

# **ENVIRONMENTAL ENGINEER'S MATHEMATICS HANDBOOK**

**Frank R. Spellman and  
Nancy E. Whiting**



**CRC PRESS**

---

Boca Raton London New York Washington, D.C.

### Library of Congress Cataloging-in-Publication Data

Spellman, Frank R.

Environmental engineer's mathematics handbook / by Frank R. Spellman, Nancy Whiting.  
p. cm.

Includes bibliographical references and index.

ISBN 1-56670-681-5 (alk. paper)

1. Environmental engineering--Mathematics--Handbooks, manuals, etc. I. Whiting,  
Nancy E. II. Title.

TD145.S676 2004  
629.8'95--dc22

2004051872

This book contains information obtained from authentic and highly regarded sources. Reprinted material is quoted with permission, and sources are indicated. A wide variety of references are listed. Reasonable efforts have been made to publish reliable data and information, but the author and the publisher cannot assume responsibility for the validity of all materials or for the consequences of their use.

Neither this book nor any part may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, microfilming, and recording, or by any information storage or retrieval system, without prior permission in writing from the publisher.

The consent of CRC Press LLC does not extend to copying for general distribution, for promotion, for creating new works, or for resale. Specific permission must be obtained in writing from CRC Press LLC for such copying.

Direct all inquiries to CRC Press LLC, 2000 N.W. Corporate Blvd., Boca Raton, Florida 33431.

**Trademark Notice:** Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation, without intent to infringe.

Visit the CRC Press Web site at [www.crcpress.com](http://www.crcpress.com)

---

© 2005 by CRC Press LLC

No claim to original U.S. Government works

International Standard Book Number 1-56670-681-5

Library of Congress Card Number 2004051872

Printed in the United States of America 1 2 3 4 5 6 7 8 9 0

## Preface

*Environmental Engineer's Mathematics Handbook* brings together and integrates in a single text the more practical math operations of environmental engineering for air, water, wastewater, biosolids and stormwater. Taking an unusual approach to the overall concept of environmental engineering math concepts, this offers the reader an approach that emphasizes the relationship between the principles in natural processes and those employed in engineered processes.

The text covers in detail the engineering principles, practices, and math operations involved in the design and operation of conventional environmental engineering works and presents engineering modeling tools and environmental algorithm examples. The arrangement of the material lends itself to several different specific environmental specialties and several different formal course formats.

Major subjects covered in this book include:

- Math concepts review
- Modeling
- Algorithms
- Air pollution control calculations
- Water assessment and control calculations
- Stormwater engineering math calculations

In our approach, we emphasize concepts, definitions, descriptions, and derivations, as well as a touch of common sense. This book is intended to be a combination textbook and reference tool for practitioners involved in the protection of the three environmental media: air, water, and land resources.

**Frank R. Spellman**

Norfolk, Virginia

**Nancy E. Whiting**

Columbia, Pennsylvania

## **Acknowledgments**

This text would not have been possible without the tireless efforts of Mimi Williams. We appreciate her astute sense of sensibility and correctness. Thanks.



# Contents

<b>PART I: FUNDAMENTAL COMPUTATION AND MODELING .....</b>	<b>1</b>
<b>Chapter 1 Conversion Factors and SI Units.....</b>	<b>3</b>
1.1 Introduction .....	3
1.2 Conversion Factors.....	3
1.3 Conversion Factors: Practical Examples .....	13
1.3.1 Weight, Concentration, and Flow.....	14
1.3.2 Water/Wastewater Conversion Examples.....	16
1.3.3 Temperature Conversions .....	22
1.4 Conversion Factors: Air Pollution Measurements.....	24
1.4.1 Conversion from Parts per Million to Micrograms per Cubic Meter .....	24
1.4.2 Conversion Tables for Common Air Pollution Measurements.....	26
1.5 Soil Test Results Conversion Factors .....	26
1.6 Conclusion.....	26
<b>Chapter 2 Basic Math Operations.....</b>	<b>31</b>
2.1 Introduction .....	31
2.2 Basic Math Terminology and Definitions .....	31
2.3 Sequence of Operations .....	32
2.3.1 Sequence of Operations — Rules .....	32
2.3.2 Sequence of Operations — Examples .....	33
2.4 Percent .....	34
2.5 Significant Digits.....	38
2.6 Powers and Exponents .....	40
2.7 Averages (Arithmetic Mean).....	41
2.8 Ratio .....	43
2.9 Dimensional Analysis .....	47
2.10 Threshold Odor Number (TON).....	53
2.11 Geometrical Measurements.....	53
2.11.1 Geometrical Calculations .....	54
2.11.1.1 Perimeter and Circumference.....	54
2.11.1.2 Area .....	57
2.11.1.3 Volume.....	60
2.12 Force, Pressure, and Head Calculations .....	64
2.12.1 Force and Pressure .....	64
2.12.2 Head.....	65
2.12.2.1 Static Head .....	65
2.12.2.2 Friction Head.....	66
2.12.2.3 Velocity Head .....	66
2.12.2.4 Total Dynamic Head (Total System Head).....	66
2.12.2.5 Pressure/Head.....	66
2.12.2.6 Head/Pressure .....	66
2.13 Review of Advanced Algebra Key Terms and Concepts .....	71

