ENVIRONMENTAL ENGINEERING

Fundamentals, Sustainability, Design

SECOND EDITION

James R. Mihelcic • Julie Beth Zimmerman

WILEY

Environmental Engineering: Fundamentals, Sustainability, Design

Second Edition

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About the Cover

Richard Buckminster Fuller (1895-1983) was an engineer, architect, poet, and designer. During his life, he pondered the question, "Does humanity have a chance to survive lastingly and successfully on planet Earth, and if so, how?" To begin to answer this question, Fuller ascribed to the "Spaceship Earth" worldview that expresses concern over the use of limited global resources and the behavior of everyone on it to act as a harmonious crew working toward the greater good.

In 1969 Fuller wrote and published a book entitled "Operating Manual for Spaceship Earth." The following quotation from this book reflects his worldview: "Fossil fuels can make all of humanity successful through science's world-engulfing industrial evolution provided that we are not so foolish as to continue to exhaust in a split second of astronomical history the orderly energy savings of billions of years' energy conservation aboard our Spaceship Earth. These energy savings have been put into our Spaceship's life-regeneration-guaranteeing bank account for use only in self-starter functions." To further communicate his ideas, Fuller developed the Dymaxion Map, shown on the cover. This map is a projection of a World map onto the surface of a polyhedron. The projection can be unfolded in many different ways and flattened out to form a two-dimensional map that retains the look and integrity of a globe map. Importantly, the Dymaxion map has no "right way up." Fuller believed that in the universe there was no "up" and "down" or "north" and "south": only "in" and "out." He linked the north-upsuperior/south-down-inferior presentation of most other world maps to cultural bias.

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Preface

Now more than ever, there has been an increasing awareness of the unsustainability trajectory our society is currently following. Occurring simultaneously, there have been numerous proclamations, international meetings, and efforts to assess the current state of affairs and begin to design new technologies, policies, and business models aimed at advancing the goal of a sustainable future. With this in mind, there is an obvious need to continue to manage and remediate legacy environmental challenges from nutrient enrichment of surface waters to groundwater contamination. At the heart of meeting these objectives is training the next generation of engineers, and environmental engineers in particular, to have a deep understanding of the fundamentals of the discipline while also possessing a keen awareness of sustainability. Reorienting the focus environmental engineering is the very motivation for this book – providing both the fundamental training to solve environmental problems as well as the broad understanding of sustainability.

As we move from the stark and egregious environmental problems that gave rise to the field of environmental engineering more than five decades ago to the more complex and global challenges of today, the field of environmental engineering must evolve as well. Looking to the future, there is a clear need for environmental engineers who are able to collaborate across disciplines and communicate broadly to the scientific community, policymakers, and the public. Sustainability presents many opportunities for environmental engineers to evolve from those who characterize, manage, and remediate existing environmental problems to those who are designing and developing new technologies that address sustainability challenges while avoiding unintended consequences. On this journey, it is imperative to honor the great legacy of this discipline – the creativity, passion, and dedication for public good – and continue to serve in the unique role of benefitting people and the planet as we move to face emerging challenges and design a more sustainable future.

This book is motivated by the discussion that is evolving from one centered on describing, characterizing, quantifying, and monitoring current environmental problems to one that is focused on the design and development of innovative new solutions. Innovation requires enhanced skills and tools beyond the fundamental and important environmental engineering curriculum including the ability to think creatively and critically, to work in interdisciplinary teams, and to consider the entire system. As shown in the table below, the very nature of the challenges faced by environmental engineers is changing.

20th Century Environmental Issues	21st Century Environmental Issues
Local	Global
Acute	Chronic
Obvious	Subtle
Immediate	Multigenerational
Discrete	Complex

This shift in focus provides students an opportunity to succeed in engineering practice and actively engage in contributing to a more sustainable future using the knowledge and foundational skills of the environmental engineering discipline. After all, the only reason to study a problem in great detail is to inform its solution and the environmental engineering profession is in a unique and prime position to advance those solutions – and ensure that they are themselves sustainable. That is, having the awareness to ensure that the solutions to sustainability challenges are carefully considered to avoid or minimize the likelihood of legacy problems and unintended consequences. In this way, it is imperative that the idea of sustainability is fully integrated into the fundamental training of environmental engineers, not an afterthought or separate from the very nature of what we do as a profession.

The evolution of the problems themselves and the level of understanding we have about these problems will require engineers to take on new skills, capabilities, and perspective about how we approach our work. It is not that the skills previously learned are antiquated and need to be replaced. Rather, it is that the traditional skills need to be augmented, complemented, and enhanced with new knowledge, new perspectives, and new awareness. The melding of the old and new fundamentals and design skills is the purpose of this text. It is our hope that this text provides engineers with the knowledge and confidence to address 21st century challenges as well as they dealt with the daunting challenges of the 20th century.

