
WATER-RESOURCES ENGINEERING

Third Edition

David A. Chin

PEARSON

Boston Columbus Indianapolis New York San Francisco Upper Saddle River
Amsterdam Cape Town Dubai London Madrid Milan Munich Paris Montreal Toronto
Delhi Mexico City Sao Paulo Sydney Hong Kong Seoul Singapore Taipei Tokyo

Library of Congress Cataloging-in-Publication Data
Chin, David A.
Water-resources engineering / David A. Chin. – 3rd ed.
p. cm.
ISBN-13: 978-0-13-283321-9 (alk. paper)
ISBN-10: 0-13-283321-2 (alk. paper)
1. Hydraulics. 2. Hydrology. 3. Waterworks. 4. Water resources
development. I. Title.
TC160.C52 2014
627–dc23
2012018911

Vice President and Editorial Director, ECS: *Marcia J. Horton*
Executive Editor: *Holly Stark*
Editorial Assistant: *Carlin Heinle*
Executive Marketing Manager: *Tim Galligan*
Marketing Assistant: *Jon Bryant*
Permissions Project Manager: *Karen Sanatar*
Senior Managing Editor: *Scott Disanno*
Production Project Manager / Editorial Production Manager: *Greg Dulles*
Cover Photo: United States Bureau of Reclamation

PEARSON

© 2013, 2010, 2006, 2000 Pearson Education, Inc.
Upper Saddle River, New Jersey 07458

All rights reserved. No part of this book may be reproduced in any form or by any means, without permission in writing from the publisher.

Pearson Prentice Hall™ is a trademark of Pearson Education, Inc.

The author and publisher of this book have used their best efforts in preparing this book. These efforts include the development, research, and testing of the theories and programs to determine their effectiveness. The author and publisher make no warranty of any kind, expressed or implied, with regard to these programs or the documentation contained in this book. The author and publisher shall not be liable in any event for incidental or consequential damages in connection with, or arising out of, the furnishing, performance, or use of these programs.

Printed in the United States of America.

10 9 8 7 6 5 4 3 2 1

ISBN: 0-13-283321-2

Pearson Education Ltd., *London*
Pearson Education Australia Pty. Ltd., *Sydney*
Pearson Education Singapore, Pte. Ltd.
Pearson Education North Asia Ltd., *Hong Kong*
Pearson Education Canada, Inc., *Toronto*
Pearson Educación de México, S.A. de C.V.
Pearson Education—Japan, *Tokyo*
Pearson Education Malaysia, Pte. Ltd.
Pearson Education, *Upper Saddle River, New Jersey*

To Andrew and Stephanie.

“But those who hope in the Lord will renew their strength. They will soar on wings like eagles; they will run and not grow weary, they will walk and not be faint.”

Isaiah 40:31

Contents

Preface	xv
1 Introduction	1
1.1 Water-Resources Engineering	1
1.2 The Hydrologic Cycle	1
1.3 Design of Water-Resource Systems	5
1.3.1 Water-Control Systems	5
1.3.2 Water-Use Systems	6
1.3.3 Supporting Federal Agencies in the United States	7
Problem	8
2 Fundamentals of Flow in Closed Conduits	9
2.1 Introduction	9
2.2 Single Pipelines	9
2.2.1 Steady-State Continuity Equation	9
2.2.2 Steady-State Momentum Equation	10
2.2.3 Steady-State Energy Equation	22
2.2.3.1 Energy and hydraulic grade lines	25
2.2.3.2 Velocity profile	27
2.2.3.3 Head losses in transitions and fittings	27
2.2.3.4 Head losses in noncircular conduits	31
2.2.3.5 Empirical friction-loss formulae	32
2.2.4 Water Hammer	35
2.3 Pipe Networks	39
2.3.1 Nodal Method	40
2.3.2 Loop Method	42
2.3.3 Application of Computer Programs	46
2.4 Pumps	46
2.4.1 Affinity Laws	51
2.4.2 Pump Selection	53
2.4.2.1 Commercially available pumps	53
2.4.2.2 System characteristics	54
2.4.2.3 Limits on pump location	55
2.4.3 Multiple-Pump Systems	58
2.4.4 Variable-Speed Pumps	60
Problems	62
3 Design of Water-Distribution Systems	70
3.1 Introduction	70
3.2 Water Demand	70
3.2.1 Per-Capita Forecast Model	71
3.2.1.1 Estimation of per-capita demand	71
3.2.1.2 Estimation of population	72
3.2.2 Temporal Variations in Water Demand	76
3.2.3 Fire Demand	77
3.2.4 Design Flows	79
3.3 Components of Water-Distribution Systems	81
3.3.1 Pipelines	81
3.3.1.1 Minimum size	82
3.3.1.2 Service lines	83
3.3.1.3 Pipe materials	83

