

Contents

Preface to the Third Edition xiii

About the Authors xv

Acknowledgements xvii

PART ONE: THEORY I

I. Groundwater in Construction 3

- 1.1 Groundwater in the Hydrologic Cycle 3
- 1.2 Origins of Dewatering 6
- 1.3 Development of Modern Dewatering Technology 6

2. The Geology of Soils 10

- 2.1 Geologic Time Frame 11
- 2.2 Formation of Soils 11
- 2.3 Mineral Composition of Soils 11
- 2.4 Rivers 12
- 2.5 Lakes 12
- 2.6 Estuaries 14
- 2.7 Beaches 14
- 2.8 Wind Deposits 14
- 2.9 Glaciers—The Pleistocene Epoch 14
- 2.10 Rock 16
- 2.11 Limestone and Coral 17
- 2.12 Tectonic Movements 19
- 2.13 Man-made Ground 19

3. Soils and Water 22

- 3.1 Soil Structure 22

3.2	Gradation of Soils	22
3.3	Porosity, Void Ratio, and Water Content	26
3.4	Relative Density, Specific Gravity, and Unit Weight	26
3.5	Capillarity and Unsaturated Flow	27
3.6	Specific Yield and Specific Retention	27
3.7	Hydraulic Conductivity	29
3.8	Plasticity and Cohesion of Silts and Clays	35
3.9	Unified Soil Classification System (ASTM D-2487)	35
3.10	Soil Descriptions	39
3.11	Visual and Manual Classification of Soils	40
3.12	Seepage Forces and Soil Stress	42
3.13	Gravity Drainage of Granular Soils	43
3.14	Drainage of Fine-grained Soils: Pore Pressure Control	44
3.15	Settlement as a Result of Dewatering	46
3.16	Preconsolidation	48
3.17	Other Side Effects of Dewatering	50
4.	Hydrology of the Ideal Aquifer	52
4.1	Definition of the Ideal Aquifer	52
4.2	Transmissivity T	53
4.3	Storage Coefficient C_s and Specific Yield	53
4.4	Pumping from a Confined Aquifer	55
4.5	Recovery Calculations	56
4.6	The Unconfined or Water Table Aquifer	57
4.7	Specific Capacity	58
5.	Characteristics of Natural Aquifers	61
5.1	Anisotropy: Stratified Soils	61
5.2	Horizontal Variability	64
5.3	Recharge Boundaries: Radius of Influence R_0	64
5.4	Barrier Boundaries	65
5.5	Delayed Release from Storage	65
6.	Dewatering Design Using Analytical Methods	66
6.1	Radial Flow to a Well in a Confined Aquifer	66
6.2	Radial Flow to a Well in a Water Table Aquifer	68
6.3	Radial Flow to a Well in a Mixed Aquifer	69
6.4	Flow to a Drainage Trench from a Line Source	69
6.5	The System as a Well: Equivalent Radius r_s	70
6.6	Radius of Influence R_0	71
6.7	Hydraulic Conductivity K and Transmissivity T	71
6.8	Initial Head H and Final Head h	72
6.9	Partial Penetration	72
6.10	Storage Depletion	73
6.11	Specific Capacity of the Aquifer	75
6.12	Cumulative Drawdown or Superposition	76
6.13	Capacity of the Well Q_w	77
6.14	Flow Net Analysis and the Method of Fragments	79

- 6.15 Concentric Dewatering Systems 80
- 6.16 Vertical Flow 81
- 6.17 Gravel Tremie 82

7. Groundwater Modeling Using Numerical Methods84

- 7.1 Models in Dewatering Practice 84
- 7.2 When to Consider a Numerical Model 87
- 7.3 Principal Steps in Model Design and Application 90
- 7.4 The Conceptual Model: Defining the Problem to Be Modeled 90
- 7.5 Selecting the Program 91
- 7.6 Introduction to MODFLOW 91
- 7.7 Verification 94
- 7.8 Calibration 94
- 7.9 Prediction and Parametric Analyses 95
- 7.10 Some Practical Modeling Problems 95
- 7.11 2-D Model: Well System in a Water Table Aquifer 95
- 7.12 Calibrating the Model 97
- 7.13 3-D Model: Partial Penetration 98
- 7.14 3-D Model: Vertical Flow 101
- 7.15 3-D Model: Transient Analysis of a Progressive Trench Excavation 102

8. Piezometers for Groundwater Measurement and Monitoring 111

- 8.1 Subsurface Conditions 111
- 8.2 Ordinary Piezometers and True Piezometers 111
- 8.3 Piezometer Construction 113
- 8.4 Verification of Piezometer Performance 115
- 8.5 Obtaining Data from Piezometers 115
- 8.6 Pore Pressure Piezometers in Fine-grained Soils 117
- 8.7 Direct Push Technologies for Piezometer Installation 118

