McGRAW-HILL SERIES IN
WATER RESOURCES AND
ENVIRONMENTAL ENGINEERING

WASTEWATER ENGINEERING: TREATMENT DISPOSAL REUSE

SECOND EDITION

METCALF & EDDY, INC.

Revised by
GEORGE TCHOBANOGLOUS
Professor of Civil Engineering
University of California, Davis

McGRAW-HILL BOOK COMPANY

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

WASTEWATER ENGINEERING
TREATMENT, DISPOSAL, REUSE

234567890KPKP7832109

This book was set in Times Roman. The editors were Frank J. Cerra
and J. W. Maisel; the production supervisor was Dominick Petrellese.
New drawings were done by J & R Services, Inc.
Kingsport Press, Inc., was printer and binder.

Library of Congress Cataloging in Publication Data

Metcalf and Eddy, Boston.
Wastewater engineering.

(McGraw-Hill series in water resources and environmental engineering)
Bibliography: p.
Includes index.
1. Sewerage. 2. Sewage disposal.
I. Tchobanoglous, George. II. Title.
TD645.M57 1979 628'.2 78-6173
ISBN 0-07-041677-X

PREFACE

Following the widespread acceptance and use of *Wastewater Engineering: Collection, Treatment, Disposal*, and the many developments in the field since it was first written, we felt that an update of the book that included use of the metric system was advisable. This second edition has been prepared (1) to keep pace with the new technical development in the field of environmental engineering since the publication of the first edition, (2) to reflect the impact of recent federal legislation dealing with water quality and pollution control, (3) to provide leadership in the wider adoption and use of the metric International System of Units (or SI, for short) in the design and analysis of treatment facilities, and most importantly (4) to make the book more useful for students, teachers, practicing engineers, and other users.

To meet the objectives established for the second edition, it was necessary to revise and rewrite the first edition completely. Because the basic data and information related to the treatment, disposal, and reuse of wastewater and sludge has expanded so dramatically in the past 6 years, the chapters in the first edition that deal with collection and pumping of wastewater have been omitted from this edition. Accordingly, the subtitle of this edition has been changed to *Treatment, Disposal, Reuse*.

The chapters that have been removed are to be issued along with new material as a separate textbook entitled *Collection and Pumping of Wastewater*. The space made available by the omission of these chapters is being taken up by new material and expanded coverage of first-edition material.

Passage of the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500) has had a major impact on wastewater engineering. New material presented in this edition reflects the changes brought about by the law. With the establishment for the first time of national goals and objectives, greater emphasis has been placed on reuse of wastewater and land disposal. A new chapter on land-treatment systems addresses the important engineering aspects associated with the treatment and disposal of wastewater and sludge on land.

Most of the world is now using some form of metric units. For this reason and because the United States is using them more and more, this edition uses the SI system along with conversions to U.S. customary units. Inasmuch as both sets of units will be in use for some time to come, we have given complete conversion tables in Appendix A. To increase the usefulness of the text, we have furnished conversions from metric-unit data to U.S. customary units in footnotes to all tables.

To make this second edition more useful as a teaching and reference text, a number of significant changes have been made. To provide the reader with a general introduction to the field of wastewater engineering, a new chapter on wastewater treatment objectives, methods, and design has been provided. The material in this chapter is intended to serve as an introduction to the chapters that follow it. Discussions dealing with fundamentals of process analysis have been gathered together and amplified under the heading "Fundamentals of Process Analysis." And to reflect current knowledge and practice, presentations of the fundamentals of the unit operations and processes used for the treatment of wastewater have all been revised. Sections dealing with the solids flux analysis for the design of secondary settling facilities and the preparation of solids balances for alternative treatment flowsheets are cited as two examples of the many new topics that have been included in this edition.

In addition, more than 60 tables containing a summary of design data and information are included. To illustrate basic concepts and physical applications more clearly, approximately 200 drawings and 90 photographs are furnished. Of this number, about 120 of the drawings and essentially all the photographs are new.

Different example problems have been prepared for this edition, with units carried through all the computational steps to facilitate the reader's understanding of the principles involved. Where appropriate, comments are included at the end of an example problem to elucidate basic concepts and highlight additional applications. To make this edition more useful, it has been reorganized such that the concepts and principles are stated clearly so that the transition from basic principles to design applications follows a more logical sequence. All these factors have contributed to making this book a more complete presentation of wastewater engineering and management by the profession of consulting engineering.

Rolf Eliassen
Chairman of the Board
Metcalf & Eddy, Inc.