3.3.2	Pumps	85
3.3.3	Valves	85
3.3.4	Meters	85
3.3.5	Fire Hydrants	86
3.3.6	Water-Storage Reservoirs	87
3.4	Performance Criteria for Water-Distribution Systems	90
3.4.1	Service Pressures	91
3.4.2	Allowable Velocities	91
3.4.3	Water Quality	91
3.4.4	Network Analysis	92
3.5	Building Water-Supply Systems	93
3.5.1	Specification of Design Flows	94
3.5.2	Specification of Minimum Pressures	94
3.5.3	Determination of Pipe Diameters	96
	Problems	101
4	Fundamentals of Flow in Open Channels	103
4.1	Introduction	103
4.2	Basic Principles	103
4.2.1	Steady-State Continuity Equation	103
4.2.2	Steady-State Momentum Equation	104
4.2.2.1	Darcy–Weisbach equation	106
4.2.2.2	Manning equation	110
4.2.2.3	Other equations	119
4.2.2.4	Velocity distribution	120
4.2.3	Steady-State Energy Equation	121
4.2.3.1	Energy grade line	125
4.2.3.2	Specific energy	125
4.3	Water-Surface Profiles	132
4.3.1	Profile Equation	132
4.3.2	Classification of Water-Surface Profiles	134
4.3.3	Hydraulic Jump	139
4.3.4	Computation of Water-Surface Profiles	143
4.3.4.1	Direct-integration method	145
4.3.4.2	Direct-step method	147
4.3.4.3	Standard-step method	148
4.3.4.4	Practical considerations	150
4.3.4.5	Profiles across bridges	154
	Problems	159
5	Design of Drainage Channels	166
5.1	Introduction	166
5.2	Basic Principles	167
5.2.1	Best Hydraulic Section	167
5.2.2	Boundary Shear Stress	170
5.2.3	Cohesive versus Noncohesive Materials	172
5.2.4	Bends	177
5.2.5	Channel Slopes	178
5.2.6	Freeboard	178
5.3	Design of Channels with Rigid Linings	180
5.4	Design of Channels with Flexible Linings	182
5.4.1	General Design Procedure	183
5.4.2	Vegetative Linings and Bare Soil	187
5.4.3	RECP Linings	197
5.4.4	Riprap, Cobble, and Gravel Linings	199
5.4.5	Gabions	203

