HAZARDOUS WASTES: SOURCES, PATHWAYS, RECEPTORS

HAZARDOUS WASTES

Sources, Pathways, Receptors

Richard J. Watts

Department of Civil & Environmental Engineering
Washington State University

JOHN WILEY & SONS, INC.
New York • Chichester • Weinheim • Brisbane • Singapore • Toronto

Acquisitions Editor: Wayne Anderson
Marketing Manager: Katherine Hepburn
Production Editor: Tony VenGraitis
Text and Cover Designer: Harry Nolan
Illustration Editor: Sigmund Malinowski
Electronic Illustrations: Radiant
Cover Photographs: Background: Biohazard cylinders © Richard Gaul 1996, FPG International
Upper right: Recycling hazardous chemicals, Casa Grande, AZ. © Jeff Heger, 1994, FPG International
Lower left: Asbestos removal, C.T. Tracy, 1994, FPG International.
Outside Production Coordination: York Production Services

This book was set in Times Roman by York Graphic Services and printed and bound by Hamilton Printing.
The cover was printed by Phoenix Color.
This book is printed on acid-free paper. ♾
The paper in this book was manufactured by a mill whose forest management programs include sustained yield harvesting of its timberlands. Sustained yield harvesting principles ensure that the numbers of trees cut each year does not exceed the amount of new growth.

Library of Congress Cataloging in Publication Data:
Watts, Richard J.
Hazardous wastes : sources, pathways, receptors / Richard J. Watts.

p. cm.
Includes index.
ISBN 0-471-00238-0 (cloth : alk. paper)
1. Hazardous wastes. I. Title.

TD1030.W38 1997 97-28360

628.4'2—dc21 CIP

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

For Maura, Leah, and Emily

Preface

Hazardous waste courses have recently been established at many universities throughout the United States; they vary in focus from management (regulations, manifest forms, etc.) to the design of unit processes for treating wastes disposed of under the Resource Conservation and Recovery Act (RCRA). This book is based on a course developed at Washington State University to provide senior and M.S. students with the scientific principles of hazardous waste management and engineering. In developing the course, and subsequently this book, I considered fundamental concepts that should be presented in an introductory hazardous waste class. After determining the knowledge required of entry-level engineers and scientists by consulting firms, industry, and government, and assessing the knowledge needed by graduate students in advanced hazardous waste classes, I developed material that covers the following topics:

- terminology, nomenclature, and properties of hazardous wastes and materials;
- behavior of hazardous chemicals in surface impoundments, soils, groundwater, and treatment systems;
- assessment of the toxicity and risk associated with exposure to hazardous chemicals;
- strategies to find information on nomenclature, transport and behavior, and toxicity for hazardous compounds; and
- application of the scientific principles of hazardous wastes to their management, remediation, and treatment.

In selecting the material for the book, I made an effort to avoid duplication of topics presented in standard environmental engineering, environmental science, and hydrogeology courses currently offered by most institutions. I also tried to develop material that would be fundamental in nature and tried to design a text that would be an educational document rather than a training manual.

Organization

The book is divided into three major parts—"Sources," "Pathways," and "Receptors"—and a fourth part that extends the fundamental principles—"Management and Design Applications." After an introductory chapter that describes hazardous waste problems and hazardous waste legislation, Chapter 2 of "Sources" provides information on nomenclature and structure of common hazardous contaminants, what industrial operations have generated the different classes of waste materials, and the types of contamination that have resulted from their disposal. In Chapter 3, the basic properties of common contaminants, such as water solubility, density, and chemical incompatibility, are covered. Source analysis, focusing on waste audits in industrial

facilities, assessment of contaminated sites, sampling, and chemical analysis, is the topic of Chapter 4.

Using quantitative problem solving, "Pathways" provides a conceptual basis for understanding the behavior of hazardous chemicals, whether they are present in soil and groundwater systems, in hazardous waste landfills, in storage tanks, or in treatment systems such as air stripping towers. Chapter 5 covers partitioning phenomena, including theory, isotherms, and estimating sorption in soil-water systems. In Chapter 6, material on the theory of volatilization is presented, including equations for estimating volatilization rates from surface impoundments and soils. Concepts of abiotic and biotic transformations as a basis for the natural attenuation of contaminants at hazardous wastes sites and the design of treatment systems are covered in Chapter 7. The material in Chapters 5 through 7 is integrated in Chapter 8, in which the atmospheric and subsurface transport of hazardous chemicals away from the source is presented.

