
HYDROLOGY
AND
WATER
QUANTITY
CONTROL

MARTIN
WANIELISTA

.....
.....
.....
—————

CONTENTS

1	Introduction	1
1.1	Organization and Content of the Text	1
1.2	Social Importance and Engineering Relevance	2
1.3	Water Budget or Mass Balance	3
1.3.1	Global Water Budget	5
1.3.2	Geographic Area Water Budgets	5
1.4	Units of Measurement	6
1.5	Computation Aids	8
1.6	Computer Programs	9
1.7	Summary	9
1.8	Problems	10
1.9	Computer-Assisted Problems	10
1.10	References	11
2	Meteorology and the Hydrologic Cycle	13
2.1	Meteorology	14
2.1.1	The Atmosphere	14
2.1.2	Water Vapor	15
2.1.3	Solar Energy	16
2.1.4	Wind	17
2.1.5	Temperature	17
2.1.6	The Variability of Data	19
2.2	Weather Systems	19
2.2.1	Convective Storms	24
2.2.2	Orographic Storms	24
2.2.3	Cyclonic Storms	25
2.2.4	Tropical Cyclones	27

2.3	Hydrologic Cycle	27
2.3.1	The Hydrologic Cycle as a Mass Balance	27
2.3.2	Surface Water Supplies	29
2.3.3	Rainfall Excess	30
2.4	Summary	32
2.5	Problems	32
2.6	References	34

3 **Precipitation** **35**

3.1	The Formation of Precipitation	35
3.2	Classification of Precipitation	36
3.3	Measurement Instrumentation	37
3.3.1	Errors in Gage Measuring	37
3.3.2	Network of Gages	39
3.3.3	Radar Measurement of Rainfall	41
3.4	Missing Data	42
3.5	Interpretation and Quantification of Precipitation	43
3.5.1	Intensity	43
3.5.2	Cumulative Rainfall Diagram	43
3.5.3	Duration of Precipitation	45
3.5.4	Dimensionless Cumulative Rainfall Diagrams	46
3.6	Extrapolation of Point Measures to Watersheds	48
3.6.1	Depth and Watershed Volumes	48
3.6.2	Intensity and Watershed Discharge	48
3.7	Average Watershed Precipitation	49
3.8	Snow	53
3.8.1	Physical Nature and Thermal Properties	54
3.8.2	Energy Budget	57
3.9	Frequency – Intensity – Duration Curves	58
3.10	Summary	63
3.11	Problems	64
3.12	Computer-Assisted Problems	69
3.13	References	70

4 **Infiltration and Evapotranspiration** **73**

4.1	Soil and Hydrologic Classifications	73
4.2	Infiltration as a Hydrologic Process	76

4.2.1	Infiltration Using Theoretical Methods	76
4.2.2	Curve Number, Infiltration, and Rainfall Excess	79
4.2.3	Water Budget	88
4.2.4	Site-Specific Infiltration	88
4.2.5	Phi (Φ) Index	92
4.3	Evapotranspiration	92
4.3.1	Evaporation	93
4.3.2	Transpiration and Evapotranspiration	100
4.3.3	Evaporation from Snow	105
4.4	Case Studies	106
4.5	Summary	110
4.6	Problems	111
4.7	Computer-Assisted Problems	117
4.8	References	118

5 Streamflow Measurements 121

5.1	Methods of Measurement	121
5.1.1	Stage	122
5.1.2	Current Meter	124
5.1.3	Dilution	129
5.1.4	Float	131
5.1.5	Indirect Method Using Manning's Equation	132
5.1.6	Direct Measure	132
5.1.7	Weirs and Flumes	134
5.1.8	Other Commonly Used Gaging and Outlet Controls	139
5.2	Network of Gages	142
5.3	Summary	146
5.4	Problems	148
5.5	Computer-Assisted Problems	154
5.6	References	154

