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Introduction 概论

1–1 WHAT IS ENVIRONMENTAL SCIENCE?

Natural Science

In the broadest sense, science is systematized knowledge derived from and tested by recognition and formulation of a problem, collection of data through observation, and experimentation. We differentiate between social science and natural science in that the former deals with the study of people and how they live together as families, tribes, communities, races, and nations, and the latter deals with the study of nature and the physical world. Natural science includes such diverse disciplines as biology, chemistry, geology, physics, and environmental science.

Environmental Science

Whereas the disciplines of biology, chemistry, and physics (and their subdisciplines of microbiology, organic chemistry, nuclear physics, etc.) are focused on a particular aspect of natural science, environmental science in its broadest sense encompasses all the fields of natural science. The historical focus of study for environmental scientists has been, of course, the natural environment. By this, we mean the atmosphere, the land, the water and their inhabitants as differentiated from the built environment. Modern environmental science has also found applications to the built environment or, perhaps more correctly, to the effusions from the built environment.

Quantitative Environmental Science

Science or, perhaps more correctly, the **scientific method,** deals with data, that is, with recorded observations. The data are, of course, a sample of the universe of possibilities. They may be representative or they may be skewed. Even if they are representative they will contain some random variation that cannot be explained with current knowledge. Care and impartiality in gathering and recording data, as well as independent verification, are the cornerstones of science.

When the collection and organization of data reveal certain regularities, it may be possible to formulate a generalization or **hypothesis.** This is merely a statement that under certain circumstances certain phenomena can generally be observed. Many generalizations are statistical in that they apply accurately to large assemblages but are no more than probabilities when applied to smaller sets or individuals.

In a scientific approach, the hypothesis is tested, revised, and tested again until it is proven acceptable.

If we can use certain assumptions to tie together a set of generalizations, we formulate a theory. For example, theories that have gained acceptance over a long time are known as **laws.** Some examples are the laws of motion, which describe the behavior of moving bodies, and the gas laws, which describe the behavior of gases. The development of a **theory** is an important accomplishment because it yields a tremendous consolidation of knowledge. Furthermore, a theory gives us a powerful new tool in the acquisition of knowledge for it shows us where to look for new generalizations. "Thus, the accumulation of data becomes less of a magpie collection of facts and more of a systematized hunt for needed information. It is the existence of classification and generalization, and above all theory that makes science an organized body of knowledge" (Wright, 1964).

Logic is a part of all theories. The two types of logic are qualitative and quantitative logic. Qualitative logic is descriptive. For example we can qualitatively state that when the amount of wastewater entering a certain river is too high, the fish die. With qualitative logic we cannot identify what "too high" means—we need quantitative logic to do that.

When the data and generalizations are quantitative, we need mathematics to provide a theory that shows the quantitative relationships. For example, a quantitative statement about the river might state that "When the mass of organic matter entering a certain river equals x kilograms per day, the amount of oxygen in the stream is y."

Perhaps more importantly, quantitative logic enables us to explore 'What if?' questions about relationships. For example, "If we reduce the amount of organic matter entering the stream, how much will the amount of oxygen in the stream increase?" Furthermore, theories, and in particular, mathematical theories, often enable us to bridge the gap between experimentally controlled observations and observations made in the field. For example, if we control the amount of oxygen in a fish tank in the laboratory, we can determine the minimum amount required for the fish to be healthy. We can then use this number to determine the acceptable mass of organic matter placed in the stream.

Given that environmental science is an organized body of knowledge about environmental relationships, then **quantitative environmental science** is an organized collection of mathematical theories that may be used to describe and explore environmental relationships.

In this book, we provide an introduction to some mathematical theories that may be used to describe and explore relationships in environmental science.

1–2 WHAT IS ENVIRONMENTAL ENGINEERING? 什么是环境工程?

Engineering 工程

Engineering is a profession that applies science and mathematics to make the properties of matter and sources of energy useful in structures, machines, products, systems, and processes.

Environmental Engineering 环境工程

The Environmental Engineering Division of the American Society of Civil Engineers (ASCE) has published the following statement of purpose that may be used to show the relationship between environmental science and environmental engineering:

> Environmental engineering is manifest by sound engineering thought and practice in the solution of problems of environmental sanitation, notably in the provision of safe, palatable, and ample public water supplies; the proper disposal of or recycle of wastewater and solid wastes; the adequate drainage of urban and rural areas for proper sanitation; and the control of water, soil, and atmospheric pollution, and the social and environmental impact of these solutions. Furthermore it is concerned with engineering problems in the field of public health, such as control of arthropod-borne diseases, the elimination of industrial health hazards, and the provision of adequate sanitation in urban, rural, and recreational areas, and the effect of technological advances on the environment (ASCE, 1977).

