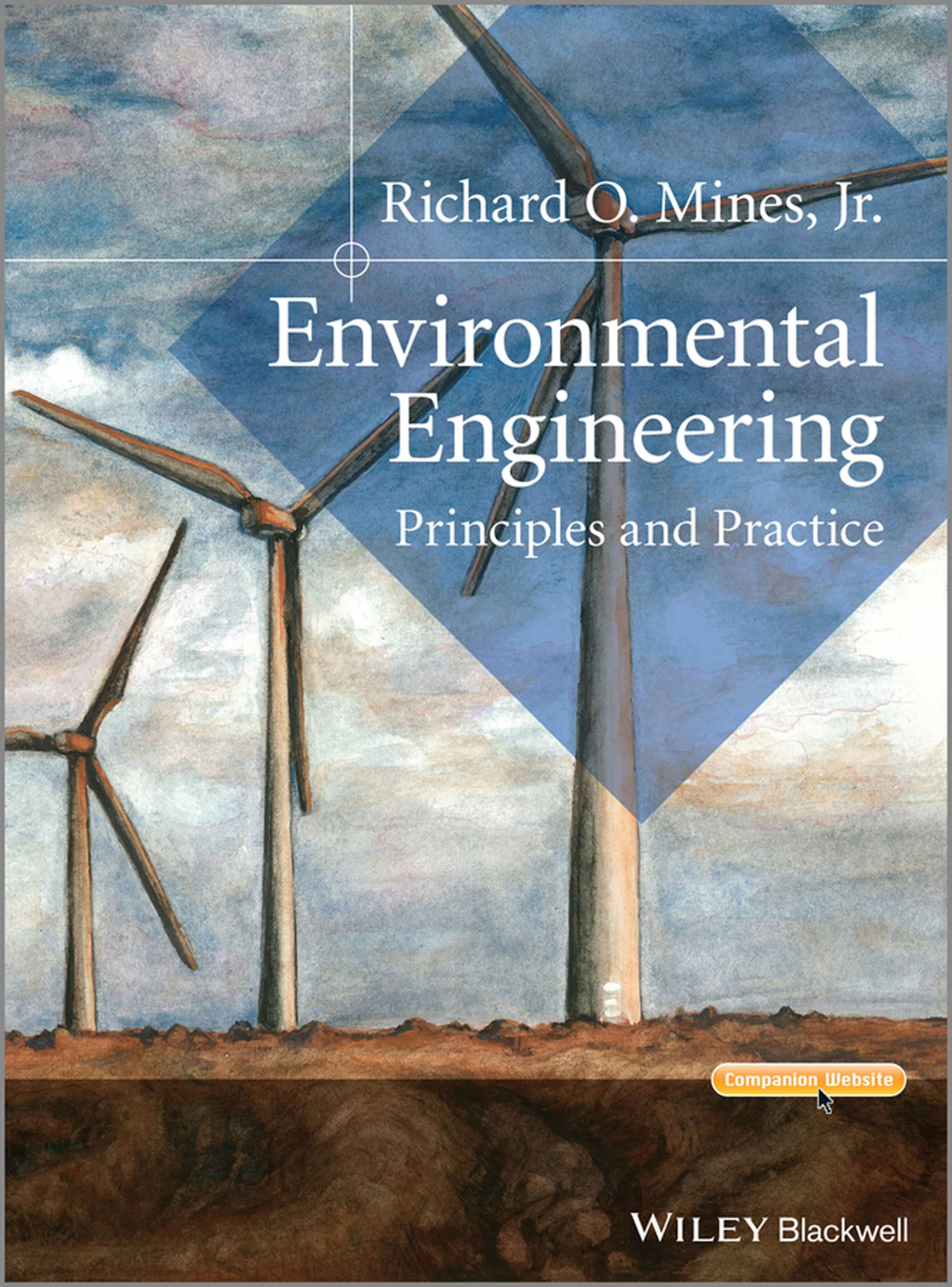

Richard O. Mines, Jr.

Environmental Engineering

Principles and Practice

Companion Website

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Environmental Engineering

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Principles and Practice

Richard O. Mines, Jr.
School of Engineering, Mercer University, Macon, Georgia, USA

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111 River Street, Hoboken, NJ 07030-5774, USA

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1 2014

This book is dedicated with sincere appreciation and gratitude to my family; my wife, Beth Pehle Mines, and my sons; R. Andrew Mines and Daniel C. Mines.

