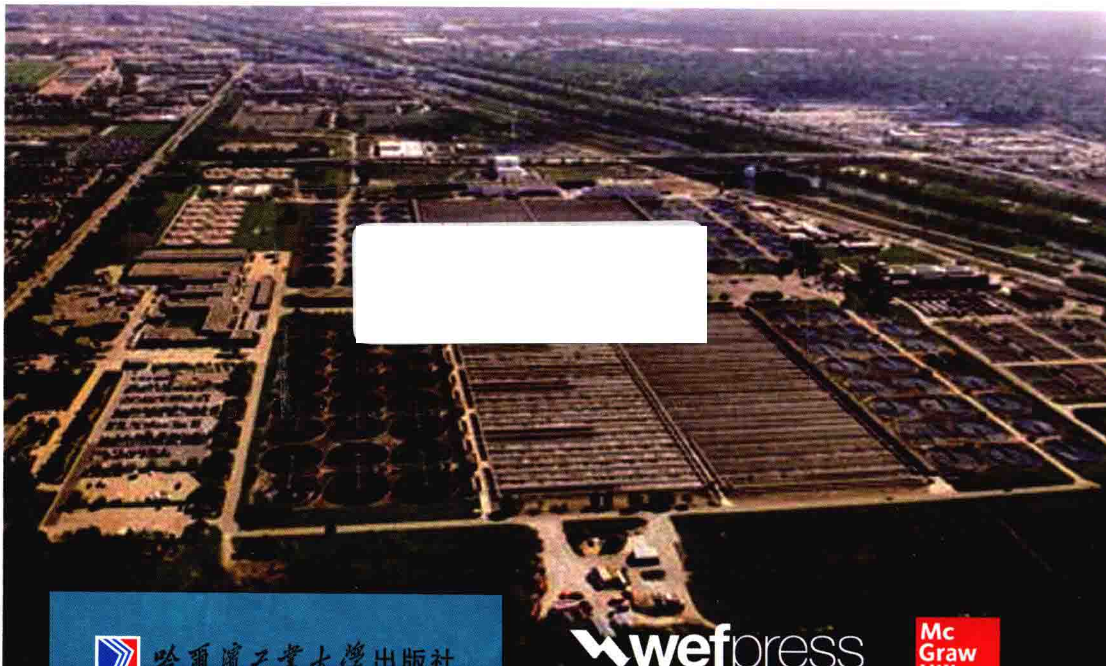
THIRD EDITION

Shun Dar Lin

WATER AND WASTEWATER CALCULATIONS MANUAL

水和废水计算手册 上册

影印版



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影印版说明

Shun Dar Lin 博士是世界水和废水处理领域权威的知名科学家之一，拥有近60年的理论研究和工程实践经验，*Water and Wastewater Calculations Manual*（3rd Ed.）就是在此基础上编写的。

本手册由 WEF(Water Environment Federation) 组织，由美国 McGraw-Hill Education 公司出版，第一版于 2001 年面市，此后一直受到专业人士的好评和关注。为飨读者，我社特将 2014 年最新版——第三版进行了原文影印，以期让读者在最短时间内了解该领域的最新动态。

本手册不仅有比较深入的理论和实践介绍，提供了地表水、地下水、饮用水处理和废水处理工程中的基本原则、最佳实践以及计算的详细方法，而且提供了大量计算题，使读者易于理解和学习书中介绍的计算方法。

本手册给出了大量案例，其解决方案是基于实际的现场数据和最新的协会标准而确定的。

本手册包含了 130 多幅插图和 100 多个表格，读者可以很快地在其中找到所需的关键数据。

本手册可作为给水排水工程、环境工程等专业科技人员的工具书，也可作为相关专业人士的学习参考书。

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Water and Wastewater Calculations Manual

Shun Dar Lin

Third Edition

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New York Chicago San Francisco
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Singapore Sydney Toronto

