely low levels. One cannot regulate something that cannot be detected. Where typical laboratory detection limits were in the mg/L range in the 1950s, they are in the μg/L or ng/L range today. In other words, detection limits are three to six orders of magnitude lower.

The point is, people in industry did not even imagine the hazards they were creating in the 1940s and 1950s. These dangers were not realized until the 1960s and 1970s. Even today we do not understand what effects extended exposure to low levels of many chemicals may cause. However, technical people have gradually become aware of environmental problems related to a wide array of synthetic chemicals, many of them herbicides and insecticides. After these problems were understood and made public, citizens and Congress had to be convinced of the seriousness of the risks, so laws could be passed to protect human health and the environment. Unfortunately, this is often a slow process.

The U.S. Environmental Protection Agency

Congress created the U.S. Environmental Protection Agency in December of 1970, giving it several missions: to establish standards to protect the environment consistent with U.S. goals; to conduct research on the adverse effects of pollution and methods and equipment for controlling it; to gather information on pollution and its effects; to use this information to strengthen environmental protection; to help others protect the environment through grants and technical assistance; and to assist the Council on Environmental quality in developing and recommending to the president new policies on protecting the environment.

The EPA is the primary agency responsible for protecting the environment, although several other agencies are also involved in particular areas. One exception is the control of nuclear wastes, where primary responsibility lies with the U.S. Department of Energy. The EPA's duties include enforcement of air quality standards, drinking water quality standards, stream discharge standards, solid and hazardous waste disposal standards, and the cleanup of abandoned hazardous waste sites. In many cases the agency encourages or allows individual states to take over the primary enforcement of these standards, but federal officials maintain overall responsibility. The EPA has divided the nation into ten regions, with an office and administrator for each. The regions are shown in Figure 2.1, the office addresses in Table 2.1.

State agencies enforce state environmental laws and regulations—and in many cases the federal regulations as well. In general, for a state to enforce the federal regulations, it must first adopt regulations equivalent to

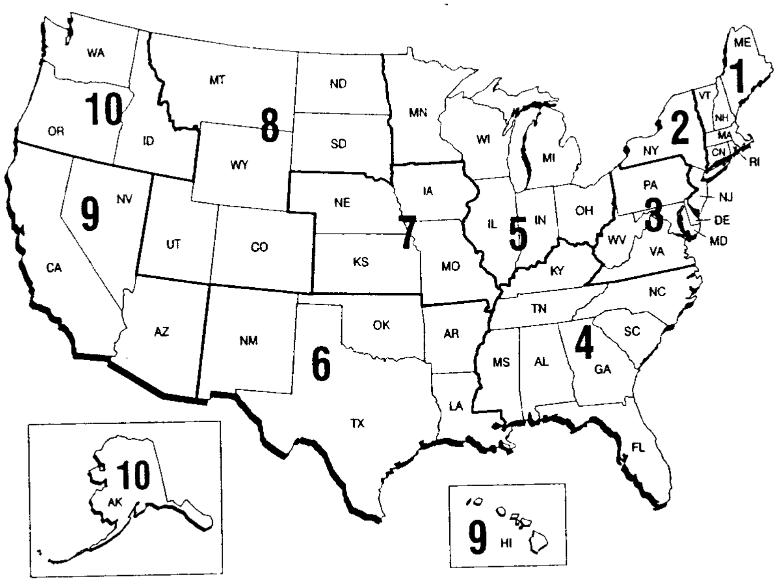

FIGURE 2.1 U.S. EPA Regions.

TABLE 2.1 U.S. EPA Regional Office Addresses

U.S. EPA Region 1 JFK Building Boston, MA 02203	U.S. EPA Region 2 26 Federal Plaza New York, NY 10278
U.S. EPA Region 3 841 Chestnut Street Philadelphia, PA 19107	U.S. EPA Region 4 345 Courtland Street, NE Atlanta, GA 30365
U.S. EPA Region 5 77 West Jackson Blvd. Chicago, IL 60604	U.S. EPA Region 6 First Interstate Bank Tower 1445 Ross Avenue, Suite 1200 Dallas, TX 75202
U.S. EPA Region 7 726 Minnesota Avenue Kansas City, KS 66101	U.S. EPA Region 8 999 18th Street, Suite 1500 Denver, CO 80202
U.S. EPA Region 9 75 Hawthorne Street San Francisco, CA 94105	U.S. EPA Region 10 1200 Sixth Avenue Seattle, WA 98101

or stricter than federal requirements. The names of state agencies vary. There is, for example, the New Jersey Department of Environmental Protection, the Arkansas State Department of Pollution Control and Ecology, and the Illinois Environmental Protection Agency.

