Understanding Environmental Pollution

Fourth Edition

Understanding Environmental Pollution examines pollution problems that range from the global to the personal for undergraduate students. This text has been updated from the third edition and contains well over 50 percent new material. Non-technical language is used whenever possible to assist in understanding the subject matter. Students will see that the responsibility for pollution is widely spread among individuals, themselves included, corporations, and governments at all levels.

To provide a background to better understand pollution, early chapters look at nature's services, toxicology, and risk assessment. Sources and impacts of pollution are addressed, along with means to reduce it. The text introduces the sometimes daunting pollution problems that confront us, including air and water pollution, global warming, energy, solid and hazardous waste, persistent chemicals, pesticides, and pollution at home. International issues are often introduced and the interrelationships between the local and international are explored. Although pollution prevention is emphasized in solving problems, students begin to see that more is needed. By the end of the book readers will have examined a circular economy with its closed-loop systems, where wastes and by-products become raw materials, where water is recycled, and where energy is used with increasing efficiency. We examine the tools available to work toward a circular economy, and to become aware of whole nations that, after strategizing, begin to take steps toward such an economy.

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"The new edition of this popular textbook is wide-ranging, engaging, and easily accessible. It is a superb resource for students studying the causes, consequences, and management of environmental pollution."

James Rothwell, University of Manchester

"Marquita Hill's *Understanding Environmental Pollution* has been an indispensable text for my environmental science course over the past ten years. She presents a wealth of information on the significant environmental issues facing our society in a well-organized, straightforward, clearly written text. I particularly applaud her section on risk management, which is applicable to the many issues she presents, and the many text-boxes among the chapters that bring to life issues, associated science, and solutions to the problems we face."

John Dorsey, Loyola Marymount University

"The Fourth Edition of *Understanding Environmental Pollution* provides a comprehensive and straightforward introduction to a wide range of environmental topics, including toxicity and risk assessment; a survey of air, water, and land pollution; energy use; and global change. A unique and intriguing focus of this book is the emphasis not merely on pollution reduction but on switching to a circular economy that features closed-loop, zero-waste, zero-emission systems and processes."

Usha Rao, St. Joseph's University

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FOURTH EDITION

Marquita K. Hill

FORMERLY OF THE UNIVERSITY OF MAINE, DEPARTMENT OF CHEMICAL ENGINEERING,
AND OF VIRGINIA POLYTECHNIC INSTITUTE'S DEPARTMENT OF BIOCHEMISTRY

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This book is dedicated with gratitude to the scientists, journalists, photographers, and citizens who were the sources of the information, analyses, and often-deep thought, as well as of the excellent photographic images found within this work. These many individuals were ever-present consultants for me as I studied, thought about, and sometimes struggled through the great quantities of materials that their work made available to me. I worked to be true to them, but am aware of the imperfections. Putting their names in footnotes was too small an acknowledgment. So, it is to them that I dedicate this book.

Brief Contents

Contents

Preface

Understanding Environmental Pollution

A quarter-century ago I found no textbook from which to teach an Issues in Environmental Pollution course. So began the development of class notes, added to by student concerns, misunderstandings, and questions, and by an ever-increasing volume of information. The result was the first edition of *Understanding Environmental Pollution*. My initial intent was to summarize the basics of many pollution issues, using language understandable to those with limited science background, yet remaining useful to those with more. Follow-up editions, because of requests to do so, have given more detail on issues, but still strive to maintain straightforward language. Likewise, again on the basis of request, an appendix on the basics of chemistry was added to the third edition.

Approach and Organization

The book's first edition was intended for first-year college students, but it became obvious that older, as well as some younger, classes were also using it. Meeting the needs of students early in their studies is still an intention. However, the book's broader scope now makes it more useful to older students as well. For example, an instructor may choose to omit Chapter 14 on "persistent, bioaccumulative, and toxic" pollutants for beginning students.

Several other texts on the market address environmental pollution. However, as one reviewer put it, "This book addresses both environmental pollution issues *and* their management. Many introductory environmental science texts focus too much on basic science for my students' needs, and do not address regulatory, social, and business approaches to controlling and reducing pollution."