9. Pumping Tests 121

- 9.1 When a Pumping Test Is Advisable 121
- 9.2 Planning the Pumping Test 122
- 9.3 Design of the Pumping Well 122
- 9.4 Piezometer Array 125
- 9.5 Duration of Drawdown and Recovery 126
- 9.6 Pumping Rate 128
- 9.7 Monitoring the Pumping Test 128
- 9.8 Analysis of Pumping Test Data 129
- 9.9 Tidal Corrections 132
- 9.10 Well Loss 134
- 9.11 Step Drawdown Tests 136
- 9.12 Testing of Low-yield Wells 137
- 9.13 Delayed Storage Release: Boulton Analysis 138

10. Surface Hydrology..... 141

- 10.1 Lakes and Reservoirs 141
- 10.2 Bays and Ocean Beaches 141

- 10.3 Rivers 141
- 10.4 Precipitation 144
- 10.5 Disposal of Dewatering Discharge 145
- 10.6 Water from Existing Structures 150

11. Geotechnical Investigation for Dewatering..... 152

- 11.1 Investigation Approach and Objectives 152
- 11.2 Preliminary Studies and Investigations 153
- 11.3 Borings 154
- 11.4 In Situ Test Methods 164
- 11.5 Piezometers and Observation Wells 167
- 11.6 Borehole Seepage Tests for Evaluation of Hydraulic Conductivity 169
- 11.7 Laboratory Analysis of Samples 178
- 11.8 Chemical Testing of Groundwater 180
- 11.9 Geophysical Methods 180
- 11.10 Pumping Tests 181
- 11.11 Permanent Effect of Structures on the Groundwater Body 181
- 11.12 Investigation of the Potential Side Effects of Dewatering 182
- 11.13 Presentation in the Bidding Documents 183

12. Pump Theory 185

- 12.1 Types of Pumps Used in Dewatering 185
- 12.2 Total Dynamic Head 189
- 12.3 Pump Performance Curves 189
- 12.4 Vacuum Pumps 190
- 12.5 Air Lift Pumping 192
- 12.6 Testing of Pumps 193

13. Groundwater Chemistry, Bacteriology, and Fouling of Dewatering Systems 195

- 13.1 Types of Corrosion 195
- 13.2 Corrosive Groundwater Conditions 196
- 13.3 Dewatering in Corrosive Groundwater Conditions 198
- 13.4 Incrustation 198
- 13.5 Mineral Incrustation 199
- 13.6 Biological Incrustation 200
- 13.7 Dewatering Systems and Incrustation 205
- 13.8 Field Evaluation of Well Fouling 208
- 13.9 Rehabilitation and Maintenance 209
- 13.10 Analysis of Groundwater 215

14. Contaminated Groundwater..... 222

- 14.1 Contaminants Frequently Encountered 222
- 14.2 Design Options at a Contaminated Site 223
- 14.3 Estimating Water Quantity to Be Treated 225
- 14.4 Other Considerations in Treatment Design 225
- 14.5 Elements of Groundwater Treatment 226
- 14.6 Recovery of Contaminated Water with Dewatering Techniques 229
- 14.7 Dynamic Barriers 232
- 14.8 Wellpoint Systems and Multiphase Contaminants 232

- 14.9 Reinjection 233
- 14.10 Health and Safety 234
- 14.11 Regulating Authorities 234

15. Piping Systems 238

- 15.1 Dewatering Pipe and Fittings 238
- 15.2 Losses in Discharge Piping 241
- 15.3 Losses in Wellpoint Header Lines 241
- 15.4 Losses in Ejector Headers 243
- 15.5 Water Hammer 243

PART TWO: PRACTICE 245

16. Choosing a Method of Groundwater Control 247

- 16.1 To Pump or Not to Pump 247
- 16.2 Open Pumping Versus Predrainage 247
- 16.3 Methods of Predrainage 250
- 16.4 Methods of Cutoff and Exclusion 253
- 16.5 Methods in Combination 253

17. Sumps, Drains, and Open Pumping 259

- 17.1 Soil and Water Conditions 259
- 17.2 Boils and Blows 259
- 17.3 Construction of Sumps 260
- 17.4 Ditches and Drains 261
- 17.5 Gravel Bedding 261
- 17.6 Slope Stabilization with Sandbags, Gravel, and Geotextiles 262
- 17.7 Use of Geotextiles 262
- 17.8 Soldier Piles and Lagging: Standup Time 263
- 17.9 Longterm Effect of Buried Drains 264
- 17.10 Leaking Utilities 264
- 17.11 Battered Wellpoints 265
- 17.12 Horizontal Wellpoints 265

