

WATER REUSE

ISSUES, TECHNOLOGIES, AND APPLICATIONS

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Water Reuse

Issues, Technologies, and Applications

Metcalf & Eddy / AECOM

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This book is dedicated to Metcalf & Eddy's James Anderson, who died of cancer in March 2006 and was therefore unable to see this book through to publication.

As Director of Technology, Jim was responsible for Metcalf & Eddy's research program and for the continued development of our textbooks. It was through his vision of the importance of water reuse in strategic water resources management that this book was brought to fruition. Jim also understood the need to train environmental engineering professionals and Metcalf & Eddy's commitment to do its part as originally conceived and carried out by Leonard Metcalf and Harrison P. Eddy nearly 100 years ago.

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Preface

With many communities approaching the limits of their available water supplies, water reclamation and reuse has become a logical option for conserving and extending available water supply by potentially (1) substituting reclaimed water for applications that do not require drinking (potable) water, (2) augmenting existing water sources and providing an additional source of water supply to assist in meeting both present and future water needs, (3) protecting aquatic ecosystems by decreasing the diversion of freshwater as well as reducing the quantity of nutrients and other toxic contaminants entering waterways, (4) postponing and reducing the need for water control structures, and (5) complying with environmental regulations by better managing water consumption and wastewater discharges. The increasing importance and recognition of water reclamation and reuse have led to the need for specialized instruction of engineering and science students in their undergraduate and graduate levels, as well as practicing engineers and scientists, and a technical reference for project managers and government officials. Aside from the need for a textbook on water reuse applications and the technologies used to treat and distribute reclaimed water, there is also the need to address the special considerations of public health, project planning and economics, public acceptance, and the diverse uses of reclaimed water in society.

ORGANIZATION OF THE TEXTBOOK AND CONTENT

This textbook, *Water Reuse: Issues, Technologies, and Applications*, is an endeavor by the authors to assemble, analyze, and synthesize a vast amount of information on water reclamation and reuse. To deal with the amount of available material, the book is organized into five parts, each dealing with a coherent body of information which is described below.

Part 1: Water Reuse: An Introduction

It is important to understand the concept of sustainable water resources management as a foundation for water reclamation and reuse. Thus, in Part 1 of this textbook, current and potential future water shortages, principles of sustainable water resources management, and the important role of water reclamation and reuse are introduced briefly. The past and current practices of water reclamation and reuse are presented, which also serve as an introduction to the subsequent engineering and water reuse applications chapters.

Part 2: Health and Environmental Concerns in Water Reuse

Health and environmental issues related to water reuse are discussed in three related chapters in Part 2. The characteristics of wastewater are introduced, followed by a discussion of the applicable regulations and their development. Because health risk analysis is an important aspect of water reuse applications, a separate chapter is devoted to this subject including tools and methods used in risk assessment, chemical risk assessment, and microbial risk assessment.

Part 3: Water Technologies and Systems for Water Reclamation and Reuse

The various technologies and systems available for the production and delivery of reclaimed water are the subject of Part 3. Although design values are presented, detailed design is not the focus of these chapters. Rather, the focus is on the dependable performance of the processes and technologies. Detailed discussions are provided with respect to constituents of concern in water reuse applications including particulate matter, dissolved constituents, and pathogenic microorganisms. Another important aspect of water reclamation is related to meeting stringent water quality performance requirements as affected by wastewater variability and process reliability, factors which are emphasized repeatedly throughout this textbook.

Part 4: Water Reuse Applications

Because water quality and infrastructure requirements vary greatly with specific water reuse application, major water reuse applications are discussed in separate chapters in Part 4: nonpotable water reuse applications including agricultural uses, landscape irrigation, industrial uses, environmental and recreational uses, groundwater recharge, and urban nonpotable and commercial uses. Indirect and direct potable reuses are discussed with several notable projects. Groundwater recharge can be considered as a form of indirect potable reuse if the recharged aquifer is interconnected to potable water production wells.

Part 5: Implementing Water Reuse

In the final Part 5 of this textbook, the focus is on planning and implementation for water reuse. Integrated water resources planning, including reclaimed water market assessment, and economic and financial analyses are presented. As technology continues to advance and cost effectiveness and the reliability of water reuse systems becomes more widely recognized, water reclamation and reuse plans and facilities will continue to expand as essential elements in sustainable water resources management. Implementation issues in water reclamation and reuse are discussed including soliciting and responding to community concerns, development of public support through educational programs, and the development of financial instruments.

IMPORTANT FEATURES OF THIS TEXTBOOK

To illustrate the principles, applications, and facilities involved in the field of water reclamation and reuse, more than 350 data and information tables and 80 detailed worked examples, more than 500 illustrations, graphs, diagrams, and photographs are included. To help the readers of this textbook hone their analytical skills and mastery of the material, problems and discussion topics are included at the end of each chapter. Selected references are also provided for each chapter.

The International System (SI) of Units is used in this textbook. The use of SI units is consistent with teaching practice in most universities in the United States and in most countries throughout the world.

To further increase the utility of this textbook, several appendixes have been included. Conversion factors from SI Units to U.S. Customary Units and the reverse are presented in Appendixes A-1 and A-2, respectively. Conversion factors used commonly for the analysis and design of water and wastewater management systems are presented in Appendix A-3. Abbreviations for SI and U.S. Customary Units are presented in Appendixes A-4 and A-5, respectively. Physical characteristics of air and selected gases

and water are presented in Appendixes B and C, respectively. Statistical analysis of data with an example is presented in Appendix D.

