SECOND EDITION

Water Resources Engineering

Larry W. Mays

Water Resources Engineering

Second Edition

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Water Resources Engineering

About the Author

Larry W. Mays is Professor in the Civil, Environmental, and Sustainable Engineering Group in the School of Sustainable Engineering and the Built Environment at Arizona State University (ASU), and former chair of the Department of Civil and Environmental Engineering. Prior to ASU he was Director of the Center for Research in Water Resources at the University of Texas at Austin, where he held an Engineering Foundation–endowed professorship. A registered professional engineer in several states, and a registered professional hydrologist, he has served as a consultant to many national and international organizations.

Professor Mays has published extensively in refereed journal publications and in the proceedings of national and international conferences. He was the author of the first edition of this book and *Optimal Control of Hydrosystems* (published by Marcel Dekker), and co-author of *Applied Hydrology* and *Hydrosystems Engineering and Management* (both from McGraw-Hill) and *Groundwater Hydrology* (published by John Wiley & Sons, Inc). He was editor-in-chief of *Water Resources Handbook, Water Distribution Systems Handbook, Urban Water Supply Management Tools, Stormwater Collection Systems Design Handbook, Urban Water Supply Handbook, Urban Stormwater Management Tools, Hydraulic Design Handbook, Water Supply Systems Security*, and *Water Resources Sustainability*, all published by McGraw-Hill. In addition, he was editor-in-chief of *Reliability Analysis of Water Distribution Systems* and co-editor of *Computer Methods of Free Surface and Pressurized Flow* published by Kluwer Academic Publishers.

Professor Mays developed the book, *Integrated Urban Water Management: Arid and Semi-arid Regions*, published by Taylor and Francis. This book was the result of volunteer work for the United Nations UNESCO-IHP in Paris. He recently was editor of the fourth edition of *Water Transmission and Distribution*, published by the American Water Works Association.

One of his major efforts is the study of ancient water systems and the relation that these systems could have on solving our problems of water resources sustainability using the concepts of traditional knowledge, not only for the present, but the future. His most recent book is *Ancient Water Technology*, published by Springer Science and Business Media, The Netherlands.

Among his honors is a distinguished alumnus award from the Department of Civil and Engineering at the University of Illinois at Champaign-Urbana and he is a Diplomate, Water Resources Engineering of the American Academy of Water Resources Engineering. He is also a Fellow of the American Society of Civil Engineers and the International Water Resources Association. He loves the mountains where he enjoys alpine skiing, hiking, and fly-fishing. In addition he loves photographing ancient water systems around the world and gardening. Professor Mays lives in Mesa, Arizona and Pagosa Springs, Colorado.

Acknowledgments

Water Resources Engineering is the result of teaching classes over the past 34 years at the University of Texas at Austin and Arizona State University. So first and foremost, I would like to thank the many students that I have taught over the years. Several of my past Ph.D. students have helped me in many ways through their review of the material and help in development of the solutions manual. These former students include Drs. Aihua Tang, Guihua Li, John Nicklow, Burcu Sakarya, Kaan Tuncok, Carlos Carriaga, Bing Zhao, El Said Ahmed, and Messele Ejeta. I would like to give special thanks to Professor Y.K. Tung of the Hong Kong University of Science and Technology. He has been a long time friend and was my very first Ph.D. student at the University of Texas at Austin. Y. K. was very gracious in providing me with some of the end of chapter problems for the hydrology chapters. I would like to acknowledge Arizona State University, especially the time afforded me to pursue this book.

I would like to thank Wayne Anderson for originally having faith in me through his willingness to first publish the book and now Jenny Welter who has worked to get this edition published.

During my academic career as a professor I have received help and encouragement from so many people that it is not possible to name them all. These people represent a wide range of universities, research institutions, government agencies, and professions. To all of you I express my deepest thanks.

Water Resources Engineering has been a part of a personal journey that began years ago when I was a young boy with a love of water. This love of water resources has continued throughout my life, even in my spare time, being an avid snow skier, fly-fisherman and hiker. Books are companions along the journey of learning and I hope that you will be able to use this book in your own exploration of the field of water resources. Have a wonderful journey.

Larry W. Mays
Mesa, Arizona
Pagosa Springs, Colorado

I would like to dedicate this book to humanity and human welfare.