5.5	Composite Linings	205
	Problems	208
6	Design of Sanitary Sewers	211
6.1	Introduction	211
6.2	Quantity of Wastewater	211
6.2.1	Residential Sources	211
6.2.2	Nonresidential Sources	212
6.2.3	Inflow and Infiltration (I/I)	213
6.2.4	Peaking Factors	214
6.3	Hydraulics of Sewers	216
6.3.1	Manning Equation with Constant n	218
6.3.2	Manning Equation with Variable n	220
6.3.3	Self-Cleansing	223
6.3.4	Scour Prevention	224
6.3.5	Design Computations for Diameter and Slope	224
6.3.6	Hydraulics of Manholes	227
6.4	System Design Criteria	229
6.4.1	System Layout	229
6.4.2	Pipe Material	229
6.4.3	Depth of Sanitary Sewer	231
6.4.4	Diameter and Slope of Pipes	231
6.4.5	Hydraulic Criteria	231
6.4.6	Manholes	231
6.4.7	Pump Stations	233
6.4.8	Force Mains	233
6.4.9	Hydrogen-Sulfide Control	234
6.4.10	Combined Sewers	236
6.5	Design Computations	236
6.5.1	Design Aids	237
6.5.1.1	Manning's n	237
6.5.1.2	Minimum slope for self-cleansing	237
6.5.2	Procedure for System Design	240
	Problems	247
7	Design of Hydraulic Structures	250
7.1	Introduction	250
7.2	Culverts	250
7.2.1	Hydraulics	250
7.2.1.1	Submerged entrances	252
7.2.1.2	Unsubmerged entrances	259
7.2.2	Design Constraints	262
7.2.3	Sizing Calculations	264
7.2.3.1	Fixed-headwater method	265
7.2.3.2	Fixed-flow method	269
7.2.3.3	Minimum-performance method	271
7.2.4	Roadway Overtopping	271
7.2.5	Riprap/Outlet Protection	274
7.3	Gates	275
7.3.1	Free Discharge	276
7.3.2	Submerged Discharge	279
7.3.3	Empirical Equations	281
7.4	Weirs	282
7.4.1	Sharp-Crested Weirs	282
7.4.1.1	Rectangular weirs	282
7.4.1.2	V-notch weirs	288

7.4.1.3	Compound weirs	291
7.4.1.4	Other types of sharp-crested weirs	293
7.4.2	Broad-Crested Weirs	294
7.4.2.1	Rectangular weirs	294
7.4.2.2	Compound weirs	297
7.4.2.3	Gabion weirs	298
7.5	Spillways	299
7.5.1	Uncontrolled Spillways	299
7.5.2	Controlled (Gated) Spillways	307
7.5.2.1	Gates seated on the spillway crest	308
7.5.2.2	Gates seated downstream of the spillway crest	309
7.6	Stilling Basins	312
7.6.1	Type Selection	312
7.6.2	Design Procedure	314
7.7	Dams and Reservoirs	318
7.7.1	Types of Dams	319
7.7.2	Reservoir Storage	322
7.7.2.1	Sediment accumulation	323
7.7.2.2	Determination of storage requirements	326
7.7.3	Hydropower	328
7.7.3.1	Turbines	328
7.7.3.2	Turbine performance	333
7.7.3.3	Feasibility of hydropower	334
Problems	335
8	Probability and Statistics in Water-Resources Engineering	344
8.1	Introduction	344
8.2	Probability Distributions	345
8.2.1	Discrete Probability Distributions	345
8.2.2	Continuous Probability Distributions	346
8.2.3	Mathematical Expectation and Moments	347
8.2.4	Return Period	350
8.2.5	Common Probability Functions	351
8.2.5.1	Binomial distribution	351
8.2.5.2	Geometric distribution	353
8.2.5.3	Poisson distribution	354
8.2.5.4	Exponential distribution	356
8.2.5.5	Gamma/Pearson Type III distribution	357
8.2.5.6	Normal distribution	360
8.2.5.7	Log-normal distribution	362
8.2.5.8	Uniform distribution	363
8.2.5.9	Extreme-value distributions	364
8.2.5.10	Chi-square distribution	371
8.3	Analysis of Hydrologic Data	372
8.3.1	Estimation of Population Distribution	372
8.3.1.1	Probability distribution of observed data	372
8.3.1.2	Hypothesis tests	376
8.3.1.3	Model selection criteria	379
8.3.2	Estimation of Population Parameters	379
8.3.2.1	Method of moments	379
8.3.2.2	Maximum-likelihood method	382
8.3.2.3	Method of L-moments	383
8.3.3	Frequency Analysis	387
8.3.3.1	Normal distribution	388
8.3.3.2	Log-normal distribution	389
8.3.3.3	Gamma/Pearson Type III distribution	390