<b>Chapter 3</b>	<b>Environmental Modeling .....</b>	<b>73</b>
3.1	Introduction .....	73
3.2	Media Material Content.....	73
3.2.1	Material Content: Liquid Phases.....	75
3.3	Phase Equilibrium and Steady State.....	78
3.4	Math Operations and Laws of Equilibrium.....	79
3.4.1	Solving Equilibrium Problems.....	79
3.4.2	Laws of Equilibrium.....	80
3.4.2.1	Ideal Gas Law .....	80
3.4.2.2	Dalton's Law .....	81
3.4.2.3	Raoult's Law .....	83
3.4.2.4	Henry's Law .....	83
3.5	Chemical Transport Systems .....	83
3.6	A Final Word on Environmental Modeling.....	84
References .....	85	
<b>Chapter 4</b>	<b>Algorithms and Environmental Engineering.....</b>	<b>87</b>
4.1	Introduction .....	87
4.2	Algorithms: What Are They?.....	87
4.3	Expressing Algorithms .....	88
4.4	General Algorithm Applications .....	89
4.5	Environmental Engineering Algorithm Applications .....	90
4.6	Dispersion Models .....	91
4.7	Screening Tools .....	91
References .....	92	
Suggested Reading.....	92	
<b>PART II: FUNDAMENTAL SCIENCE AND STATISTICS REVIEW .....</b>	<b>93</b>	
<b>Chapter 5</b>	<b>Fundamental Chemistry and Hydraulics .....</b>	<b>95</b>
5.1	Introduction .....	95
5.2	Fundamental Chemistry .....	95
5.2.1	Density and Specific Gravity .....	96
5.2.2	Water Chemistry Fundamentals .....	99
5.2.2.1	The Water Molecule .....	99
5.2.2.2	Water Solutions .....	100
5.2.2.3	Concentrations .....	101
5.2.2.4	Predicting Solubility.....	103
5.2.2.5	Colligative Properties .....	103
5.2.2.6	Colloids/Emulsions.....	104
5.2.2.7	Water Constituents .....	105
5.2.2.8	Simple Solutions and Dilutions .....	112
5.2.2.9	Chemical Reactions .....	115
5.2.2.10	Chemical Dosages (Water and Wastewater Treatment).....	120
5.3	Fundamental Hydraulics .....	126
5.3.1	Principles of Water Hydraulics .....	126
5.3.1.1	Weight of Air.....	126
5.3.1.2	Weight of Water .....	126
5.3.1.3	Weight of Water Related to the Weight of Air .....	127
5.3.1.4	Water at Rest .....	128

5.3.1.5	Gauge Pressure .....	128
5.3.1.6	Water in Motion .....	129
5.3.1.7	Discharge .....	129
5.3.1.8	The Law of Continuity.....	130
5.3.1.9	Pipe Friction .....	131
5.3.2	Basic Pumping Calculations .....	131
5.3.2.1	Pumping Rates.....	132
5.3.3	Calculating Head Loss .....	133
5.3.4	Calculating Head .....	134
5.3.5	Calculating Horsepower and Efficiency.....	134
5.3.5.1	Hydraulic Horsepower (WHP).....	135
5.3.5.2	Pump Efficiency and Brake Horsepower (bhp).....	135
References .....		138
Suggested Reading.....		138
<b>Chapter 6</b>	<b>Statistics Review .....</b>	<b>139</b>
6.1	Statistical Concepts .....	139
6.2	Measure of Central Tendency .....	139
6.3	Basic Statistical Terms .....	139
6.4	DMR Calculations.....	140
6.4.1	Loading Calculation .....	140
6.4.2	Monthly Average Loading Calculations .....	141
6.4.3	30-Day Average Calculation .....	141
6.4.4	Moving Average .....	142
6.4.5	Geometric Mean .....	143
6.4.5.1	Logarithm (Log) Method.....	144
6.4.5.2	N <sup>th</sup> Root Calculation Method.....	144
6.5	Standard Deviation.....	145
6.6	Conclusion.....	147
<b>PART III: MATH CONCEPTS: AIR POLLUTION CONTROL.....</b>	<b>149</b>	
<b>Chapter 7</b>	<b>Air Pollution Fundamentals .....</b>	<b>151</b>
7.1	Introduction .....	151
7.1.1	Six Common Air Pollutants .....	152
7.1.1.1	Ground-Level Ozone .....	152
7.1.1.2	Nitrogen Oxides .....	153
7.1.1.3	Particulate Matter .....	153
7.1.1.4	Sulfur Dioxide (SO <sub>2</sub> ).....	153
7.1.1.5	Carbon Monoxide (CO) .....	153
7.1.1.6	Lead .....	154
7.2	Gases .....	154
7.2.1	The Gas Laws.....	155
7.2.1.1	Boyle's Law.....	156
7.2.1.2	Charles's Law .....	157
7.2.1.3	Gay-Lussac's Law .....	157
7.2.1.4	The Combined Gas Law .....	158
7.2.1.5	The Ideal Gas Law .....	158
7.2.1.6	Composition of Air .....	159