Preface

AUDIENCE

Water Resources Engineering can be used for the first undergraduate courses in hydraulics, hydrology, or water resources engineering and for upper level undergraduate and graduate courses in water resources engineering design. This book is also intended as a reference for practicing hydraulic engineers, civil engineers, mechanical engineers, environmental engineers, and hydrologists.

TOPICAL COVERAGE

Water resources engineering, as defined for the purposes of this book, includes both water use and water excess management. The fundamental water resources engineering processes are the hydrologic processes and the hydraulic processes. The common threads that relate to the explanation of these processes are the fundamentals of fluid mechanics using the control volume approach. The hydraulic processes include pressurized pipe flow, open-channel flow, and groundwater flow. Each of these in turn can be subdivided into various processes and types of flow. The hydrologic processes include rainfall, evaporation, infiltration, rainfall-runoff, and routing, all of which can be further subdivided into other processes. Knowledge of the hydrologic and hydraulic processes is extended to the design and analysis aspects. This book, however, does not cover the water quality management aspects of water resources engineering.

HISTORY OF WATER RESOURCES DEVELOPMENT

Water resources development has had a long history, basically beginning when humans changed from being hunters and food gatherers to developing of agriculture and settlements. This change resulted in humans harnessing water for irrigation. As humans developed, they began to invent and develop technologies, and to transport and manage water for irrigation. The first successful efforts to control the flow of water were in Egypt and Mesopotamia. Since that time humans have continuously built on the knowledge of water resources engineering. This book builds on that knowledge to present state-of-the-art concepts and practices in water resources engineering.

NEW TO THIS EDITION

The *Second Edition* provides the most up-to-date information along with a remarkable range and depth of coverage. In addition to other changes, two new chapters have been added that explore water resources sustainability and water resources management for sustainability:

Chapter 2: Water Resources Sustainability, defines water resources sustainability, discusses challenges and specific examples of water resources systems, as well as examples of water resources unsustainability.

Chapter 19: Water Resources Management for Sustainability, introduces the idea of integrated water resources management, law related to water resources, methodologies for both arid and semi-arid regions, economics, systems analysis techniques, and uncertainty and risk-reliability analysis for sustainable design.

Principles of Flow in Hydrosystems, which was previously Chapter 2 in the *First Edition*, has now been integrated with Chapter 3 in the *Second Edition.*

Homework Problems: There are over 300 new problems in the *Second Edition*, resulting in a total of over 670 end-of-chapter problems, expanding the applications to which students are exposed.

New and updated graphics and photos: Over 50 new diagrams, maps and photographs have been integrated throughout the chapters to reinforce important concepts, and support student visualization and appreciation of water resources systems and engineering.

HALLMARK FEATURES

Breadth and Depth: The text includes a breadth and depth of topics appropriate for undergraduate courses in hydraulics, hydrology, or water resources engineering, or as a comprehensive reference for practicing engineers.

Control Volume Approach: Hydrologic and hydraulic processes are explained through their relationship to the control volume approach in fluid mechanics.

Visual program: Hundreds of diagrams, maps, and photographs illustrate concepts, and reinforce the importance and applied nature of water resources engineering.

CHAPTER ORGANIZATION

Water Resources Engineering is divided into five subject areas: Water Resources Sustainability, Hydraulics, Hydrology, Engineering Analysis and Design for Water Use, and Engineering Analysis and Design for Water Excess Management.

Water resources sustainability includes: Chapter 1 which is an introduction to water resources sustainability; Chapter 2 addresses water resources sustainability; and Chapter 19 water resources management for sustainability. Chapter 11 on water withdrawals and uses, Chapter 13 on water for hydroelectric generation, and Chapter 14 on water excess management also contain material related to water resources sustainability.

Hydraulics consists of five chapters that introduce the basic processes of hydraulics: Chapter 3 presents a basic fluid mechanics review and the control volume approach for continuity, energy, and momentum; and Chapters 4, 5, and 6 cover pressurized flow, open-channel flow, and groundwater flow, respectively. Chapter 18 covers the basics of sedimentation and erosion hydraulics.

Hydrology is covered in four chapters: Chapter 7 on hydrologic processes; Chapter 8 on rainfall-runoff analysis; Chapter 9 on routing; and Chapter 10 on probability and frequency analysis.

