

Contents

Foreword xvii

Preface xix

Acknowledgments xxii

1 Introduction 1

1.1 The Beginning 1

1.1.1 Historical Perspectives 2

1.2 Importance of Waste Management in Sustainability, Ecological Health, and Climate Change 4

1.2.1 Waste Management and Environmental Sustainability 6

1.2.2 Waste Management and Human and Ecological Health 8

1.2.3 Waste Management and Climate Change 9

1.3 Overview of Waste Generation in the United States and Other Countries 10

1.4 Future Perspectives on Waste Management 12

1.5 Summary 13

Study Questions 14

References 15

Supplementary Readings 15

Web Resources 15

Acronyms/Symbols 16

2 Essentials of Geology, Geotechnics, and Toxicology 17

2.1 Introduction 17

2.2 Basic Concepts 18

2.3 Geologic Cycles 27

2.3.1 Rock Cycle 27

2.3.2 Water (Hydrologic) Cycle 29

2.3.3 Tectonic Cycle 30

2.3.3.1 Significance of Plate Movement 33

2.3.4 Geochemical Cycle 33

2.3.5 Climate Cycle 33

2.4 Earth Materials 33

2.4.1 Rocks as Earth Materials 34

2.4.1.1 Igneous Rocks 34

2.4.1.2 Sedimentary Rocks 34

2.4.1.3 Metamorphic Rocks 34

2.4.1.4	Engineering Properties and Behavior of Rock Materials	34
2.4.2	Soils as Earth Material	35
2.4.3	Soil Formation	36
2.4.3.1	Soil Profile	37
2.4.3.2	Soil Texture	37
2.5	Index Properties of Soils	38
2.5.1	Void Ratio, Porosity, and Degree of Saturation	39
2.5.2	Density	40
2.5.3	Moisture (Water) Content	40
2.5.4	Grain-Size Distribution	41
2.5.5	Atterberg Limits	41
2.5.6	Permeability	44
2.6	Soil Classification Systems	45
2.6.1	Soil Classification	45
2.7	Hydrogeology	47
2.7.1	Groundwater Occurrence	48
2.7.2	Types of Aquifers	49
2.7.3	Groundwater Movement	50
	Essentials of Toxicology	52
2.8	Introduction	52
2.8.1	Toxicity and Toxicity Rating	53
2.8.2	Types of Toxic Effects	53
2.9	Dose–Response Relationship	55
2.9.1	Hypersensitivity and Hyposensitivity	57
2.10	Exposure Paths of Toxicants to Humans	58
2.10.1	Ingestion	58
2.10.2	Inhalation	58
2.10.3	Dermal Contact	58
2.10.4	Injection	58
2.11	Teratogenesis, Mutagenesis, and Carcinogenesis	58
2.11.1	Teratogenesis	58
2.11.2	Mutagenesis	59
2.11.3	Carcinogenesis	59
2.12	Assessment of Health Risks of Hazardous Waste	59
2.13	Summary	60
	Study Questions	60
	References	62
	Supplemental Readings	63
	Web Resources	63
	Acronyms/Symbols	63
3	Environmental Laws	64
3.1	History and Evolution of Environmental Laws in the United States	64
3.1.1	Foundation and Strength of US Environmental Laws	66
3.2	Important Environmental Laws	66
3.2.1	The Rivers and Harbors Act	69
3.2.2	The Atomic Energy Act	70

3.2.3	Solid Waste Disposal Act	70
3.2.4	Resource Recovery Act	70
3.2.5	National Environmental Policy Act	70
3.2.6	Occupational Safety and Health Act	70
3.2.7	Federal Water Pollution Control (Renamed Clean Water) Act	71
3.2.8	Clean Air Act	71
3.2.9	Marine Protection, Research, and Sanctuary Act	73
3.2.10	Federal Insecticide, Fungicide, and Rodenticide Act	73
3.2.11	Safe Drinking Water Act	73
3.2.12	Resource Conservation and Recovery Act	80
3.2.13	Surface Mining Control and Reclamation Act	80
3.2.14	Uranium Mill Tailings and Radiation Control Act	81
3.2.15	Comprehensive Environmental Response, Compensation, and Liability Act	81
3.2.16	Superfund Amendments and Reauthorization Act	81
3.2.17	Hazardous and Solid Waste Amendments Act	83
3.2.18	Underground Storage Tanks Act	83
3.2.19	Toxic Substance Control Act	83
3.2.20	Low-Level Radioactive Waste Policy Act	84
3.2.21	Nuclear Waste Policy Act	84
3.2.22	Emergency Planning and Community Right-to-Know Act	84
3.2.23	Medical Waste Tracking Act	86
3.2.24	Indoor Radon Abatement Act	86
3.2.25	Pollution Prevention Act	86
3.3	Summary	86
	Study Questions	87
	References	88
	Web Resources	88
	Acronyms/Symbols	88
4	Municipal Solid Waste	89
4.1	Historical Perspective	89
4.1.1	The United States Public Health Service and the American Public Works Association	90
4.2	Introduction	91
4.2.1	Environmental and Health Impacts from Mismanagement of Municipal Solid Waste	93
4.3	US Laws Regulating Solid Waste Management	102
4.3.1	The Solid Waste Disposal Act	102
4.3.2	The Resource Conservation and Recovery Act	102
4.4	Source, Composition, and Quantity of MSW	103
4.4.1	MSW Composition	103
4.4.1.1	Special Wastes	106
4.4.2	Quantity of MSW	106
4.5	Collection and Disposal of MSW	107
4.5.1	MSW Disposal	107
4.5.2	Land Disposal	109
4.5.3	Incineration and Waste-to-Energy Conversion	110

