Contents

Acknowledgments, xv
Preface, xvii
About the companion website, xix

1 Natural resources engineering opportunities, 1
   1.1 Definitions, 2
   1.2 The hydrologic cycle and the water–soil–air–biotic continuum, 3
   1.3 Changing land uses due to societal forces, 4
   1.4 Natural resources and ecological engineering scope addressed in this text, 5
      1.4.1 Flood prevention, 5
      1.4.2 Erosion control, 6
      1.4.3 Water quality renovation and management, 6
      1.4.4 Drainage, 7
      1.4.5 Irrigation, 7
      1.4.6 Bioremediation, 8
      1.4.7 Watershed–stream assessment, 8
      1.4.8 Ecological Engineering, 8
   1.5 Outlook, 11
   References, 14

Part One: Quantifying the Hydrologic Cycle

2 Precipitation, 19
   2.1 Precipitation mechanisms, types, and measurement, 19
      2.1.1 Precipitation defined, 19
      2.1.2 Condensation, 20
      2.1.3 Dynamic cooling, 20
      2.1.4 Contact and radiation cooling, 20
      2.1.5 Seasonal effects, 20
      2.1.6 Precipitation characteristics, 21
      2.1.7 Gaging precipitation, 21
      2.1.8 Measuring snowfall, 23
2.2 Precipitation analysis, 23
2.3 Introduction to hydrologic frequency analysis, 25
  2.3.1 Return period analysis, 26
2.4 Local-scale precipitation analysis, 29
  2.4.1 Thiessen polygon method, 29
2.5 Calculating storm magnitudes for design purposes, 30
  2.5.1 Storm simulation, 30
  2.5.2 Probable maximum precipitation, 34
2.6 Pollution transport by precipitation, 34
2.7 The water quality storm, 35
2.8 Climate change and precipitation, 35
2.9 Outlook, 36
References, 37

3 Infiltration, 39
  3.1 Infiltration, percolation, and subsurface flow defined, 39
  3.2 Factors affecting infiltration of aqueous materials, 40
  3.2.1 Soil, 40
  3.2.2 Vegetation and soil organic matter, 40
  3.2.3 Other, 40
  3.3 Darcy’s law, 41
  3.4 Water infiltration and percolation prediction, 45
  3.4.1 Horton equation, 45
  3.4.2 Holton equation, 46
  3.4.3 Kostiakov equation, 46
  3.4.4 Phillip equation, 46
  3.4.5 Green–Ampt equation, 47
  3.5 Infiltration measurement, 50
  3.6 Pollutant transport by subsurface flow, 51
  3.7 Outlook, 53
References, 55

4 Evapotranspiration, 57
  4.1 Background and factors affecting evapotranspiration, 57
  4.2 Evaporation prediction approaches, 58
  4.3 Evaporation from water surfaces based solely on aerodynamic effects or mass balance, 58
  4.4 Evaporation prediction from the energy-balance–Bowen-ratio method, 60
4.5 Reference evaporation prediction accounting for aerodynamic effects and energy balance – the Penman–Monteith combination equation method, 62

4.6 Empirical and approximate methods for $E_p$, 70

4.6.1 Jensen–Haise, 70
4.6.2 The FAO modified Blaney–Criddle method, 71
4.6.3 Priestly–Taylor method, 72
4.6.4 Bowen ratio ET method, 73
4.6.5 Comprehensive soil–canopy simulation, 73

4.7 Physical simulation and measurements of ET, 74

4.7.1 Evaporation and evapotranspiration measurement, 75
4.7.2 Evapotranspiration in forest plantations and urban settings, 76
4.7.3 Pollutants and evaporation suppression, 76

4.8 Outlook, 77

References, 79

5 Runoff, 81

5.1 Background, 81

5.1.1 Hydrograph shapes with compact watersheds, 83

5.2 Watershed or catchment delineation, 84

5.3 Runoff volume for a compact watershed, 86

5.3.1 The National Resource Conservation Service runoff volume (curve number equation), 86
5.3.2 $\phi$ index, 92
5.3.3 The WQS calculation, 92

