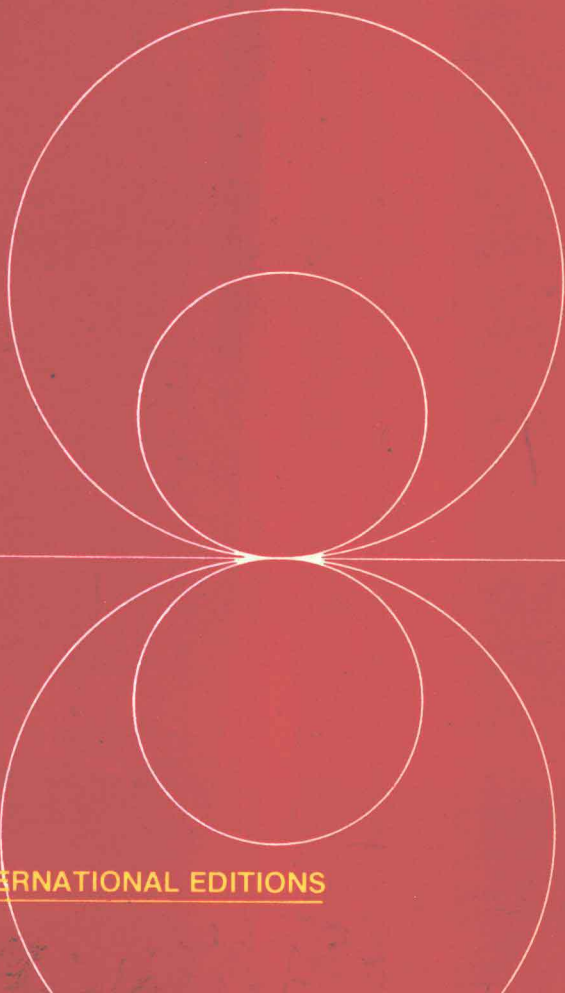


# ENVIRONMENTAL ENGINEERING

HOWARD S. PEAVY  
DONALD R. ROWE  
GEORGE TCHOBANOGLOUS



McGRAW-HILL INTERNATIONAL EDITIONS  
Civil Engineering Series

---

# ENVIRONMENTAL ENGINEERING

---

**Howard S. Peavy**

*Professor of Civil Engineering  
Montana State University*

**Donald R. Rowe**

*Professor of Civil Engineering  
King Saud University  
Saudi Arabia*

**George Tchobanoglous**

*Professor of Civil Engineering  
University of California, Davis*

**McGraw-Hill Book Company**

New York St. Louis San Francisco Auckland Bogotá Hamburg  
London Madrid Mexico Montreal New Dehli  
Panama Paris São Paulo Singapore Sydney Tokyo Toronto

**ENVIRONMENTAL ENGINEERING**  
INTERNATIONAL EDITION, 1985

Exclusive rights by McGraw-Hill Book Co., Singapore for manufacture and export. This book cannot be re-exported from the country to which it is consigned by McGraw-Hill.

**8 9 10 BJE 2 0**

Copyright © 1985 by McGraw-Hill, Inc.  
All rights reserved. No part of this publication may be reproduced or distributed in any form or by any means, or stored in a data base or a retrieval system, without the prior written permission of the publisher.

This book was set in Times Roman.  
The editors were Kiran Verma and David A. Damstra.  
The production supervisor was Leroy A. Young.

**Library of Congress Cataloging in Publication Data**

Peavy, Howard S.  
Environmental engineering.

(McGraw-Hill series in water resources and environmental engineering)

Includes bibliographical references and indexes.