Contents

4.5.4	Composting	112
4.6	Physical and Chemical Properties of MSW	112
4.6.1	Moisture Content	113
4.6.2	Density	114
4.6.3	Volume Reduction	114
4.6.4	Compaction Ratio	115
4.6.5	Permeability	115
4.6.6	Energy (Heat) Content	115
4.6.7	Field Capacity	116
4.6.8	Particle Size Distribution	116
4.7	Landfill	118
4.7.1	Types of Landfills	119
4.7.2	Daily Operation of a Sanitary Landfill	120
4.7.3	Landfill Leachate	121
4.7.4	Landfill Gases	123
4.7.4.1	Landfill Gas Formation	123
4.7.5	Landfill Design	125
4.7.5.1	Landfill Siting Restrictions	126
4.7.6	Landfill Design Criteria	127
4.7.6.1	Leachate Collection and Removal System	129
4.7.6.2	Landfill Gas Collection and Extraction System	130
4.7.7	Landfill Area Requirement	131
4.7.8	Landfill Site Selection	132
4.7.8.1	Defining Purpose and Scope	132
4.7.8.2	Office Study and Data Collection	132
4.7.8.3	Field Investigations	133
4.8	Bioreactor Landfill	134
4.9	Waste Audit	136
4.9.1	Waste Audit Methodology	136
4.10	Summary	138
	Study Questions	138
	References	140
	Supplemental Reading	142
	Web Resources	143
	Acronyms/Symbols	143
5	Hazardous Waste	145
5.1	Introduction	145
5.1.1	Hazardous Substance and Hazardous Waste	146
5.1.2	Environmental and Health Problems	146
5.2	US Laws Regulating Hazardous Waste	155
5.2.1	Resource Conservation and Recovery Act	155
5.2.2	Toxic Substances Control Act	156
5.2.3	Comprehensive Environmental Response, Compensation, and Liability Act	156
5.2.4	Hazardous and Solid Waste Amendments	157
5.2.5	Underground Storage Tanks Act	157
5.2.6	Superfund Amendments and Reauthorization Act	158

5.2.7	Emergency Planning and Community-Right-to-Know Act	158
5.2.8	Frank R. Lautenberg Chemical Safety for the 21st Century Act (Lautenberg Chemical Safety Act)	159
5.3	Definition and Classification of Hazardous Waste	159
5.3.1	The United States Environmental Protection Agency Criteria	159
5.3.1.1	Listed Waste	160
5.3.1.2	Characteristic Waste	161
5.3.2	EU's Classification of Hazardous Waste	165
5.4	Sources and Generators of Hazardous Waste	166
5.4.1	Categories of Hazardous Waste Generators	169
5.5	Storage and Transportation of Hazardous Waste	170
5.5.1	Hazardous Waste Storage	171
5.5.2	Hazardous Waste Transportation	171
5.6	Treatment of Hazardous Waste	172
5.6.1	Hazardous Waste Treatment Methods	173
5.6.1.1	Neutralization	173
5.6.1.2	Sorption	173
5.6.1.3	Precipitation	174
5.6.1.4	Reverse Osmosis	174
5.6.1.5	Stripping	175
5.7	Hazardous Waste Treatment and Disposal	175
5.7.1	Land Disposal	176
5.7.1.1	Regulatory Aspects of Land Disposal	176
5.7.2	Land Disposal Restrictions	176
5.7.2.1	Key Provisions of the LDR Program	177
5.7.2.2	Land Treatment/Disposal	177
5.7.3	Secure Landfill	178
5.7.3.1	Waste Piles	178
5.7.3.2	Surface Impoundments	180
5.7.3.3	Mine Storage/Disposal	181
5.7.3.4	Deep Well Injection	181
5.7.4	Thermal Treatment Methods	182
5.7.4.1	Incineration	182
5.7.4.2	Pyrolysis	183
5.7.4.3	Other Thermal Destruction Methods	183
5.7.5	Biological Methods	184
5.7.6	Miscellaneous Disposal Methods	184
5.7.6.1	Permeable Reactive Barriers	184
5.7.6.2	Vitrification	186
5.7.6.3	Wetlands	186
5.7.6.4	Combination Methods	187
5.7.7	Sustainable (Green) Remediation	190
5.7.7.1	Triad Approach	190
5.8	Superfund Program and Cleanup of Hazardous Waste Sites in the United States	191
5.8.1	Remedial Actions under RCRA and CERCLA	192
5.9	Summary	193
	Study Questions	194