George Tchobanoglous
Professor of Civil Engineering
University of California, Davis

ACKNOWLEDGMENTS

Metcalf & Eddy, Inc., is fortunate in having had the services of Dr. George Tchobanoglous as consultant on many important engineering projects over the past decade. But we believe that his greatest contribution to the firm—and, it is hoped, to the profession of wastewater engineering—is this complete revision and expansion of the first edition of our book. His devotion to this task entailed far more than conceptual design and writing. He had responsibility for the entire project, including coordination of the activities, reviews, and contributions of many of the members of the staffs of our Boston and Palo Alto offices.

No undertaking of the magnitude involved in the preparation of this new edition can be accomplished alone. Thus it is with grateful appreciation that we acknowledge the assistance of the following individuals. From the Palo Alto office, Ronald W. Crites served as coordinator for the project, also being responsible for the preparation of Chapter 13 on land-treatment systems. Franklin L. Burton read portions of the manuscript and made technical and editorial comments. Donald J. Schroeder helped secure photographs and checked metric units. Arthur L. Holland coordinated standardization of the figures, most of which were drawn by Diosdado C. Cantimbuhan. In addition to typing the final manuscript, Donald F. Newton made valuable editorial contributions. Marcella S. Tennant served again as general technical editor. Her editing skills are reflected throughout the text, especially in its readability.

Personnel from the Boston office reviewed the manuscript to ensure its consistency with current practice and provided much of the information given in the summary tables. Francis C. Sampson was in charge of the Boston review. David P. Bova served as general coordinator: he reviewed all the chapters and was responsible for providing much of the data used in preparation of tables. Abu M. Z. Alam, Bradley W. Behrman, Stephen L. Bishop, John G. Chalas, Joseph Goss, David S. Graber, Frank M. Gunby, Jr., Winfield A. Peterson, Francis C. Tyler, and Jakobs P. Vittands reviewed various chapters. Randolf A. Johnson helped with the photographs. Allen J. Burdoin, a consultant to Metcalf & Eddy, reviewed and revised portions of the manuscript.

Other individuals who reviewed various sections and contributed to the preparation of this text include Takashi Asano, Max E. Burchett, Jeffrey R. Hauser, Larry J. Karns, Edward D. Schroeder, Sam A. Vigil, and George E. Wilson. Mark R. Matsumoto reviewed all the example problems and checked the metric units. Rosemary Tchobanoglous typed the rough draft and provided moral support. Professor Edward Foree of the University

of Kentucky reviewed the manuscript for the publisher and made valuable editorial suggestions.

We also wish to acknowledge the many constructive comments received from teachers, as well as practicing engineers, who used the first edition. Wherever possible, we have incorporated their suggestions in this revised edition.

Finally, we acknowledge our gratitude to Peter J. Gianacakes, president of Metcalf & Eddy, Inc., for his leadership on this edition and his commitment of the resources of the firm to the accomplishment of this important task.

Rolf Eliassen
Chairman of the Board
Metcalf & Eddy, Inc.

CONTENTS

CHAPTER

ONE

WASTEWATER ENGINEERING: AN OVERVIEW

Every community produces both liquid and solid wastes. The liquid portion—wastewater—is essentially the water supply of the community after it has been fouled by a variety of uses. From the standpoint of sources of generation, wastewater may be defined as a combination of the liquid or water-carried wastes removed from residences, institutions, and commercial and industrial establishments, together with such groundwater, surface water, and storm water as may be present.

If untreated wastewater is allowed to accumulate, the decomposition of the organic materials it contains can lead to the production of large quantities of malodorous gases. In addition, untreated wastewater usually contains numerous pathogenic or disease-causing microorganisms that dwell in the human intestinal tract or that may be present in certain industrial wastes. It also contains nutrients, which can stimulate the growth of aquatic plants, and it may contain toxic compounds. For these reasons, the immediate and nuisance-free removal of wastewater from its sources of generation, followed by treatment and disposal, is not only desirable but also necessary in an industrialized society. In the United States, it is now mandated by numerous federal and state laws.

Wastewater engineering is that branch of environmental engineering in which the basic principles of science and engineering are applied to the problems of water-pollution control. The ultimate goal—wastewater management—is the protection of the environment in a manner commensurate with economic, social, and political concerns.

To provide an initial perspective of the treatment, disposal, and reuse of wastewater, a brief review of the historical background, current status, and expected new directions in these areas of wastewater engineering is presented in