Contents

Contributing Authors

André J. Butler
Associate Professor and Chair
Environmental Engineering Department
Mercer University
Macon, GA, USA

John C. Little, Ph.D., P.E.
Charles Edward Via, Jr. Professor
Department of Civil and Environmental Engineering
Virginia Tech
Blacksburg, VA, USA

Zhe Liu, Ph.D.
Department of Civil and Environmental Engineering
Virginia Tech
Blacksburg, VA, USA

Philip T. McCreanor, Ph.D.
Associate Professor
Mercer University School of Engineering
Macon, GA, USA

John T. Novak, Ph.D.
Professor of Civil and Environmental Engineering
Virginia Tech
Blacksburg, VA, USA

Paige J. Novak, Professor
Resident Fellow of the Institute on the Environment
Department of Civil Engineering
University of Minnesota
Minneapolis, MN, USA

Arthur B. Nunn, III, QEP
President
The Air Compliance Group, LLC
Roanoke, VA, USA

Peter Vikesland, Ph.D.
Professor of Civil and Environmental Engineering
Virginia Tech
Blacksburg, VA, USA

Preface

Intended Audience

Environmental Engineering : Principles and Practice is written for an advanced undergraduate course or a first-semester graduate course in environmental engineering. The target audience is students pursuing the civil and/or environmental engineering curriculum. However, the text may be used by students in chemical and mechanical engineering where several environmental concepts are of interest; especially those on water and wastewater treatment, air pollution, and sustainability. The text is a good resource for practicing engineers, since it covers the major environmental topics and provides numerous, step-by-step examples to facilitate learning and problem solving.

Goals and Motivation

The text was written to provide a clear and concise understanding of the major topic areas facing environmental professionals. For each topic, the theoretical principles are introduced, followed by numerous examples illustrating the proper process design approach. This approach is thought by the author to be an effective educational method. It was desired that this text be more practical, methodical, and functional for students – providing knowledge and background, as well as opportunities for application, through problems and examples that would facilitate understanding. Another motivation for writing the text evolved from the frustration of using texts that students do not read because of their complexity and emphasis on the theoretical aspects, while providing insufficient detail in the example problems for students to follow.

Unique Features

Several items unique to our text include:

1. **Problem Solving Scheme**: Chapter 1 provides a reliable problem solving scheme for students along with introducing them to statistical analysis. Proper analysis and communication of data are incorporated into the chapter. From our experience, many upper-level engineering students are still struggling with these concepts. Also, graduate students often find this type of material most beneficial. We are not aware of another environmental engineering textbook that introduces these critical tools to students.
2. **Example Problems with both US and SI Units**: The text is enriched by a multitude of example problems that incorporate both SI and the more customary English unit systems. We feel that many texts fall short in both these areas by not providing students with examples that help explain difficult technical concepts, and by only focusing on one system of units only. More importantly, our text provides step-by-step procedures for solving the difficult concepts, where other texts skip several steps before arriving at the final answer.
3. **Water and Wastewater Design Chapters**: Substantial material is presented on the selection and design of unit operations and processes used to treat drinking water and domestic wastewater. Numerous step-by-step examples lead the novice or the seasoned practitioner through the process.
4. **Sustainability**: A complete chapter has been devoted to sustainability, which is currently a hot topic. Special emphasis is placed on the causes and consequences of global climate change. Ecological Footprint is defined, and alternative energies, including solar power, wind energy, and geothermal energy, are presented. Carbon sequestration is explained, along with the capture, compression, transport, and storage of carbon dioxide. An example illustrating the Ecological Footprint and Life Cycle Assessment procedure is provided.
5. **Public Health Chapter**: Many environmental engineering text books omit public health topics. We provide an expansive view of this topic in a chapter entitled "Environmental Health". Toxicological pathways relevant to chemical exposures are described, in addition to pertinent organ and cellular systems involved in the ingestion, inhalation, dermal absorption, and placental transfer of toxic substances. Utilization of potency factors and chronic daily intake values for lifetime risk, and LOAEL, NOAEL, and RfD values are discussed. The epidemiology triangle, to describe the dissemination of an infectious disease, is discussed along with the thirteen factors responsible for disease dissemination that affect emergence and reemergence.

About the Book

Salient points of each chapter are presented below:

1. **Introduction to Environmental Engineering and Problem Solving**: Chapter 1 provides the historical context of environmental engineering. A six-step problem-solving method is introduced. Analyzing experimental error and calculating error estimates is presented. Most importantly, statistical analyses using linear-regression, correlation coefficient, coefficient of determination, and application of the Student's t-test and one-way Analysis of Variance is presented.