7.3	Particulate Matter .....	160
7.4	Pollution Emission Measurement Parameters .....	160
7.5	Standard Corrections .....	161
	References .....	162
<b>Chapter 8</b>	<b>Gaseous Emission Control .....</b>	<b>163</b>
8.1	Introduction .....	163
8.2	Absorption .....	163
8.2.1	Solubility .....	166
8.2.2	Equilibrium Solubility and Henry's Law .....	166
8.2.3	Material (Mass) Balance .....	168
8.2.4	Sizing Packed Column Diameter and Height of an Absorber .....	172
8.2.4.1	Packed Tower Absorber Diameter .....	172
8.2.4.2	Sizing the Packed Tower Absorber Height .....	175
8.2.4.3	Sizing the Plate (Tray) Tower .....	179
8.2.4.4	Theoretical Number of Absorber Plates or Trays .....	181
8.3	Adsorption .....	183
8.3.1	Adsorption Steps .....	184
8.3.2	Adsorption Forces — Physical and Chemical .....	184
8.3.3	Adsorption Equilibrium Relationships .....	185
8.3.3.1	Isotherm .....	185
8.3.3.2	Isostere .....	186
8.3.3.3	Isobar .....	186
8.3.4	Factors Affecting Adsorption .....	187
8.3.4.1	Temperature .....	188
8.3.4.2	Pressure .....	188
8.3.4.3	Gas Velocity .....	188
8.3.4.4	Bed Depth .....	189
8.3.4.5	Humidity .....	192
8.3.4.6	Contaminants .....	192
8.4	Incineration .....	193
8.4.1	Factors Affecting Incineration for Emission Control .....	193
8.4.1.1	Temperature .....	193
8.4.1.2	Residence Time .....	193
8.4.1.3	Turbulence .....	194
8.4.1.4	Oxygen Requirement .....	194
8.4.1.5	Combustion Limit .....	195
8.4.1.6	Flame Combustion .....	195
8.4.1.7	Heat .....	195
8.4.2	Incineration Example Calculations .....	196
8.5	Condensation .....	199
8.5.1	Contact Condenser Calculations .....	199
8.5.2	Surface Condenser Calculations .....	201
	References .....	206
<b>Chapter 9</b>	<b>Particulate Emission Control .....</b>	<b>207</b>
9.1	Particulate Emission Control Basics .....	207
9.1.1	Interaction of Particles with Gas .....	207
9.1.2	Particulate Collection .....	208
9.2	Particulate Size Characteristics and General Characteristics .....	209
9.2.1	Aerodynamic Diameter .....	209

9.2.2	Equivalent Diameter.....	209
9.2.3	Sedimentation Diameter.....	209
9.2.4	Cut Diameter .....	210
9.2.5	Dynamic Shape Factor .....	210
9.3	Flow Regime of Particle Motion .....	210
9.4	Particulate Emission Control Equipment Calculations .....	216
9.4.1	Gravity Settlers.....	216
9.4.2	Gravity Settling Chamber Theoretical Collection Efficiency.....	217
9.4.3	Minimum Particle Size.....	219
9.4.4	Cyclones .....	223
9.4.4.1	Factors Affecting Cyclone Performance .....	223
9.4.6	Electrostatic Precipitator (ESP).....	228
9.4.6.1	Collection Efficiency .....	228
9.4.6.2	Precipitator Example Calculations .....	230
9.4.7	Baghouse (Fabric) Filters .....	236
9.4.7.1	Air-to-Filter (Media) Ratio .....	237
9.4.7.2	Baghouse Example Calculations.....	237
	References .....	247
<b>Chapter 10 Wet Scrubbers for Emission Control.....</b> 249		
10.1	Introduction .....	249
10.1.1	Wet Scrubbers.....	249
10.2	Wet Scrubber Collection Mechanisms and Efficiency (Particulates) .....	250
10.2.1	Collection Efficiency .....	251
10.2.2	Impaction .....	251
10.2.3	Interception .....	252
10.2.4	Diffusion .....	252
10.2.5	Calculation of Venturi Scrubber Efficiency .....	253
10.2.5.1	Johnstone Equation .....	253
10.2.5.2	Infinite Throat Model .....	254
10.2.5.3	Cut Power Method .....	260
10.2.5.4	Contact Power Theory .....	261
10.2.5.5	Pressure Drop .....	265
10.3	Wet Scrubber Collection Mechanisms and Efficiency (Gaseous Emissions).....	266
10.4	Assorted Venturi Scrubber Example Calculations .....	266
10.4.1	Scrubber Design of a Venturi Scrubber .....	266
10.4.2	Spray Tower.....	274
10.4.3	Packed Tower.....	276
10.4.4	Packed Column Height and Diameter .....	280
10.5	Summary of Key Points .....	285
	References .....	285
<b>PART IV: MATH CONCEPTS: WATER QUALITY .....</b> 287		
<b>Chapter 11 Running Waters .....</b> 289		
11.1	Balancing the “Aquarium”.....	289
11.1.1	Sources of Stream Pollution.....	290
11.2	Is Dilution the Solution?.....	291
11.2.1	Dilution Capacity of Running Waters.....	292
11.3	Discharge Measurement.....	292