Methods of Regulation

Speed laws in this country are regulated by posting the legal speed limit on each highway, and spot checking motorists to ensure compliance. There is no way to prevent motorists from speeding if they desire to do so. However, they run a risk of being apprehended by police officers using radar or other speed detection instruments. The penalty for speeding is usually a fine. Environmental laws often work in a similar manner. The city or industry (discharger) must obtain a permit that states the types of pollutants that may be discharged and the allowable amounts. The permit is equivalent to highway speed limit signs. The discharger must monitor the levels of the various pollutants, an action analogous to a driver watching a speedometer, and keep these below the permitted levels. One difference, however, is that the discharger, as a part of the permit, must not only check levels of various pollutants, but also submit reports on these levels every 3 months. This would be equivalent to the government requiring you, to turn in quarterly summaries of the maximum speeds at which you drive each day.

When dischargers violate their permit conditions, they must notify the revolving state loan program over a period of 4 years. [1]. In addition, it required permits for storm water discharge from city streets, parking lots, and industrial areas.

Air Quality Regulations. Since air pollution has two major sources—industry, including power plants, and highway vehicles—the approach to regulating and improving air quality is somewhat different from that applied to other types of pollution. The federal government has approached this by requiring limits on emissions from industries and power plants and by requiring auto manufacturers to produce vehicles with improved emissions. The first federal legislation in this area was the Air Pollution Control Act of 1955, PL 84-159. It did not really control air pollution, but it did provide for research on its effects and training of pollution control personnel. The law was a small first step. Other legislation followed in 1962 and 1963, and in 1965 the Motor Vehicle Air Pollution Control Act, PL89-272, was passed. This began the auto emissions controls that remain in effect. Other laws were passed in 1967, 1970, and 1977, and controls on industries and power plants have gradually increased. The most recent major legislation is the Clean Air Act Amendments of 1990, which requires reductions in air pollutants in major cities not in compliance with air quality standards. The 1990 measure tightens emission requirements for automobiles and trucks and places additional controls on almost 200 toxic air pollutants [5].

)RY METHODS

Water quality standards can be based on either the quality of the effluent being introduced into the environment or on the quality of the surrounding environment, or both. Each method has advantages. Standards maintaining a set environmental quality are probably best for the environment. But they are difficult to regulate. Where multiple dischargers exist, it is often difficult to prove which is responsible, and in some cases, several dischargers may be responsible for a single adverse condition. An extreme example is metropolitan smog. Do you blame the industries present? If so, which ones? Do you blame the automobiles emitting pollutants? The trucks and busses? In reality, all are partially responsible. So how do you reduce smog? Possible options are shown in Table 2.2.

Environmental Quality-Based Standards

Environmental quality–based standards* focus on the quality of the receiving water or local air. A discharger may release pollutants in any

*Environmental quality–based standards are often called **stream-based standards** when applied to water, although the concept applies to lake or ocean water as well. When applied to air quality, these requirements are often termed ambient air quality standards.