Engineering analysis and design for water use consists of three chapters: Chapter 11 on water withdrawals and uses; Chapter 12 on water distribution systems; and Chapter 13 on water for hydroelectric generation.

Engineering analysis and design for water excess management includes four chapters: Chapter 14 on water excess management; Chapter 15 on stormwater control using storm sewers and detention; Chapter 16 on stormwater control using street and highway drainage and culverts; and Chapter 17 on the design of hydraulic structures for flood control storage systems.

COURSE SUGGESTIONS

Several first courses could be taught from this book: a first course on hydraulics, a first course on hydrology, a first course on water resources engineering analysis and design, and a first course on hydraulic design. The flowcharts on the following pages illustrate the topics and chapters that could be covered in these courses.

This is a comprehensive book covering a large number of topics that would be impossible to cover in any single course. This was done purposely because of the wide variation in the manner in which faculty teach these courses or variations of these courses. Also, to make this book more valuable to the practicing engineer or hydrologist, the selection of these topics and the extent of coverage in each chapter were considered carefully. I have attempted to include enough example problems to make the theory more applicable, more understandable, and most of all more enjoyable to the student and engineer.

Students using this book will most likely have had an introductory fluid mechanics course based on the control volume approach. Chapter 3 should serve as a review of basic fluid concepts and the control volume approach. Control volume concepts are then used in the succeeding chapters to introduce the hydrologic and hydraulic processes. Even if the student or engineer has not had an introductory course in fluid mechanics, this book can still be used, because the concepts of fluid mechanics and the control volume approach are covered.

MOTIVATION

I sincerely hope that this book will be a contribution toward the goal of better engineering in the field of water resources. I constantly remind myself of the following quote from Baba Diodum: "In the end we will conserve only what we love, we will love only what we understand, and we will understand only what we are taught."

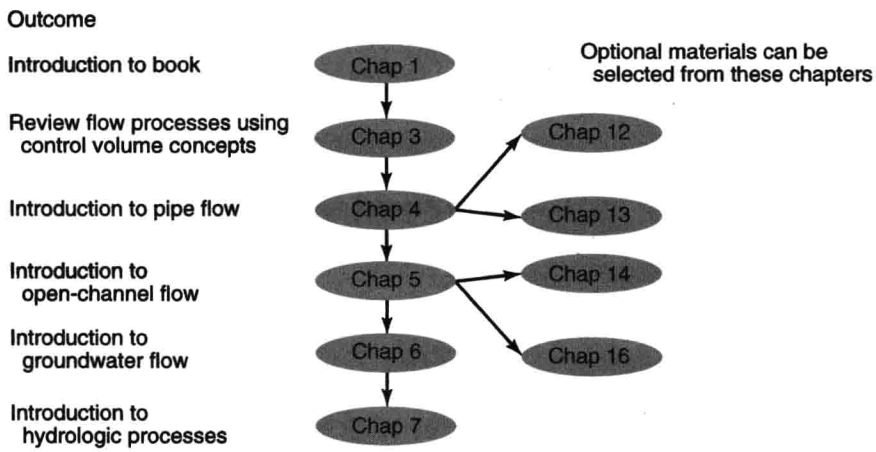
This book has been another part of a personal journey of mine that began as a young boy with an inquisitive interest and love of water, in the streams, creeks, ponds, lakes, rivers, and oceans, and water as rain and snow. Coming from a small Illinois town situated between the Mississippi and Illinois Rivers near Mark Twain's country, I began to see and appreciate at an early age the beauty, the useful power, and the extreme destructiveness that rivers can create. I hope that this book will be of value in your journey of learning about water resources.

WEB SITE

The Web site for this book is located at www.wiley.com/college/mays and includes the following resources:

- *Errata listing*: a list of any corrections that may be found in this book.
- *Figures from text*: non-copyrightable figures are available for making lecture slides or transparencies.
- *Solutions Manual for Instructors*: Includes solutions to all problems in the book. This resource is password-protected, and available only to instructors who have adopted this book for their course. Visit the Instructor Companion site portion of the Web site at www.wiley.com/college/mays to register for a password.