11.4	Time of Travel.....	293
11.5	Dissolved Oxygen (DO) .....	294
11.5.1	DO Correction Factor.....	295
11.6	Biochemical Oxygen Demand.....	296
11.6.1	BOD Test Procedure.....	297
11.6.2	Practical BOD Calculation Procedure .....	297
11.6.2.1	Unseeded BOD Procedure .....	297
11.6.2.2	Seeded BOD Procedure .....	298
11.7	Oxygen Sag (Deoxygenation).....	299
11.8	Stream Purification: A Quantitative Analysis.....	300
	References .....	304
<b>Chapter 12 Still Waters .....</b> ..... 305		
12.1	Introduction .....	305
12.2	Still Water Systems.....	307
12.3	Still Water System Calculations .....	307
12.3.1	Still Water Body Morphometry Calculations .....	307
12.3.1.1	Volume.....	307
12.3.1.2	Shoreline Development Index ( $D_L$ ).....	308
12.3.1.3	Mean Depth .....	308
12.4	Still Water Surface Evaporation.....	312
12.4.1	Water Budget Model .....	312
12.4.2	Energy Budget Model .....	312
12.4.3	Priestly–Taylor Equation .....	313
12.4.4	Penman Equation.....	313
12.4.5	DeBruin–Keijman Equation .....	313
12.4.6	Papadakis Equation .....	314
	References .....	314
<b>Chapter 13 Groundwater .....</b> ..... 315		
13.1	Groundwater and Aquifers.....	315
13.1.1	Groundwater Quality .....	317
13.1.2	GUDISW .....	317
13.2	Aquifer Parameters.....	317
13.2.1	Aquifer Porosity .....	317
13.2.2	Specific Yield (Storage Coefficient).....	318
13.2.3	Permeability (K).....	318
13.2.4	Transmissivity (T) .....	318
13.2.5	Hydraulic Gradient and Head .....	319
13.2.6	Flow Lines and Flow Nets .....	319
13.3	Groundwater Flow .....	319
13.4	General Equations of Groundwater Flow .....	320
13.4.1	Steady Flow in a Confined Aquifer .....	321
13.4.2	Steady Flow in an Unconfined Aquifer .....	321
	References .....	322
<b>Chapter 14 Basic Hydraulics .....</b> ..... 323		
14.1	Introduction .....	323
14.2	Basic Concepts .....	323
14.2.1	Stevin's Law .....	325

