



# HAZARDOUS WASTES

Sources, Pathways, Receptors

Richard J. Watts

*Department of Civil & Environmental Engineering  
Washington State University*



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Chapter 4. The history of the development of the modern scientific method.

*For Maura, Leah, and Emily*

Chapter 5. The history of the development of the modern scientific method. Chapter 6. The history of the development of the modern scientific method. Chapter 7. The history of the development of the modern scientific method.

Chapter 8. The history of the development of the modern scientific method. Chapter 9. The history of the development of the modern scientific method. Chapter 10. The history of the development of the modern scientific method.

Chapter 11. The history of the development of the modern scientific method. Chapter 12. The history of the development of the modern scientific method. Chapter 13. The history of the development of the modern scientific method.

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Chapter 17

Organization

Chapter 18. The history of the development of the modern scientific method. Chapter 19. The history of the development of the modern scientific method. Chapter 20. The history of the development of the modern scientific method.

# 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 waste 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.

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Richard J. Watts  
Pullman, Washington

### Acronyms and Abbreviations

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

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