5.4 Peak runoff rate with compact watersheds, 93

5.4.1 Rational method, 93
5.4.2 The NRCS TR-55 graphical method, 98
5.4.3 The ASABE drainage ditch design flowrate, 101
5.4.4 The US Geological Survey (USGS) runoff equations, 103

5.5 Selecting the design storm, 103

5.5.1 Runoff and peak flow using frequency analysis, 104
5.5.2 The unit hydrograph and runoff hydrograph development, 104
5.5.3 Runoff hydrograph development for complex watersheds and the storms-generalized NRCS TR-20 method, 106

5.6 Frequency analysis of runoff, 111

5.7 Runoff from complex watersheds, 112

5.8 Outlook, 114

References, 118
Part Two: Field- and Farm-Scale Water Quality

6 Water erosion, 123
   6.1 Background, 124
   6.2 Factors affecting water erosion, 124
      6.2.1 Climate, 124
      6.2.2 Soil, 124
      6.2.3 Vegetation, 125
      6.2.4 Topography, 125
   6.3 Soil erosion versus sediment yield, 125
   6.4 Soil loss tolerance, 126
   6.5 Water erosion types, 126
      6.5.1 Interrill erosion, 126
      6.5.2 Rill erosion, 126
      6.5.3 Gully erosion, 128
      6.5.4 Stream channel erosion, 128
   6.6 Erosion mechanics, 128
      6.6.1 Raindrop dislodgement, 128
      6.6.2 Flow-induced erosion, 129
   6.7 Predicting soil detachment and upland erosion, 129
      6.7.1 $R_{ft}$, 131
      6.7.2 $K_{sl}$, 131
      6.7.3 $L_{tf}$, 134
      6.7.4 $S_{f}$, 136
      6.7.5 $C_{prac}$, 136
      6.7.6 $P_{prac}$, 136
      6.7.7 Summary, 138
   6.8 The weighted $R_{ft}C_{prac}$ factor for average annual erosion computation, 138
   6.9 Prediction of sediment yield, 142
   6.10 Legal aspects, 145
   6.11 Modeling approaches for sediment yield prediction, 145
   6.12 Erosion control practices in agriculture, 148
      6.12.1 Contouring, 149
      6.12.2 Strip cropping, 149
      6.12.3 Terracing, 149
      6.12.4 Conservation tillage, 149
   6.13 Erosion and sediment control with construction, 149
6.14 Erosion and nutrient pollution, 152
6.15 Outlook, 152
References, 156

7 Water quality and management at farm/field scales, 159
7.1 Water quality background, 159
7.2 Important concepts and selected pollution measurement techniques, 163
  7.2.1 Concepts and definitions, 163
  7.2.2 Physical measures of pollution, 164
  7.2.3 Chemical measures of pollution, 164
  7.2.4 Biological measures of pollution, 165
  7.2.5 Summary, 165
7.3 Scale effects, 165
7.4 Best management practices for nonpoint pollution abatement, 169
  7.4.1 Selected BMP nomenclature, 170
  7.4.2 Structural and nonstructural management approach, 171
  7.4.3 Crop and animal production, 172
  7.4.4 Best Management Practices and ecology, 174
7.5 Quantitative removal and renovation of selected pollution constituents, 176
7.6 Modeling pollution fate and transport, 178
7.7 Outlook, 179
References, 181

Part Three: Water management on the field and farm scales

8 Open channel hydraulics – fundamentals, 185
  8.1 Hydraulics fundamentals, 185
    8.1.1 Channel elements and nomenclature, 185
    8.1.2 Fluid statics review, 187
    8.1.3 General and uniform flow relationships, 187
  8.2 Channel design and construction, 194
    8.2.1 Type A – solutions involving the Manning equation and continuity equation without additional constraints, 196
    8.2.2 Type B – Manning equation and continuity equation subject to velocity constraints; erodible waterway stability design, 198
    8.2.3 Type C – solve the Manning equation and continuity channel subject to the minimal wetted perimeter with or without side slope $z$ constraint: the economic channel, 201
    8.2.4 Flow transition analyses, 203
    8.2.5 Hydrograph routing in a channel or stream, 204
## Contents

