THIRD EDITION

Shun Dar Lin

WATER AND WASTEWATER CALCULATIONS MANUAL

水和废水计算手册 上册

影印版

哈爾濱工業大學出版社
HARBIN INSTITUTE OF TECHNOLOGY PRESS

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黑版贸审字08-02014-094号

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ISBN 978-0-07-181981-7
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图书在版编目（CIP）数据

水和废水计算手册：第3版 = Water and wastewater calculations manual : third edition. 上册：英文 /（美）林顺达主编. —影印本. —哈尔滨 : 哈尔滨工业大学出版社，2015.6
ISBN 978-7-5603-5053-0

Ⅰ. ①水… Ⅱ. ①林… Ⅲ. ①水处理 - 手册 - 英文 ②废水处理 - 手册 - 英文
Ⅳ. ①TU991.2-62 ②X703-62

中国版本图书馆CIP数据核字(2014)第280087号

材料科学与工程
图书工作室

责任编辑 杨 桦 许雅莹 张秀华
出版发行 哈尔滨工业大学出版社
社 址 哈尔滨市南岗区复华四道街10号 邮编 150006
传 真 0451-86414749
网 址 http://hitpress.hit.edu.cn
印 刷 哈尔滨市石桥印务有限公司
开 本 660mm × 980mm 1/16 印张 20
版 次 2015 年 6 月第 1 版 2015 年 6 月第 1 次印刷
书 号 ISBN 978-7-5603-5053-0
定 价 100.00元

（如因印刷质量问题影响阅读，我社负责调换）

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

New York Chicago San Francisco
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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

Preface 11

上册

Chapter 1. Streams and Rivers 1

1 General 2
2 Point Source Dilution 2
3 Discharge Measurement 3
4 Time of Travel 4
5 Dissolved Oxygen and Water Temperature 5
6 Biochemical Oxygen Demand Analysis 10
7 Streeter–Phelps Oxygen Sag Formula 13
8 BOD Models and K_1 Computation 14
9 Determination of Reaeration Rate Constant K_2 41
10 Sediment Oxygen Demand 49
11 Organic Sludge Deposits 52
12 Photosynthesis and Respiration 54
13 Natural Self-Purification in Streams 55
14 SOD of DO Usage 78
15 Apportionment of Stream Users 79
16 Velz Reaeration Curve (a Pragmatic Approach) 87
17 Stream DO Model (a Pragmatic Approach) 92
18 Biological Factors 107
References 121

Chapter 2. Lakes and Reservoirs 125

1 Lakes and Impoundment Impairments 125
2 Lake Morphometry 126
3 Water Quality Models 130
4 Evaporation 131
5 The Clean Lakes Program 137
References 176

Chapter 3. Groundwater 179

1 Definition 180
2 Hydrogeologic Parameters 184
3 Steady Flows in Aquifers 195
4 Anisotropic Aquifers 197
5 Unsteady (Nonequilibrium) Flows 198
6 Groundwater Contamination 211
7 Setback Zones 217
References 224

Chapter 4. Fundamental and Treatment Plant Hydraulics 227

1 Definitions and Fluid Properties 228
2 Water Flow in Pipes 236
3 Pumps 265
4 Water Flow in Open Channels 272
5 Flow Measurements 291
References 306

中册

Chapter 5. Public Water Supply 307

1 Sources and Quantity of Water 308
2 Population Estimates 311
3 Water Requirements 315
4 Regulations for Water Quality 321
5 Water Treatment Processes 343
6 Aeration and Air Stripping 345
7 Solubility Equilibrium 370
8 Coagulation 373
9 Flocculation 382
10 Sedimentation 386
11 Granular Media Filtration 396
12 Membrane Processes 407
13 Water Softening 450
14 Ion Exchange 463
15 Iron and Manganese Removal 481
16 Activated Carbon Adsorption 486
17 Residual from Water Plant 490
18 Disinfection 495
19 Water Fluoridation 539
References 547