References	195
Supplementary Reading	196
Web Resources	196
Acronyms/Symbols	197

6 Medical Waste 198

6.1	Introduction and Historical Context 198
6.1.1	Definition 200
6.2	Nature, Source, and Quantity of Medical Waste 202
6.2.1	Nature of Medical Waste 202
6.2.2	Sources of Medical Waste 204
6.2.3	Wastes from Major Health Care Establishments 206
6.2.4	Quantity of Medical Waste 207
6.3	Hazards Associated with Regulated Medical Waste 210
6.4	Treatment and Disposal of Medical Waste 216
6.4.1	Methods of Treatment and Disposal of Regulated Medical Waste 217
6.4.1.1	Thermal Treatment 217
6.4.1.2	Biological Treatment 220
6.4.1.3	Chemical Treatment 220
6.4.1.4	Radiation-based Treatment 221
6.5	The COVID-19 Pandemic and Its Impact on Waste Management 221
6.5.1	The Great Pandemic of 2020 and Medical Waste 222
6.5.2	COVID-19 Waste 225
6.5.2.1	Determination of the Quantity of COVID-19 Waste 225
6.5.3	Reducing COVID-19 Waste Quantity 227
6.5.4	Waste Management Industry's Response to COVID-19 228
6.6	Summary 228
	Study Questions 229
	References 230
	Supplementary Reading 232
	Web Resources 232
	Acronyms/Symbols 233

7 Nuclear Waste 234

7.1	Introduction 234
7.1.1	Nuclear Waste 235
7.1.2	Types of Nuclear Waste 235
7.1.3	High-Level Wastes: SNF and HLW 235
7.1.4	Nuclear Waste Management 237
7.1.5	Early Years of Nuclear Waste Management in the USA 237
7.2	Basics of Nuclear Science 238
7.2.1	Radioactive Elements 238
7.2.2	Radioactive Minerals 239
7.2.3	Nuclear Fission and Electric Power Generation 239
7.2.4	Energy Potential of Radioactive Elements and Use of Nuclear Energy 240

7.2.4.1	Nuclear Energy for Electric Power Generation	242
7.2.4.2	Other Uses of Nuclear Energy	245
7.3	Radioactivity, Natural and Induced Radiation, and Half-Life	246
7.3.1	Radioactivity	246
7.3.2	Radiotoxicity	247
7.3.3	Radiation Exposure and Acceptable Radiation Dose	248
7.3.4	Induced Radioactivity	249
7.3.5	Naturally Occurring Radioactive Materials and Technologically Enhanced Radioactive Materials	250
7.3.6	Radioactive Decay and Half-life	251
7.4	Nuclear Waste	252
7.4.1	Sources of Nuclear Waste	253
7.4.2	Nuclear (Uranium) Fuel Cycle	254
7.4.2.1	Spent Fuel Reprocessing	256
7.4.3	Waste Forms and Packaging	256
7.4.4	Nuclear Waste Management	257
7.4.5	Nuclear Waste Classification	258
7.4.5.1	The IAEA System	259
7.4.5.2	The US System	259
7.5	Laws Regulating Management of Nuclear Waste	262
7.5.1	EU's Nuclear Waste Management Law	262
7.5.2	The United States Nuclear Waste Management Laws	262
7.5.2.1	Low-Level Radioactive Waste	263
7.5.2.2	High-Level Nuclear Waste	263
7.6	Nuclear Waste Storage and Transportation	266
7.6.1	Transportation of Nuclear Waste	266
7.6.2	LLW Transportation	266
7.6.3	TU/ILW Transportation	266
7.6.4	HLW/SNF Transportation	267
7.7	Nuclear Waste Disposal	267
7.7.1	Low-Level Radioactive Waste Disposal	268
7.7.2	Transuranic Waste Disposal	268
7.7.3	High-Level Nuclear Waste Disposal	269
7.7.4	HLW Management in the United States	272
7.7.4.1	The Lyons Salt Mine Project	275
7.7.4.2	Other US Repository Sites	276
7.7.4.3	Politics of the Yucca Mountain Project	276
7.8	Global Status of HLW Disposal	277
7.8.1	Quantity of HLW	277
7.8.2	United States	277
7.8.3	Finland HLW Repository	281
7.8.4	Sweden	283
7.8.5	France	285
7.8.6	HLW Management in Other Countries	285
7.8.6.1	Shared Repository Concept	285