1. Environmental engineering. I. Rowe, Donald R.  
II. Tchobanoglous, George. III. Title. IV. Series.

TD145.P43 1985 628 84-3854

ISBN 0-07-049134-8

**When ordering this title use ISBN 0-07-100231-6**

**Printed in Singapore**

---

# **ENVIRONMENTAL ENGINEERING**

---

## **McGraw-Hill Series in Water Resources and Environmental Engineering**

**Rolf Eliassen, Paul H. King, and Ray K. Linsley**

*Consulting Editors*

**Bailey and Ollis:** *Biochemical Engineering Fundamentals*

**Bishop:** *Marine Pollution and Its Control*

**Biswas:** *Models for Water Quality Management*

**Bockrath:** *Environmental Law for Engineers, Scientists, and Managers*

**Bouwer:** *Groundwater Hydrology*

**Canter:** *Environmental Impact Assessment*

**Chanlett:** *Environmental Protection*

**Gaudy and Gaudy:** *Microbiology for Environmental Scientists and Engineers*

**Haimes:** *Hierarchical Analysis of Water Resources Systems: Modelling and  
Optimization of Large-Scale Systems*

**Hall and Dracup:** *Water Resources Systems Engineering*

**Linsley and Franzini:** *Water Resources Engineering*

**Linsley, Kohler, and Paulhus:** *Hydrology for Engineers*

**Metcalf & Eddy, Inc.:** *Wastewater Engineering: Collection and Pumping of Wastewater*

**Metcalf & Eddy, Inc.:** *Wastewater Engineering: Treatment, Disposal, Reuse*

**Peavy, Rowe, and Tchobanoglous:** *Environmental Engineering*

**Rich:** *Low-Maintenance, Mechanically-Simple Wastewater Treatment Systems*

**Sawyer and McCarty:** *Chemistry for Environmental Engineering*

**Steel and McGhee:** *Water Supply and Sewerage*

**Tchobanoglous, Theisen, and Eliassen:** *Solid Wastes; Engineering Principles and  
Management Issues*

Engineers and scientists from a number of related disciplines have been involved in the development of an academic basis for the understanding and management of the environment. The management of water quality has been dealt with in microbiology and sanitary engineering courses; air pollution problems have been covered in chemical and/or mechanical engineering courses; and the management of solid waste, long neglected by academicians, has been chiefly the purvey of those directly responsible for hauling and disposal operations.

During the last 10 to 13 years, schools of engineering have made considerable progress toward bringing the principles drawn from many related academic disciplines together and unifying them under the title *environmental engineering*. Not surprisingly, texts in this relatively new subject area have developed along classical, separatist lines. Thus, there have been a number of texts featuring in-depth treatment of one specific area (i.e., water, air, solid waste) and few texts attempting to treat the subject of environmental engineering as a whole.

The purpose of *Environmental Engineering* is to bring together and integrate in a single text the more general subject matter of the three principal areas of environmental engineering—water, air, and solid-waste management. And, as Chap. 1 indicates, this integration goes beyond binding three texts in a single cover.

*Environmental Engineering* introduces a unique approach to the overall concept of environmental engineering, an approach that emphasizes the relationship between the principles observed in natural purification processes and those employed in engineered processes. First, the physical, chemical, mathematical, and biological principles of defining, quantifying, and measuring environmental quality are described. Next, the processes by which nature assimilates waste material are discussed and the natural purification processes that form the bases of engineered systems are detailed. Finally, the engineering principles and practices involved in the design and operation of conventional environmental engineering works are covered at length.

The breadth and depth of the material in this book precludes complete coverage in a one-semester or one-quarter course. However, the arrangement of the material lends itself to several different course formats.

1. For introductory engineering courses at the sophomore or junior level, Chaps. 1, 2, 3, 7, 8, and 10 provide an overview of the principles involved in environmental engineering systems. These chapters assume a basic knowledge of chemistry, biology, physics, and mathematics. However, because many engineering curricula contain few chemistry and even fewer biology or microbiology courses, the chapters review these subjects in detail. The introductory sections of Chaps. 4, 5, 9, 11, and 12 may be utilized to add relevance to the theoretical discussions. A course following this format will satisfy ABET requirements for engineering science.
2. If the first approach is used for an introductory course, the remaining chapters (4, 5, 6, 9, 11, and 12) can be used as a follow-up course in environmental engineering design. This course should be restricted to engineering students at the junior or senior level who have completed basic fluid mechanics. Such a course would meet ABET's engineering design criteria.
3. A more classical approach would be to use the first six chapters as a text for a one-semester or one-quarter course in water and wastewater engineering. A second one-semester/quarter course on air-pollution control and solid-waste management would use Chaps. 7 through 12. Designed for junior- or senior-level engineering students that have completed basic fluid mechanics, these two courses will meet ABET criteria for engineering design and science, or an approximate one to one ratio.
4. Chapters 1, 2, 3, 7, 8, and 10 can also be used for a companion course in environmental science for nonengineering students, provided allowance is made for the limited mathematical background of the students.