ABOUT THE AUTHOR

Shun Dar Lin, Ph.D., is one of the world's leading water and wastewater scientists with more than 50 years of practical and academic experience in the field. He is Professor Emeritus at the University of Illinois at Urbana-Champaign. A registered professional engineer in Illinois and in Taiwan. Dr. Lin has published more than 100 papers, articles, and reports related to water and wastewater engineering, and to water resources. He has taught and conducted research since 1960 at the Institute of Public Health of the National Taiwan University. In 1986, Dr. Lin received the Water Quality Division Best Paper Award for "*Giardia lamblia* and Water Supply" from the American Water Works Association. He developed the enrichment-temperature acclimation method for recovery enhancement of stressed fecal coliform which has been adopted in the *Standard Methods for the Examination of Water and Wastewater* since the 18th Edition (1990). Dr. Lin is a life member of the American Society of Civil Engineers, the American Water Works Association, and the Water Environment Federation. He currently serves on many Task Force Committees for the *Standard Methods*. Dr. Lin was appointed by the Governor of Illinois to the Illinois Pollution Control Board as a Board Member (2008-2010). He is a consultant to the governments of Taiwan and the United States and for private firms.

ABOUT WEF

Founded in 1928, the Water Environment Federation (WEF) is a not-for-profit technical and educational organization of 36,000 individual members and 75 affiliated Member Associations representing water quality professionals around the world. WEF members, Member Associations and staff proudly work to achieve our mission to provide bold leadership, champion innovation, connect water professionals, and leverage knowledge to support clean and safe water worldwide. To learn more, visit www.wef.org.

Cover: *The Stickney Water Reclamation Plant in Cicero, Illinois, shown in 2013. The facility is owned and operated by the Metropolitan Water Reclamation District of Greater Chicago (MWRD). Stickney is the largest wastewater treatment facility in the world and serves 2.38 million people in a 260 square mile area including the central part of Chicago and 43 suburban communities.*

Preface

This manual presents the basic principles and concepts relating to water/wastewater engineering and provides illustrative examples of the subject covered. To the extent possible, examples rely on practical field data and regulatory requirements have been integrated into the environmental design process. Each of the calculations provided herein is solved step-by-step in a streamlined manner that is intended to facilitate understanding. Examples (step-by-step solutions) range from calculations commonly used by operators to more complicated calculations required for research or design. For calculations provided herein using the US customary units, readers who use the International System may apply the conversion factors listed in Appendix E. Answers are also generally given in SI units for most of problems solved by the US customary units.

This book has been written for use by the following readers: students taking coursework relating to "Public Water Supply," "Wastewater Engineering," and "Stream Sanitation"; practicing environmental (sanitary) engineers; regulatory officers responsible for the review and approval of engineering project proposals; operators, engineers, and managers of water and/or wastewater treatment plants; and other professionals, such as chemists and biologists, who need some knowledge of water/wastewater issues. This work will benefit all operators and managers of public water supply and of wastewater treatment plants, environmental design engineers, military environmental engineers, undergraduate and graduate students, regulatory officers, local public works engineers, lake managers, and environmentalists.

Advances and improvements in many fields are driven by competition or the need for increased profits. It may be fair to say, however, that advances and improvements in environmental engineering are driven instead by regulation. The US Environmental Protection Agency (US EPA) sets up maximum contaminant levels, which research and project designs must reach as a goal. The step-by-step solution examples provided in this book are guided by the integration of rules and regulations on every aspect of water and wastewater. The author has performed an extensive literature survey as well as with his 50 years environmental engineering experiences on natural water, drinking water supply, and wastewater treatments to compile them in this book. Rules and regulations are described as simply as possible, and practical examples are given.