Students reading this text do need a basic understanding of science, but this author works to make the text accessible to non-scientists. Similarly, laws and regulations are described in general terms, not detail. The book addresses the social environment that allowed society to produce such mammoth amounts of pollutants and wastes.

Starting with the first edition, *Understanding Environmental Pollution* has discussed pollution prevention for each issue, along with who bears the responsibility for prevention: governments, businesses, and individuals. The importance of recycling, treatment, and disposal is also presented. Students are also invited to consider that wastes need not always be wastes; for example, we look at industrial ecology in which pollutants and wastes become integrated into other products or uses. The book also highlights the importance of individual actions in reducing pollution. Citizens and businesses are urged to consider that, although we cannot yet eliminate pollutants and wastes, we can greatly minimize them. Moreover, students are encouraged to envision the theme of this book's last chapter: "zero waste, zero pollution."

Changes in This Edition

Greater effort is taken in this fourth edition to treat pollution issues holistically. One example is found in two tables in Chapter 1. The purpose of the tables is to prepare students to put many of the pollution issues they will encounter into a framework that will be useful throughout the text.

The first of these tables, Table 1.3, is "Earth's nine life-support systems and the risks they face." This table, along with Chapter 1 more broadly, introduces *planetary boundaries* along with the warning that humans must take action to reverse course when a planetary boundary is crossed.[1] When this textbook comes to an issue relevant to a planetary boundary, readers are often referred back to this table. Although the numerical boundary noted for each issue has uncertainties, it signals to students the seriousness of a particular problem, a seriousness then supported by information given in this textbook.

The second table, Table 1.4, also relevant to later chapters, is "Pollutants from burning fossil fuels." This table identifies these pollutants and the specific problems with which they are associated. Again, when pertinent topics are reached in later chapters, readers are referred back to this table.

In addition to the considerable updating of the main text, the book's references have also been updated; many are easily accessed government sites. One example of where the book has been updated is a greater emphasis on *fine particulates* ($PM_{2.5}$); their seriousness has become increasingly recognized. Another pollutant, *bioavailable nitrogen*, was already seen as serious in the 2010 edition, but has now crossed a planetary boundary.

Although pollution in the USA is emphasized here, readers will see that most pollution issues are international

in scope. Global warming and stratospheric ozone depletion are obvious examples, but there are many others. The increasing pollution of the oceans is a shared global problem, as are air pollutants. There is an increasing awareness of *transboundary pollutants*, sometimes to the extent that living in a country with good pollutant regulations may not adequately protect the citizens of that country. Ozone produced in China is carried via wind currents to the west coast of the USA – enough to make it difficult for California to meet its ozone standards. Fine particulates can be traced over many thousands of miles, and mercury can be carried worldwide. However, the seriousness of a particular pollution problem and a government's ability to deal with it varies greatly. For instance, Western countries usually manage their municipal solid waste relatively well, but mega-cities in poor countries may be unable to even adequately collect it. And particular problems, such as contaminated drinking water or poor control of emissions from industrial facilities, *are* much more prevalent in less-developed countries than in Western ones. China is often used to illustrate the environmental downsides of rapid industrialization occurring alongside poor emission controls. At the same time, we see blatant examples of pollution and careless management in Western countries, including the USA. Interactions between pollution, poverty, and population are seen as important and are often pointed out.

Coverage

Background: The first four chapters provide information to allow readers more knowledgeable thinking about pollution, even before looking at specific issues. Nature's vital services to all living creatures are examined along with the danger that humans pose to those services. Chemical risk and how to evaluate it is examined. Chapter 3 delves into toxicity, a risk of pollution that greatly concerns us. Chapter 4 examines how we assess the risks of chemical exposure.

Although the USA is used as the example in discussing pollution issues, readers will recognize that most pollution issues are internationally important. When a chapter raises an issue that is serious enough that it may cross, or has already crossed, a planetary boundary for one or more of Earth's life-support systems, that is noted, and the chapter provides the information to support that belief.

