SECOND EDITION

Introduction to Hydrology

Warren Viessman, Jr.

Environment and Natural Resources Policy Division Library of Congress

John W. Knapp

Virginia Military Institute

Gary L. Lewis

University of Nebraska

Terence E. Harbaugh

IEP-Dun-Donnelley HARPER & ROW, PUBLISHERS New York Hagerstown San Francisco London

Contents

Preface xiii

1 Introduction

- 1-1 Hydrology Defined 1
- 1-2 A Brief History
- 1-3 The Hydrologic Cycle 3
- 1-4 The Hydrologic Budget 4
- 1-5 Application of the Hydrologic Equation 8

1

- 1-6 Hydrologic Data 10
- 1-7 Common Units of Measurements 10

1

- 1-8 Application of Hydrology to Environmental Problems 11
- Problems 12

References 13

2 Precipitation 15

- 2-1 Water Vapor 15
- 2-2 Precipitation 21
- 2-3 Distribution of the Precipitation Input 30
- 2-4 Point Precipitation 33
- 2-5 Areal Precipitation 35

vii

2-6 Probable Maximum Precipitation 36
2-7 Gross and Net Precipitation Inputs 38
Problems 40
References 42

3 Hydrologic Abstractions 43

3-1 Evaporation 43

3-2 Transpiration 53

3-3 Evapotranspiration 56

3-4 Simulation of Evapotranspiration 57

3-5 Interception 61

3-6 Depression Storage 64

3-7 Infiltration 67

Problems 81

References 85

4 Streamflow 89

- 4-1 Basin Characteristics Affecting Runoff 89
- 4-2 Some Elementary Precipitation-Streamflow Relationships 99
- 4-3 The Hydrograph 102
- 4-4 Components of the Hydrograph 102
- 4-5 Surface Flow Phenomenon Within a Watershed
- 4-6 Hydrograph Components 105
- 4-7 Groundwater Recession 108
- 4-8 Separation Techniques 111
- 4-9 Time Base of the Hydrograph 112
- 4-10 Basin Lag and Time of Concentration 113
- 4-11 Unit Hydrograph Development 116
- 4-12 Derivation of Unit Hydrographs 117
- 4-13 S-Hydrographs and Lagging Methods 126
- 4-14 Matrix Methods of Unit Hydrographs 131

4-15 Synthetic Methods of Unit Hydrographs 134

4-16 Synder's Method 134

4-17 SCS Method 138

4-18 Gray's Method 140

4-19 Simulation Methods in Hydrology 144

- 4-20 Statistical and Probability Approaches to Runoff Determination 148
- 4-21 Streamflow Forecasting 149 Problems 150

References 154

5

Point-Frequency Analysis 157

- 5-1 Concepts of Probability 158
- 5-2 Probability Distributions 161

103

5-3 Moments of Distributions 166 5-4 **Distribution Characteristics** 167 5-5 Types of Probability Distributions 171 5-6 **Continuous Frequency Distributions** 173 5-7 Frequency Analysis 175 5-8 **Plotting Distributions** 176 5-9 **Frequency Factors** 178 5-10 Reliability of Statistical Frequency Studies 1835-11 Additional Frequency Analyses 186 Problems 192199 References **Regional Analysis: Joint Distributions and** Time Series 201 6-1 Additional Probability Concepts 2016-2 Multivariate Distributions 2056-3 Fitting Regression Equations 207 6-4 Stochastic Time Series 2106-5 Generalized Hydrologic Characteristics 214 6-6 Multiple Regression Techniques 220 Problems 224 References 228 Hydrologic and Hydraulic Routing 231 7-1 Hydrologic River Routing 2327-2 Hydrologic Reservoir Routing by the Storage Indication Method 2407-3 Hydrologic Watershed Routing 2447-4 Hydraulic River Routing 249 7-5 Hydraulic Reservoir Routing 2697-6 Hydraulic Watershed Routing 272Problems 283References 288Groundwater Hydrology 2918-1 Introduction 291 8-2 Groundwater Flow—General Properties 293Subsurface Distribution of Water 8-3 293.8-4 Geologic Considerations 2958-5 Fluctuations in Groundwater Level 2968-6 Groundwater-Surfacewater Relationships 296 8-7 Hydrostatics 2978-8 Groundwater Flow 2978-9 Darcy's Law 2988-10 Permeability 300

6

7

x

8-11 Velocity Potential 302

8-12 Hydrodynamic Equations 3028-13 Flowlines and Equipotential Lines 306 8-14 Boundary Conditions 3108-15 Flow Nets 311 8-16 Variable Hydraulic Conductivity 314 8-17 Anisotropy 315 8-18 Dupuit's Theory 315 8-19 Methods for Developing Groundwater Supplies 3208-20 Steady Unconfined Radial Flow Toward a Well 3218-21 Steady Confined Radial Flow Toward a Well 322 8-22 Well in a Uniform Flow Field 323 8-23 Well Fields 325 8-24 The Method of Images 326 8-25 Unsteady Flow 328 8-26 Leaky Aquifers 333 8-27 Partially Penetrating Wells 333 8-28 Salt Water Intrusion 334 8-29 Computers and Numerical Methods in Groundwater Hydrology 334 8-30 Groundwater Basin Development 335 Problems 335 References 339

9

Snow Hydrology 343

9-1 Introduction 343

9-2 Snow Accumulation and Runoff 344

9-3 Snow Measurements and Surveys 346

9-4 Point and Areal Snow Characteristics 347

9-5 The Snowmelt Process 349

9-6 Snowmelt Runoff Determinations 363 Problems 387

References 387

10 Hydrologic Synthesis and Simulation 389

- 10-1 Hydrologic Synthesis 390
- 10-2 Hydrologic Simulation 399
- 10-3 Major Hydrologic Simulation Models 408
- 10-4 Continuous Streamflow Simulation Model Studies

10-5 Rainfall-Runoff, Event Simulation Models 451

- 10-6 Groundwater Simulation 478
- 10-7 Digital Simulation in Snow Hydrology 492

10-8 Hydrologic Simulation Applications496Problems497

References 499

433

11 Urban and Small Watershed Hydrology 503 11-1 Introduction 503 11-2 Peak Flow Formulas for Urban and Small 506 Watersheds. 11-3 Urban Runoff Models 52911-4 Small Watershed Simulation Using Equations of Gradually Varied Unsteady Flow 558 11-5 Land Use Effects 563 Problems 570 References 573 12 Hydrologic Design 577 12-1 Data for Hydrologic Design 578 12-2 Frequency Levels in Hydrologic Design 581 12-3 Design Storms 59212-4 Minor Structure Design-SCS Method 616 12-5 Airport Drainage Design 637 12-6 Design of Urban Storm Drain Systems 638 Problems 644 References 646 13 Water Quality Models 647 13-1 Water Quality Models 647 13-2 A Crude Water Quality Model of Lake Flushing Rates 650 13-3 Chen and Orlob Model 658 13-4 Lombardo and Franz Model 659 13-5 QUAL-1 and DOSAG-1 Simulation Models 663 13-6 EPA Storm Water Management Model 667 13-7 University of Cincinnati Urban Runoff Model 669 13-8 Groundwater Quality Modeling 669 Problems 670 References 670 Appendix A 675 Matrix Definition 675 Transpose of a Matrix 675 Determinant of a Matrix 676 Cofactor 676 The Adjoint Matrix 676 Equality of Matrices 676 Matrix Multiplication 676 The Inverse Matrix 677 Solution of a System of Linear Equations 677 Error 678