Whatever the approach used, the text should leave students with a clear understanding of the principles of all three of the major areas of environmental engineering. User comments and suggestions concerning the effectiveness of this approach would be greatly appreciated.

The authors wish to acknowledge the fact that development and publication of *Environmental Engineering* would not have been possible without the help and inspiration of our former professors, the challenge and motivation of our students, the assistance and encouragement of our colleagues, the patience and forbearance of our editors, and the support and understanding of our families.

Howard S. Peavy  
Donald R. Rowe  
George Tchobanoglous

---

# **ENVIRONMENTAL ENGINEERING**

---



---

# CONTENTS

---

Preface	xiii
<b>1 Introduction</b>	<b>1</b>
1-1 The Environment	1
1-2 The Impact of Humans upon the Environment	2
1-3 The Impact of the Environment upon Humans	4
1-4 Improvement of Environmental Quality	6
1-5 The Role of the Environmental Engineer	7
References	8

## Part 1 Water

---

<b>2 Water Quality: Definitions, Characteristics, and Perspectives</b>	<b>11</b>
2-1 The Hydraulic Cycle and Water Quality	12
<b>PHYSICAL WATER-QUALITY PARAMETERS</b>	<b>14</b>
2-2 Suspended Solids	15
2-3 Turbidity	17
2-4 Color	18
2-5 Taste and Odor	20
2-6 Temperature	22
<b>CHEMICAL WATER-QUALITY PARAMETERS</b>	<b>23</b>
2-7 Chemistry of Solutions	23
2-8 Total Dissolved Solids	28
2-9 Alkalinity	31
2-10 Hardness	35
2-11 Fluoride	36
2-12 Metals	37
2-13 Organics	38
2-14 Nutrients	44

	<b>BIOLOGICAL WATER-QUALITY PARAMETERS</b>	46
2-15	Pathogens	47
2-16	Pathogen Indicators	50
	<b>WATER QUALITY REQUIREMENTS</b>	54
2-17	In-Stream Standards	54
2-18	Potable Water Standards	55
2-19	Wastewater Effluent Standards	56
	Discussion Topics and Problems	57
	References	62
<b>3</b>	<b>Water Purification Processes in Natural Systems</b>	63
	<b>PHYSICAL PROCESSES</b>	64
3-1	Dilution	64
3-2	Sedimentation and Resuspension	65
3-3	Filtration	66
3-4	Gas Transfer	66
3-5	Heat Transfer	71
	<b>CHEMICAL PROCESSES</b>	73
3-6	Chemical Conversions	73
	<b>BIOCHEMICAL PROCESSES</b>	74
3-7	Metabolic Processes	75
3-8	Microorganisms in Natural Water Systems	79
	<b>RESPONSE OF STREAMS TO BIODEGRADABLE ORGANIC WASTE</b>	83
3-9	Dissolved-Oxygen Balance	83
3-10	Dissolved-Oxygen Model	85
3-11	Organic Discharge and Stream Ecology	94
	<b>APPLICATION OF NATURAL PROCESSES IN ENGINEERED SYSTEMS</b>	98
3-12	Physical Processes	98
3-13	Chemical Processes	99
3-14	Biological Processes	99
	Discussion Topics and Problems	100
	References	103
<b>4</b>	<b>Engineered Systems for Water Purification</b>	104
4-1	Historical Overview of Water Treatment	105
4-2	Water-Treatment Processes	107
	<b>WATER-TREATMENT PROCESSES: THEORY AND APPLICATION</b>	109
4-3	Aeration	110
4-4	Solids Separation	113
4-5	Settling Operations	123
4-6	Coagulation	131
4-7	Softening	151

