THIRD EDITION

Shun Dar Lin

WATER AND WASTEWATER CALCULATIONS MANUAL

水和废水计算手册 中册

影印版

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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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Chapter

5

Public Water Supply

1 Sources and Quantity of Water

The sources of a water supply may include rainwater, surface waters, and groundwater. During the water cycle, rainwater recharges the surface waters and groundwater. River, stream, natural pond, impoundment, reservoir, and lake waters are major surface water sources. Some communities use groundwater, such as galleries, wells, aquifers, and springs as their water supply sources.

Water supplies may be drawn from a single source or from a number of different ones. The water from multiple sources could be mixed before distribution or separately distributed. Any new source water has to be approved by the federal, state, and related authorities. The quantity of water needed varies with season, geography, size and type of community, and culture. A water supply system may provide for domestic, industrial and commercial, public services, fire demands,

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Runoff refers to the precipitation that reaches a stream or river. Theoretically, every unit volume of water passing the observation station should be measured, and the sum of all these units passing in a certain period of time would be the total runoff. However, this value is not available due to cost. Observations should be carried out at reasonably close intervals so that the observed flow over a long period of time is the sum of flows for the individual shorter periods of observation and not the sum of the observed rates of flow multiplied by the total period.

Example 1: Records of observations during a month (30 days) period show a flow rate 2.3 cfs (0.065 m^3/s) for 8 days, 3.0 cfs (0.085 m^3/s) for 10 days, 56.5 cfs (16.0 m^3/s) for 1 day, 12.5 cfs (0.354 m^3/s) for 2 days, 5.3 cfs (0.150 m^3/s) for 6 days, and 2.65 cfs (0.075 m^3/s) for 3 days. What is the mean flow rate?

solution:

$$Q = \frac{2.3 \times 8 + 3.0 \times 10 + 56.5 \times 1 + 12.5 \times 2 + 5.3 \times 6 + 2.65 \times 3}{30}$$

$$= 5.66\ (\text{ft}^3/\text{s})$$

$$= 0.160\ \text{m}^3/\text{s}$$

Example 2: The mean annual rainfall is 81 cm (32 in). A horizontal projected roof area is 300 m^2 (3230 ft^2). Make a rough estimate of how much water can be caught.

solution:

Step 1. Calculate annual gross yield, V_y

$$V_y = 300\ \text{m}^2 \times 0.81\ \text{m/yr} = 243\ \text{m}^3/\text{yr}$$

$$= 0.666\ \text{m}^3/\text{d}$$

Step 2. Estimate net yield V_n

According to Fair *et al.* (1966), $V_n = \frac{2}{3} V_y$

$$V_n = \frac{2}{3} V_y = \frac{2}{3}(243\ \text{m}^3/\text{yr}) = 162\ \text{m}^3/\text{yr}$$

$$= 0.444\ \text{m}^3/\text{d}$$

Step 3. Estimate the water that can be stored and then used, V_u

$$V_u = 0.5V_n = 0.5(162\ \text{m}^3/\text{yr}) = 81\ \text{m}^3/\text{yr}$$

or $= 2860\ \text{ft}^3/\text{yr}$

$$= 0.5(0.444\ \text{m}^3/\text{d}) = 0.222\ \text{m}^3/\text{d}$$

or $= 7.83\ \text{ft}^3/\text{d}$

Example 3: Determine the rainfall-runoff relationship.

Using a straight line method of calculating average. The given values are as follows:

Year	Rainfall, in	Runoff, cfs/miles^2
1988	15.9	26.5
1989	19.4	31.2
1990	23.9	38.6
1991	21.0	32.5
1992	24.8	37.4
1993	26.8	40.2
1994	25.4	38.7
1995	24.3	36.4
1996	27.3	39.6
1997	22.7	34.5

solution:

Step 1. Write a straight line equation as $y = mx + b$ in which m is the slope of the line, and b is the intercept on the Y = axis.