14.2.2	Density and Specific Gravity .....	325
14.2.3	Force and Pressure .....	327
14.2.4	Hydrostatic Pressure.....	329
14.2.5	Head.....	329
	14.2.5.1    Static Head .....	330
	14.2.5.2    Friction Head.....	330
	14.2.5.3    Velocity Head .....	330
	14.2.5.4    Total Dynamic Head (Total System Head).....	330
	14.2.5.5    Pressure/Head.....	330
	14.2.5.6    Head/Pressure.....	331
14.3	Flow/Discharge Rate: Water in Motion.....	331
14.3.1	Area/Velocity .....	333
14.3.2	Pressure/Velocity .....	334
14.4	Bernoulli's Theorem.....	334
14.4.1	Bernoulli's Equation.....	334
14.5	Calculating Major Head Loss.....	337
14.5.1	C Factor.....	338
14.6	Characteristics of Open-Channel Flow.....	338
14.6.1	Laminar and Turbulent Flow.....	338
14.6.2	Uniform and Varied Flow .....	338
14.6.3	Critical Flow .....	338
14.6.4	Parameters Used in Open Channel Flow.....	339
	14.6.4.1    Hydraulic Radius.....	339
	14.6.4.2    Hydraulic Depth .....	339
	14.6.4.3    Slope, S.....	340
14.7	Open-Channel Flow Calculations .....	340
References	.....	341
<b>Chapter 15</b>	<b>Water Treatment Process Calculations .....</b>	<b>343</b>
15.1	Introduction .....	343
15.2	Water Source and Storage Calculations .....	344
15.2.1	Water Source Calculations .....	344
	15.2.1.1    Well Drawdown.....	344
	15.2.1.2    Well Yield .....	346
	15.2.1.3    Specific Yield.....	347
	15.2.1.4    Well Casing Disinfection .....	348
	15.2.1.5    Deep-Well Turbine Pump Calculations .....	348
15.2.3	Vertical Turbine Pump Calculations .....	349
15.3	Water Storage .....	354
15.3.1	Water Storage Calculations .....	355
15.3.2	Copper Sulfate Dosing .....	356
15.4	Coagulation, Mixing, and Flocculation .....	357
15.4.1	Coagulation.....	357
15.4.2	Mixing.....	358
15.4.3	Flocculation .....	359
15.4.4	Coagulation and Flocculation General Calculations .....	359
	15.4.4.1    Chamber and Basin Volume Calculations .....	359
	15.4.4.2    Detention Time .....	361
	15.4.4.3    Determining Dry Chemical Feeder Setting (Pounds per Day) .....	362

15.4.4.4	Determining Chemical Solution Feeder Setting (Gallons per Day).....	363
15.4.4.5	Determining Chemical Solution Feeder Setting (Milliliters per Minute) .....	363
15.4.5	Determining Percent of Solutions .....	364
15.4.5.1	Determining Percent Strength of Liquid Solutions.....	366
15.4.5.2	Determining Percent Strength of Mixed Solutions .....	366
15.4.6	Dry Chemical Feeder Calibration .....	367
15.4.6.1	Solution Chemical Feeder Calibration.....	368
15.4.7	Determining Chemical Usage .....	370
	15.4.7.1 Paddle Flocculator Calculations.....	371
15.5	Sedimentation Calculations.....	372
15.5.1	Tank Volume Calculations.....	372
	15.5.1.1 Calculating Tank Volume .....	373
15.5.2	Detention Time .....	373
15.5.3	Surface Overflow Rate .....	375
15.5.4	Mean Flow Velocity .....	376
15.5.5	Weir Loading Rate (Weir Overflow Rate).....	377
15.5.6	Percent Settled Biosolids.....	378
15.5.7	Determining Lime Dosage (Milligrams per Liter).....	379
15.5.8	Determining Lime Dosage (Pounds per Day) .....	383
15.5.9	Determining Lime Dosage (Grams per Minute) .....	383
15.5.10	Particle Settling (Sedimentation) .....	384
15.5.11	Overflow Rate (Sedimentation). ....	388
15.6	Water Filtration Calculations .....	390
15.6.1	Flow Rate through a Filter (Gallons per Minute) .....	390
15.6.2	Filtration Rate.....	393
15.6.3	Unit Filter Run Volume (UFRV).....	395
15.6.4	Backwash Rate .....	397
15.6.5	Backwash Rise Rate .....	398
15.6.6	Volume of Backwash Water Required (Gallons).....	399
15.6.7	Required Depth of Backwash Water Tank (Feet) .....	400
15.6.8	Backwash Pumping Rate (Gallons per Minute) .....	401
15.6.9	Percent Product Water Used for Backwashing .....	402
15.6.10	Percent Mud Ball Volume .....	403
15.6.11	Filter Bed Expansion .....	404
15.6.12	Filter Loading Rate .....	405
15.6.13	Filter Medium Size.....	406
15.6.14	Mixed Media .....	407
15.6.15	Head Loss for Fixed Bed Flow .....	408
15.6.16	Head Loss through a Fluidized Bed .....	409
15.6.17	Horizontal Washwater Troughs .....	411
15.6.18	Filter Efficiency .....	412
15.7	Water Chlorination Calculations .....	413
15.7.1	Chlorine Disinfection .....	413
15.7.2	Determining Chlorine Dosage (Feed Rate) .....	414
15.7.3	Calculating Chlorine Dose, Demand, and Residual.....	415
15.7.4	Breakpoint Chlorination Calculations .....	417
15.7.5	Calculating Dry Hypochlorite Feed Rate .....	419
15.7.6	Calculating Hypochlorite Solution Feed Rate .....	422
	15.7.7 Calculating Percent Strength of Solutions.....	423

15.7.8	Calculating Percent Strength Using Dry Hypochlorite .....	424
15.7.9	Calculating Percent Strength Using Liquid Hypochlorite.....	424
15.8	Chemical Use Calculations .....	425
15.8.1	Chlorination Chemistry .....	426
	References .....	428