The text includes calculations for surface water, groundwater, drinking water treatment, and wastewater engineering. Chapter 1 comprises calculations for river and stream waters. Stream sanitation had been studied for nearly 100 years. By mid-twentieth century, theoretical and empirical models for assessing waste-assimilating capacity of streams were well developed. Dissolved oxygen and biochemical oxygen demand in streams and rivers have been comprehensively illustrated in this book. Apportionment of stream users and pragmatic approaches for stream dissolved oxygen models also first appeared in this manual. From the 1950s through the 1980s, researchers focused extensively on wastewater treatment. In the 1970s, rotating biological contactors became a hot subject. Design criteria and examples for all of these are included in this volume. Some treatment and management technologies are no longer suitable in the United States. However, they are still of some use in developing countries. Chapter 1 is a comprehensive documentation on evaluation of water qualities of streams and reservoirs.

Chapter 2 is a compilation of adopted methods and documented research. In the early 1980s, the US EPA published Guidelines for Diagnostic and Feasibility Study of Public Owned Lakes (Clean Lakes Program, or CLP). This was intended to be as a guideline for lake management. CLP and its calculation (evaluation) methods are presented for the first time in this volume. Hydrological, nutrient, and sediment budgets and evaporation are presented for reservoir and lake waters. Techniques for conducting diagnostic/feasibility study on lakes and reservoirs, classification of lake water quality, and assessment of the lake trophic state index, and lake use support are also presented.

Calculations for groundwater are given in Chapter 3. They include groundwater hydrology, flow in aquifers, pumping and its influence zone, setback zone, and soil remediation. Well setback zone is regulated by the state EPA. Determinations of setback zones are also included in the book. Well function for confined aquifers is presented in Appendix B.

Hydraulics for environmental engineering is included in Chapter 4. This chapter covers fluid (water) properties and definitions, hydrostatics, fundamental concepts of water flow in pipes, weirs, orifices, and in open channels, and flow measurements. Pipe networks for water supply distribution systems and hydraulics for water and wastewater treatment plants are also included.

Chapters 5 and 6 cover the unit process for drinking water and wastewater treatments, respectively. The US EPA developed design criteria and guidelines for almost all unit processes. These two chapters depict the integration of regulations (or standards) into water and wastewater design procedures. Drinking water regulations and membrane filtration are updated in Chapter 5. The section of "Health Risks" has been deleted in this edition. For the interested readers, please refer to the second edition. Pellet softing and log-removed by disinfection are unique in this book. Calculations for log-removal of pathogens are illustrated. Although the pellet softening process is not accepted in the United States, it has been successfully used in many other countries. It is believed that this is the first presentation of pellet softening in US environmental engineering books.

The collection and treatment (conventional and advanced) are covered in Chapter 6. Sludge treatments and biosolid manaagement (uses and disposal) are also included. Complecated calculations for the application of biosolids on agricultural lands are presented. Chapters 5 and 6 are the heart of the book and provide the theoretical considerations of unit processes, traditional (or empirical) design concepts, and integrated regulatory requirements. Drinking water quality standards, wastewater effluent standards, and several new examples have also been added.

The current edition corrects certain computational, typographical, and grammatical errors found in the previous edition.

Dr. Achlesh Daverey and Prof. Jih-Gaw Lin, both of National Chiao Tung University, Hsinchu, Taiwan, and Mr. Der-ming Lee of Leaderman & Associates Co, Taipei, Taiwan, prepared the draft of Section 28.4, SNAD process. Maggi Lan of Leaderman & Associates Co. provided the data inputs for the SNAD process. Raghavi Khullar did excellent editing the final draft. Amy Stonrbreaker of McGraw-Hill managed this project. The author also wishes to acknowledge Meiling Lin, for typing the manuscript. Ben Movahed, President of WATEK Engineering, reviewed a part of the section of membrane filtration. Alex Ya Ching Wu, Plant Manager of Cheng-Ching Lake Advanced Water Purification Plant in Taiwan, provided the operational manual for pellet softening. Jessica Moorman, Editor of *Water & Waste Digest*, provided 2006 drinking water regulatory updates. Thanks to Dr. Chuan-jui Lin, Dr. C. Eddie Tzeng, Nancy Simpson, Jau-hwan Tzeng, Heather Lin, Christine Murphy (in Brazil), Tracy Pierceall, and Karen Swanson. Robert Greenlee, Luke Lin, Kevin Lin, and Lucy Lin for their assistance. Any reader suggestions and comments will be greatly appreciated.