2 **Essential Chemistry Concepts**: A review of essential chemical concepts, along with thermodynamic principles and the kinetics of reactions, is discussed. Numerous examples are provided so that the novice and practitioner can apply the appropriate chemistry to various environmental applications.

3 **Water and Wastewater Characteristics**: Conventional physical, chemical, and biological characteristics of water and wastewater are described. A brief presentation of the analytical procedures for measuring traditional water quality parameters is presented. Numerous tables comparing the characteristics of ground water, surface water, wastewater, and stormwater are provided.

4 **Essential Biology Concepts**: Chapter 4 provides the background material necessary for understanding the role of organisms, and especially how microorganisms are used for treating wastewater, sludges, contaminated ground waters, and soils. A brief discussion of prokaryotic and eukaryotic cells is presented, followed by a presentation of the relationship between energy and synthesis reactions involving heterotrophic and autotrophic organisms. Ecological topics are addressed with particular emphasis on the carbon, nitrogen, phosphorus, and sulfur cycles, and their role in biology. The Streeter-Phelps dissolved oxygen model, along with limnological terms such as eutrophication, stratification, and turnover, are discussed.

5 **Environmental Systems: Modeling and Reactor Design**: This chapter serves as the foundation for modeling and designing reactor systems for treating water and wastewater. The chapter begins with a discussion of material balances and the application of the Law of Conservation of Matter. This is followed by how one determines the rate and order of reaction. Particular emphasis is placed on the design of batch, complete-mix, and plug flow reactors containing reactive and non-reactive contaminants. The chapter ends with the application of the Law of Conservation of Energy, which is essential in performing energy balances.

6 **Design of Water Treatment Systems**: Chapter 6 provides detailed information on the objectives of water treatment and proper selection of appropriate unit operations and processes necessary to meet primary and secondary drinking water standards. Numerous examples are presented for designing conventional and advanced water treatment systems, along with systems for handling water treatment residuals. A discussion of various disinfectants and what to consider when selecting the appropriate disinfectant is presented.

7 **Design of Wastewater Treatment Systems**: Analogous to the water treatment systems chapter, Chapter 7 deals with the design of conventional and advanced systems used for treating municipal wastewater. This chapter focuses on the use of biological wastewater systems, such as trickling filters, rotating biological contactors (RBCs), activated sludge processes, sequencing batch reactors (SBRs), and single-sludge biological nutrient removal (BNR) processes for removing nitrogen and phosphorus from wastewater. Sludge volume and mass relationships are discussed, along with various sludge thickening, dewatering, and stabilizing processes. The characteristics and use of indicator organisms as surrogate parameters for pathogens is presented, along with a guide to selecting the appropriate chemicals for disinfecting wastewater effluent.

8 **Municipal Solid Waste Management**: Chapter 8 identifies and describes the primary regulations for solid waste disposal in the United States. Solid waste generation and disposal trends along with the composition of generated, disposed, and recycled solid waste streams in the US are described. Examples showing how to calculate the composition of a generated waste, the moisture content of MSW, the energy content of a waste, and how to size a landfill are presented. The chapter concludes with the procedure for determining the volume and rate of landfill gas production.

9 **Air Pollution**: The types, sources, and effects of air pollutants, including local and global impacts is presented in Chapter 9. Meteorological fundamentals and impact on the evaluation of air pollutant emissions and basis for atmospheric dispersion modeling are discussed. Various examples illustrating the basic design and function of various types of air pollution control technologies for gaseous and particulate air pollutants are provided.

10 **Environmental Sustainability**: Chapter 10 provides an overview on sustainability. The causes and consequences of global climate change are presented, along with the detrimental effects of rapid human development. Estimating ecological footprints and evaluation of alternative forms of renewable energy are addressed. Carbon sequestration is explained. An example of using Ecological Footprint and Life Cycle Assessment method is presented.

11 **Environmental Public Health**: Toxicological pathways relevant to chemical exposures are described, in addition to pertinent organ and cellular systems involved in the ingestion, inhalation, dermal absorption, and placental transfer of toxic substances. Disease, epidemiology, and toxicology are defined. Acute and chronic exposures are compared and contrasted. Utilization of potency factors and chronic daily intake values for lifetime risk and LOAEL, NOAEL, and RfD values are discussed. The epidemiology triangle to describe the dissemination of an infectious disease is discussed, along with the thirteen factors responsible for disease dissemination that affect emergence and reemergence.

