## Contents

**Preface**  page ix

1 The realm of hydroclimatology  1  
1.1 Water as a unifying concept  1  
1.2 The global hydrologic cycle  5  
1.3 Hydroclimatology defined  6  
1.4 Emergence of the hydrologic cycle  8  
1.5 Two climates for two hydrologic cycles  14  
1.6 Hydroclimatic data  21  
1.7 Data quality  21  
Review questions  23

2 The climate system and the hydrologic cycle  24  
2.1 Climate and water  24  
2.2 Scale considerations  25  
2.3 Dynamic climate  26  
2.4 The climate system  27  
2.5 The atmospheric subsystem  30  
2.6 Feedbacks  31  
2.7 The hydrologic cycle  32  
2.8 The radiation balance  34  
2.9 Selective atmospheric response to solar radiation  39  
2.10 Terrestrial radiation and the greenhouse effect  43  
2.11 Global radiation balance  45  
2.12 Surface radiation balance  47  
2.13 Planetary energy balance  48  
2.14 The water balance  49  
Review questions  54
3 Measuring hydroclimate atmospheric components 55
  3.1 An atmospheric focus 55
  3.2 Surface data 56
  3.3 Radiation 57
  3.4 Temperature 61
  3.5 Atmospheric pressure 63
  3.6 Humidity 66
  3.7 Radiosonde upper-air measurements 68
      Review questions 73

4 Measuring hydroclimate terrestrial components 74
  4.1 A terrestrial focus 74
  4.2 Terrestrial hydroclimatic data 75
  4.3 Precipitation formation 76
  4.4 Rainfall 78
  4.5 Snowfall 80
  4.6 Wind 86
  4.7 Soil moisture 88
  4.8 Evaporation and evapotranspiration 102
  4.9 Streamflow 117
  4.10 Estimating areal hydroclimatic data 122
      Review questions 125

5 Remote sensing and hydroclimate data 126
  5.1 Remote sensing data 126
  5.2 Satellites 128
  5.3 Radiation data from satellites 140
  5.4 Remotely sensed temperature 142
  5.5 Derived pressure from satellite data 144
  5.6 Atmospheric humidity from satellites 145
  5.7 Rainfall remote sensing 146
  5.8 Snow remote sensing 153
  5.9 Surface wind remote sensing 159
  5.10 Soil moisture remote sensing 160
  5.11 Evapotranspiration remote sensing 162
  5.12 Runoff remote sensing 164
      Review questions 164

6 The runoff process and streamflow 165
  6.1 Transforming precipitation into runoff 165
  6.2 Factors affecting runoff 165
  6.3 Precipitation input 168
  6.4 Interception 169
  6.5 Infiltration 172
## Contents

6.6 Overland flow 174  
6.7 Throughflow or interflow 174  
6.8 Groundwater 176  
6.9 The hydrograph 177  
6.10 Rainfall runoff 181  
6.11 Snow and runoff 190  
6.12 Lakes as surface storage 200  
6.13 Wetlands and runoff 203  
6.14 Reservoirs and streamflow 204  
6.15 Watershed models 207  
Review questions 210

7 Hydroclimate spatial variations 212  
7.1 Spatial scale 212  
7.2 Global atmospheric hydroclimate 213  
7.3 The radiation balance 214  
7.4 Temperature 218  
7.5 Atmospheric humidity 219  
7.6 Atmospheric pressure 223  
7.7 Atmospheric circulation 230  
7.8 Global terrestrial hydroclimate 235  
7.9 Precipitation 235  
7.10 Evapotranspiration 242  
7.11 Soil moisture 243  
7.12 Runoff 244  
7.13 Regional hydroclimate 248  
7.14 Local hydroclimate 256  
Review questions 260

8 Hydroclimate temporal variations 262  
8.1 Temporal scale 262  
8.2 Earth’s climate in perspective 264  
8.3 Tree-ring reconstructions 269  
8.4 Ocean–atmosphere influences on hydroclimate 272  
8.5 Madden–Julian Oscillation 273  
8.6 El Niño, La Niña, and the Southern Oscillation 275  
8.7 North Atlantic Oscillation 282  
8.8 Pacific–North American teleconnection pattern 284  
8.9 Pacific Decadal Oscillation 286  
8.10 Recent temperature trends 289  
8.11 Recent precipitation trends 293  
8.12 Recent streamflow trends 296  
8.13 Recent lake level trends 300  
Review questions 304
Contents

9 Floods: the hydroclimatic extreme of excessive moisture 305
  9.1 Hydroclimatic extreme events 305
  9.2 Flood hydroclimatology 307
  9.3 Flash floods 310
  9.4 Mediterranean Europe flash floods 311
  9.5 United States flash floods 315
  9.6 General floods 325
  9.7 The 2002 central Europe flood 326
  9.8 The 1993 Midwestern United States flood 331
  Review questions 343

10 Drought: the hydroclimatic extreme of deficient moisture 344
  10.1 Negative moisture anomalies 344
  10.2 Drought hydroclimatology 346
  10.3 Drought indices 347
  10.4 Proxy evidence of drought 352
  10.5 Drought causes 354
  10.6 West Africa Sahel drought 356
  10.7 Western United States drought 361
  10.8 Midwestern United States 1988 drought 364
  10.9 Summer 2003 European drought 368
  10.10 Drought and wildfires 373
  10.11 Looking ahead 379
  Review questions 382

References 383
Index 418