Neither environmental science nor environmental engineering should be confused with heating, ventilating, or air conditioning (HVAC), nor with landscape architecture. Neither should they be confused with the architectural and structural engineering functions associated with built environments, such as homes, offices, and other workplaces.

1–3 HISTORICAL PERSPECTIVE 历史的观点

Overview 概要

Recognizing that environmental science has its roots in the natural sciences and that the most rudimentary forms of generalization about natural processes are as old as civilizations, then environmental science is indeed very old. Certainly, the Inca cultivation of crops and the mathematics of the Maya and Sumerians qualify as early applications of natural science. Likewise the Egyptian prediction and regulation of the annual floods of the Nile demonstrate that environmental engineering works are as old as civilization. On the other hand if you asked Archimedes or Newton or Pasteur what field of environmental engineering and science they worked in, they would have given you a puzzled look indeed! For that matter, even as late as 1687 the word science was not in vogue; Mr. Newton's treatise alludes only to *Philosophiae Naturalis Principa Mathematics (Natural Philosophy and Mathematical Principles).*

Engineering and the sciences as we recognize them today began to blossom in the 18th century. The foundation of environmental engineering as a discipline may be considered to coincide with the formation of the various societies of civil engineering in the mid-1800s (e.g., the American Society of Civil Engineers in 1852). In the first instances and well into the 20th century, environmental engineering was known as sanitary engineering because of its roots in water purification. The name changed in the late 1960s and early 1970s to reflect the broadening scope that included not only efforts to purify water but also air pollution, solid waste management and the many other aspects of environmental protection that are included in the environmental engineer's current job description.

Although we might be inclined to date the beginnings of environmental science to the 18th century, the reality is that at any time before the 1960s there was virtually no reference to environmental science in the literature.

Although the concepts of ecology had been firmly established by the 1940s and certainly more than one individual played a role, perhaps the harbinger of environmental science as we know it today was Rachel Carson and, in particular, her book *Silent Spring* (Carson, 1962). By the mid-1970s environmental science was firmly established in academia, and by the 1980s recognized subdisciplines (environmental chemistry, environmental biology, etc.) that characterize the older disciplines of natural sciences had emerged.

Hydrology

Citations for the following section originally appeared in Chow's *Handbook of Applied Hydrology* (1964). The modern science of hydrology may be considered to have begun in the 17th century with measurements. Measurements of rainfall, evaporation, and capillarity in the Seine were taken by Perrault (1678). Mariotte (1686) computed the flow in the Seine after measuring the cross section of the channel and the velocity of the flow.

The 18th century was a period of experimentation. The predecessors for some of our current tools for measurement were invented in this period. These include Bernoulli's piezometer, the Pitot tube, Woltman's current meter, and the Borda tube. Chézy proposed his equation to describe uniform flow in open channels in 1769.

The grand era of experimental hydrology was the 19th century. The knowledge of geology was applied to hydrologic problems. Hagen (1839) and Poiseulle (1840) developed the equation to describe capillary flow, Darcy published his law of groundwater flow (1856), and Dupuit developed a formula for predicting flow from a well (1863).

During the 20th century, hydrologists moved from empiricism to theoretically based explanations of hydrologic phenomena. For example, Hazen (1930) implemented the use of statistics in hydrologic analysis, Horton (1933) developed the method for determining rainfall excess based on infiltration theory, and Theis (1935) introduced the nonequilibrium theory of hydraulics of wells. The advent of high-speed computers at the end of the 20th century led to the use of finite element analysis for predicting the migration of contaminants in soil.

Water Treatment

The provision of water and necessity of carrying away wastes were recognized in ancient civilizations: a sewer in Nippur, India, was constructed about 3750 B.C.E.; a sewer dating to the 26th century B.C.E. was identified in Tel Asmar near Baghdad, Iraq (Babbitt, 1953). Herschel (1913), in his translation of a report by Roman water commissioner Sextus Frontinus, identified nine aqueducts that carried over $3 \times 10^5\ m^3 \cdot d^{-1}$ of water to Rome in 97 A.D.

Over the centuries, the need for clean water and a means for wastewater disposal were discovered, implemented, and lost to be rediscovered again and again. The most recent rediscovery and social awakening occurred in the 19th century.

In England, the social awakening was preceded by a water filtration process installed in Paisley, Scotland, in 1804 and the entrepreneurial endeavors of the Chelsea Water Company, which