8.3.3.4	Log-Pearson Type III distribution	391
8.3.3.5	Extreme-value Type I distribution	393
8.3.3.6	General extreme-value (GEV) distribution	394
8.4	Uncertainty Analysis	395
	Problems	397
9	Fundamentals of Surface-Water Hydrology I: Rainfall and Abstractions	401
9.1	Introduction	401
9.2	Rainfall	401
9.2.1	Measurement of Rainfall	403
9.2.2	Statistics of Rainfall Data	405
9.2.2.1	Rainfall statistics in the United States	410
9.2.2.2	Secondary estimation of IDF curves	410
9.2.3	Spatial Averaging and Interpolation of Rainfall	416
9.2.4	Design Rainfall	421
9.2.4.1	Return period	421
9.2.4.2	Rainfall duration	422
9.2.4.3	Rainfall depth	422
9.2.4.4	Temporal distribution	422
9.2.4.5	Spatial distribution	428
9.2.5	Extreme Rainfall	429
9.2.5.1	Rational estimation method	430
9.2.5.2	Statistical estimation method	430
9.2.5.3	World-record precipitation amounts	432
9.2.5.4	Probable maximum storm	432
9.3	Rainfall Abstractions	433
9.3.1	Interception	433
9.3.2	Depression Storage	437
9.3.3	Infiltration	437
9.3.3.1	The infiltration process	439
9.3.3.2	Horton model	442
9.3.3.3	Green–Ampt model	447
9.3.3.4	NRCS curve-number model	453
9.3.3.5	Comparison of infiltration models	460
9.3.4	Rainfall Excess on Composite Areas	461
9.4	Baseflow	464
	Problems	468
10	Fundamentals of Surface-Water Hydrology II: Runoff	473
10.1	Introduction	473
10.2	Mechanisms of Surface Runoff	473
10.3	Time of Concentration	474
10.3.1	Overland Flow	474
10.3.1.1	Kinematic-wave equation	474
10.3.1.2	NRCS method	478
10.3.1.3	Kirpich equation	481
10.3.1.4	Izzard equation	481
10.3.1.5	Kerby equation	482
10.3.2	Channel Flow	484
10.3.3	Accuracy of Estimates	486
10.4	Peak-Runoff Models	487
10.4.1	The Rational Method	487
10.4.2	NRCS-TR55 Method	492
10.5	Continuous-Runoff Models	495
10.5.1	Unit-Hydrograph Theory	495
10.5.2	Instantaneous Unit Hydrograph	501

10.5.3	Unit-Hydrograph Models	502
10.5.3.1	Snyder unit-hydrograph model	503
10.5.3.2	NRCS dimensionless unit hydrograph	506
10.5.3.3	Accuracy of unit-hydrograph models	509
10.5.4	Time-Area Models	509
10.5.5	Kinematic-Wave Model	514
10.5.6	Nonlinear-Reservoir Model	515
10.5.7	Santa Barbara Urban Hydrograph Model	517
10.5.8	Extreme Runoff Events	519
10.6	Routing Models	520
10.6.1	Hydrologic Routing	520
10.6.1.1	Modified Puls method	520
10.6.1.2	Muskingum method	524
10.6.2	Hydraulic Routing	531
10.7	Water-Quality Models	533
10.7.1	Event-Mean Concentrations	533
10.7.2	Regression Equations	535
10.7.2.1	USGS model	535
10.7.2.2	EPA model	537
	Problems	539
11	Design of Stormwater-Collection Systems	545
11.1	Introduction	545
11.2	Street Gutters	545
11.3	Inlets	549
11.3.1	Curb Inlets	550
11.3.2	Grate Inlets	554
11.3.3	Combination Inlets	560
11.3.4	Slotted Inlets	565
11.4	Roadside and Median Channels	566
11.5	Storm Sewers	567
11.5.1	Calculation of Design Flow Rates	568
11.5.2	Pipe Sizing and Selection	571
11.5.3	Manholes	576
11.5.4	Determination of Impervious Area	577
11.5.5	System-Design Computations	578
11.5.6	Other Design Considerations	583
	Problems	584
12	Design of Stormwater-Management Systems	586
12.1	Introduction	586
12.2	Performance Goals	586
12.2.1	Quantity Control	586
12.2.2	Quality Control	586
12.3	Design of Stormwater Control Measures	587
12.3.1	Storage Impoundments	587
12.3.1.1	Detention basins—Design parameters	588
12.3.1.2	Wet detention basins	590
12.3.1.3	Dry detention basins	592
12.3.1.4	Design of outlet structures	593
12.3.1.5	Design for flood control	599
12.3.2	Infiltration Basins	603
12.3.3	Swales	605
12.3.3.1	Retention swales	606
12.3.3.2	Biofiltration swales	607
12.3.4	Vegetated Filter Strips	610