## PART V: MATH CONCEPTS: WASTEWATER ENGINEERING.....429

<b>Chapter 16</b>	<b>Wastewater Calculations .....</b>	<b>431</b>
16.1	Introduction .....	431
16.2	Preliminary Treatment Calculations .....	431
16.2.1	Screening .....	432
16.2.2	Screenings Removal Calculations.....	432
16.2.3	Screenings Pit Capacity Calculations .....	433
16.2.4	Headloss through Bar Screen.....	435
16.2.5	Grit Removal .....	435
16.2.6	Grit Removal Calculations.....	435
16.2.7	Grit Channel Velocity Calculation .....	437
16.2.7.1	Required Settling Time .....	438
16.2.7.2	Required Channel Length .....	439
16.2.7.3	Velocity of Scour.....	439
16.3	Primary Treatment Calculations .....	440
16.3.1	Process Control Calculations .....	440
16.3.2	Surface Loading Rate (Surface Settling Rate/Surface Overflow Rate).....	440
16.3.3	Weir Overflow Rate (Weir Loading Rate).....	441
16.3.4	Primary Sedimentation Basins .....	442
16.4	Biosolids Pumping .....	444
16.4.1	Percent Total Solids (% TS).....	444
16.4.2	BOD and SS Removed, Pounds per Day .....	445
16.5	Trickling Filter Calculations .....	445
16.5.1	Trickling Filter Process Calculations .....	446
16.5.2	Hydraulic Loading.....	446
16.5.3	Organic Loading Rate .....	448
16.5.4	BOD and SS Removed.....	449
16.5.5	Recirculation Flow .....	449
16.5.6	Trickling Filter Design .....	450
16.6	Rotating Biological Contactors (RBCs) .....	451
16.6.1	RBC Process Control Calculations .....	452
16.6.2	Hydraulic Loading Rate .....	452
16.6.3	Soluble BOD .....	453
16.6.4	Organic Loading Rate .....	455
16.6.5	Total Media Area .....	456
16.6.6	Modeling RBC Performance .....	456
16.6.7	RBC Performance Parameter .....	456
16.7	Activated Biosolids .....	457
16.7.1	Activated Biosolids Process Control Calculations .....	457
16.7.2	Moving Averages .....	457
16.7.3	BOD or COD Loading .....	458
16.7.4	Solids Inventory .....	459
16.7.5	Food-to-Microorganism Ratio (F/M Ratio) .....	459

16.7.6	Gould Biosolids Age .....	462
16.7.7	Mean Cell Residence Time (MCRT) .....	463
16.7.8	Estimating Return Rates from SBV <sub>60</sub> (SSV <sub>60</sub> ) .....	465
16.7.9	Biosolids (Sludge) Volume Index (BVI).....	466
16.7.10	Mass Balance: Settling Tank Suspended Solids .....	467
16.7.11	Mass Balance Calculation.....	467
16.7.12	Biosolids Waste Based Upon Mass Balance .....	467
16.7.13	Aeration Tank Design Parameters.....	469
16.7.14	Lawrence and McCarty Design Model.....	470
16.7.14.1	Complete Mix with Recycle .....	470
16.7.15	Effluent Microorganism and Substrate Concentrations .....	472
16.7.15.1	Process Design and Control Relationships .....	472
16.7.15.2	Sludge Production .....	473
16.7.15.3	Oxygen Requirements .....	473
16.8	Oxidation Ditch Detention Time .....	474
16.9	Treatment Ponds.....	475
16.9.1	Treatment Pond Parameters.....	475
16.9.2	Treatment Pond Process Control Calculations .....	475
16.9.2.1	Hydraulic Detention Time, Days .....	476
16.9.2.2	BOD Loading .....	476
16.9.2.3	Organic Loading Rate .....	477
16.9.2.4	BOD Removal Efficiency.....	477
16.9.2.5	Population Loading .....	478
16.9.2.6	Hydraulic Loading, Inches/Day (Overflow Rate).....	478
16.9.3	Aerated Ponds.....	478
16.10	Chemical Dosage Calculations .....	479
16.10.1	Chemical Dosing .....	479
16.10.2	Chemical Feed Rate .....	479
16.10.3	Chlorine Dose, Demand, and Residual.....	481
16.10.3.1	Chlorine Dose.....	481
16.10.3.2	Chlorine Demand .....	481
16.10.3.3	Chlorine Residual .....	482
16.10.4	Hypochlorite Dosage .....	482
16.10.5	Chemical Solutions.....	484
16.10.6	Mixing Solutions of Different Strengths .....	486
16.10.7	Solution Mixtures Target Percent Strength .....	487
16.10.8	Solution Chemical Feeder Setting, GPD .....	487
16.10.9	Chemical Feed Pump — Percent Stroke Setting.....	489
16.10.10	Chemical Solution Feeder Setting, Milliliters per Minute .....	489
16.10.11	Chemical Feed Calibration .....	490
16.10.12	Average Use Calculations .....	493
16.11	Biosolids Production and Pumping Calculations .....	494
16.11.1	Process Residuals .....	494
16.11.2	Primary and Secondary Solids Production Calculations .....	495
16.11.3	Primary Clarifier Solids Production Calculations.....	495
16.11.4	Secondary Clarifier Solids Production Calculation .....	496
16.11.5	Percent Solids .....	497
16.11.6	Biosolids Pumping .....	497
16.11.7	Estimating Daily Biosolids Production.....	498
16.11.8	Biosolids Production (Pounds per Million Gallons) .....	498