18. Deep Well Systems 267

- 18.1 Testing During Well Construction 267
- 18.2 Well Installation and Construction Methods 267
- 18.3 Wellscreen and Casing 279
- 18.4 Filter Packs 285
- 18.5 Development of Wells 291
- 18.6 Well Construction Details 295
- 18.7 Pressure Relief Wells, Vacuum Wells 300
- 18.8 Wells That Pump Sand 300
- 18.9 Systems of Low-capacity Wells 304

19. Wellpoint Systems 307

- 19.1 Suction Lifts 307
- 19.2 Single and Multistage Systems 310

19.3	Wellpoint Design	310
19.4	Wellpoint Spacing	313
19.5	Wellpoint Depth	315
19.6	Installation of Wellpoints	318
19.7	Filter Sands	320
19.8	Wellpoint Pumps, Header, and Discharge Piping	321
19.9	Tuning Wellpoint Systems	323
19.10	Air/Water Separation	326
19.11	Automatic Mops	326
19.12	Vertical Wellpoint Pumps	326
19.13	Wellpoints for Stabilization of Fine-grained Soils	329
19.14	Wellpoint Systems for Trench Work	331

20. Ejector Systems and Other Methods..... 336

20.1	Two-pipe and Single-pipe Ejectors	336
20.2	Ejector Pumping Stations	338
20.3	Ejector Efficiency	339
20.4	Design of Nozzles and Venturis	340
20.5	Ejector Risers and Swings	344
20.6	Ejector Headers	344
20.7	Ejector Installation	345
20.8	Ejectors and Groundwater Quality	345
20.9	Ejectors and Soil Stabilization	349
20.10	Drilled Horizontal Wells	349
20.11	Trencher Drains	355

21. Groundwater Cutoff Structures..... 358

21.1	Cutoff Terminology and Efficiency	358
21.2	Steel Sheet Piling	358
21.3	Slurry Trenches	367
21.4	Slurry Diaphragm Walls	379
21.5	Secant Piles	390
21.6	Deep Soil Mixing	398
21.7	Tremie Seals	405

22. Grouting Methods 410

22.1	Permeation Grouting	410
22.2	Jet Grouting	439
22.3	Rock Curtain Grouting	456
22.4	Grouting of Structures and Flowpaths	474

23. Dewatering and Groundwater Control for Soft Ground Tunneling 491

23.1	Soft Ground Tunneling Methods with Conventional Dewatering	491
23.2	Ground Behavior	495
23.3	Mixed-face Ground Conditions	497
23.4	Dewatering Design for Tunnels	497
23.5	Methods of Tunnel Predrainage	499
23.6	Tunneling Techniques with Built-in Groundwater Control	500

23.7	Compressed Air Tunneling	504
23.8	Dewatering of Access Shafts, Penetrations, and Starter Tunnels	505
24.	Ground Freezing.....	508
24.1	General Principles	508
24.2	Freezing Applications	509
24.3	Freezing Methods and Equipment	515
24.4	Ground Freezing and Soils	528
24.5	Design	533
24.6	Effect of Groundwater Movement	534
24.7	Ground Movement Potential as a Result of Artificial Freezing	534
25.	Artificial Recharge.....	539
25.1	Recharge Applications	539
25.2	Design Objectives	540
25.3	Potential Problems with Recharge Water and Plugging of Wells	541
25.4	Sources of Recharge Water	543
25.5	Treatment of Recharge Water	544
25.6	Construction of Recharge Systems	545
25.7	Operation and Maintenance of Recharge Systems	550
25.8	Permits for Recharge Operations	550
26.	Electrical Design for Dewatering Systems.....	556
26.1	Electrical Motors	556
26.2	Motor Controls	561
26.3	Power Factor	564
26.4	Electric Generators	564
26.5	Switchgear and Distribution Systems	566
26.6	Grounding of Electrical Circuits	570
26.7	Cost of Electrical Energy	570
27.	Long-term Dewatering Systems	572
27.1	Types of Long-term Systems	572
27.2	Access for Maintenance	572
27.3	Instrumentation and Controls	575
28.	Dewatering Costs.....	577
28.1	Format of the Estimate	577
28.2	Basic Cost Data	577
28.3	Mobilization	578
28.4	Installation and Removal	578
28.5	Operation and Maintenance	579
28.6	Summary	581
28.7	Specialty Dewatering Subcontractor Quotations	581
29.	Dewatering Specifications, Allocation of Risk, Dispute Avoidance, and Resolution of Disputes.....	584
29.1	Performance Specifications	585

29.2	Owner-designed Dewatering Systems	586
29.3	Specified Minimum Systems	586
29.4	Dewatering Submittals	586
29.5	Third-party Damage Caused by Dewatering	587
29.6	Differing Site Conditions	588
29.7	Disputes Review Board	595

Appendix A 597

Appendix B 603

Appendix C 620

Index 623