If a hazardous contaminant moves in the environment by one of the routes described in "Pathways," receptors (e.g., humans or wildlife) may be affected—the basis for the "Receptors" part. Chapter 9 deals with fundamental human and mammalian toxicology and explains the ways in which chemicals may be toxic. Quantitative toxicology and industrial hygiene are covered in Chapter 10, which serves as a basis for assessing the toxicity of hazardous contaminants. Chapter 11 emphasizes all of the concepts from previous chapters by addressing risk assessment. Risk is a function of exposure (covered under "Pathways") and hazard (covered under "Receptors"). Using the material of Chapters 2 through 10, the student not only becomes capable of conceptualizing hazardous waste dynamics and exposure through quantitative problem solving, but also develops the ability to perform elementary risk assessments.

In the final part, "Management and Design Applications," the fundamental principles of *sources, pathways*, and *receptors* are applied to hazardous waste management, remediation, and treatment. Remediation and treatment designs may be considered applications of the pathways covered in Part Two. An overview of pollution prevention, remediation, treatment and disposal is presented in Chapter 12. The principles learned in "Pathways" are then applied to the design of selected hazardous waste treatment systems in Chapter 13, based on each of the four chemodynamic pathways:

Pathway	Treatment Application
Sorption	Granular activated carbon
Volatilization	Air stripping
Abiotic transformations	Advanced oxidation processes
Biotic transformations	Slurry bioreactors

Use of This Book

Hazardous Wastes: Sources, Pathways, Receptors contains enough material to allow flexibility in teaching a one-semester hazardous waste course. If the class is taught in an environmental science or hydrogeology program where students do not have a design emphasis, Chapters 1 through 11 will provide a science-based hazardous waste course. A civil engineering course with a 33% design content would include Part Four, "Management and Design Applications," but omit parts of Chapters 5, 9, 10, and 11. Another option is a two-semester sequence in hazardous waste engineering. The first semester would emphasize engineering science and use Chapters 1 through 11; the sec-

ond semester would consist of the design of hazardous waste treatment systems and could use Chapters 12 and 13 along with selected design manuals or hazardous waste design texts as they become available.

Chapter 2, "Common Hazardous Wastes: Nomenclature, Industrial Uses, Disposal Histories," should no doubt be covered, at least in part, if students have not completed organic chemistry. If organic chemistry is a prerequisite for the class, covering Chapter 2 may not be necessary. One option for students with a background in organic chemistry may be to rapidly cover Chapter 2 so that they have familiarity with chemicals germane to hazardous waste management (e.g., chlorinated solvents, PCBs, dioxins). Another alternative would be to provide information on classes of chemicals at specific points of the text. For example, detailed information on solvents could be presented in Chapter 6, "Volatilization," because most solvents are volatile organic compounds.

Some sections of the text have less problem solving content, and may receive less emphasis in lectures and deferred to the student as reference material. Some of these sections include 2.6, "Explosives"; 2.10, "Metals and Inorganic Nonmetals"; 4.6, "Sampling away from the Source"; 11.3, "Ecological Risk Assessments"; and a number of topics in Chapters 9 and 10 on toxicology.

Based on the flexibility inherent in the text, potential emphases of a one-semester course include (1) hazardous wastes with a science emphasis, and (2) hazardous wastes with engineering science and design components.

Hazardous Wastes (Science Emphasis). A fundamental approach to the concepts of hazardous wastes, with the study of both currently generated hazardous wastes and the assessment and characterization of contaminated sites, would focus on the majority of Parts One, "Sources," Two, "Pathways," and Three, "Receptors":

Chapter	Topic
1	Introduction
2	Common Hazardous Wastes: Nomenclature, Industrial Uses, Disposal Histories
3	Common Hazardous Wastes: Properties and Classification
4	Source Analysis
5	Partitioning, Sorption, and Exchange at Surfaces
6	Volatilization
7	Abiotic and Biotic Transformations
8	Dynamics of Transport away from the Source
9	Concepts of Hazardous Waste Toxicology
10	Quantitative Toxicology
11	Hazardous Waste Risk Assessment