12 **Hazardous Waste Management**: Chapter 12 presents an overview of what constitutes a hazardous compound or hazardous waste. Common groups of hazardous wastes are presented, in addition to important physical and chemical characteristics of a contaminant that determine its fate, treatment options available, and the likely risk and pathways for exposure. Henry's law, the octanol-water partition coefficient, and Darcy's law are discussed, as well

as how they relate to hazardous waste management. Various remediation and treatment methods, along with what considerations are relevant for deciding on an appropriate treatment option. Advantages and disadvantages of *in situ* and *ex situ* treatment are delineated.

Course Suggestions

We will provide guidance, describing how a faculty member might use the text for an upper-level undergraduate course and as a first-semester graduate course.

Instructor Resources

The following resources will be available to instructors on the book website:

- **Solutions Manual** – Complete solutions for end of chapter problems will be provided to instructors who require the text for their course. It will be provided on the book website as PDF files.
- **Image Gallery** – Images from the text in electronic form, suitable for use in lecture slides. This includes all figures and all tables from the book.

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The preparation of a book can take on a life of its own. It consumes every wakening moment until the entire project is completed. There are few gratifying experiences in life that can compete with publishing a book!

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About the Cover Artist

Angela Mines Plunkett, sister of Richard Mines, is an Associate Faculty Member at Saddleback College in Mission Viejo, California. Angela has a Bachelor of Arts from Mary Baldwin College in Staunton, Virginia; a Master of Education from the University of Virginia, Charlottesville; a Bachelor of Fine Arts from California State University Long Beach; and a Master of Fine Arts from California State University Long Beach.

About the Author

Richard O. Mines, Jr. is a Professor of Environmental Engineering and Director of the MSE/MS Programs in the School of Engineering at Mercer University in Macon, Georgia. He graduated from the Virginia Military Institute with a BS in Civil Engineering in 1975, from the University of Virginia with a ME in Civil Engineering in 1977, and from Virginia Polytechnic Institute and State University with a PhD in Civil Engineering in 1983.

Dr. Mines has had over 26 years of teaching experience at the Virginia Military Institute, University of South Florida, and Mercer University. He has over seven years of experience with the following engineering consultants: Hodges, Harbin, Newberry, and Tribble; CH_2M Hill; BLACK & VEATCH; and William Matotan & Associates. During his consulting years, he served as an Adjunct Professor at Santa Fe Community College in Gainesville, Florida, and at the University of South Florida, in Tampa.

Dr. Mines is a registered Professional Engineer in Florida (Retired), New Mexico, and Virginia (Inactive); a licensed private pilot; and a certified scuba diver. He has authored/co-authored over 100 technical and educational papers. Dr. Mines is the senior author of *Introduction to Environmental Engineering*, published by Prentice-Hall. He has taught and conducted research on: oxygen uptake rate and oxygen transfer in wastewater treatment systems; aerator testing; suspended growth biological systems using the following processes: Modified Ludzack-Ettinger process, Virginia Initiative Process, and sequencing batch reactor for accomplishing nutrient removal; modeling of bionutrient removal systems; and engineering education.

During his career, Dr. Mines has been a member of the following professional societies: American Society of Civil Engineers (ASCE), American Water Works Association (AWWA), Water Environment Federation (WEF), and American Society for Engineering Education (ASEE).

His awards and honors include election as a Fellow in ASCE (2007) and a Fellow in the Environmental and Water Resources Institute (2013). He received the Tony Tilmans Section Service Award for the ASEE-SE section in 2011. Dr. Mines was a Mercer on Mission Fellow to Malawi, Africa during summer 2010, and Mercer University Commons Fellow in 2008. He received the following awards from the American Society for Engineering Education: 2003 – 04 Outstanding ASEE Zone II Campus Representative Award; 2003 – 04 Outstanding ASEE Campus Representative Award for Southeastern Section; 2002 – 03 Outstanding ASEE Zone II Campus Representative Award; and 2002 – 03 Outstanding ASEE Campus Representative Award for Southeastern Section; and 2001 – 02 Outstanding ASEE Campus Representative Award for Southeastern Section. Dr. Mines was selected a Baylor University Faith in Vocations Fellow in 2002 and a 2001 National Teaching Effectiveness Institute Fellow of ASEE.