16.11.9	Biosolids Production (Wet Tons per Year).....	498
16.11.10	Biosolids Pumping Time .....	499
16.12	<b>Biosolids Thickening .....</b>	<b>501</b>
16.12.1	Thickening .....	501
16.12.2	Gravity/Dissolved Air Flotation Thickener Calculations .....	501
16.12.2.1	Estimating Daily Sludge Production .....	501
16.12.2.2	Surface Loading Rate, Gallons per Day per Square Foot.....	502
16.12.2.3	Solids Loading Rate, Pounds per Day per Square Foot .....	502
16.12.3	Concentration Factor ( $C_f$ ).....	503
16.12.4	Air-to-Solids Ratio .....	503
16.12.5	Recycle Flow in Percent.....	504
16.12.6	Centrifuge Thickening Calculations.....	504
16.13	<b>Stabilization.....</b>	<b>505</b>
16.13.1	Biosolids Digestion .....	505
16.13.2	Aerobic Digestion Process Control Calculations .....	505
16.13.2.1	Volatile Solids Loading, Pounds per Square Foot per Day .....	505
16.13.2.2	Digestion Time, Days.....	506
16.13.2.3	pH Adjustment.....	506
16.13.3	Aerobic Tank Volume.....	507
16.13.4	Anaerobic Digestion Process Control Calculations.....	508
16.13.4.1	Required Seed Volume in Gallons .....	508
16.13.4.2	Volatile Acids-to-Alkalinity Ratio .....	508
16.13.4.3	Biosolids Retention Time.....	509
16.13.4.4	Estimated Gas Production (Cubic Feet per Day).....	509
16.13.4.5	Volatile Matter Reduction (Percent) .....	509
16.13.4.6	Percent Moisture Reduction in Digested Biosolids.....	510
16.13.4.7	Gas Production .....	510
16.14	<b>Biosolids Dewatering and Disposal.....</b>	<b>512</b>
16.14.1	Biosolids Dewatering .....	512
16.14.2	Pressure Filtration Calculations .....	512
16.14.3	Plate and Frame Press .....	512
16.14.3.1	Solids Loading Rate .....	513
16.14.3.2	Net Filter Yield.....	513
16.14.4	Belt Filter Press .....	514
16.14.4.1	Hydraulic Loading Rate .....	514
16.14.4.2	Biosolids Feed Rate .....	516
16.14.5	Solids Loading Rate .....	516
16.14.6	Flocculant Feed Rate .....	517
16.14.7	Flocculant Dosage .....	517
16.14.8	Total Suspended Solids .....	518
16.14.9	Rotary Vacuum Filter Dewatering Calculations .....	519
16.14.9.1	Filter Loading .....	519
16.14.10	Filter Yield .....	520
16.14.11	Vacuum Filter Operating Time.....	520
16.14.12	Percent Solids Recovery.....	521
16.14.13	Sand Drying Beds .....	522
16.14.14	Sand Drying Beds Process Control Calculations .....	522
16.14.14.1	Total Biosolids Applied.....	522
16.14.14.2	Solids Loading Rate .....	522
16.14.14.3	Biosolids Withdrawal to Drying Beds .....	523
16.14.15	Biosolids Disposal .....	524

16.15	Land Application Calculations.....	524
16.15.1	Disposal Cost.....	524
16.15.2	Plant Available Nitrogen (PAN).....	524
16.15.3	Application Rate Based on Crop Nitrogen Requirement.....	525
16.15.4	Metals Loading.....	526
16.15.5	Maximum Allowable Applications Based upon Metals Loading.....	526
16.15.6	Site Life Based on Metals Loading .....	526
16.16	Biosolids to Compost.....	527
16.16.1	Composting Calculations .....	527
16.16.1.1	Blending Dewatered Biosolids with Composted Biosolids .....	528
16.16.1.2	Compost Site Capacity Calculation .....	528
16.17	Wastewater Lab Calculations.....	529
16.17.1	The Wastewater Lab .....	529
16.17.2	Composite Sampling Calculation (Proportioning Factor) .....	530
16.17.3	Composite Sampling Procedure and Calculation .....	530
16.17.4	Biochemical Oxygen Demand (BOD) Calculations.....	531
16.17.4.1	$BOD_5$ (Unseeded).....	531
16.17.4.2	$BOD_5$ (Seeded).....	532
16.17.5	BOD 7-Day Moving Average.....	532
16.17.6	Moles and Molarity .....	533
16.17.6.1	Moles .....	533
16.17.6.2	Normality.....	535
16.17.7	Settleability (Activated Biosolids Solids) .....	536
16.17.8	Settleable Solids .....	537
16.17.9	Biosolids Total Solids, Fixed Solids, and Volatile Solids .....	538
16.17.10	Wastewater Suspended Solids and Volatile Suspended Solids.....	540
16.17.11	Biosolids Volume Index (BVI) and Biosolids Density Index (BDI) .....	542
	References .....	543