Questions: Starting in Chapter 5, four basic questions are asked for the pollutants studied in that chapter. What are the pollutants of concern? Why are they of concern? What are their sources? And how can their emissions be reduced?

Air: Chapter 5 illustrates the striking ways that *ambient air pollution* adversely influences life and the environment. *Atmospheric aerosol loading* is particularly concerning, but it has not been possible to set a planetary boundary for it. *Global warming* is believed to have already crossed its planetary boundary, but *ocean acidification*, although increasingly serious, has not (Chapter 7). These air pollution problems, as well as *acid rain* (Chapter 6) largely result from burning fossil fuels. *Energy production and use* (Chapter 8) emphasizes alternative low-polluting and *renewable fuels*.

Stratospheric ozone depletion is caused by specific synthetic organic chemicals (Chapter 9). Loss of stratospheric ozone had threatened to cross its planetary boundary, but the Montreal Protocol banned the most dangerous pollutants.

Water pollution (Chapter 10) is also a worldwide problem; one extremely serious pollutant, *bioavailable nitrogen*, largely results from runoff of overused fertilizer and from animal waste. This form of nitrogen has led to large *dead zones* in the oceans, areas void of life, and has already crossed its planetary boundary.

Fresh water overuse is trending toward a planetary boundary.[2] Its overuse results in water scarcity, which enhances *drinking water pollution* (Chapter 11). Two major pollutants are *microbes* and *nitrates*, the former most common in poorer countries and the latter in developed countries. Another pollutant having tragic effects is *arsenic*, often found at poisonous levels in the tube wells of poor countries.

Waste: The best-known solid waste is *municipal solid waste* (MSW) (Chapter 12), which is best managed when pollution prevention is an option. MSW becomes a danger when great amounts are generated without the means to handle it, as happens in large cities in poor countries. Increasing amounts of waste plastics are entering our seas, and these endanger the life forms that live there. These plastics do not biodegrade, but do break down into microplastics, which can enter the food chain; they have become environmentally ubiquitous. Microplastics fit into the chemical pollution or novel entities category and pose increasing problems, even dangers.

Hazardous waste (HW) (Chapter 13) is generated by many industries. In earlier years HW was often left unprotected and later often became *Superfund* sites requiring clean-up. Hazardous waste sites contain long-lived and toxic pollutants, including lead, asbestos, and dioxins. In particular, poor countries have great difficulty in handling HW.

Chemicals of special concern include *persistent, bioaccumulative, toxic* chemicals (PBTs) (Chapter 14). Even low environmental concentrations pose problems. Some PBTs are banned but, being long-lived, they linger on; examples include example DDT (dichlorodiphenyltrichloroethane),

polychlorinated biphenyls (PCBs), and perfluorinated chemicals. An increasing number are banned by the Stockholm Convention.

Metals (Chapter 15) are elemental. Thus, even low emissions, if ongoing, can lead to harmful build-up in soil or water. Three – *lead*, *cadmium*, and *mercury* – are classed as PBTs.

Pesticides: Almost everyone, homeowners included, uses pesticides (Chapter 16), but controversy continues as to when and how they should be used. Emphasis is placed in this text on techniques to lessen dependence on pesticides. *Integrated pest management* is particularly important.

Pollution at home: Air pollution is typically higher inside homes than outside (Chapter 17). Householders, often unbeknownst to themselves, are typically responsible for this problem; combustion pollutants, volatile organic chemicals (VOCs), excessive moisture, dust and dirt, and biological pollutants such as molds are problematic pollutants. Others include radon, old lead paint, and asbestos. Also found in homes are hazardous chemicals and household hazardous waste. All of these pose risks that can be lowered or eliminated. In less-developed countries, indoor air pollution often results from smoke in the home from cooking and heating.

Zero waste, zero emissions may currently be unrealistic (Chapter 18), but increasingly people pursue it a realistic goal. The zero-waste approach believes that wastes and pollutants can become useful resources, a philosophy that has motivated people to seek means to accomplish this. The intention of *industrial ecology* is to integrate society's activities seamlessly into the environment. Developing closed-loop systems could greatly increase our efficiency in using resources. Tools that assist in working toward this goal include *lifecycle assessment* (LCA), *design for the environment* (DfE), *servicizing*, and *product stewardship*. *Green chemistry* aims to design hazards out of chemical products and processes. Businesses, cities, and whole countries have made zero waste their goal.