Step 2. Write an equation for each year in which the independent variable is X (rainfall) and the dependent variable is Y (runoff). Group the equations, in two groups, and alternate the years. Then, total each group.

1988	$26.5 = 15.9\ m + b$	1989	$31.2 = 19.4\ m + b$
1990	$38.6 = 23.9\ m + b$	1991	$32.5 = 21.0\ m + b$
1992	$37.4 = 24.8\ m + b$	1993	$40.2 = 26.8\ m + b$
1994	$38.7 = 25.4\ m + b$	1995	$36.4 = 24.3\ m + b$
1996	$39.6 = 27.3\ m + b$	1997	$34.5 = 22.7\ m + b$
Sum	$180.8 = 117.3\ m + 5b$		$174.8 = 114.2\ m + 5b$

Step 3. Solve the total of each group of equations simultaneously for m and b

$$\begin{aligned} 180.8 &= 117.3m + 5b \\ -\ (174.8 &= 114.2m + 5b) \\ \hline 6.0 &= 3.1m \\ m &= 1.94 \end{aligned}$$

Step 4. Substituting for m and solving for b

$$180.8 = 117.3(1.94) + 5b$$
$$5b = -46.76$$
$$b = -9.35$$

Step 5. The equation of straight line of best fit is

$$Y = 1.94X - 9.35$$

where X = rainfall, in
Y = runoff, cfs/miles^2

Example 4: A watershed has a drainage area of 1000 ha (2470 acres). The annual rainfall is 927 mm (36.5 in). The expected evaporation loss is 292 mm (11.5 in) per year. The estimated loss to groundwater is 89 mm (3.5 in) annually. Estimate the amount of water that can be stored in a lake and how many people can be served, assuming 200 L(c · d) is needed.

solution:

Step 1. Using a mass balance

R (rainfall excess) = P (precipitation) − E (evaporation) − G (loss to groundwater)

R = 927 mm − 292 mm − 89 mm
= 546 mm

Step 2. Convert R from mm to m^3 (volume) and L

$$R = 564\,\text{mm} \times \frac{1\,\text{m}}{1000\,\text{mm}} \times 1000\,\text{ha} \times \frac{10{,}000\,\text{m}^2}{1\,\text{ha}}$$
$$= 5.46 \times 10^6\,\text{m}^3$$
$$= 5.46 \times 10^6\,\text{m}^3 \times 10^3\ \text{L}/1\,\text{m}^3$$
$$= 5.46 \times 10^9\,\text{L}$$

Step 3. Compute the people that can be served

$$\text{Annual usage per capita} = 200\ \text{L/(c} \cdot \text{d)} \times 365\ \text{days}$$
$$= 7.3 \times 10^4\ \text{L/c}$$
$$\text{No. of people served} = \frac{5.46 \times 10^9\,\text{L}}{7.3 \times 10^4\,\text{L/c}}$$
$$= 74{,}800\ \text{capita}$$

2 Population Estimates

Prior to the design of a water treatment plant, it is necessary to forecast the future population of the communities to be served. The plant should be sufficient generally for 25 to 30 years. It is difficult to estimate the population growth due to economic and social factors involved. However, a few methods have been used for forecasting population. They include the arithmetic method and uniform percentage growth rate method (Clark and Viessman, 1966; Steel and McGhee, 1979; Viessman and Hammer, 1993). The first three methods are short-term (<10 years) forecasting.

2.1 Arithmetic method

This method of forecasting is based upon the hypothesis that the rate of increase is constant. It may be expressed as follows:

$$\frac{dp}{dt} = k_a \tag{5.1}$$

where p = population
t = time, year
k_a = arithmetic growth rate constant

Rearrange and integrate the above equation; p_1 and p_2 are the populations at time t_1 and t_2, respectively.

$$\int_{p_1}^{p_2} dp = \int_{t_1}^{t_2} k_a dt$$

We get

$$p_2 - p_1 = k_a(t_2 - t_1)$$

or

$$k_a = \frac{p_2 - p_1}{t_2 - t_1} = \frac{\Delta p}{\Delta t} \tag{5.2a}$$

$$p_t = p_0 + k_a t \tag{5.2b}$$

where p_t = population at future time
p_0 = present population, usually use p_2 (recent censused)