12.3.5	Bioretention Systems	610
12.3.6	Exfiltration Trenches	612
	12.3.6.1 General design guidelines	613
	12.3.6.2 Design for flood control	614
	12.3.6.3 Design for water-quality control	616
12.3.7	Subsurface Exfiltration Galleries	617
12.4	Selection of SCMs for Water-Quality Control	618
	12.4.1 Nonstructural SCMs	618
	12.4.2 Structural SCMs	618
	12.4.3 Other Considerations	619
12.5	Major Drainage System	619
	Problems	619
13	Estimation of Evapotranspiration	624
13.1	Introduction	624
13.2	Penman–Monteith Equation	624
	13.2.1 Aerodynamic Resistance	625
	13.2.2 Surface Resistance	626
	13.2.3 Net Radiation	627
	13.2.3.1 Shortwave radiation	627
	13.2.3.2 Longwave radiation	629
	13.2.4 Soil Heat Flux	630
	13.2.5 Latent Heat of Vaporization	631
	13.2.6 Psychrometric Constant	631
	13.2.7 Saturation Vapor Pressure	632
	13.2.8 Vapor-Pressure Gradient	632
	13.2.9 Actual Vapor Pressure	632
	13.2.10 Air Density	633
13.3	Application of the PM Equation	634
13.4	Potential Evapotranspiration	637
13.5	Reference Evapotranspiration	638
	13.5.1 FAO56-Penman–Monteith Method	639
	13.5.2 ASCE Penman–Monteith Method	643
	13.5.3 Evaporation Pans	644
	13.5.4 Empirical Methods	648
13.6	Actual Evapotranspiration	651
	13.6.1 Index-of-Dryness Method	651
	13.6.2 Crop-Coefficient Method	653
	13.6.3 Remote Sensing	653
13.7	Selection of ET Estimation Method	654
	Problems	654
14	Fundamentals of Groundwater Hydrology I: Governing Equations	656
14.1	Introduction	656
14.2	Darcy’s Law	662
	14.2.1 Hydraulic Conductivity	666
	14.2.1.1 Empirical formulae	666
	14.2.1.2 Classification	670
	14.2.1.3 Anisotropic properties	670
	14.2.1.4 Stochastic properties	674
14.3	General Flow Equation	676
14.4	Two-Dimensional Approximations	681
	14.4.1 Unconfined Aquifers	681
	14.4.2 Confined Aquifers	687
14.5	Flow in the Unsaturated Zone	691
	Problems	696