Hallmark Features

CHANGES TO THIS SECOND EDITION

In the 2nd edition several key updates were made to the structure and content of this textbook.

- The book is still based on applying foundational principles related to physics, chemistry, biology, risk, mass balances, and sustainability which are applied to the design and operation of technology and strategies used to manage and mitigate environmental problems found in land, water, and air.
- There is continued emphasis on problems important to the United States and the world, with a focus on pollution prevention and resource recovery while still providing information to design treatment processes.
- Chapter 1 was rewritten and is now titled "Sustainable Design, Engineering, and Innovation." It de-emphasizes problems that are driving engineering practice, and instead focuses on the paradigm shift from managing environmental problems with regulations to a framework of sustainability using EPA's Green Book and Path Forward. The Chapter on Air Resources Engineering (Chapter 11) was totally rewritten and now includes discussion and application of Gaussian Plume Models and emphasis of demand management strategies along with traditional air pollution control technologies.
- The text has been reduced from 14 to 11 total chapters which we believe will assist instructors that use the book in a semester course and the text has been aligned with the National Academy of Engineering's focus on Grand Challenges related to managing carbon and nitrogen. With the more

pronounced emphasis on innovation and sustainability in the 2nd edition, there are enhancements towards a deeper integration of systems thinking throughout the text and problems. One notable example of this is the recrafting the chapters related to water which now appear as one chapter focused "Water: Quantity and Quality" (Chapter 7) and a second focused on "Wastewater and Stormwater: Collection, Treatment, Resource Recovery" (Chapter 9). In this way, water is considered holistically as a resource including a discussion of water reuse.

- We added several topics brought to the authors' attention by users of the text, e.g., a section on calculating a carbon footprint in Chapter 2 (Environmental Measurements), enhanced section on energy balances in Chapter 4 (Physical Processes), better definition of a watershed and the addition of the Rational Method that is integrated with examples of how land use impacts water quality in Chapter 7 (Water: Quantity and Quality), integration of methods that emphasize resource recovery associated with management of wastewater (Chapter 9), and a section in Chapter 11 (Air Quality Engineering) that emphasizes the use of demand management as solution to air pollution problems. Given the critical need to ensure that sustainability and interdisciplinarity are integral to the training of environmental engineers, the stand-alone chapters "Green Engineering" and "The Built Environment" from the first edition were eliminated, and instead, the relevant content was integrated into other chapters.
- Several educational modules (in powerpoint and video format) to assist an instructor in integration of sustainability and other important environmental engineering topics have been developed and are available as instructor support materials (see below). There is also an increased emphasis on practical field orientated applications of engineering practice and a fifty percent increase in end of chapter problems, for a total of 445. In addition, the solutions manual has been carefully reviewed and updated.

A FOCUS ON SUSTAINABLE DESIGN

Perhaps one of the most important aspects of the textbook is that it will focus the student on the elements of *design*. Design of products, processes, and systems will be essential not only in responding to the environmental issues in ways that our profession has done historically but also in informing the design of new products, processes, and systems to reduce or eliminate problems from occurring in the first place.

To use the tools of green engineering design truly to design for sustainability, students need a command of the framework for this design. The framework perhaps can be summarized in the *four I's*: (1) Inherency, (2) Integration, (3) Interdisciplinary, and (4) International.

Inherency As a reader proceeds through the text; it will become obvious that we are not merely looking at how to change the conditions or circumstances that make a product, process, or system a problem. Readers will understand the *inherent* nature of the material and energy inputs and outputs so that they are able to understand the fundamental basis of the hazard and the root causes of the adverse consequence they seek to address. Only through this inherency approach can we begin to design for sustainability rather than generating elegant technological bandages for flawed conceptions.

Integration Our historical approaches toward many environmental issues have been fragmented—often by media, life cycle, culture, or geographic region. Understanding that energy is inextricably linked to water, water to climate change, climate change to food production, food production to health care, health care to societal development, and so on will be essential in the new paradigm of sustainable design. It is equally necessary to understand that we cannot think about approaching any environmental problem without looking at the problem across all elements of its life cycle. There have been countless attempts to improve environmental circumstances that have resulted in unintended problems that have often been worse than the problem they intended to fix. Attempts to increase drinking water supply in Bangladesh resulted in widespread arsenic poisoning. Attempts to increase crop yields through the production of pesticides in Bhopal, India, resulted in one of the greatest chemical tragedies of our time. Understanding the complex interconnections and ensuring the *integration* of multiple factors in the development of solutions is something that 21st century environmental engineering requires.

Interdisciplinary To achieve the goals of sustainable design, environmental engineers will be working increasingly with a wide array of other disciplines. Technical disciplines of chemistry and biology and other engineering disciplines will be essential but so will the disciplines of economics, systems analysis, health, sociology, and anthropology. This text seeks to introduce the *interdisciplinary* dimensions that will be important to the successful environmental engineer in this century.