2.2 Constant percentage growth rate method

The hypothesis of constant percentage or geometric growth rate assumes that the rate increase is proportional to population. It can be written as

$$\frac{dp}{dt} = k_p\, p \tag{5.3a}$$

Integrating this equation yields

$$\ln p_2 - \ln p_1 = k_p(t_2 - t_1)$$

$$k_p = \frac{\ln p_2 - \ln p_1}{t_2 - t_1} \tag{5.3b}$$

The geometric estimate of population is given by

$$\ln p = \ln p_2 + k_p (t - t_2) \tag{5.3c}$$

2.3 Declining growth method

This is a decreasing rate of increase on the basis that the growth rate is a function of its population deficit. Mathematically, it is given as

$$\frac{dp}{dt} = k_d(p_s - p) \tag{5.4a}$$

where p_s = saturation population, assumed value

Integration of the above equation gives

$$\int_{p_1}^{p_2} \frac{dp}{p_s - p} = k_d \int_{t_1}^{t_2} dt$$

$$-\ln\frac{p_s - p_2}{p_s - p_1} = k_d(t_2 - t_1)$$

Rearranging

$$k_d = -\frac{1}{t_2 - t_1} \ln \frac{p_s - p_2}{p_s - p_1} \tag{5.4b}$$

The future population p is

$$p = p_0 + (p_s - p_0)(1 - e^{-k_d t}) \tag{5.4c}$$

where p_0 = population of the base year

2.4 Logistic curve method

The logistic curve-fitting method is used for modeling population trends with an S-shape for large population center, or nations for long-term population predictions. The logistic curve form is

$$p = \frac{p_s}{1 + e^{a + b\Delta t}} \tag{5.5a}$$

where p_s = saturation population

a, b = constants

They are

$$p_s = \frac{2p_0 p_1 p_2 - p_1^2(p_0 + p_2)}{p_0 p_2 - p_1^2} \tag{5.5b}$$

$$a = \ln \frac{p_s - p_0}{p_0} \tag{5.6}$$

$$b = \frac{1}{n} \ln \frac{p_0(p_s - p_1)}{p_1(p_s - p_0)} \tag{5.7}$$

where n = time interval between successive censuses

Substitution of these values in Eq. (5.5a) gives the estimation of future population of p for any period Δt beyond the base year corresponding to p_0.

Example: A mid-size city recorded populations of 113,000 and 129,000 in the April 2000 and April 2010 census, respectively. Estimate the population in January 2019 by comparing the (a) arithmetic method, (b) constant percentage method, and (c) declining growth method.

solution:

Step 1. Solve with the arithmetic method

Let t_1 and t_2 for April 2000 and April 2010, respectively

$$\Delta t = t_2 - t_1 = 10 \text{ years}$$

Using Eq. (5.2a) $$k_a = \frac{p_2 - p_1}{t_2 - t_1} = \frac{129{,}000 - 113{,}000}{10} = 1600$$

Predict p_t for January 2019 from t_2, using Eq. (5.2b)

$$t = 8.75 \text{ years}$$

$$\begin{aligned} p_t &= p_2 + k_a t \\ &= 129{,}000 + 1600 \times 8.75 \\ &= 143{,}000 \end{aligned}$$

Step 2. Solve with constant percentage method, using Eq. (5.3b)

$$k_p = \frac{\ln p_2 - \ln p_1}{t_2 - t_1} = \frac{\ln 129{,}000 - \ln 113{,}000}{10}$$

$$= 0.013243$$

Then using Eq. (5.3c) $$\begin{aligned} \ln p &= \ln p_2 + k_p (t - t_2) \\ &= \ln 129{,}000 + 0.013243 \times 8.75 \\ &= 11.8834 \\ p &= 144{,}800 \end{aligned}$$