下册

Chapter 6. Wastewater Engineering 553

1 What Is Wastewater? 555
2 Characteristics of Wastewater 555
3 Sewer Systems 564

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4 Quantity of Wastewater 567
5 Urban Stormwater Management 571
6 Design of Storm Drainage Systems 573
7 Precipitation and Runoff 573
8 Stormwater Quality 578
9 Sewer Hydraulics 584
10 Sewer Appurtenances 584
11 Pumping Stations 590
12 Sewer Construction 594
13 Wastewater Treatment Systems 596
14 Screening Devices 603
15 Comminutors 608
16 Grit Chamber 608
17 Flow Equalization 610
18 Sedimentation 614
19 Primary Sedimentation Tanks 629
20 Biological (Secondary) Treatment Systems 639
21 Activated-Sludge Process 643
22 Trickling Filter 718
23 Rotating Biological Contactor 733
24 Dual Biological Treatment 748
25 Stabilization Ponds 748
26 Secondary Clarifier 757
27 Effluent Disinfection 764
28 Advanced Wastewater Treatment 774
29 Sludge (Residuals) Treatment and Management 824
30 Wetlands 889
References 912

Appendix A. Illinois Environmental Protection Agency's Macroinvertebrate Tolerance List 921

Appendix B. Well Function for Confined Aquifers 927

Appendix C. Solubility Product Constants for Solution at or near Room Temperature 933

Appendix D. Freundlich Adsorption Isotherm Constants for Toxic Organic Compounds 937

Appendix E. Factors for Conversion 941

Index 946

Chapter

1

Streams and Rivers

1	General	2
2	Point Source Dilution	2
3	Discharge Measurement	3
4	Time of Travel	4
5	Dissolved Oxygen and Water Temperature	5
	5.1 Dissolved oxygen saturation	7
	5.2 Dissolved oxygen availability	9
6	Biochemical Oxygen Demand Analysis	10
7	Streeter–Phelps Oxygen Sag Formula	13
8	BOD Models and K_1 Computation	14
	8.1 First-order reaction	15
	8.2 Determination of deoxygenation rate and ultimate BOD	18
	8.3 Temperature effect on K_1	32
	8.4 Second-order reaction	37
9	Determination of Reaeration Rate Constant K_2	41
	9.1 Basic conservation	41
	9.2 From BOD and oxygen sag constants	43
	9.3 Empirical formulas	45
	9.4 Stationary field monitoring procedure	46
10	Sediment Oxygen Demand	49
	10.1 Relationship of sediment characteristics and SOD	51
	10.2 SOD versus DO	51
11	Organic Sludge Deposits	52
12	Photosynthesis and Respiration	54
13	Natural Self-Purification in Streams	55
	13.1 Oxygen sag curve	55
	13.2 Determination of k_r	62
	13.3 Critical point on oxygen sag curve	64
	13.4 Simplified oxygen sag computations	77
14	SOD of DO Usage	78
15	Apportionment of Stream Users	79
	15.1 Method 1	81
	15.2 Method 2	83
	15.3 Method 3	85

16 Velz Reaeration Curve (a Pragmatic Approach) 87
16.1 Dissolved oxygen used 87
16.2 Reaeration 87
17 Stream DO Model (a Pragmatic Approach) 92
17.1 Influence of a dam 92
17.2 Influence of tributaries 95
17.3 DO used 98
17.4 Procedures of pragmatic approach 99
18 Biological Factors 107
18.1 Algae 107
18.2 Indicator bacteria 109
18.3 Macroinvertebrate biotic index 120
References 121

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)

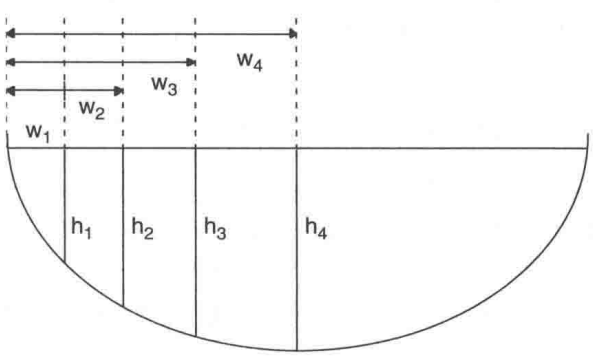
$$C_d = \frac{Q_u C_u + Q_e C_e}{Q_u + Q_e}$$

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

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

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:



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

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

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

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

$$= 262.7\ ft^2$$

Step 2. Find volume

$$\text{Distance of the reach} = (64.8 - 62.5)\ \text{miles}$$

$$= 2.3\ \text{miles} \times 5280\ \frac{ft}{\text{mile}}$$

$$= 12{,}144\ ft$$

$$V = 262.7\ ft^2 \times 12{,}144\ ft$$

$$= 3{,}190{,}000\ ft^3$$

Step 3. Find t

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

$$= \frac{3{,}190{,}000\ ft^3}{34.8\ ft^3/s \times 86{,}400\ s/d}$$

$$= 1.06\ \text{days}$$

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

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