6 Hydrographs 155

6.1	Hydrograph Properties	155
6.1.1	Hydrograph Records	157
6.1.2	Stream Types by Streamflow Hydrograph Analysis	157
6.2	Watershed Characteristics	160
6.2.1	Watershed Boundaries	160
6.2.2	Drainage System and Land Cover	161

6.2.3	Area Storm Coverage	163
6.2.4	Stream Order	164
6.3	Mathematical Description	166
6.3.1	Mathematical Description of the Rising Limb	167
6.3.2	Hydrograph Base Flow Separation (Recession Limb)	168
6.4	Unit Hydrograph from Streamflow Data	173
6.4.1	A Convolution Computation Procedure Using Discrete Time Data	176
6.4.2	Matrix Procedure	183
6.4.3	Computation Procedure for Deriving a Unit Hydrograph	184
6.5	Convolution with Continuous Time Function Form	186
6.5.1	Convolution and Constant Rainfall Excess	188
6.5.2	Convolution and Variable Rainfall Excess	192
6.6	Summary	198
6.7	Problems	199
6.8	Computer-Assisted Problems	204
6.9	References	206

7 Synthetic Hydrographs 207

7.1	Watershed Data	208
7.2	Time of Concentration	209
7.2.1	Izzard's Formula	209
7.2.2	Kerby's Equation	210
7.2.3	Kirpich's Equation	210
7.2.4	Kinematic Wave	211
7.2.5	Soil Conservation Service	212
7.2.6	Manning's Equation	214
7.3	Rainfall Excess	215
7.4	Runoff Hydrographs and Watershed Shapes	219
7.5	Peak Discharge and Hydrograph Shape	221
7.5.1	Rational Method Rainfall Intensity Runoff Relationship	221
7.5.2	The Rational Hydrograph	224
7.6	The SCS Hydrograph	228
7.7	Synthetic Unit Hydrograph	232
7.8	SCS Synthetic Unit Hydrograph	235
7.9	Contributing Area Method	241
7.10	The Santa Barbara Urban Hydrograph Method	251

- 7.11 The Discrete Unit – Time Hydrograph Method 257
- 7.12 Summary 259
- 7.13 Problems 260
- 7.14 Computer-Assisted Problems 265
- 7.15 References 266

8 Flow Routing 269

- 8.1 Theoretical Basis 270
- 8.2 Kinematic Wave 271
 - 8.2.1 Overland Flow 275
 - 8.2.2 Kinematic Parameters for Channel Shapes 276
- 8.3 Routing by the Inventory Equation 280
- 8.4 Routing by the Muskingum Method 286
 - 8.4.1 Muskingum Routing Constants K and c 288
 - 8.4.2 Additional Methods for Estimating K and c 289
- 8.5 Summary 295
- 8.6 Problems 295
- 8.7 Computer-Assisted Problems 298
- 8.8 References 298

9 Probability and Statistics for Hydrologic Descriptors 301

- 9.1 Terminology 302
- 9.2 Probability and Statistics Concepts 302
 - 9.2.1 Definition of Probability 302
 - 9.2.2 Independence 302
 - 9.2.3 Conditional Probability 304
 - 9.2.4 Empirical Probability 304
 - 9.2.5 Probability Properties 305
 - 9.2.6 Graphical Presentations of Probability 306
 - 9.2.7 Central Tendency and Variability 307
- 9.3 Probability Distributions 311
 - 9.3.1 Binomial Distribution 311
 - 9.3.2 Poisson Distribution 312
 - 9.3.3 Normal Distribution 314
 - 9.3.4 Log-Normal Distribution 315
 - 9.3.5 Exponential Distribution 316