8.2.6 Channel seepage losses, 205  
8.2.7 Construction, 205  

8.3 Outlook, 208  
References, 212  

9 Vegetated waterways and bioswales, 215  
9.1 Vegetated waterways and diversions, 215  
9.1.1 Background, 215  
9.1.2 Channel planning, 216  
9.1.3 Design procedures, 217  
9.2 Bioswales, 222  
9.2.1 Design, 222  
9.2.2 Vegetated filter strips, 223  
9.2.3 Construction and maintenance, 223  
9.3 Outlook, 225  
References, 226  

10 On-site erosion management, 229  
10.1 Terraces on the farm, 230  
10.1.1 Background, 230  
10.1.2 The revised ULSE terrace spacing for erosion prevention, 232  
10.1.3 Terrace channel length, cross-section, maximum grade, and capacity, 233  
10.1.4 Terrace outlet selection, 238  
10.1.5 Tile outlet terraces, 238  
10.1.6 Parallel terrace system planning and design, 243  
10.1.7 Layout, construction, and maintenance, 244  
10.2 Erosion and sediment control in urban areas, 244  
10.3 Outlook, 247  
References, 251  

11 Hydraulics of water management structures, 253  
11.1 Structure types, 254  
11.2 Hydraulic concepts, 258  
11.2.1 Specific energy, 258  
11.2.2 Hydraulic jump, 258  
11.2.3 Subcritical–supercritical flow transitions, 259  
11.3 Stage–discharge relationships of weir inlets and flumes, 259  
11.3.1 Selected weir applications, 260  
11.4 Discharge relations of orifices and sluice gate inlet devices, 265  
11.4.1 Orifice and sluice gate applications, 265
11.5 Flow hydraulics of closed conduits, 265
  11.5.1 Submerged inlets and free discharge, 266
  11.5.2 Submerged inlet and submerged outlet (Category C), 272
  11.5.3 Inlets and outlets that are not submerged (Categories D and E), 273
11.6 Stage–discharge curves for culverts and spillways, 275
11.7 Closed conduit systems for urban storm water collection, 281
11.8 Water measurement structures for irrigation and aquaculture, 282
11.9 Ecologic suitability, 282
11.10 Outlook, 284

References, 287

12 Hydraulics of Impoundments, 289

  12.1 Soils fundamentals for embankment construction, 290
    12.1.1 Soil survey, 290
    12.1.2 Soil properties, 290
    12.1.3 Soil classification, 292
  12.2 Flood routing through reservoirs and related structures, 297
    12.2.1 NRCS TR-55 routing, 297
    12.2.2 Storage routing, 298
  12.3 General pond design, 303
    12.3.1 Pond site selection, 303
    12.3.2 Pond and embankment seepage prediction and control, 306
    12.3.3 Embankment profile, protection, and volume, 308
    12.3.4 Spillway design, 312
    12.3.5 Embankment safety-selection of design storm, 314
  12.4 Applications, 314
    12.4.1 Agricultural pond, 314
    12.4.2 Sedimentation basins, traps, and barriers, 316
    12.4.3 Siting, construction, and safety issues, 322
  12.5 Outlook, 323

References, 329

13 Shallow Groundwater Management, 331

  13.1 Surface drainage, 332
  13.2 Subsurface flow fundamentals, 333
  13.3 Pipe drainage, 335
    13.3.1 Pipe placement, 335
    13.3.2 Design drainage rates and capacity, 338
    13.3.3 Drainage system design and installation, 341
13.4 Shallow wells, 347
  13.4.1 Applications, 347
13.5 Uniform infiltration and drainage to a nearby stream, 353
13.6 Outlook, 354