SHUN DAR LIN
Chicago, Illinois

Contents

Chapter

1

Streams and Rivers

1 General

This chapter presents calculations on stream sanitation. The main portion covers the evaluation of water assimilative capacities of rivers or streams. The procedures include classical conceptual approaches and pragmatic approaches: the conceptual approaches use simulation models, whereas Butts and his coworkers (1973, 1974, 1981) of the Illinois State Water Survey use a pragmatic approach. Observed dissolved oxygen (DO) and biochemical oxygen demand (BOD) levels are measured at several sampling points along a stream reach. Both approaches are useful for developing or approving the design of wastewater treatment facilities that discharge their effluents into a stream.

In addition, biological factors such as algae, indicator bacteria, diversity index, and macroinvertebrate biotic index are also presented.

2 Point Source Dilution

Point source pollutants are commonly regulated by a deterministic model for an assumed design condition having a specific probability of occurrence. A simplistic dilution and/or balance equation can be written as

$$C_d = \frac{Q_u C_u + Q_e C_e}{Q_u + Q_e} \tag{1.1}$$

where C_d = completely mixed constituent concentration downstream of the effluent, mg/L

Q_u = stream flow upstream of the effluent, cubic feet per second, cfs or m^3/s

C_u = constituent concentration of upstream flow, mg/L

Q_e = flow of the effluent, cfs or m^3/s

C_e = constituent concentration of the effluent, mg/L

Under the worst case, a 7-day, 10-year low flow is generally used for stream flow condition, for design purposes.

Example: A power plant pumps 27 cfs from a stream, with a flow of 186 cfs. The discharge of the plant's ash-pond is 26 cfs. The boron concentrations for upstream water and the effluent are 0.051 and 8.9 mg/L, respectively. Compute the boron concentration in the stream after completely mixing.

solution: By Eq. (1.1)

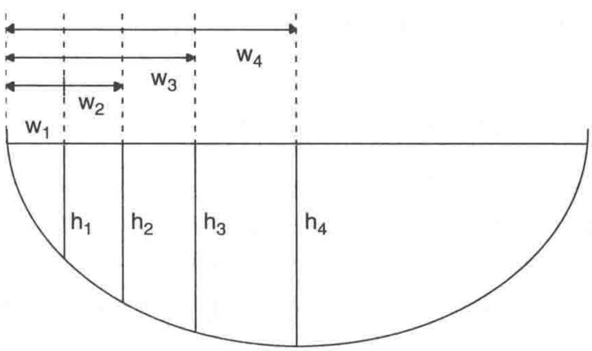
$$C_{\mathrm{d}} = \frac{Q_{\mathrm{u}}C_{\mathrm{u}} + Q_{\mathrm{e}}C_{\mathrm{e}}}{Q_{\mathrm{u}} + Q_{\mathrm{e}}}$$

$$= \frac{(186 - 27)(0.051) + 26 \times 8.9}{(186 - 27) + 26}$$

$$= 1.29 \text{ (mg/L)}$$

3 Discharge Measurement

Discharge (flow rate) measurement is very important to provide the basic data required for river or stream water quality. The total discharge for a stream can be estimated by float method with wind and other surface effects, by die study, or by actual subsection flow measurement, depending on cost, time, manpower, local conditions, etc. The discharge in a stream cross section can be measured from a subsection by the following formula:



$$Q = \text{Sum (mean depth} \times \text{width} \times \text{mean velocity)}$$

$$Q = \sum_{n=1}^{n} \frac{1}{2}(h_n + h_{n-1}) \times (w_n - w_{n-1}) \times \frac{1}{2}(v_n + v_{n-1}) \tag{1.2}$$