Dr. Mines is a member of Chi Epsilon Honor Society (1992) and the Order of the Engineer (1992). He received teaching awards from the American Society of Civil Engineers Student Chapter at the University of South Florida as Professor of the Year in 1994 – 95 and 1996 – 1997. Dr. Mines was selected by the faculty at the University of South Florida for a Teaching Incentive Program (TIP) Award in 1995 – 96, 1996 – 1997, and 1997 – 1998. For his many years of service to the Florida Water and Environment Association, he received the FWEA Service Award in 1998. During the summer 1997, he was a Faculty Research Program Fellow, Air Force Office of Scientific Research at Eglin Air Force Base, Ft. Walton Beach, Florida.

Not only is Dr. Mines a scholar, but a true athlete. He was elected into the Bath County, Virginia Athletic Hall of Fame in January 2007 having letter in football, basketball, and baseball while in high school. While attending the Virginia Military Institute, he began running and lettered in cross-country, indoor track, and outdoor track. He was selected Captain of the VMI Cross-country team, Co-captain of the indoor track team, and Tri-captain of the outdoor track team. Over the last 40 years, Dr. Mines has logged approximately 70,000 miles and successfully completed 56 marathons, five of which were at Boston.

He and his family reside in Macon, Georgia where they are active members of Martha Bowman Memorial United Methodist Church.

About the Companion Website

This book is accompanied by a companion website:

www.wiley.com/go/mines/environmentalengineeringprinciples

The website includes:

- Complete solutions for end of chapter problems
- Powerpoints of all figures from the book for downloading
- PDFs of all tables from the book for downloading

Chapter 1

Introduction to environmental engineering and problem solving

André J. Butler

Learning Objectives

After reading this chapter, you should be able to:

- appreciate the historical context of environmental engineering;
- discuss significant national and international environmental concerns;
- outline prominent environmental statutes;
- apply a six-step problem-solving method to engineering problems;
- effectively communicate analysis results in tables and figures;
- analyze experimental data;
- estimate experimental error;
- apply the concepts of variance and standard deviation to describe the uncertainty in experimental data;
- calculate error estimates associated with experimental data;
- use linear-regression analysis to describe the strength of relationship between two variables;
- quantify the magnitude of the relationship between two variables using the sample correlation coefficient and the coefficient of determination;
- apply the Student's t-test and the one-way Analysis of Variance (ANOVA) to determine if sample groups are statistically different.

1.1 History of environmental engineering

The civilizations of our ancient history were deeply and innately connected to the realm of religion and spirituality. Profoundly influenced by the natural world, there is no religion left untouched by our spiritual connection to the environment. Since the beginning of time, humans have sought comfort and healing in the earth. It is where we find sustenance, protection and beauty – but we struggle to live in harmony with it.

Our reverence for the world around us is exemplified by the prophets of our oldest religions and their desire to seek and renew their connection to the Divine through retreating into nature. Moses, Jesus, Buddha, and Muhammad all independently retreated to nature for renewal. Similarly, while living in the forest, the Hindu sages wrote the Vedic scriptures that fueled today's democratic pluralistic Indian civilization. Finally, three to five thousand years ago, Taoism and Confucianism encouraged their followers to mimic the patterns of nature, while Aristotle taught that one could understand life through imitating nature.

Further evidence of our storied relationship with the environment is in our sacred scriptures. For instance, the Old Testament of the Bible teaches that God expects humans to be the stewards of nature, and that we can learn from it:

> *The land is mine and you are but aliens and my tenants. Throughout the country that you hold as a possession, you must provide for the redemption of the land*
>
> *(Lev. 25:23–24).*

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But ask the animals, and they will teach you, or the birds in the sky, and they will tell you, or speak to the earth, and it will teach you, or let the fish in the sea inform you

(Job 12: 7–8).

Islam's Holy book, the Qur'an, stresses balance and proportion and challenges the rights of man to change this balance and destroy Allah's creation:

And produced therein all kinds of things in due balance

(Surah 15, verse 19).

Verily, all things have We created in proportion and measure

(Surah 54, verse 49).

Buddhist scripture suggests how humans should treat the natural world, and the result of living selfishly in light of communion with it:

Rajah Koravya had a king banyan tree called Steadfast, and the shade of its widespread branches was cool and lovely. Its shelter broadened to twelve leagues … None guarded its fruit, and none hurt another for its fruit. Now there came a man who ate his fill of fruit, broke down a branch, and went his way. Thought the spirit dwelling in that tree, "How amazing, how astonishing it is, that a man should be so evil as to break off a branch of the tree, after eating his fill. Suppose the tree were to bear no more fruit." And the tree bore no more fruit.