The Appendix "Basic Concepts in Chemistry" was written in response to requests for basic information on chemistry. Introductory concepts are provided along with how they relate to specific pollutants.

Notes

1. Rockström, J., Steffen, W., Noone, K., et al. Planetary boundaries: Exploring the safe operating space for humanity. *Ecology & Society*, 14(2), 2009. Crossing into the region of one of these boundaries – or thresholds – means a greater risk of irreversible, and perhaps abrupt environmental change. Numerical values are given to each. These concepts were developed by Johan Rockström and his colleagues in the publication noted here; they include an explanation of what is involved in determining each individual boundary. Updates on the initial 2009 work continue to be published.
2. Fresh water is not the same as drinking water. Fresh water is water that is not salty, such as the found in freshwater lakes. Fresh water must often be purified to be safe to drink.

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I extend ongoing gratitude to Dr. John C. Hassler, my husband. For over 20 years he has faithfully and patiently cared for my computer hardware and software; maintained all changes to this text; and assisted me in any and all computer problems.

Abbreviations and Acronyms

ABCs	atmospheric brown clouds
ACEEE	American Council for an Energy-Efficient Economy
ADI	acceptable daily intake
AMOC	Atlantic Meridional Overturning Circulation
ARPA-E	Advanced Research Projects Agency – Energy
BAT	best available technology
BC	black carbon
BOD	biochemical oxygen demand
Bt	*Bacillus thuringiensis*
C&DD	construction and demolition debris
CAA	Clean Air Act
CAFO	concentrated animal feeding operation
CCD	colony collapse disorder
CCS	carbon capture and storage
CDC	Centers for Disease Control and Prevention
CE	circular economy
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act (Superfund)
CFC	chlorofluorocarbon
CFL	compact fluorescent lamp
CHP	combined heat and power
COP	Conference of the Parties
COPD	chronic obstructive pulmonary disease
CPSC	Consumer Product Safety Commission
CSO	combined sewer overflow
CSP	concentrated solar power
CWA	Clean Water Act
DBP	disinfection by-product
DfD	design for disassembly
DfE	design for the environment
DNA	deoxyribonucleic acid
DOE	Department of Energy
EANET	Acid Deposition Monitoring Network in East Asia
EFSA	European Food Safety Authority
EMF	electromagnetic field
EPA	Environmental Protection Agency
EPR	extended producer responsibility (also called *take-back*)
ETS	environmental tobacco smoke
EV	electric vehicle
FAO	Food and Agriculture Organization
FDA	Food and Drug Administration
FEMA	Federal Emergency Management Authority
FFDCA	Federal Food, Drug and Cosmetics Act
FIFRA	Federal Insecticide Fungicide and Rodenticide Act

FQPA	Food Quality Protection Act
GE	General Electric
GEO	genetically engineered organism
GHG	greenhouse gas
GHP	geothermal heat pump
GI	gastrointestinal
GLP	good laboratory practice
GWP	greenhouse warming potential
HABs	harmful algae blooms
HAP	hazardous air pollutant (also referred to as a toxic air pollutant)
HBEF	Hubbard Brook Experimental Forest
HCFC	hydrochlorofluorocarbon
HEI	Health Effects Institute
HEPA	high efficiency particulate air (filter)
HFC	hydrofluorocarbon
HHW	household hazardous waste
HPV	high production volume
HW	hazardous waste
HWTS	household water treatment and safe storage
IARC	International Agency for Research on Cancer
INMS	International Nitrogen Management System
IPCC	Intergovernmental Panel on Climate Change
IPM	integrated pest management
IR	infrared
IRIS	Integrated Risk Information System
LCA	lifecycle assessment
LED	light-emitting diode
LEED	Leadership in Energy and Environmental Design
MACT	maximum available control technology
MATS	Mercury and Air Toxics Standards
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MDEQ	Michigan Department of Environmental Quality
MPG	miles per gallon
MSW	municipal solid waste
MTD	maximum tolerated dose
MW	molecular weight
NAAQS	National Ambient Air Quality Standards
NAPAP	National Acid Precipitation Assessment Program
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NiCd	nickel–cadmium
NIMBY	not in my backyard
NOAA	National Oceanic and Atmospheric Administration
NOAEL	no observed adverse effect level
NPL	National Priority List
NPS	nonpoint source
NRC	National Research Council
NTP	National Toxicology Program
NUE	nitrogen-use efficiency
ODC	ozone-depleting chemical
ODP	ozone depletion potential