Milestone water reuse projects and research studies in the United States and a summary of water reclamation and reuse in selected countries of the world are presented in Appendixes E-1 and E-2, respectively. Evolution of nonpotable reuse criteria and groundwater recharge regulations in California is presented in Appendix F. Dimensionless well function $W(u)$ values are presented in Appendix G. Finally, interest factors and their use are presented and illustrated in Appendix H.

With recent Internet developments, it is now possible to view many of the facilities discussed in this textbook through satellite images using one of the many search engines available on the Internet. Where appropriate, global positioning coordinates for water reuse facilities of interest are given to allow viewing of these facilities in their natural setting.

USE OF THIS TEXTBOOK

Enough material is presented in this textbook to support a variety of courses for one or two semesters or three quarters at either the undergraduate or graduate level. The specific topics to be covered will depend on the time available and the course objectives. Three suggested course plans are presented below.

Course Plan I

Course Title:	Survey of Water Reuse
Setting:	1 semester or 1 quarter, stand-alone class
Target:	Upper division or MS, environmental science major
Course Objectives:	Introduce important considerations influencing water reuse planning and implementation.

Sample outline:

Topic	Chapters	Sections
Introduction to water reuse	1, 2	All
Wastewater characteristics	3	3-1, 3-2, 3-5 to 3-8
Regulations for water reuse	4	4-1 to 4-7
Public health protection and risk assessment	5	5-1 to 5-5, 5-9
Introduction to water reclamation technologies	6	All
Infrastructure for water reuse	12, 13, 14, 15	12-1, 12-2, 13-1, 13-2, 13-6, 14-1, 14-2, 15-1, 15-2
Overview of disinfection for reuse applications	11	11-1, 11-2
Introduction to water reuse applications	16	All
Perspectives on water reuse planning	25	25-1 to 25-4
Perspectives on public acceptance	26	26-1 to 26-3

Course Plan II

Course Title: Water Reuse Applications
 Setting: 1 semester or 1 quarter class
 Target: Upper division or MS, environmental engineering major
 Course Objectives: Introduce nonconventional engineering aspects of water reuse including satellite, decentralized, and onsite treatment and reuse systems. An overview of various water reuse applications are introduced.

Sample outline:

Topic	Chapters	Sections
Introduction to water reclamation and reuse	1, 2	1-1 to 1-5, 2-1
Wastewater characteristics	3	3-1, 3-2, 3-5 to 3-8
Water reuse regulations and guidelines	4	4-1 to 4-4, 4-6 to 4-8
Public health protection and risk assessment	5	5-1 to 5-5, 5-8, 5-9
Introduction to water reclamation technologies	6	6-1 to 6-5
Overview of disinfection for reuse applications	11	11-1, 11-2
Introduction to water reuse applications	16	All
Reclaimed water use for irrigation	17, 18	17-1 to 17-3, 18-1 to 18-2, 18-4 to 18-5
Reclaimed water use for industrial processes	19	19-1 to 19-3
Urban nonirrigation, environmental, and recreational uses	20, 21	20-1, 20-2, 21-1
Indirect potable reuse by groundwater and surface water augmentation	22, 23	22-1 to 22-2, 22-7, 23-1 to 23-3, 23-8
Economic and financial analysis	25	25-6 to 25-9
Public participation and public acceptance	25, 26	25-3, 26-1 to 26-3

Course Plan III

Course Title: Advanced Treatment Technologies and Infrastructure for Water Reuse Applications
 Setting: 1 semester or 1 quarter class
 Target: MS level, environmental engineering major
 Course Objectives: Introduce treatment technologies important in water reuse. Introduce reliability issues, concept of probability distribution in assessing disinfection performance, and future directions. The course will be a stand-alone class on advanced treatment, or part of a wastewater treatment class that covers both conventional and advanced technologies emphasizing water reclamation, recycling, and reuse.

This textbook is a useful supplement to a companion textbook, *Wastewater Engineering: Treatment and Reuse*, 4th ed., (Tchobanoglous, G., F.L. Burton, and H.D. Stensel) for the following topics:

Sample outline:

Topic	Chapters	Sections
Introduction to water reuse	1, 2	All
Wastewater characteristics	3	3-1, 3-2, 3-5 to 3-8
Introduction to water reclamation and reuse	6, 16	6-2 to 6-4, 16-1 to 16-4
Membrane filtration, membrane bioreactor	7, 8	7-5, 7-6, 8-5
Nanofiltration, reverse osmosis, and electrodialysis	9	9-1 to 9-4
Adsorption, Advanced oxidation	10	10-1, 10-2, 10-6, 10-7
Disinfection	11	11-1 to 11-3, 11-5, 11-6, 11-8
Alternative systems for water reuse	12, 13	12-1, 12-2, 13-1, 13-2, 13-6,
Infrastructure for water reuse	14, 15	14-1, 14-2, 15-1 to 15-3

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This textbook, *Water Reuse: Issues, Technologies, and Application* is a tribute to the pioneering planners and engineers who were able to look ahead of their time and push forward the frontiers of water reclamation and reuse from obscure practice to a growing discipline in sustainable water resources management. Based on the widespread acceptance of water reuse and the development of new treatment technologies and applications, it is an appropriate time to produce a comprehensive textbook on the subject. A book of this magnitude, however, could not have been written without the assistance of numerous individuals, some are acknowledged below and others who remain in the background. The authors are particularly grateful to many individuals who contributed the information through personal contacts and the “grey” literature as well as conference and symposium proceedings.

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