(Anguttara Nikaya iii.368).

Confucianism also stresses care for the environment, encouraging its followers to pursue a better way of living, not just for the earth but for the rest of their community:

If you do not allow nets with too fine a mesh to be used in large ponds, then there will be more fish and turtles than they can eat; if hatchets and axes are permitted in the forests on the hills only in the proper seasons, then there will be more timber than they can use … This is the first step along the kingly way.

(Mencius I.A.3)

As might be expected, the bulk of this book is focused on:

1. the basic science and math principles required to describe and analyze the environment, and
2. the design and application of traditional unit operations and processes that are commonly used by environmental engineers to protect human health and the environment.

Before we learn to design the future, however, let us recall and learn from our past. We must recognize that modern civilizations were not the first to encounter and search for solutions to environmental problems or to embrace environmental activism. We start this discussion by providing a brief overview of environmental history in an effort to add perspective to our current state, in the hope that one day the relationship between humans and the environment will no longer prove to be one of continued turmoil, but one of unity and wholeness.

The backbone of this historical discussion has been built from the work of Mark Neuzil and William Kovarik and their book entitled *Mass Media and Environmental Conflict*. If this brief snapshot of environmental history peaks your interest, you are encouraged to begin further exploration through this excellent resource. An overview of the environmental history timeline from the book can be accessed online at http://www.runet.edu/~wkovarik/envhist/.

From the beginning of human history, humans have aimed to rise above and separate themselves from their animal counterparts. No longer content living at the mercy of nature, we sought to harness the ground in order to provide dependable nourishment for ourselves and our family. This new-found agricultural consistency soon blossomed into communities and cities, each with their own language, culture and religion. However, as these groups grew, it quickly became obvious that humankind had a responsibility to reconcile our lifestyle within a healthy, thriving earth; otherwise, we could face a lack of clean air, water, and other natural resources necessary for life. We needed to find ways to engineer the environment so the earth could continue to support our need to create, control and expand.

The following sections of this chapter outline humankind's pursuit of a better earth throughout written history, up to our present day regulations and standards.

1.1.1 Early civilization (the rise of humankind to ancient Rome)

Early civilization experienced many scientific and social developments that continue to fascinate modern-day engineers and experts – creations like Stonehenge and the Great Pyramid, the development of agriculture, written language, and mathematics. These advancements marked the rise of culture and structured society. Humans were no longer simply coexisting with the earth – rather, we were reaching out to conquer and control our environment.

1.1.1.1 Solid Waste Management

One of the earliest issues surrounding mankind and the environment is garbage and its disposal. When humans lived as nomadic hunter-gatherers, they could leave their solid waste wherever was most convenient for them, often buried. Since the hunter-gatherer lifestyle prompted continual movement, rodents, insects, and natural processes had time and opportunity to degrade the waste and return it to the soil. As we abandoned the nomadic lifestyle in favor of permanent settlement, however, the disposal practices followed for generations before were no longer appropriate. Leaving waste from food and fuel outside the home would invite vectors to thrive and breed among the urban developments, encouraging disease and destruction of food stored by the community.

1.1.1.2 Sustainability and Public Health

As civilization developed, resource conservation also became a growing need, with a focus on encouraging sustainable lifestyles for the people inhabiting certain areas. If they were careless, whole communities could lose access to resources staple to their development, health, and economy. As early as 6000 BCE, deforestation was blamed for the rise and fall of communities in southern Israel and, in 2700 BCE, it factored into the demise of Sumeria (now southern Iraq). Large-scale commercial timbering continued with the Phoenicians (2600 BCE), the Minoans (1450 BCE) and within the ancient city-state of Troy (1200 BCE).

1.1.1.3 Water Management

Clean, fresh water for drinking, bathing, and agriculture is vital for the support of a healthy, growing community. While most areas depended on surface water for their needs (a great example would be those who settled between the Tigris and Euphrates Rivers in the area known as the Fertile Crescent), the Chinese were using wells as deep as 1,500 ft to obtain drinking water for centuries before the modern era, and possibly used alum to clarify their water (Symons, 2001).

There is evidence that the Romans built dams, sometimes as high as 15 m, to create drinking water reservoirs. Ancient Rome is well known for its elaborate network of sewers and aqueducts, which, although built c. 500 BCE, provided a new standard of public health that was unmatched until the mid-18th century. Roman ruins show the use of open channels to carry human excreta from public baths and palaces. Disinfection of surface water was also exhibited in ancient times by the Egyptians, as they were using some form of chlorine for disinfection as early as 3000 BCE.