International Many well-intentioned engineering solutions fail by not considering the very different context found in the diversity of nations around the world. Although water purification or municipal waste may seem like they can be dealt with through identical processes anywhere in the world, it has been shown repeatedly that the local factors—geographic, climatic, cultural, socioeconomic, political, ethnic, and historical—can all play a role in the success or failure of an environmental engineering solution. The *international* perspective is an important one this textbook emphasizes and incorporates into the fundamentals of the training of environmental engineers.

MATERIAL AND ENERGY BALANCES AND LIFE CYCLE THINKING

The book provides a rigorous development of energy and mass balance concepts with numerous easy-to-follow example problems. It then applies mass and energy balance concepts to a wide range of natural and engineered systems and different environmental media. The book has appropriate coverage of life cycle assessment and provides a life cycle–thinking approach in discussion throughout other chapters.

PEDAGOGY AND ASSESSMENT

Beyond including the elements mentioned previously to prepare engineers for the 21st century, this book also incorporates changes in pedagogy and assessment that provide structure for delivering this new information in a meaningful education experience.

Fink's Taxonomy of Significant Learning One such element is the use of Fink's taxonomy of significant learning in guiding the development of learning objectives for each chapter as well as in example and homework problems. Fink's taxonomy recognizes six domains beyond traditional foundational knowledge, including: foundational knowledge; application of knowledge; integration of knowledge; human dimensions of learning and caring; and learning how to learn. Without much background on the taxonomy, it is clear from these knowledge domain headings alone that these areas recognized by Fink are critical to an engineer tasked with designing solutions to many of today's sustainability challenges.

Important Equations Boxes around important equations indicate for students which are most critical.

Learning Exercises Learning exercises at the end of each chapter include 445 problems that not only ask students to solve traditional numerical problems of assessment and design but also challenge students to research problems and innovate solutions at different levels: campus, apartment, home, city, region, state, or world.

Discussion Topics To further emphasize the importance of the domains of knowledge discussed in the previous paragraph, the book encourages classroom discussions and interaction between students as well as between the students and the instructor. These discussion topics are noted by a symbol in the margin.

Online Resources for Further Learning Online resources for further learning and exploration are listed in margins where appropriate. These resources provide students the opportunity to explore topics in much greater detail and learn of geographical commonalities and uniqueness to specific environmental engineering issues. More important, use of these online resources prepares students better for professional practice by expanding their knowledge of information available at government and nongovernment Web sites.

BOOK WEB SITE

Additional resources for students and instructors are available on the book Web site, located at www.wiley.com/college/mihelcic.

Classroom Materials for Instructors Through an NSF Course, Curriculum, and Laboratory Improvement grant awarded to three of this book's authors (Qiong Zhang, Julie Beth Zimmerman, and James Mihelcic) and to Linda Vanasupa (California Polytechnic State University), we have developed in-depth educational materials (learning objectives, editable slide presentations, assessments, activities) on the following six topics:

1. Systems Thinking
2. (Introduction to) Sustainability
3. Systems Thinking: Population
4. Systems Thinking: Energy
5. Systems Thinking: Material
6. Systems Thinking: Water

All materials are available at the following stable link for download: http://works.bepress.com/lvanasup/

Each set provides an array of classroom materials whose design aligns with educational research on how to foster more significant learning and includes:

- Learning objectives within several critical areas of learning (foundational knowledge, application of knowledge, integration of knowledge, human dimensions of learning and caring, and learning how to learn)
- A set of editable and notated slides for faculty to present lecture material
- Active learning exercises that range from two-minute to three-hour investments; notated guides for faculty using the exercises
- A set of assessment activities that includes learning objectives, criteria for assessment, and standards for judging the criteria

In addition, Linda Vanasupa and Qiong Zhang developed 24 video tutorials related to this material that are published at Open Education Resource (OER) Commons under "The Sustainability Learning Suites." These 24 videos are organized around the themes: systems thinking; sustainable development; energy; water; population; and materials.

http://www.oercommons.org/authoring/1660-the-sustainability-learning-suites/view

These materials have also been submitted for publication at: National Science Digital Library (Nsdl.org).

ADDITIONAL RESOURCES FOR INSTRUCTORS

Additional resources for instructors to support this text include:

- Updated Solutions Manual containing solutions for all 445 end-of-chapter problems in the text.
- Image Gallery with illustrations from the text appropriate for use in lecture slides.

These resources are available only to instructors who adopt the text. Please visit the instructor section of the Web site at www.wiley.com/college/mihelcic to register for a password.

