

Hydraulic Engineering

John A. Roberson
John J. Cassidy
M. Hanif Chaudhry



Houghton Mifflin Company Boston
Dallas / Geneva, Illinois
Palo Alto / Princeton, New Jersey

To our wives:
Amy, Alice, and Shamim

Copyright © 1988 by Houghton Mifflin Company. All rights reserved.
No part of this work may be reproduced or transmitted in any form or by
any means, electronic or mechanical, including photocopying and
recording, or by any information storage or retrieval system, without the
prior written permission of Houghton Mifflin Company unless such
copying is expressly permitted by federal copyright law. Address inquiries
to Permissions, Houghton Mifflin Company, One Beacon Street, Boston,
Massachusetts 02108.

Art by Boston Graphics, Inc.

Printed in the U.S.A.
Library of Congress Catalog Card Number: 87-81367
ISBN: 0-395-38123-1

ABCDEFGHIJ-H-9543210-8987

Con

Preface

Chapter 1

1-1

1-2

1-3

Chapter 2

2-1

2-2

2-3

2-4

2-5

2-6

2-7

2-8

2-9

Chapter 3

3-1

3-2

Contents

Preface	ix
Chapter 1 Introduction	1
1-1 Scope of Hydraulic Engineering	2
1-2 Historical Perspective	8
1-3 Trends for the Future	16
Chapter 2 Hydrology	20
2-1 General Considerations	21
2-2 Project Needs	21
2-3 Hydrologic Cycle	22
2-4 Statistics and Probability	26
2-5 Precipitation	38
2-6 Surface Runoff	59
2-7 Streamflow	78
2-8 Obtaining Hydrologic Data	91
2-9 Computer Programs for Hydrology	93
Chapter 3 Groundwater	107
3-1 General Considerations	108
3-2 Occurrence of Groundwater	109

3-3	Principles of Groundwater Flow	112
3-4	One-Dimensional Steady Groundwater Flow	116
3-5	Well Hydraulics	121
3-6	Pumping Tests	133
3-7	Recharging or Injection Wells	135
3-8	Boundaries of Aquifers	136
3-9	Well Fields	138
3-10	Groundwater Recharge and Safe Yield	140
3-11	Other Analytical Tools	143
Chapter 4	Open Channel Flow	164
4-1	General Considerations	165
4-2	Steady-Uniform Flow in Open Channels	165
4-3	Steady-Nonuniform Flow in Open Channels	180
4-4	Measurement of Discharge in Open Channels	208
4-5	Unsteady-Nonuniform Flow in Open Channels	217
Chapter 5	Closed Conduit Flow	240
5-1	General Considerations	241
5-2	Energy Equation	241
5-3	Head Loss	243
5-4	Head-Discharge Relations for Pump or Turbine	262
5-5	Conduit Systems	263
5-6	Instruments and Procedures for Discharge Measurement	276
5-7	Forces and Stresses in Pipes and Bends	284
5-8	Pipe Materials	294
5-9	Large Conduit Design	297
Chapter 6	Dams and Reservoirs	311
6-1	The Planning Process	312

- 6-2 Types of Dams 314
- 6-3 River Diversion 335
- 6-4 Dam Safety 339
- 6-5 Reservoirs 346

Chapter 7 Hydraulic Structures 372

- 7-1 Functions of Hydraulic Structures 373
- 7-2 Dam Appurtenances 374
- 7-3 Hydroelectric Facilities 396
- 7-4 Pump Intake Structures 401
- 7-5 Cavitation in Hydraulic Structures 402
- 7-6 Experimental Design 408
- 7-7 Diffusers for Wastewater 415
- 7-8 Thermal Effluent Diffusers for Power Plants 424

Chapter 8 Hydraulic Machinery 432

- 8-1 An Introduction to Pumps and Turbines 433
- 8-2 Dimensionless Parameters for Turbomachines 436
- 8-3 Axial-Flow Pumps 438
- 8-4 Radial- and Mixed-Flow Pumps 441
- 8-5 Performance Characteristics Under Abnormal Operating Conditions 446
- 8-6 Specific Speed 447
- 8-7 Multistage Pumps 449
- 8-8 Cavitation Pumps and Suction Limitations 450
- 8-9 Pumps Operating in a Pipe System 454
- 8-10 Pumps Operated in Combination 456
- 8-11 Hydraulic Turbines 458
- 8-12 Pump Turbines 477
- 8-13 Viscous Effects 478
- 8-14 Other Types of Pumps 479

Chapter 9	Flood Control	493
9-1	Flooding and Historical Control	494
9-2	Control of Flooding	500
9-3	Flood Plain Management	505
9-4	Delineation of the Flood Plain	506
9-5	Flood Plain Encroachment	516
9-6	Risk Within the Flood Plain	519
9-7	Reservoir Operation for Flood Control	524
9-8	Nonstructural Aspects of Flood Control	532
Chapter 10	Mathematical Modeling of Hydraulic Systems	540
10-1	Mathematical Models	541
10-2	Errors in Numerical Analysis	545
10-3	Interpolations	545
10-4	Nonlinear Algebraic Equations	548
10-5	Quadrature	555
10-6	Linear Algebraic Equations	556
10-7	Ordinary Differential Equations	558
10-8	Finite-Difference Approximations	566
Chapter 11	Unsteady Closed-Conduit Flow	572
11-1	Definitions	573
11-2	Time for Flow Establishment in a Pipe	575
11-3	Pressure Change Produced by a Velocity Change	577
11-4	Wave Speed	580
11-5	Pressure Wave Propagation and Reflections	581
11-6	Governing Equations	583
11-7	Solution of Momentum and Continuity Equations	589
11-8	Method of Characteristics	589
11-9	Boundary Conditions	592

11-10	Computational Procedure	597	
11-11	Transients Caused by Pumps	601	
11-12	Control Devices	603	
11-13	Surge Tank Water-Level Oscillations	604	
Chapter 12	Unsteady Free-Surface Flows		610
12-1	Definitions	611	
12-2	Governing Equations	612	
12-3	Methods of Solution	616	
12-4	Method of Characteristics	616	
12-5	Finite-Difference Methods	619	
12-6	Explicit Methods	620	
12-7	Implicit Finite-Difference Methods	621	
12-8	Comparison of Explicit and Implicit Methods	627	
12-9	Approximate Methods for Flood Routing	628	
Appendix			638
Index			651