1.1.1.4 Air Quality

Air pollution from natural sources, such as volcanic eruption and forest fires caused by lightning, occurred long before communal living. However, it is important to note that when humans harnessed fire, anthropogenic activity became a major contributor to indoor and outdoor air pollution. Air pollution was complicated further as humans began to pursue metalworking, smelting lead, silver and copper to make coins, jewelry and tools.

Mineral deposits are typically harvested as sulfides (Cu_2S, PbS, ZnS). The smelting process produces primary ore, sulfur dioxide and other pollutants. For example, the smelting process for lead begins by pulverizing and heating such that:

$$2PbS + 3O_2 \rightarrow 2PbO + 2SO_2$$

The ore is further reduced by heating with carbon:

$$PbO + C \rightarrow Pb + CO$$

The end products, metallic lead and carbon monoxide, are toxic. Additionally, air pollution resulted from burning wood, tanning, and from decaying trash.

Rome's poor air quality led Emperor Nero's tutor and self-proclaimed Socratic philosopher, Seneca, to state in 61 CE:

> "*As soon as I escaped from the oppressive atmosphere of the city, and from that awful odor of reeking kitchens which, when in use, pour forth a ruinous mess of steam and soot, I perceived at once that my health was mending.*"

1.1.2 The Middle Ages (500–1500)

The Middle Ages gave rise to such great things as algebra, the printing press, the clock, and the Magna Carta (an article that heavily influenced the United States Constitution and the Bill of Rights). Despite these contributions, this time period is one of the more somber for western culture. The Middle Ages were marked by a dramatic increase in urban population, due to feudalism and, thus, an influx of poor people who owned no land. Subsequently, any problems with waste, water, and air pollution rose exponentially and, coupled with several famines and a widespread series of pestilences, it became obvious that drastic change was required in order to provide for the health and welfare of these communities.

1.1.2.1 Solid Waste Management

The heavy influx of people into cities posed a tremendous solid waste problem. There was little room to dispose of garbage, which was either burned, buried, or left in the streets – practices that encouraged poor air quality and served as a breeding ground for pests and vermin, bringing with them filth and disease. In light of the Black Death – a pandemic that destroyed 30–60% of the European population during that time – it was time to start rethinking what practices should be permitted for the sake of public and occupational health. By 1366, the city of Paris required butchers to dispose of animal carcasses outside the city instead of in the streets.

1.1.2.2 Water Management

Along with the fall of Rome came the fall of support for its extensive system that provided water to the public. Communities had to revert to wells and surface water, which were often contaminated due to overuse and overpopulation. Much of this contamination resulted from human excreta, which were not disposed of in a sanitary fashion. In fact, a common practice of the 13th and 14th centuries was to empty chamber pots from upstairs windows into the street gutters below.

Sewage covered the streets of Europe during the Middle Ages, often contaminating water supplies. Improvements began in 1589, when Sir John Harrington invented the water closet in England and published a book entitled *The Metamorphosis of Ajax*, in which he provided a complete description. While Parliament had passed an act in 1388 forbidding the throwing of filth and garbage into ditches, rivers, and waterways, there was still a lack of proper sewerage, and his invention was largely ignored. It was not until the 1690s that Paris became the first European city to build an extensive sewer system and such tools as the water closet became more practical in everyday life.

1.1.2.3 Air Quality

Burning wood, coal and garbage was common practice on the streets and in homes during this time, which exacerbated the poor air quality. From 1560 to 1600, England was rapidly becoming industrialized, and wood shortages led to an increased burning of sea-coal. Sea-coal has a high sulfur content and, when burned, produces air pollutants such as sulfur dioxide, carbon monoxide, carbon dioxide, nitrogen oxides, soot, and particulate matter. In 1661, John Evelyn proposed a solution to London's air pollution through his pamphlet *Fumifugium, or the Inconvenience of the Aer and Smoake of London Dissipated*. Evelyn wrote several notable passages, including:

> *The immoderate use of, and indulgence to, sea-coale in the city of London exposes it to one of the fowlest inconveniences and reproaches that can possibly befall so noble and otherwise incomparable City … Whilst they are belching it forth their sooty jaws, the City of London resembles the face rather of Mount Aetna, the Court of Vulcan … or the suburbs of Hell [rather] than an assembly of rational creatures.*

Later, in 1684, he wrote that the smoke was so severe that "*hardly could one see across the street, and this filling lungs with its gross particles exceedingly obstructed the breast, so as one would scarce breathe*."