4-8	Filtration	165
4-9	Disinfection	182
	OTHER WATER-TREATMENT PROCESSES	190
4-10	Dissolved Solids Removal	190
	Discussion Topics and Problems	198
	References	204
<b>5</b>	<b>Engineered Systems for Wastewater Treatment and Disposal</b>	<b>207</b>
5-1	Wastewater Characteristics	208
5-2	Effluent Standards	211
5-3	Terminology in Wastewater Treatment	212
	PRIMARY TREATMENT	217
5-4	Screening	217
5-5	Comminuting	220
5-6	Grit Removal	221
5-7	Flow Measurement	224
5-8	Primary Sedimentation	224
	SECONDARY TREATMENT	229
5-9	Growth and Food Utilization	230
5-10	Suspended-Culture Systems	234
5-11	Activated Sludge	234
5-12	Ponds and Lagoons	248
5-13	Attached-Culture Systems	255
5-14	Secondary Clarification	268
5-15	Disinfection of Effluents	277
	SLUDGE TREATMENT AND DISPOSAL	278
5-16	Sludge Characteristics	279
5-17	Sludge Thickening	281
5-18	Sludge Digestion	285
5-19	Sludge Disposal	292
	ADVANCED WASTEWATER TREATMENT	294
5-20	Nutrient Removal	295
5-21	Solids Removal	301
	WASTEWATER DISPOSAL AND REUSE	302
5-22	Wastewater Disposal	303
5-23	Wastewater Reuse	306
	Discussion Topics and Problems	314
	References	322
<b>6</b>	<b>Environmental Engineering Hydraulics Design</b>	<b>324</b>
	WATER DISTRIBUTION SYSTEMS	324
6-1	Methods of Distributing Water	324
6-2	Distribution Reservoirs	326
6-3	Distribution Systems	331

6-4	Distribution System Components	333
6-5	Capacity and Pressure Requirements	335
6-6	Design of Distribution Systems	337
6-7	Hydraulic Analysis of Distribution Systems	338
6-8	Cross-Connections in Distribution Systems	346
6-9	Construction of Water Distribution Systems	347
6-10	Pumping Required for Water Supply Systems	348
	WASTEWATER COLLECTION	348
6-11	Types of Collection Systems	349
6-12	Types of Sewers	349
6-13	Collection System Appurtenances	353
6-14	Basic Considerations in the Design of Sewers	354
6-15	Design of Sanitary Sewers	360
6-16	Preparation of Contact Drawings and Specifications	369
6-17	Construction of Sewers	371
6-18	Maintenance of Sewers	371
6-19	Design of Stormwater Sewers	371
	WATER AND WASTEWATER PUMPING	372
6-20	Pumps	372
6-21	Pump Drive Units	375
6-22	Pump Application Terminology and Usage	378
6-23	Pump Operating Characteristics and Curves	384
6-24	Analysis of Pump Systems	390
6-25	Pump Stations for Water and Wastewater	397
	HYDRAULIC ANALYSIS OF WATER AND WASTEWATER TREATMENT	397
6-26	Treatment Plant Design	397
6-27	Preparation of Hydraulic Profiles	399
	Discussion Topics and Problems	406
	References	412

## Part 2 Air

---

7	Air Quality: Definitions, Characteristics, and Perspectives	417
	AIR POLLUTION—PAST, PRESENT, AND FUTURE	418
7-1	Historical Overview	418
7-2	Global Implications of Air Pollution	420
7-3	Units of Measurement	424
7-4	Sources of Pollutants	426
	CLASSIFICATION OF POLLUTANTS	429
7-5	Particulates	431
7-6	Hydrocarbons	442
7-7	Carbon Monoxide	445
7-8	Oxides of Sulfur	449