TABLE 2.2 Methods of Controlling Air Pollution in Cities

SOURCE	POLLUTANTS	METHODS OF CONTROL
Industries	Volatile organics	Require reduced emissions
	Volatile chlorofluorocarbons	Require reduced emissions
	Particulate inorganics	Require reduced emissions
Automobiles	Hydrocarbons	Improve discharge nozzles at filling stations and ventilation in gasoline tanks
	Products of incomplete combustion	Require better combustion efficiency of auto makers and emission testing and regular engine maintenance of drivers. Limit gasoline suppliers to oxygenated fuels
	Chlorofluorocarbons from air conditioners	Require the redesign of automobile air conditioners so vehicles made in the future can use other refrigerants.

quantity that does not cause the receiving water or local air quality to drop below established minimums. **Receiving water quality standards** have advantages. They maintain the water or air quality above a preset minimum, and dischargers can get rid of larger quantities of water pollutants during high-flow/low-temperature periods or more air pollutants during windy/low-temperature periods. However, there are significant disadvantages as well. One is the difficulty of enforcement, particularly where there are multiple dischargers within a given stream reach or local area. Also, water conditions are hard to monitor. A discharger's required effluent quality varies with the stream flow, wind currents, and temperature, so monitoring must be continuous. In many cases dischargers need to take measurements elsewhere because upstream contaminant levels affect the amounts of pollutants that can be discharged, on site. And to benefit from such standards, industries must have highly trained personnel and real-time monitoring equipment. Thus, it is difficult for most dischargers to maintain compliance.

Effluent-Based Standards

Effluent-based standards concentrate on the quality of the discharger—either water or air. With this type of requirement, a discharger has definite parameters to meet, and workers do not have to concern themselves with variations in stream flow, weather conditions, temperature or other receiving water or air conditions. Complying with effluent-based standards is also easier from the standpoint of consistency. There is a specific allowable level for each pollutant based on discharge concentration, discharge mass, or both. The discharger must keep contaminants below that limit.

For the same reasons it is also easier for regulatory agencies to monitor effluent-based standards. One apparent disadvantage of them, however, is that they do not allow flexibility in protecting the ambient environmental quality. But since streams can better assimilate wastes during cooler weather and high water flows, different effluent standards can be set for different seasons. Such an approach combines advantages of the two regulatory methods, and similar flexibility can be built into air pollution control as well.

ENTAL ETHICS

A corporation is in business to make a profit for its shareholders. Its primary purpose is not to protect the environment. However, businesses are required to comply with environmental regulations—a process that normally requires a significant investment in both capital expenditure and operating costs. When environmental regulations are applied fairly overall, other factors usually play a dominant role in determining the relative profitability of competing companies. However, where one facility operates in a location where environmental regulations are more stringent than those experienced by competitors, it may be required to operate at lower profit, or at a loss. Or it may have to raise its prices. Few companies are successful at selling equivalent products at prices higher than those of the competition. And companies cannot operate at a loss for extended periods. They must either close or move to areas where environmental regulations are less restrictive. Applied uniformly, federal standards are the fairest method of providing environmental protection while allowing businesses to compete.

There are exceptions to the free-market rule that companies cannot sell products for long at uncompetitive prices. Particularly in recent years, some consumers have been willing to spend more for "environmentally friendly" products. A number of such products—including everything from recycled paper made into bathroom tissue to automobiles to fast food to many small consumer goods packaged in recyclable paper—are doing well. So progress is being made.

Questions

1. Distinguish between effluent-based standards and water quality–based standards.

2. Distinguish between ambient air quality standards and air emission standards.
3. Using the government documents or science/engineering section of your library, write one- to two-page summaries of
   a. PL 92-500
   b. Superfund
   c. CERCLA
   d. Current wastewater treatment regulations
4. What session of Congress enacted PL 92-500? How many other acts were passed in that session before this legislation?
5. Determine what EPA region you are in. Where is the regional headquarters?

References

1. J. M. Kovalic, *The Clean Water Act of 1987*, Water Pollution Control Federation, Alexandria, Virginia, 1987.
2. U.S. Environmental Protection Agency, "Report to Congress: Disposal of Hazardous Wastes," Office of Solid Waste Management, SW-115, Washington, DC, 1973.
3. U.S. Environmental Protection Agency, "Solid Waste Disposal Facility Criteria; Final Rule," Federal Register, 40 CFR Parts 257 and 258, October 9, 1991.
4. *Water Quality and Treatment*, 3rd ed., The American Water Works Association, McGraw-Hill Book Co., 1971.
5. A. L. Alm, "The Clean Air Act," *Environmental Science and Technology*, vol. 25, no. 3 (March 1991), p. 383.