First Undergraduate Hydraulics Course



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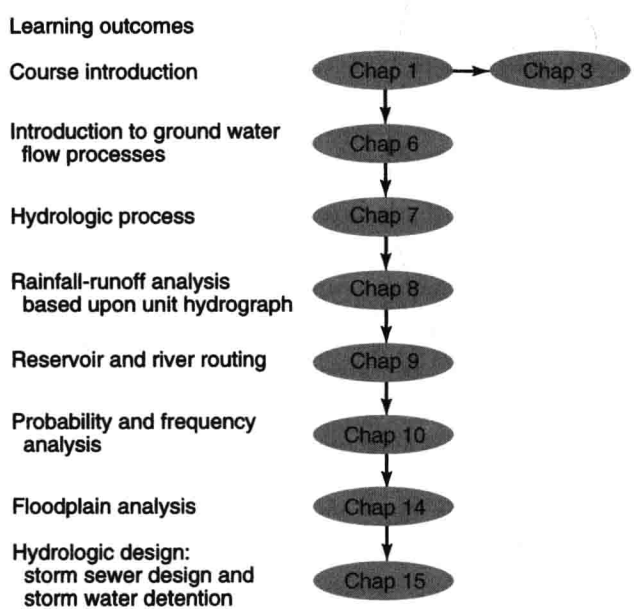

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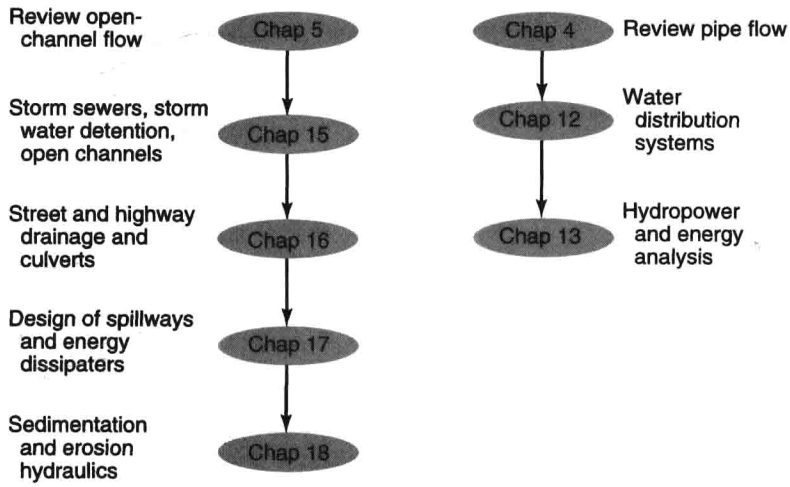
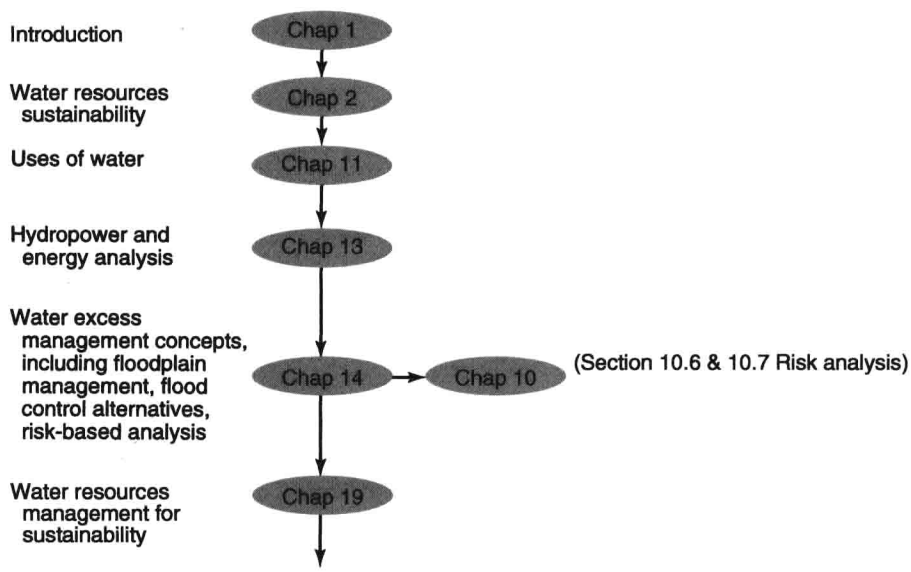


Water Resources Engineering and Sustainability



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