Hazardous Wastes (Engineering Science with Engineering Design Components). Because engineering science (covered in Part Two, "Pathways") serves as the basis for engineering design, a one-semester hazardous waste class with approximately 33%–50% engineering design content would focus primarily on Parts Two, "Pathways," and Four, "Management and Design Applications," with support from Part One, "Sources":

Chapter	Topic
1	Introduction
2	Common Hazardous Wastes: Nomenclature, Industrial Uses, Disposal Histories
3	Common Hazardous Wastes: Properties and Classification
4	Source Analysis
5	Partitioning, Sorption, and Exchange at Surfaces
6	Volatilization
7	Abiotic and Biotic Transformations
8	Dynamics of Transport away from the Source
12	Approaches to Hazardous Waste Minimization, Remediation, Treatment, and Disposal
13	Design of Selected Pathway Applications

Other emphases may also be created using appropriate sections of the text. Some other potential areas of emphasis include contaminated site management, RCRA hazardous waste management, contaminant fate and transport, and hazardous waste risk assessment.

Metric units are used in most cases throughout the book, with English units following parenthetically. The only cases in which English units receive primary emphasis are in the presentation of historical or anecdotal information, which occurs mostly in Chapters 1 and 2.

Acknowledgments

Completion of this text would have not been possible without the assistance of a group of gracious colleagues and students. My former graduate student Alex Jones served as an invaluable aide de camp during his time in Pullman by tracking down references, developing tables and figures, solving example and chapter problems, and proofreading the manuscript. My colleagues at Washington State University, particularly Drs. Wade Hathhorn, Jim Hoover, Brian Lamb, and Amy Teel, provided helpful suggestions on the manuscript. Dr. Hoover was instrumental in obtaining photographs of the Hanford nuclear reservation, and Dr. Teel's eye for detail was invaluable as she helped in proofreading the manuscript. Drs. Tom Hess of the University of Idaho and Dave Atkinson of the Idaho National Engineering and Environmental Laboratory also provided valuable comments. Numerous former students provided assistance, including Brett Bottenberg, Gerry Brown, Jay Bower, Brett Freeborn, Dan Haller, Michael Harrington, Jimmy Howsakeng, Pat McGuire, Rolf Parsloe, and Cindy Spencer. I would also like to thank Kathy Cox for typing sections of the manuscript.

The John Wiley & Sons review team provided thorough guidance on the pedagogical development, presentation, and accuracy of the manuscript. This excellent group of reviewers included Dr. Paul Bishop (University of Cincinnati), Dr. Peter Fox (Arizona State University), Dr. Mriganka Ghosh (University of Tennessee), Dr. John Harkin (University of Wisconsin), Dr. Steve Hrudey (University of Alberta), Dr. Glenn Miller (University of Nevada), Dr. Jeffrey Peirce (Duke University), and Dr. Jim Seiber (University of Nevada). I am also indebted to the editors at John Wiley & Sons, including the late Cliff Robichaud, Wayne Anderson, Catherine Beckham, and Sharon Smith. I

would also like to thank Tony VenGraitis and Sigmund Malinowski at John Wiley & Sons and Kirsten Kauffman at York Production Services.

On a more personal note, I would like to thank my wife, Lennis Boyer, who tolerated long hours of writing while she was practicing medicine. Finally, the seeds for this project were no doubt planted decades ago by my mother and late father, who taught me the importance of environmental quality at an early age by inspiring me to stalk *Salmo aquabonita* through alpine "greensfields."