References, 356

14 Introduction to irrigation, 359
  14.1 Irrigation systems overview, 360
  14.2 Soil–water–plant relations, 362
    14.2.1 Plant available water, 365
    14.2.2 The vadose zone, 367
  14.3 Soil intake rate, 369
  14.4 Water quality issues and leaching requirement for crop well-being, 369
  14.5 Irrigation efficiency, 372
    14.5.1 Conveyance efficiency, 372
    14.5.2 Water application efficiency, 372
    14.5.3 Water use efficiency, 372
    14.5.4 Other irrigation effectiveness indicators, 373
  14.6 Effective rainfall and irrigation scheduling, 374
  14.7 Computing ET requirements – peak ET, 376
  14.8 Computing ET requirements – seasonal water use, 376
  14.9 Irrigation pumping rate for meeting ET requirements, 377
  14.10 Water rights and legal underpinnings, 378
  14.11 Manual or wheel-move lateral sprinkler system design, 378
    14.11.1 Field data, 379
    14.11.2 Irrigation interval, 380
    14.11.3 Lateral sprinkler system set time, 380
    14.11.4 Lateral sprinkler system spacing, 380
    14.11.5 Sprinkler nozzle selection, 380
    14.11.6 Number of sprinklers per lateral system, 382
    14.11.7 Sizing the lateral sprinkler system, 382
    14.11.8 Pressure at lateral sprinkler inlets, 382
    14.11.9 Sizing the mainline, 384
    14.11.10 Sizing and positioning the centrifugal pump, 384
    14.11.11 Sprinkler irrigation design summary, 387
  14.12 Center pivot system specification, 390
    14.12.1 System size, 390
14.12.2 System rotation interval, 391
14.12.3 System flowrate, 391
14.12.4 Maximum application rate, 391
14.13 Linear move irrigation machines, 394
14.14 Design for nontraditional applications, 394
14.15 Microirrigation system design with pressure compensated emitters, 397
14.16 Safety, 401
14.17 Outlook, 401
References, 405

Part Four: Basin-scale Processes

15 Ecological assessment and engineering, 409
15.1 Watershed assessment background, 410
15.2 Watershed assessment methods, 411
  15.2.1 Predominant physical processes, 411
  15.2.2 Predominant biologically related processes, 432
  15.2.3 Predominant chemical processes, 441
15.3 Principles of ecological engineering and ecosystem services, 445
  15.3.1 Ecological engineering, 445
  15.3.2 Ecosystem services, 446
15.4 Outlook, 447
References, 450

Appendices

A Ethics, stakeholder views, case studies, and precision, 457
  A catalog of ethical views, 458
  Making sense of the ethical catalogue – one person’s view, 461
  Resource economics – “social traps”, 462
  Case study one – pitcher plant community viability, 463
  Case study 2 – a hypothetical case concerning clean water act compliance, 466
  Significant digits and presentation precision, 467
  References, 468

B Selected Excel® and other software package solutions, 471
  Selected symbolic solutions, 472
  Determining bottom width and depth in a trapezoidal channel with known slope, side slope, and permissible velocity, 472
  Determining depth and side slope in a triangular channel with known slope and permissible velocity, 473
Determining slope and depth in a triangular channel with known flow rate, permissible velocity and side slope \( z \), 473

References, 474

C Tractive force method for waterway design, 475

Riprap-lined or earthen waterways, 475

Vegetated waterways, 477

References, 479

D Land forming, structure selection, installation, and forces on conduits, 481

Land forming computations, 481

Impoundment and embankment volume calculations, 483

Setting slope stakes for cuts and fills, 486

Techniques for installation of channels and other structures, 486

Layout of circular curves, 487

Small channels or minor topography modifications, 489

Terrace construction and layout, 491

Post-construction stormwater management options, 494

Dry detention pond, 494

Extended wet detention pond, 494

Constructed wetlands, 494

Grass swale, 494

Filter strip and level spreader, 495

Infiltration trench, 495

Oil/grit separator, 495

Source (EPA post-construction) key definitions, 495

Materials specifications for channels and structures, 498

Rural road construction, 498

Buried pipe loading, 499

Trench safety, 502

References, 503

E Selected units conversions, 505

Index, 507