7.9	Nuclear Waste From Reactor Decommissioning	287
7.10	Summary	288
	Study Questions	290
	References	290
	Supplemental Reading	294
	Web Resources	294
	Acronyms/Symbols	295
	Unit Conversions	295

8 Electronic Waste 296

8.1	Introduction	296
8.1.1	Metals in e-Waste	297
8.1.2	Definition of Electronic Waste	298
8.1.2.1	The United States	299
8.1.2.2	European Union	299
8.1.2.3	United Nations	299
8.2	Laws Regulating Electronic Waste	302
8.2.1	The United States	302
8.2.2	The United Nations	302
8.2.3	The EU	304
8.3	Nature and Composition of Electronic Waste	304
8.3.1	Planned Obsolescence	305
8.3.2	Material Composition of e-Waste	306
8.3.3	Material Composition of Desktop Computers	308
8.3.4	Material Composition of Laptops	309
8.3.5	Material Composition of Tablets	311
8.3.6	Material Composition of Mobile Phones	311
8.4	E-Waste Quantity	312
8.4.1	Estimation of e-Waste Quantity	314
8.5	E-Waste Recycling and Recovery of Valuable Metals	316
8.5.1	Metal Recovery from E-Waste	317
8.5.2	Benefits and Challenges of e-Waste Recycling	318
8.6	Health and Environmental Impacts	319
8.6.1	Informal E-Waste Recycling	319
8.6.2	Health and Environmental Impacts of Informal Recycling	321
8.7	Sustainable Management of E-Waste	324
8.7.1	United Nations Sustainable Development Goals and E-Waste	324
8.7.2	Other Measures for Sustainable E-Waste Management	326
8.8	Summary	326
	Study Questions	327
	References	328
	Supplementary Readings	331
	Web Resources	331
	Acronyms/Symbols	331

9	Waste Minimization	332
9.1	Introduction	332
9.2	Definitions	333
9.3	Approaches to Waste Minimization	334
9.4	Recycling	339
9.4.1	Plastic Recycling	342
9.5	Innovative Waste Minimization Technologies	344
9.5.1	Innovation in Plastic Packaging	344
9.5.2	Microfactories	345
9.5.3	Repurposing	346
9.5.4	NGOs' Efforts	346
9.6	Waste Exchange	348
9.7	Zero Waste	349
9.7.1	Evolution and Implementation of the Zero Waste Concept	349
9.7.2	Tool for Measuring ZW Success	350
9.8	Ship Recycling	351
9.8.1	Methods of Ship Recycling	351
9.8.2	Ship Recycling – A Hazardous Occupation	352
9.8.3	Modern Ship Recycling Industry	354
9.8.4	International Treaties	358
9.9	Airplane Recycling	359
9.9.1	Airplane Recycling Market	359
9.9.2	Airplane Recycling Standards	359
9.9.3	Airplane Recycling	360
9.9.4	Composites	361
9.9.4.1	Composites Recycling	362
9.10	Summary	363
	Study Questions	364
	References	365
	Supplemental Reading	367
	Web Resources	367
	Acronyms/Symbols	368
10	Pharmaceuticals and Personal Care Products	369
10.1	Introduction	369
10.1.1	Definition of PPCPs	371
10.1.2	Nature of PPCPs	372
10.1.3	What Comprises PPCPs	373
10.2	Concerns for PPCPs	373
10.3	Sources of PPCPs in the Environment	375
10.3.1	PPCPs in Sewage Treatment Plants	377
10.3.2	Occurrence of PPCPs in Drinking Water	378
10.4	Environmental Impacts of PPCPs	378
10.4.1	PPCPs in Drinking Water and Its Health Impact	378

10.4.2	Treatment Technologies for PPCPs' Removal	379
10.5	Forensic Applications of PPCPs	380
10.5.1	PPCPs' Application in Geological Dating	380
10.6	Research Status and Future Needs	382
10.7	Summary	383
	Study Questions	384
	References	385
	Supplementary Reading	387
	Web Resources	387
	Acronyms/Symbols	388
Glossary		389
Index		414
Geologic Time Scale		431
Common Units and Conversion Factors		432
United Nations' classification of countries based on income (as of July 2021)		435