Step 3. Solve with declining growth method
Assuming

$$p_s = 200{,}000$$

Using Eq. (5.4b)

$$k_d = -\frac{1}{t_2 - t_1} \ln \frac{p_s - p_2}{p_s - p_1}$$

$$= -\frac{1}{10} \ln \frac{200{,}000 - 129{,}000}{200{,}000 - 113{,}000}$$

$$= 0.02032$$

From Eq. (5.4c)

$$\begin{aligned} p &= p_0 + (p_s - p_0)(1 - e^{-k_d t}) \\ &= 129{,}000 + (200{,}000 - 129{,}000)(1 - e^{-0.02032 \times 8.75}) \\ &= 129{,}000 + 71{,}000 \times 0.163 \\ &= 140{,}600 \end{aligned}$$

3 Water Requirements

The uses of water include domestic, commercial and industrial, public services such as fire fighting and public buildings, and unaccounted pipeline system losses and leakage. The average usage in the United States for the above four categories are 220, 260, 30, and 90 L per capita per day (L/(c · d)), respectively (Tchobanoglous and Schroeder, 1985). These correspond to 58, 69, 8, and 24 gal/(c · d), respectively. Total municipal water use averages 600 L/(c · d) or 160 gal/(c · d) in the United States.

The maximum daily water use ranges from about 120% to 400% of the average daily use with a mean of about 180%. Maximum hourly use is about 150% to 12,000% of the annual average daily flow; and 250% to 270% are typically used in design.

3.1 Fire demand

Fire demand for water is often the determining factor in the design of mains. Distribution is a short-term, small quantity but with a large flow rate. According to uniform fire code, the minimum fire flow requirement for a one- and two-family dwelling shall be 1000 gal per min (gpm). For the water demand for fire fighting based on downtown business districts and high-value areas for communities of 200,000 people or less, the National Board of Fire Underwriters (1974) recommended the following fire flow rate and population relationship:

$$Q = 3.86\sqrt{p}\,(1 - 0.01\sqrt{p}) \quad \text{(SI units)} \qquad (5.8a)$$

$$Q = 1020\sqrt{p}\,(1 - 0.01\sqrt{p}) \quad \text{(US customary units)} \qquad (5.8b)$$

where Q = discharge, m^3/min or gal/min (gpm)
p = population in thousands

The required flow rate for fire fighting must be available in addition to the coincident maximum daily flow rate. The duration during the required fire flow must be available for 4 to 10 h. National Board of Fire Underwriters recommends providing for a 10-h fire in towns exceeding 2500 in population.

The Insurance Services Office Guide (International Fire Service Training Association, 1993) for determination of required fire flow recommends the formula

$$F = 18\,C\sqrt{A} \quad \text{(US customary units)} \tag{5.9a}$$

$$F = 320\,C\sqrt{A} \quad \text{(SI units)} \tag{5.9b}$$

where F = required fire flow, gpm or m^3/d
C = coefficient related to the type of construction
A = total floor area, ft^2 or m^2

C value	Construction	Maximum flow, gpm (m^3/d)
1.5	wood frame	8000 (43,600)
1.0	ordinary	8000 (43,600)
0.9	heavy timber type building	
0.8	noncombustible	6000 (32,700)
0.6	fire-resistant	6000 (32,700)

Example 1: A 4-story building of heavy timber type has 715 m^2 (7700 ft^2) of ground area. Calculate the water requirement for fire fighting.

solution: Using Eq. (5.9b)

$$\begin{aligned} F &= 320\,C\sqrt{A} \\ &= 320 \times 0.9\sqrt{4 \times 715} \\ &= 15{,}400\ (\text{m}^3/\text{d}) \\ \text{or} \quad &= 2800 \text{ gpm} \end{aligned}$$

Example 2: A 5-story building of ordinary construction has 7700 ft^2 (715 m^2) of ground area communicating with a 3-story building of ordinary construction of 9500 ft^2 (880 m^2) ground area. Compute the required fire flow.