7-9	Oxides of Nitrogen	455
7-10	Photochemical Oxidants	461
7-11	Indoor Air Pollution	463
	<b>AIR-QUALITY MANAGEMENT CONCEPTS</b>	464
	Discussion Topics and Problems	477
	References	480
<b>8</b>	<b>Meteorology and Natural Purification Processes</b>	483
	<b>ELEMENTAL PROPERTIES OF THE ATMOSPHERE</b>	483
8-1	Scales of Motion	484
8-2	Heat	486
8-3	Pressure	491
8-4	Wind	493
8-5	Moisture	495
8-6	Relative Humidity	495
	<b>INFLUENCE OF METEOROLOGICAL PHENOMENA ON AIR QUALITY</b>	495
8-7	Lapse Rates and Dispersion	496
8-8	Pressure Systems and Dispersion	498
8-9	Winds and Dispersion	498
8-10	Moisture and Dispersion	499
8-11	Modeling	499
	<b>EFFECTS OF AIR POLLUTION ON METEOROLOGICAL CONDITIONS</b>	507
8-12	Changes on the Mesoscale and Microscale	508
8-13	Changes on the Macroscale	509
	Discussion Topics and Problems	510
	References	512
<b>9</b>	<b>Engineered Systems for Air Pollution Control</b>	514
9-1	Atmospheric Cleansing Processes	514
9-2	Approaches to Contaminant Control	516
	<b>CONTROL DEVICES FOR PARTICULATE CONTAMINANTS</b>	518
9-3	Gravitational Settling Chambers	520
9-4	Centrifugal Collectors	523
9-5	Wet Collectors	528
9-6	Fabric Filters (Baghouse Filters)	533
9-7	Electrostatic Precipitators (ESP)	536
	<b>CONTROL DEVICES FOR GASEOUS CONTAMINANTS</b>	540
9-8	Adsorption	540
9-9	Absorption	545
9-10	Condensation	557
9-11	Combustion	559
9-12	Automotive Emission Control	563

Discussion Topics and Problems	565
References	567

## Part 3 Solid Waste

---

<b>10 Solid Waste: Definitions, Characteristics, and Perspectives</b>	<b>573</b>
<b>TYPES OF SOLID WASTES</b>	<b>573</b>
10-1 Municipal Wastes	574
10-2 Industrial Wastes	574
10-3 Hazardous Wastes	575
<b>SOURCES OF SOLID WASTES</b>	<b>575</b>
10-4 Sources of Municipal Wastes	575
10-5 Sources of Hazardous Wastes	576
<b>PROPERTIES OF SOLID WASTES</b>	<b>576</b>
10-6 Physical Composition	576
10-7 Chemical Composition	582
10-8 Changes in Composition	588
<b>SOLID-WASTE MANAGEMENT: AN OVERVIEW</b>	<b>588</b>
10-9 Materials Flow in Society	588
10-10 Reduction in Raw Materials Usage	589
10-11 Reduction in Solid-Waste Quantities	590
10-12 Reuse of Solid-Waste Materials	590
10-13 Materials Recovery	591
10-14 Energy Recovery	592
10-15 Day-to-Day Solid-Waste Management	592
Discussion Topics and Problems	592
References	593
<b>11 Engineered Systems for Solid-Waste Management</b>	<b>594</b>
11-1 Functional Elements	594
<b>SOLID WASTE GENERATION</b>	<b>594</b>
11-2 Typical Generation Rates	595
11-3 Estimation of Solid-Waste Quantities	598
11-4 Factors That Affect Generation Rates	598
<b>ON-SITE HANDLING, STORAGE, AND PROCESSING</b>	<b>598</b>
11-5 On-Site Handling	599
11-6 On-Site Storage	599
11-7 On-Site Processing of Solid Wastes	601
<b>COLLECTION OF SOLID WASTES</b>	<b>601</b>
11-8 Collection Services	601
11-9 Types of Collection Systems	605