9.3.6	Gumbel Distribution	317
9.3.7	Log-Pearson Type III	318
9.4	Recurrence Interval and Risk	319
9.4.1	Evaluation of Risk	321
9.4.2	Limited Samples and Uncertainty	323
9.5	Empirical Frequency Distribution Analysis	324
9.5.1	Histogram Development	324
9.5.2	Plotting Position Formulae	325
9.5.3	Annual and Partial Duration Series	327
9.5.4	Daily and True Internal Comparisons	331
9.6	Regression and Correlation Analysis	333
9.6.1	Bivariate Case	333
9.6.2	Correlation	336
9.7	Summary	337
9.8	Problems	338
9.9	Computer-Assisted Problems	343
9.10	References	344

10 Groundwater Hydrology 345

10.1	The Occurrence of Groundwater	346
10.1.1	Porosity	347
10.1.2	Permeability	347
10.1.3	Factors Affecting Permeability	350
10.1.4	Some Common Permeability Values	351
10.2	Aquifers and Springs	353
10.2.1	Aquifers — An Example	354
10.3	Movement of Groundwaters	356
10.4	Flow in a Confined Aquifer	359
10.5	Flow in an Unconfined Aquifer	360
10.6	Uniform Infiltration and Drainage	362
10.7	Well Systems	363
10.7.1	Yield of a Confined Aquifer	365
10.7.2	Yield of an Unconfined Aquifer at Equilibrium	367
10.7.3	Unsteady Flow	369
10.8	Conjunctive Use	371
10.9	Summary	371
10.10	Problems	372
10.11	References	374

11 **Volume and Peak Discharge Management** **375**

- 11.1 Surface Water Availability from Streamflow 376**
 - 11.1.1 Volume and Yield of a Surface Water Reservoir **377**
 - 11.1.2 Mass Curve (Ripple's Method) **377**
 - 11.1.3 Modification of Storage Volumes **380**
 - 11.1.4 Stochastic Models **381**
 - 11.1.5 Random Generation (Independent Events) **383**
 - 11.1.6 Serial Correlation **386**
- 11.2 Design Storms 387**
 - 11.2.1 Design Storm Frequency **388**
 - 11.2.2 Design Duration and Distribution **389**
- 11.3 Hydrograph Attenuation in a Stormwater Detention Basin 400**
 - 11.3.1 Storage and Outflow Hydrographs **404**
 - 11.3.2 Case Studies **406**
- 11.4 Culverts 415**
- 11.5 Off-Line Retention (Infiltration Ponds) 422**
- 11.6 Swale Design 426**
- 11.7 French Drains 429**
- 11.8 Summary 431**
- 11.9 Problems 432**
- 11.10 Computer-Assisted Problems 441**
- 11.11 References 442**

Appendices 444

- Appendix A Notation 445**
- Appendix B Metric Units with English Equivalents 453**
- Appendix C Nondimensional Rainfall and Frequency – Intensity Duration Curves 459**
- Appendix D Statistical Tables 467**
- Appendix E Derivation of Equations for Swale Design 487**
 - E.1 Triangular Shaped Swale **487**
 - E.2 Trapezoidal Shaped Swale **492**
- Appendix F Gutter, Inlets, and Roadways 497**
 - F.1 Introduction **497**
 - F.2 Gutter Designs **498**
 - F.3 Inlet Designs **502**
 - F.4 Reference **505**

Appendix G	Derivation of the Functional Forms of the Continuous Time Convolution Formulas	507
	G.1 Routing Function	508
Appendix H	Selected Hydrologic Soil Classifications	511
Appendix I	Computer Program Descriptions and Example Outputs	531
	I.1 Content and Organization	531
	I.2 Computer Configuration	532
	I.3 Caring for and Copying the Diskettes	533
	I.4 Initiating the Programs	534
	I.5 Hydrographs and the Matrix Method (Hydrology Programs Menu Three)	535
	I.6 Bivariate Regression Curve Fit (Hydrology Programs Menu Five)	538
	I.7 Continuous Convolution (Hydrology Programs Menu Four)	539
	I.8 SMADA/SCS, Santa Barbara, Rational (Hydrology Programs Menu One)	540
	I.9 KINEMAT (Time of Concentration) (Hydrology Programs (Menu Two)	555
Index		557