Genesis of the Book

In 1999, we published a book titled *Fundamentals of Environmental Engineering* (John Wiley & Sons). One strength of *Fundamentals of Environmental Engineering* is that it provides in-depth coverage of the basic environmental engineering fundamentals required for design, operation, analysis, and modeling of both natural and engineered systems. The book you are reading now, *Environmental Engineering: Fundamentals, Sustainability, Design*, not only includes updated chapters on those same fundamentals with continued strong emphasis on material and energy balances and inclusion of issues of energy, nutrient management, and carbon, but also includes

application of those fundamental skills to design and operate strategies to implement source reduction, resource recovery, and treatment.

Acknowledgements

As we marvel and appreciate all those who have dedicated themselves to leaving the world a better place than they found it—environmental engineers and others—we are grateful for all the talented people who have helped make this book possible and are poised to change the very nature of the field of environmental engineering.

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Finally, thanks to Karen, Paul, Kennedy, Aquinnah, and Mac for embracing the vision of this project over the past several years.

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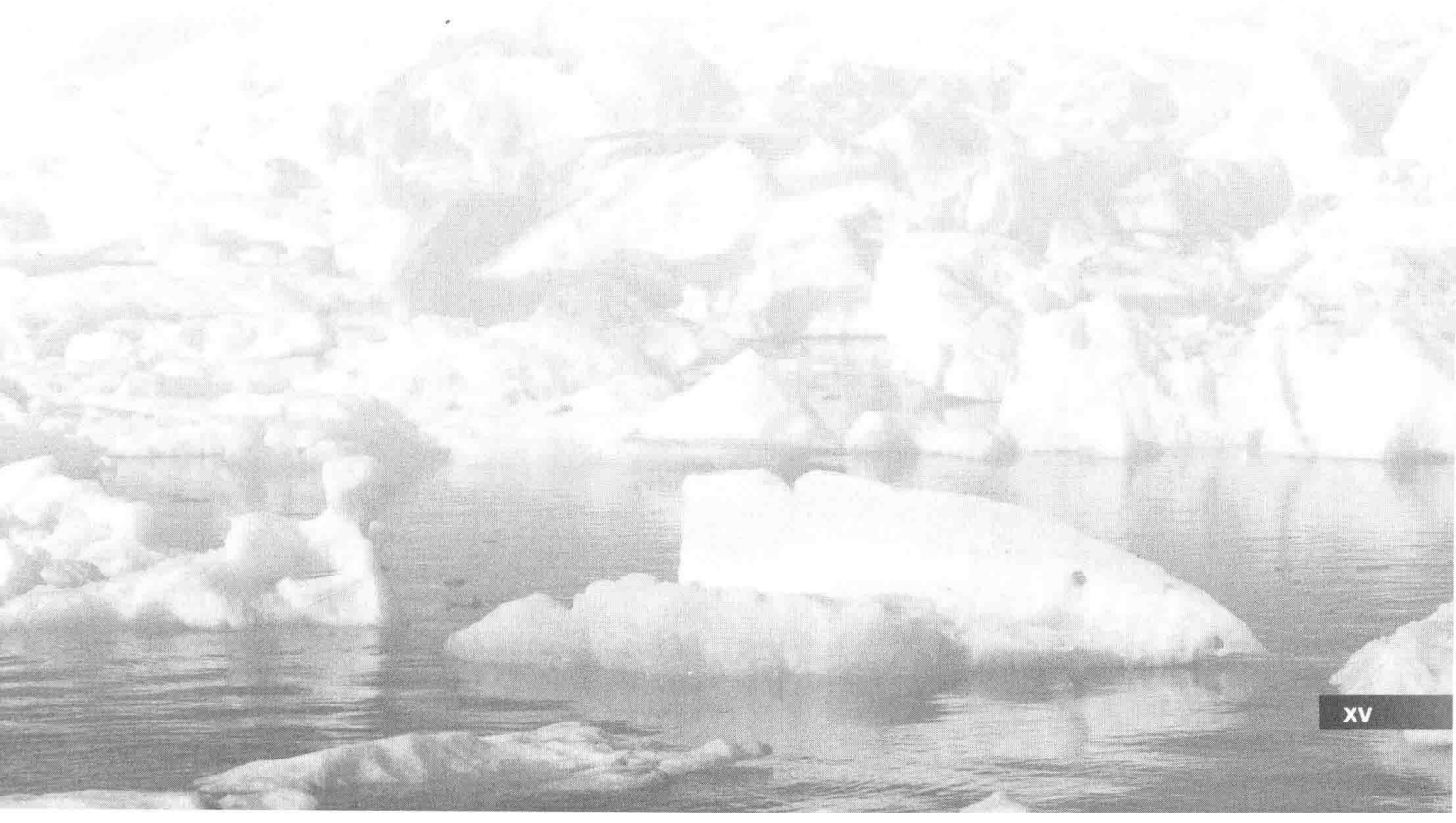

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