15	Fundamentals of Groundwater Hydrology II: Applications	700
15.1	Introduction	700
15.2	Steady-State Solutions	700
15.2.1	Unconfined Flow Between Two Reservoirs	700
15.2.2	Well in a Confined Aquifer	702
15.2.3	Well in an Unconfined Aquifer	706
15.2.4	Well in a Leaky Confined Aquifer	709
15.2.5	Well in an Unconfined Aquifer with Recharge	713
15.2.6	Partially Penetrating Wells	714
15.3	Unsteady-State Solutions	718
15.3.1	Well in a Confined Aquifer	718
15.3.2	Well in an Unconfined Aquifer	728
15.3.3	Well in a Leaky Confined Aquifer	736
15.3.4	Other Solutions	741
15.4	Principle of Superposition	741
15.4.1	Multiple Wells	742
15.4.2	Well in Uniform Flow	744
15.5	Method of Images	746
15.5.1	Constant-Head Boundary	746
15.5.2	Impermeable Boundary	750
15.5.3	Other Applications	752
15.6	Saltwater Intrusion	752
	Problems	761
16	Design of Groundwater Systems	771
16.1	Introduction	771
16.2	Design of Wellfields	771
16.3	Wellhead Protection	774
16.3.1	Delineation of Wellhead Protection Areas	774
16.3.2	Time-of-Travel Approach	775
16.4	Design and Construction of Water-Supply Wells	777
16.4.1	Types of Wells	777
16.4.2	Design of Well Components	778
16.4.2.1	Casing	779
16.4.2.2	Screen intake	779
16.4.2.3	Gravel pack	783
16.4.2.4	Pump	784
16.4.2.5	Other considerations	785
16.4.3	Performance Assessment	788
16.4.4	Well Drilling	793
16.5	Design of Aquifer Pumping Tests	794
16.5.1	Pumping Well	794
16.5.2	Observation Wells	795
16.5.3	Field Procedures	796
16.6	Design of Slug Tests	798
16.7	Design of Exfiltration Trenches	803
16.8	Seepage Meters	808
	Problems	809
17	Water-Resources Planning	815
17.1	Introduction	815
17.2	Planning Process	815
17.3	Economic Feasibility	818
17.3.1	Compound-Interest Factors	819
17.3.1.1	Single-payment factors	819
17.3.1.2	Uniform-series factors	820

17.3.1.3	Arithmetic-gradient factors	820
17.3.1.4	Geometric-gradient factors	821
17.3.2	Evaluating Alternatives	823
17.3.2.1	Present-worth analysis	823
17.3.2.2	Annual-worth analysis	825
17.3.2.3	Rate-of-return analysis	825
17.3.2.4	Benefit–cost analysis	828
Problems	829
A	Units and Conversion Factors	831
A.1	Units	831
A.2	Conversion Factors	832
B	Fluid Properties	834
B.1	Water	834
B.2	Organic Compounds Found in Water	834
B.3	Air at Standard Atmospheric Pressure	836
C	Statistical Tables	837
C.1	Areas Under Standard Normal Curve	837
C.2	Frequency Factors for Pearson Type III Distribution	839
C.3	Critical Values of the Chi-Square Distribution	841
C.4	Critical Values for the Kolmogorov–Smirnov Test Statistic	842
D	Special Functions	843
D.1	Error Function	843
D.2	Bessel Functions	844
D.2.1	Definition	844
D.2.2	Evaluation of Bessel Functions	844
D.2.2.1	Bessel function of the first kind of order n	844
D.2.2.2	Bessel function of the second kind of order n	845
D.2.2.3	Modified Bessel function of the first kind of order n	845
D.2.2.4	Modified Bessel function of the second kind of order n	845
D.2.2.5	Tabulated values of useful Bessel functions	845
D.3	Gamma Function	848
D.4	Exponential Integral	849
E	Pipe Specifications	850
E.1	PVC Pipe	850
E.2	Ductile-Iron Pipe	850
E.3	Concrete Pipe	851
E.4	Physical Properties of Common Pipe Materials	851
F	Unified Soil Classification System	852
F.1	Definition of Soil Groups	852
F.2	Terminology	853
	Bibliography	854
	Index	912

Preface

Water-resources engineers design systems to control the quantity, quality, timing, and distribution of water to support human habitation and the needs of the environment. Water-supply and flood-control systems are commonly regarded as essential infrastructure for developed areas, and as such water-resources engineering is a core specialty area in civil engineering. Water-resources engineering is also a specialty area in environmental engineering, particularly with regard to the design of water-supply systems, wastewater-collection systems, and water-quality control in natural systems.