TABLE 1.1 Velocity and Discharge Measurements and Discharge Calculations

(1) Distance from 0, ft	(2) Depth, ft	(3) Velocity, ft/s	(4) Width, ft	(5) Mean depth, ft	(6) Mean velocity, ft/s	(7) = (4) × (5) × (6) Discharge, cfs
0	0	0				
2	1.1	0.52	2	0.55	0.26	0.3
4	1.9	0.84	2	1.50	0.68	2.0
7	2.7	1.46	3	2.30	1.15	7.9
10	3.6	2.64	3	3.15	2.05	19.4
14	4.5	4.28	4	4.05	3.46	56.1
18	5.5	6.16	4	5.00	5.22	104.4
23	6.6	8.30	5	6.05	7.23	349.9
29	6.9	8.88	6	6.75	8.59	302.3
35	6.5	8.15	6	6.70	7.52	302.3
40	6.2	7.08	5	6.35	6.62	210.2
44	5.5	5.96	4	5.85	6.52	152.2
48	4.3	4.20	4	4.90	5.08	99.6
50	3.2	2.22	2	3.75	3.21	24.1
52	2.2	1.54	2	2.70	1.88	10.2
54	1.2	0.75	2	1.45	1.15	3.3
55	0	0	1	0.35	0.38	0.1
						1559.0*

*The discharge is 1559 cfs.

If equal width w

$$Q = \sum_{n=1}^{n} \frac{w}{4}(h_n + h_{n-1})(v_n + v_{n-1}) \tag{1.2a}$$

where Q = discharge, cfs or m^3/s
w_n = nth distance from initial point 0, ft or m
h_n = nth water depth, ft or m
v_n = nth velocity, ft/s or m/s

Velocity v is measured by a velocity meter, of which there are several types.

Example: Data obtained from the velocity measurement are listed in the first three columns of Table 1.1. Determine the flow rate at this cross section.

solution: Summarized field data and complete computations are shown in Table 1.1. The flow rate is 1559 cfs.

4 Time of Travel

The time of travel can be determined by dye study or by computation. The river time of travel and stream geometry characteristics can be computed using a volume displacement model. The time of travel is determined at any specific reach as the channel volume of the reach divided by the flow as follows:

$$t = \frac{V}{Q} \times \frac{1}{86{,}400} \tag{1.3}$$

where t = time of travel at a stream reach, days
V = stream reach volume, ft^3 or m^3
Q = average stream flow in the reach, ft^3/s(cfs) or m^3/s
86,400 = a factor, s/day

Example: The cross-sectional areas at river miles 62.5, 63.0, 63.5, 64.0, 64.5, and 64.8 are, respectively, 271, 265, 263, 259, 258, and 260 ft^2 at a surface water elevation. The average flow is 34.8 cfs. Find the time of travel for a reach between river miles 62.5 and 64.8.

solution:

Step 1. Find average area in the reach

$$\begin{aligned}\text{Average area} &= \frac{1}{6}(271 + 265 + 263 + 259 + 258 + 260)\ \text{ft}^2\\ &= 262.7\ \text{ft}^2\end{aligned}$$

Step 2. Find volume

$$\begin{aligned}\text{Distance of the reach} &= (64.8 - 62.5)\ \text{miles}\\ &= 2.3\ \text{miles} \times 5280\ \frac{\text{ft}}{\text{mile}}\\ &= 12{,}144\ \text{ft}\\ V &= 262.7\ \text{ft}^2 \times 12{,}144\ \text{ft}\\ &= 3{,}190{,}000\ \text{ft}^3\end{aligned}$$

Step 3. Find t

$$\begin{aligned}t &= \frac{V}{Q} \times \frac{1}{86{,}400}\\ &= \frac{3{,}190{,}000\ \text{ft}^3}{34.8\ \text{ft}^3/\text{s} \times 86{,}400\ \text{s/d}}\\ &= 1.06\ \text{days}\end{aligned}$$

5 Dissolved Oxygen and Water Temperature

Dissolved oxygen (DO) and water temperature are most commonly in situ monitored parameters for surface waters (rivers, streams, lakes, reservoirs, wetlands, oceans, etc.). DO concentration in milligrams per