OECD	Organization for Economic Cooperation and Development
OSHA	Occupational Safety and Health Agency
P^2	pollution prevention
PAH	polycyclic aromatic hydrocarbon
PBT	persistent, bioaccumulative, toxic
PCB	polychlorinated biphenyl
pCi/L	picocuries per liter
PFAS	perfluoroakyl chemicals
PFOS	perfluorooctane sulfonates
PM_{10}	particulate matter that is less than 10 microns in diameter
$PM_{2.5}$	particulate matter that is less than 2.5 microns in diameter
POP	persistent organic pollutant
POU	point of use
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
PSC	polar stratospheric cloud
PV	photovoltaic
RCRA	Resource Conservation and Recovery Act
REACH	Registration, Evaluation and Authorization of Chemicals
RfD	reference dose
RQ	reportable quantity
SDWA	Safe Drinking Water Act
SS	suspended solids
TRI	Toxic Release Inventory
TSCA	Toxic Substances Control Act
TUR	toxics use reduction
UNDP	UN Development Program
UNEP	UN Environmental Program
UNICEF	UN International Children's Emergency Fund
USDA	US Department of Agriculture
USGS	US Geological Survey
UV	ultraviolet
VOCs	volatile organic compounds
WCED	World Commission on Environment and Development
WEF	World Economic Forum
WHO	World Health Organization
WMH	waste management hierarchy
WMO	World Meteorological Organization
WWAP	World Water Assessment Program
XHTZ	Xi'an High-Tech Zone

Chemical Abbreviations and Formulas

^{14}C	carbon-14
^{238}U	uranium-238
^{40}K	potassium-40
BaP	benzo(a)pyrene
BPA	bisphenol A
CCA	chromated copper arsenate
CCl_2F_2	Freon-12
CFC-12	Freon

CH_2Cl_2	dichloromethane
CH_3Br	methyl bromide
CH_3Cl	methyl chloride
CH_4	methane
ClO	chlorine monoxide
CO	carbon monoxide
CO_2	carbon dioxide
DDE	Dichlorodiphenyldichloroethene
DDT	Dichlorodiphenyltrichloroethane
DEHP	Di(2-ethylhexyl) phthalate
DES	Diethylstilbestrol
dioxin	2,3,7,8-TCDD (sometimes refers to the whole dioxin family)
DMSO	Dimethyl sulfoxide)
H^+	acid hydrogen ion
HCHO	formaldehyde
HCl	hydrochloric acid
MIC	methylisocyanate
MTBE	methyl tertiary butyl ether
N	nitrogen
N_2	nitrogen (diatomic nitrogen)
N_2O	nitrous oxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
O	single oxygen atom
O_2	oxygen (diatomic oxygen)
O_3	ozone (triatomic oxygen)
P_2O_5	phosphorus pentoxide
PAN	peroxyacyl nitrate
PBDE	polybrominated diphenyl ether
PERC	tetrachloroethylene
PET	polyethylene terephthalate
PFC	perfluorocarbon
Po	polonium)
PVC	polyvinylchloride
Rn	radon
SF_6	sulfur hexafluoride
SO_2	sulfur dioxide
TBT	tributyltin
TCDD	2,3,7,8-tetrachlorodibenzo-*p*-dioxin ("dioxin's" most toxic form)
TCE	trichloroethylene
TCS	triclosan
THM	trihalomethane