The technical and scientific bases for most water-resources applications are in the areas of hydraulics and hydrology, and this text covers these areas with depth and rigor. The fundamentals of closed-conduit flow, open-channel flow, surface-water hydrology, groundwater hydrology, and water-resources planning and management are all covered in detail. Applications of these fundamentals include the design of water-distribution systems, hydraulic structures, sanitary-sewer systems, stormwater-management systems, and water-supply wellfields. The design protocols for these systems are guided by the relevant ASCE, WEF, and AWWA manuals of practice, as well as USFHWA design guidelines for urban and transportation-related drainage structures, and USACE design guidelines for hydraulic structures. The topics covered in this book constitute the technical background expected of water-resources engineers. This text is appropriate for undergraduate and first-year graduate courses in hydraulics, hydrology, and water-resources engineering. Practitioners will also find the material in this book to be a useful reference on appropriate design protocols.

The book has been organized in such a way as to sequentially cover the theory and design applications in each of the key areas of water-resources engineering. The theory of flow in closed conduits is covered in Chapter 2, including applications of the continuity, momentum, and energy equations to flow in closed conduits, calculation of water-hammer pressures, flows in pipe networks, affinity laws for pumps, pump performance curves, and procedures for pump selection and assessing the performance of multi-pump systems. The design of public water-supply systems and building water-supply systems are covered in Chapter 3, which includes the estimation of water demand, design of pipelines, pipeline appurtenances, service reservoirs, performance criteria for water-distribution systems, and several practical design examples. The theory of flow in open channels is covered in Chapter 4, which includes applications of the continuity, momentum, and energy equations to flow in open channels, and computation of water-surface profiles. The design of drainage channels is covered in Chapter 5, which includes the application of design standards for determining the appropriate channel dimensions for various channel linings, including vegetative and non vegetative linings. The design of sanitary-sewer systems is covered in Chapter 6, which includes design approaches for estimating the quantity of wastewater to be handled by sewers; sizing sewer pipes based on self-cleansing and capacity using the ASCE-recommended tractive-force method; and the performance of manholes, force mains, pump stations, and hydrogen-sulfide control systems are also covered. Design of the most widely used hydraulic structures is covered in Chapter 7, which includes the design of culverts, gates, weirs, spillways, stilling basins, and dams. This chapter is particularly important since most water-resources projects rely on the performance of hydraulic structures to achieve their objectives. The bases for the design of water-resources systems are typically rainfall and/or surface runoff, which are random variables that must generally be specified probabilistically. Applications of probability and statistics in water-resources engineering are covered in detail in Chapter 8, with particular emphasis on the analysis of hydrologic data and uncertainty analysis in predicting hydrologic variables. The fundamentals of surface-water hydrology are covered in Chapters 9 and 10. These chapters cover the statistical characterization of rainfall for design applications, methodologies for estimating peak runoff and runoff hydrographs, methodologies for routing runoff hydrographs through detention basins, and methods for estimating the quality of surface runoff. The design of stormwater-collection systems is covered in Chapter 11,

including the design of stormwater inlets and storm sewers. Stormwater-management systems are designed to treat stormwater prior to discharge into receiving waters, and the design of these systems is covered in Chapter 12. Several state-of-the-art design examples for the most commonly used stormwater-control measures are provided, including the design of infiltration basins, swales, filter strips, bioretention systems, and exfiltration trenches. The estimation of evapotranspiration, which is usually the dominant component of seasonal and annual water budgets in arid areas and a core component in the design of irrigation systems, is covered in Chapter 13. The fundamentals of groundwater hydrology are covered in Chapters 14 and 15, including an exposition on Darcy's law, derivation of the general groundwater flow equation, practical solutions to the groundwater flow equation, and methods to assess and control saltwater intrusion in coastal aquifers. Applications of groundwater hydrology to the design of wellfields, the delineation of wellhead protection areas, and the design of wells, aquifer pumping tests, slug tests, and exfiltration trenches are all covered. Water-resources planning typically includes identifying alternatives and ranking the alternatives based on specified criteria. Chapter 17 covers the conventional approaches for identifying and ranking alternatives and the bases for the economic evaluation of these alternatives.

In summary, this book provides an in-depth coverage of the subject areas that are fundamental to the practice of water-resources engineering. A firm grasp of the material covered in this book along with complementary practical experience are the foundations on which water-resources engineering is practiced at the highest level. Throughout the entire textbook, equations contained within boxes represent derived equations that are particularly useful in engineering applications. In contrast, equations without boxes are typically intermediate equations within an analysis leading to a derived useful equation.