Richard J. Watts
Pullman, Washington

Acronyms and Abbreviations

AA - Atomic Absorption
ACGIH - American Conference of Governmental Industrial Hygienists
ACMA - Agricultural Chemicals Manufacturing Association
ADI - Acceptable Daily Intake
AOPs - Advanced Oxidation Processes
ARARs - Applicable or Relevant and Appropriate Requirements
BCF - Bioconcentration Factor
BDST - Bed Depth Service Time
BTEX - Benzene, Toluene, Ethylbenzene, and Xylenes
CAA - Clean Air Act
CAS - Chemical Abstract Service
CCA - Copper chrome arsenate
CDI - Chronic Daily Intake
CEC - Cation exchange capacity
CERCLA - Comprehensive Environmental Response, Compensation and Liability Act
CERCLIS - Comprehensive Environmental Response, Compensation and Liability Information System
CFR - Code of Federal Regulations
CFSTR - Continuous Flow Stirred Tank Reactor
CMA - Chemical Manufactures Association
CMC - Critical Micelle Concentration
CSI - Common Sense Initiative
CWA - Clean Water Act
2,4-D - 2,4-Dichlorophenoxyacetic acid
DBCP - 1,2-Dibromo-3-chloropropane
DCE - Dichloroethylene (various isomers)
DDT - Dichlorodiphenyltrichloroethane
DNAPL - Dense Nonaqueous Phase Liquid
DOT - Department of Transportation
DSMA - Disodium methyl arsenate
EBDC - Ethylene-*bis*-dithiocarbamate
ECD - Electron Capture Detector
ED - Effective dose
EDB - Ethylene dibromide
ELP - Environmental Leadership Program
EP - Extraction Procedure (toxicity test)
EPA - Environmental Protection Agency
EPCRA - Emergency Planning and Community Right-to-Know Act
FID - Flame Ionization Detector
GAC - Granular activated carbon
GC - Gas Chromatography
HAP - Hazardous Air Pollutant
HI - Hazard Index
HLW - High-level wastes (nuclear)
HPLC - High-Performance Liquid Chromatography
HRS - Hazard Ranking System
HSWA - Hazardous and Solid Waste Amendments of 1984
IARC - International Agency for Research on Cancer
ICP - Inductively Coupled Plasma
IUPAC - International Union of Pure and Applied Chemists
LD - Lethal dose

LEPC - Local Emergency Planning Committee
LFL - Lower Flammability Limit
LLW - Low-level wastes (nuclear)
LNAPL - Light Nonaqueous Phase Liquid
MCL - Maximum Contaminant Level
MEK - Methyl ethyl ketone
MIBK - Methyl isobutyl ketone
MS - Mass Spectrometer
MSDS - Material Safety Data Sheet
MSMA - Monosodium methyl arsenate
NAAQS - National Ambient Air Quality Standards
NCP - National Contingency Plan
NFPA - National Fire Protection Association
NOAEL - No Observed Adverse Effect Level
NPDES - National Pollutant Discharge Elimination System
NPL - National Priorities List
OCDD - Octachlorodibenzo-*p*-dioxin
OU - Operable Unit
OVA - Organic Vapor Analyzer
PA - Preliminary Assessment
PAHs - Polycyclic Aromatic Hydrocarbons
PCBs - Polychlorinated Biphenyls
PCDDs - Polychlorinated Dibenzo-*p*-dioxins
PCDFs - Polychlorinated Dibenzofurans
PCE - Perchloroethylene
PCP - Pentachlorophenol
PFR - Plug Flow Reactor
PID - Photoionization Detector
PPA - Federal Pollution Prevention Act (of 1990)
PRP - Potentially Responsible Party
QSARs - Quantitative Structural-Activity Relationships
RCRA - Resource Conservation and Recovery Act
RI/FS - Remedial Investigation/ Feasibility Study
RfD - Reference Dose
ROD - Record of Decision
SARA - Superfund Amendments and Reauthorization Act (of 1986)
SCAP - Superfund Comprehensive Accomplishments Plan
SDWA - Safe Drinking Water Act
SERC - State Emergency Response Commission
SF - Slope factor
SI - Site Inspection
SOC - Soil organic carbon
SOM - Soil organic matter
STEL - Short-Term Exposure Limit
SVE - Soil Vapor Extraction
2,4,5-T - 2,4,5-Trichlorophenoxyacetic acid
TCA - 1,1,1-Trichloroethane
TCDD - 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin
TCE - Trichloroethylene
TEF - Toxicity Equivalent Factor
TLV - Threshold Limit Value
TNT - 2,4,6-Trinitrotoluene
TOC - Total Organic Carbon
TPH - Total Petroleum Hydrocarbons
TRI - Toxics Release Inventory
TCLP - Toxicity Characteristic Leaching Procedure
TSCA - Toxic Substances Control Act
TSD - Treatment, Storage, and Disposal (facilities)
TWA - Time-Weighted Average
UFL - Upper Flammability Limit
UN/NA - United Nations/North American
USTs - Underground Storage Tanks
VOA - Volatile Organic Analysis
VOCs - Volatile Organic Compounds
WHO - World Health Organization

Table of Contents

APPENDICES