The situation was more hopeful when James I succeeded Queen Elizabeth and demanded that harder, cleaner-burning coal from Scotland be used within his household, but it would be decades before air pollution was addressed as a public health issue.

1.1.2.4 Public Health

While modern solid waste management practices were unavailable, legislation like the aforementioned restrictions on dumping waste marked a greater government involvement in the health of its citizens. Also, during this time period, the growing development of industry began to muster some concerns about the health impacts of common occupational practices. In 1473, Ulrich Ellenbog wrote the first pamphlet on occupational disease and injuries among goldsmiths. Ellenbog's pamphlet was followed by a similar treatise in 1556 by Agricola (Georgius Bauer), which further outlined the techniques and occupational hazards of assaying, mining, and smelting a variety of metals.

1.1.3 The Age of Enlightenment (1650–1800)

The Age of Enlightenment gave rise to a new era of scientific, philosophical, and humanitarian study. During this time, the United States achieved independence from Britain, Leibniz and Newton invented calculus, we lent our ear to the musical stylings of Beethoven, Mozart, and Bach and investigated the writings of John Locke, Immanuel Kant, and Voltaire. The newfound pursuit of reason yielded many familiar names into the world of science, like Fahrenheit, Celsius, Bernoulli, Kepler, and Venturi, to name a few. This quest for knowledge also marked the beginning of better public health, as humanitarians felt it was necessary to spread the recent discoveries in science and medicine to provide good health and hygiene to everyone.

1.1.3.1 Solid Waste Management

During this time period, populations within urban environments continued to blossom, further encouraging illness and disease despite past regulations and development. Public health laws were inconsistent from state to state and city to city, so people continued to live in the manner that they felt best. These practices varied immensely, depending on the values and lifestyles of the citizens in the region. For example, while Benjamin Franklin led a group in Philadelphia in an attempt to regulate waste disposal and water pollution, Jonathan Swift noted the despicable contents within London's gutters, "sweeping from butchers' stalls, dung, guts, and blood … "

1.1.3.2 Sustainability

As the world was developing new scientific and technological discoveries, many people were beginning to use this knowledge to enhance the health and sustainability of our environment. By 1762, Jared Eliot was promoting soil conservation in his *Essays on Field Husbandry in New England*. History even recalls men and women of the Bishnoi faith protesting the demolition of a grove of khejri trees at the hands of an Indian maharaja, even forfeiting their lives to stop the destruction. The villagers who died that day in 1730 knew of the immense value of the khejri tree, which they used for medicine, firewood, and food, among many other beneficial uses. The maharaja halted the demolition, but not before 363 people lost their lives. Conservation was also alive and well in the Western world, evidenced by Benjamin Franklin's plea to France and Germany in 1784, urging them to switch from wood to coal in an attempt to save their forests.

1.1.3.3 Water Management

The Age of Enlightenment provided a few great advances in the realm of water quality. Filtration became a more viable treatment technique, with Frenchman Joseph Army creating a filter out of a perforated box filled with sponges in 1746 (*The Quest for Pure Water*, 1981). In 1791, an upflow sand filter with a downflow washing system was invented by James Peacock. In 1744, a limited distribution public water supply was started in New York City. In 1772, Providence, RI also began distributing a public water supply within the city. Public water became even more readily available as London installed the first modern municipal sewers in 1800.

1.1.3.4 Air Quality

By the 1700s, sea coal importation to London had grown dramatically, and similar developments occurred in cities worldwide as business prepared for the Industrial Revolution. In 1804, Presley Neville wrote regarding Pittsburgh: "the general dissatisfaction which prevails and the frequent complaints which are exhibited, in consequence of the Coal Smoke from many buildings in the Borough, particularly from smithies and blacksmith shops … " The smoke affected the "comfort, health and … peace and harmony" of the new city. At this time, the best remedy was to build higher chimneys.

1.1.3.5 Public Health

The push for intellectual advancement in the 18th century helped to provide insight into the causes and effects of illness in humans. In 1723, the lead in alcohol stills was shown to cause serious abdominal pains. In 1775, English scientist Percival Potts noted that chimney sweeps had an unusually high incidence of cancer. Further attempts at monitoring occupational health were reflected as Sir Thomas Percival formed the Manchester Board of Health to supervise textile mills and recommended hours and working conditions.