11-10	Determination of Vehicle and Labor Requirements	607
11-11	Collection Routes	615
	<b>TRANSFER AND TRANSPORT</b>	618
11-12	Transfer Stations	620
11-13	Location of Transfer Stations	622
11-14	Transfer Means and Methods	622
	<b>PROCESSING TECHNIQUES</b>	626
11-15	Mechanical Volume Reduction	627
11-16	Thermal Volume Reduction	627
11-17	Manual Component Separation	627
	<b>ULTIMATE DISPOSAL</b>	628
11-18	Landfilling with Solid Wastes	628
11-19	Design and Operation of Landfills	638
11-20	Landfarming	646
11-21	Deep-Well Injection	647
	Discussion Topics and Problems	648
	References	652
<b>12</b>	<b>Engineered Systems for Resource and Energy Recovery</b>	653
	<b>PROCESSING TECHNIQUES</b>	653
12-1	Mechanical Size Alteration	654
12-2	Mechanical Component Separation	656
12-3	Magnetic and Electromechanical Separation	656
12-4	Drying and Dewatering	657
	<b>MATERIALS-RECOVERY SYSTEMS</b>	657
12-5	Materials Specifications	657
12-6	Processing and Recovery Systems	657
12-7	System Design and Layout	659
	<b>RECOVERY OF BIOLOGICAL CONVERSION PRODUCTS</b>	659
12-8	Composting (Aerobic Conversion)	660
12-9	Anaerobic Digestion	663
	<b>RECOVERY OF THERMAL CONVERSION PRODUCTS</b>	665
12-10	Combustion of Waste Materials	665
12-11	Incineration with Heat Recovery	670
12-12	Use of Refuse-Derived Fuels (RDF)	671
12-13	Gasification	671
12-14	Pyrolysis	672
	<b>RECOVERY OF ENERGY FROM CONVERSION PRODUCTS</b>	672
12-15	Energy-Recovery Systems	673
12-16	Efficiency Factors	674
12-17	Determination of Energy Output and Efficiency	675

<b>MATERIALS- AND ENERGY-RECOVERY SYSTEMS</b>	<b>675</b>
Discussion Topics and Problems	677
References	677

**Appendixes**

<b>A</b> Quantities and Units	<b>679</b>
<b>B</b> Conversion Factors	<b>683</b>
<b>C</b> Properties of Water and Air	<b>693</b>
<b>D</b> Water Quality Standards	<b>696</b>

**Indexes**

Name Index	11
Subject Index	



## INTRODUCTION

Environmental engineering has been defined as the branch of engineering that is concerned with protecting the environment from the potentially deleterious effects of human activity, protecting human populations from the effects of adverse environmental factors, and improving environmental quality for human health and well-being. [1-2]

As the above definition implies, humans interact with their environment—sometimes adversely impacting the environment and sometimes being adversely impacted by pollutants in the environment. An understanding of the nature of the environment and of human interaction with it is a necessary prerequisite to understanding the work of the environmental engineer.

### 1-1 THE ENVIRONMENT

Simply stated, the environment can be defined as one's surroundings. In terms of the environmental engineer's involvement, however, a more specific definition is needed. To the environmental engineer, the word *environment* may take on global dimensions, may refer to a very localized area in which a specific problem must be addressed, or may, in the case of contained environments, refer to a small volume of liquid, gaseous, or solid materials within a treatment plant reactor.

The global environment consists of the atmosphere, the hydrosphere, and the lithosphere in which the life-sustaining resources of the earth are contained. The *atmosphere*, a mixture of gases extending outward from the surface of the earth, evolved from elements of the earth that were gasified during its formation and metamorphosis. The *hydrosphere* consists of the oceans, the lakes and streams, and the shallow groundwater bodies that interflow with the surface water. The *lithosphere* is the soil mantle that wraps the core of the earth.

The *biosphere*, a thin shell that encapsulates the earth, is made up of the atmosphere and lithosphere adjacent to the surface of the earth, together with the