## PART VI: MATH CONCEPTS: STORMWATER ENGINEERING ..... 545

<b>Chapter 17</b>	Stormwater Engineering Calculations .....	547
17.1	Introduction .....	547
17.2	Stormwater Terms and Acronyms.....	548
17.3	Hydrologic Methods .....	553
17.3.1	Precipitation.....	555
17.3.1.1	Frequency .....	556
17.3.1.2	Intensity–Duration–Frequency (I–D–F) Curves .....	556
17.3.1.3	SCS 24-H Storm Distribution.....	557
17.3.1.4	Synthetic Storms .....	558
17.3.1.5	Single Event vs. Continuous Simulation Computer Models.....	559
17.4	Runoff Hydrographs.....	560
17.5	Runoff and Peak Discharge .....	560
17.6	Calculation Methods .....	561
17.6.1	The Rational Method .....	561
17.6.1.1	Assumptions .....	562
17.6.1.2	Limitations.....	562
17.6.1.3	Design Parameters .....	563
17.6.2	Modified Rational Method .....	565
17.6.2.1	Assumptions .....	565

17.6.2.2	Limitations.....	565
17.6.2.3	Design Parameters.....	565
17.6.3	SCS Methods — TR-55 Estimating Runoff.....	567
17.6.3.1	Limitations.....	567
17.6.3.2	Information Needed.....	568
17.6.3.3	Design Parameters.....	568
17.6.4	TR-55 Graphical Peak Discharge Method.....	575
17.6.4.1	Limitations.....	575
17.6.4.2	Information Needed.....	575
17.6.4.3	Design Parameters.....	575
17.6.5	TR-55 Tabular Hydrograph Method .....	576
17.6.5.1	Limitations.....	576
17.6.5.2	Information Needed.....	577
17.6.5.3	Design Parameters.....	577
17.7	General Stormwater Engineering Calculations .....	578
17.7.1	Detention, Extended-Detention, and Retention Basin Design Calculations .....	578
17.7.2	Allowable Release Rates .....	578
17.7.3	Storage Volume Requirements Estimates .....	579
17.7.4	Graphical Hydrograph Analysis — SCS Methods .....	579
17.7.4.1	Procedure.....	580
17.7.5	TR-55: Storage Volume for Detention Basins (Short-Cut Method).....	582
17.7.5.1	Information Needed.....	582
17.7.6	Graphical Hydrograph Analysis, Modified Rational Method Critical Storm Duration.....	584
17.7.6.1	Information Needed.....	586
17.7.7	Modified Rational Method, Critical Storm Duration — Direct Solution .....	587
17.7.7.1	Storage Volume .....	588
17.7.7.2	Rainfall Intensity .....	589
17.7.7.3	Maximum Storage Volume.....	591
17.7.7.4	Information Needed.....	591
17.7.8	Stage–Storage Curve .....	595
17.7.8.1	Storage Volume Calculations .....	595
17.7.9	Water Quality and Channel Erosion Control Volume Calculations .....	597
17.7.9.1	Retention Basins — Water Quality Volume .....	597
17.7.9.2	Extended-Detention Basins — Water Quality Volume and Orifice Design .....	598
17.7.9.3	Extended-Detention Basins — Channel Erosion Control Volume and Orifice Design.....	602
17.7.10	Multistage Riser Design.....	604
17.7.10.1	Information Needed.....	604
17.7.11	Emergency Spillway Design .....	620
17.7.12	Hydrograph Routing.....	630
17.8	Conclusion.....	636
	References .....	637

Para tener acceso completo a este libro usted debe solicitarlo de manerla formal a la Coordinación del Programa de Doctorado Interinstitucional en Ciencias Ambientales mediante el **Formato de Préstamo Bibliográfico** ([descargar formato](#)) y remitirlo al siguiente correo:

**[dicambientales@unicauca.edu.co](mailto:dicambientales@unicauca.edu.co)**



DOCTORADO INTERINSTITUCIONAL EN  
CIENCIAS AMBIENTALES

