THIRD EDITION

WATER AND WASTEWATER CALCULATIONS MANUAL

Shun Dar Lin

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for the water quality professional

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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.

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Water and Wastewater Calculations Manual

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

$$C_{\mathrm{d}} = \frac{Q_{\mathrm{u}}C_{\mathrm{u}} + Q_{\mathrm{e}}C_{\mathrm{e}}}{Q_{\mathrm{u}} + Q_{\mathrm{e}}} \tag{1.1}$$

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.

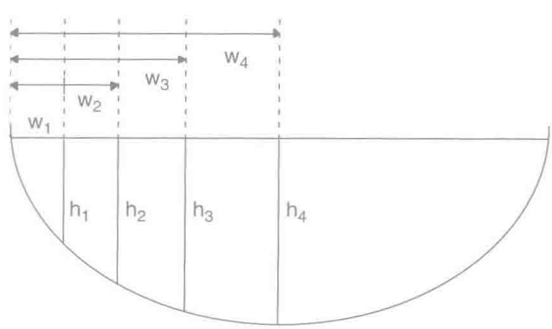
Example: A power plant pumps 27 cfs from a stream, with a flow of 186 cfs. The discharge of the plant's ash-pond is 26 cfs. The boron concentrations for upstream water and the effluent are 0.051 and 8.9 mg/L, respectively. Compute the boron concentration in the stream after completely mixing.

solution: By Eq. (1.1)

$$
\begin{aligned}
C_{\rm d} &= \frac{Q_{\rm u}C_{\rm u} + Q_{\rm e}C_{\rm e}}{Q_{\rm u} + Q_{\rm e}} \\
&= \frac{(186 - 27)(0.051) + 26 \times 8.9}{(186 - 27) + 26} \\
&= 1.29 \text{ (mg/L)}
\end{aligned}
$$

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

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

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 liter (mg/L) is a measurement of the amount of oxygen dissolved in water. It can be determined with a DO meter or by a chemical titration method.

The DO in water has an important impact on aquatic animals and plants. Most aquatic animals, such as fish, require oxygen in the water to survive. The two major sources of oxygen in water are from diffusion from the atmosphere across the water surface and the photosynthetic oxygen production from aquatic plants such as algae and macrophytes. Important factors that affect DO in water (Fig. 1.1) may include water temperature, aquatic plant photosynthetic activity, wind and wave mixing, organic contents of the water, and sediment oxygen demand.

Excessive growth of algae (bloom) or other aquatic plants may provide very high concentration of DO, so called supersaturation. On the other hand, oxygen deficiencies can occur when plant respiration depletes oxygen beyond the atmospheric diffusion rate. This can occur especially during the winter ice cover period and when intense decomposition of organic matter in the lake bottom sediment occurs during the summer. These oxygen deficiencies will result in fish being killed.

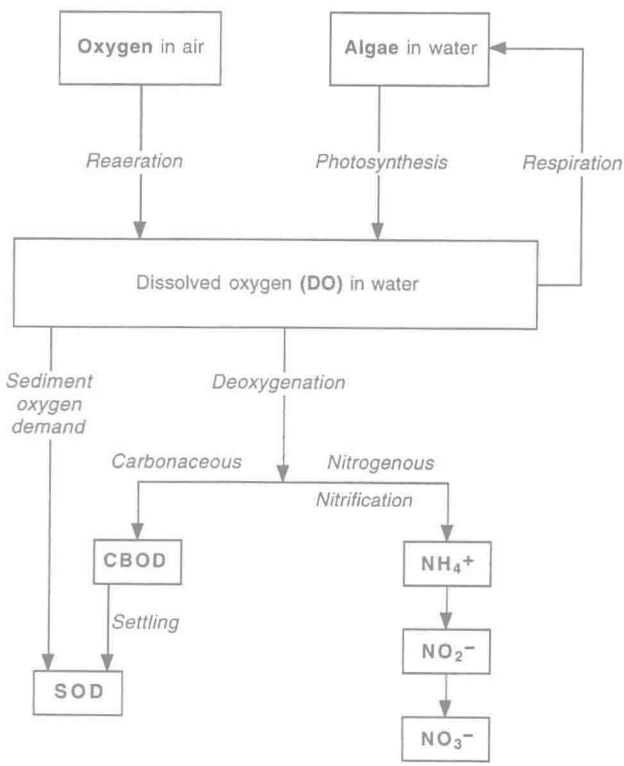


Figure 1.1 Factors affecting dissolved oxygen concentration in water.

5.1 Dissolved oxygen saturation

DO saturation (DO_{sat}) values for various water temperatures can be computed using the American Society of Civil Engineers' formula (American Society of Civil Engineering Committee on Sanitary Engineering Research, 1960):

$$DO_{sat} = 14.652 - 0.41022T + 0.0079910T^2 - 0.000077774T^3 \quad (1.4)$$

where DO_{sat} = dissolved oxygen saturation concentration, mg/L
T = water temperature, °C

This formula represents saturation values for distilled water ($\beta = 1.0$) at sea level pressure. Water impurities can increase the saturation level ($\beta > 1.0$) or decrease the saturation level ($\beta < 1.0$), depending on the surfactant characteristics of the contaminant. For most cases, β is assumed to be unity. The DO_{sat} values calculated from the above formula are listed in Table 1.2 (example: DO_{sat} = 8.79 mg/L, when T = 21.3°C) for water temperatures ranging from zero to 30°C (American Society of Engineering Committee on Sanitary Engineering Research, 1960).

Example 1: Calculate DO saturation concentration for a water temperature at 0, 10, 20, and 30°C, assuming $\beta = 1.0$.

solution:

(a) At T = 0°C

$$\begin{aligned} DO_{sat} &= 14.652 - 0 + 0 - 0 \\ &= 14.652 \text{ (mg/L)} \end{aligned}$$

(b) At T = 10°C

$$\begin{aligned} DO_{sat} &= 14.652 - 0.41022 \times 10 + 0.0079910 \times 10^2 - 0.000077774 \times 10^3 \\ &= 11.27 \text{ (mg/L)} \end{aligned}$$

(c) At T = 20°C

$$\begin{aligned} DO_{sat} &= 14.652 - 0.41022 \times 20 + 0.0079910 \times 20^2 - 0.000077774 \times 20^3 \\ &= 9.02 \text{ (mg/L)} \end{aligned}$$

(d) At T = 30°C

$$\begin{aligned} DO_{sat} &= 14.652 - 0.41022 \times 30 + 0.0079910 \times 30^2 - 0.000077774 \times 30^3 \\ &= 7.44 \text{ (mg/L)} \end{aligned}$$

The DO saturation concentrations generated by the formula must be corrected for differences in air pressure caused by air temperature changes and