This book is a reflection of the author's belief that water-resources engineers must gain a firm understanding of the depth and breadth of the technical areas that are fundamental to their discipline, and by so doing will be more innovative, view water-resource systems holistically, and be technically prepared for a lifetime of learning. On the basis of this vision, the material contained in this book is presented mostly from first principles, is rigorous, is relevant to the practice of water-resources engineering, and is reinforced by detailed presentations of design applications.

Many persons have contributed in various ways to this book and to my understanding of water-resources engineering, and to recognize all of those who have helped me along the way would be a book onto itself. However, special recognition is deserved by Professor LaVere Merritt of Brigham Young University for his expert advice and detailed review of the chapter on design of sanitary sewers and Professor Dixie Griffin of Louisiana Tech for his extensive feedback and constructive comments throughout the years on the present and previous editions of this book. I am also grateful to Professors John Miknis of Pennsylvania State University, Jacob Ogaard of the University of Iowa, Francisco Olivera of Texas A&M University, and Ken Lee of the University of Massachusetts Lowell, for reviewing this book.

What's New in the Third Edition

The third edition of this book contains much new and updated material and is significantly reorganized relative to the previous edition. The most notable changes are as follows:

- The book contains 17 chapters compared to 7 chapters in the previous edition. In the previous edition, most of the chapters were quite long and contained both theory and practical examples. In the present edition, theory-oriented chapters have been separated from practice-oriented chapters. The material in all chapters has been revised and updated, with some chapters being almost entirely rewritten as described below.
- Coverage of the design of drainage channels (Chapter 5) has been completely rewritten. Subsequent to the previous edition of the book, the Federal Highway Administration thoroughly revised their urban drainage design manual, Hydraulic Engineering Circular No.22 (HEC-22), which provides the primary design guidelines for the design of drainage channels in the United States. The updated chapter in this book is consistent with the latest edition of HEC-22. Appendix F describing the unified soil classification system has been added to support the design applications contained in this chapter.

- Coverage of the design of sanitary-sewers (Chapter 6) has been completely rewritten to be consistent with the latest version of the ASCE Manual of Practice No.60 (MOP 60) on the design of sanitary sewers. The latest version of MOP 60 is a significant departure from previous versions of MOP 60 in that the tractive-force design approach is now recommended as the preferred approach for designing sanitary sewers. The updated chapter emphasizes the tractive-force approach and contains the key design aids provided in ASCE Manual of Practice No.60.
- Coverage of the design of stormwater-management systems (Chapter 12) has been significantly revised and updated. Over the past several years, much has been learned about the performance and design of various stormwater control measures (SCMs) and the latest design approaches to these systems are incorporated in the revised chapter. These design approaches are consistent with the latest version of ASCE Manual of Practice No.87.
- In addition to updating the coverage on most topics covered in the book, several new topics have been added. For example, coverage of water hammer, variable-speed pumps, water-surface profiles across bridges, design of dams and reservoirs, and uncertainty analysis have all been added.
- Many new end-of-chapter problems have been added to support the revised coverage in the book, and several problems from the previous edition have been removed or modified.

In summary, this new edition reflects the state-of-the-art of water-resources engineering and is intended provide the necessary competencies expected by the profession. The redesigned chapters, which are shorter in length than previous chapters, are intended to provide a more focused treatment of individual cognate topics and hence contribute to more effective learning by those using this textbook.

DAVID A. CHIN

Water resources development 22. Urban water resource problems in vector-borne disease with special reference 23. Hydraulic, hydrologic and hydrogeologic approaches 24. Surface Water 25. Water Resource Engineering is part of Civil and Environmental engineering education courses and technology degree programs of various universities. Graduates of the Water Resources Engineering Master's programme are primarily employed as academics or scientists at universities and research institutions and as engineers or managers in government agencies, drinking water companies, consulting companies or NGOs. Water resources engineers play a decisive role in the development and management of aquifers and river basins.