Contents

Preface xv
Acknowledgments xxi

I Urban Contexts and Sustainability 1

1 Introduction 3
  1.1 On the Path to Scenario B 4
  1.2 Objective: Integrate Infrastructure Networks 5
  1.3 Why Cities? 8
  1.4 Civitas 10
  1.5 Book Outline 12
  1.6 Measures and Units 13
  1.7 Missing Topics 17
  1.8 Conclusion 18
Problem Set 19
Notes 20
References 21

2 Sustainability 23

  2.1 Defining Sustainability 24
    2.1.1 Formal Definition of Sustainability 24
    2.1.2 Peak Oil, and Why Fossil Fuels Are Unsustainable 30
  2.2 Sustainability Principles 33
    2.2.1 Two Principles of Sustainability 33
    2.2.2 Limitations and Further Considerations 35
      2.2.2.1 The Rebound Effect 35
      2.2.2.2 Controlling Interdependencies 36
  2.3 The Triple Bottom Line of Sustainability 36
  2.4 The IPAT Equation and the Kaya Identity 39
## Contents

2.5 Planetary Boundaries and Nonlinearities 42
2.6 Conclusion 46
Problem Set 47
Notes 50
References 51

3 Population 53

3.1 Malthus and an Essay on the Principle of Population 55
3.2 Short-Term Population Predictions 59
  3.2.1 Geometric Growth Phase 60
  3.2.2 Arithmetic Growth Phase 62
  3.2.3 Declining Growth Phase 62
3.3 Long-Term Population Predictions 65
3.4 The Cohort-Survival Method 69
3.5 Conclusion 72
Problem Set 77
Notes 82
References 83

4 Urban Planning 85

4.1 A Brief History of Urban Planning 88
  4.1.1 The Neolithic Era 88
  4.1.2 Ancient Greece and Rome 89
  4.1.3 Medieval Towns and the Renaissance 92
  4.1.4 Baroque Planning, the Expansion of Cities, and the Pedshed 93
  4.1.5 The City Beautiful, the Garden City, and the Radiant City 95
  4.1.6 Greenbelt Towns and the City of Highways 100
4.2 Essentials of Urban Planning 103
  4.2.1 A City Is Not a Tree 103
  4.2.2 The Image of the City 107
  4.2.3 Eyes on the Street 109
4.3 Urban Design and Desirable Traits 111
  4.3.1 Lynch’s Five Dimensions and Two Metacriteria 112
  4.3.2 Jacobs’s Four Conditions for Diversity 115
4.4 Conclusion 117
Problem Set 120
Notes 121
References 122
II Urban Engineering and Infrastructure Systems 125

5 Electricity 127

5.1 Fundamentals of Electricity 129
   5.1.1 Basics of Electricity 129
   5.1.2 Kirchhoff’s Laws and Load Types 133
   5.1.3 Series and Parallel Circuits 135
   5.1.4 Alternating Current and Direct Current 138
   5.1.5 Three-Phase Power 140
   5.1.6 The Power Grid 142

5.2 Electricity Demand 145
   5.2.1 Temporal and Spatial Analysis of Electricity Demand in the United States 146
   5.2.2 Real-Time Electricity Demand 148
   5.2.3 Typical Power Rating of Appliances 151

5.3 Electricity Generation 151
   5.3.1 Coal-Fired Power Plants 155
   5.3.2 Oil- and Natural Gas–Fired Power Plants 157
   5.3.3 Nuclear Power Plants 157
   5.3.4 Geothermal Power Plants 158
   5.3.5 Biomass Power Plants 159
   5.3.6 Solar Thermal Power Plants 159
   5.3.7 Hydroelectric Power Plants 161
   5.3.8 Wind Farms 162
   5.3.9 Wave and Tide Power 164
   5.3.10 Solar Photovoltaic Power Plants 166
   5.3.11 Greenhouse Gas Emission Factors 169

5.4 Future Grid 171
   5.4.1 Electricity Storage 171
   5.4.2 Smart Grid and Microgrid 172

5.5 Conclusion 174

Problem Set 175
Notes 180
References 182

6 Water 185

6.1 Fundamentals of Water Resources Engineering 187
   6.1.1 Surface Water Hydrology 187
      6.1.1.1 Watershed 187
      6.1.1.2 Hyetographs and Hydrographs 189
      6.1.1.3 Intensity-Duration-Frequency Curves 191
6.1.2 Flow in Closed Conduits 194
   6.1.2.1 Conservation of Energy 196
   6.1.2.2 Friction Losses 198
   6.1.2.3 Pumps 199
   6.1.2.4 Pipe Networks 200
6.1.3 Flow in Open Channels 203
   6.1.3.1 The Manning Equation 203
   6.1.3.2 Energy, Critical Flow, and the Froude Number 206
6.1.4 Groundwater Engineering 208
   6.1.4.1 Groundwater Hydrology 209
   6.1.4.2 Darcy’s Law 210
   6.1.4.3 Pumps 210
6.2 Water Demand 213
   6.2.1 Water Consumption Trends 213
   6.2.2 Water Demand by End Use 215
   6.2.3 Water Demand by Household Size 217
   6.2.4 Water Demand by Hour 217
6.3 Water and Wastewater Treatment 220
   6.3.1 Water Treatment 220
   6.3.2 Wastewater Treatment 221
6.4 Stormwater Management 223
   6.4.1 Sewer Systems 223
   6.4.2 Green Infrastructure and Low-Impact Development 226
   6.4.3 Runoff Modeling 229
      6.4.3.1 Rational Method 229
      6.4.3.2 Natural Resources Conservation Service Curve Number Model 232
6.5 Energy Use in Water 237
6.6 Conclusion 241
Problem Set 242
Notes 248
References 251

7 Transport 253

7.1 Fundamentals of Transport 255
   7.1.1 Traffic Flow Theory 256
   7.1.2 Pedestrian Flow 262
   7.1.3 Public Transit Planning 265
7.2 Travel Demand 275
   7.2.1 Trips 275
   7.2.2 Distance Traveled 277
   7.2.3 Mode Share 281
7.2.4 Greenhouse Gas Emission Factors 284
7.2.5 Origin-Destination Matrix 287
7.3 Transport and Land Use 290
7.4 Transport Modeling and the Four-Step Model 293
  7.4.1 Trip Generation 295
  7.4.2 Trip Distribution 297
  7.4.3 Mode Split 299
  7.4.4 Assignment 301
7.5 Conclusion 306
Problem Set 308
Notes 316
References 318

8 Buildings 321

8.1 Fundamentals of Thermal Comfort and Heat Transfer 324
  8.1.1 Principles of Thermal Comfort 325
  8.1.2 Fundamentals of Heat Transfer 326
    8.1.2.1 Conduction 327
    8.1.2.2 Convection 332
    8.1.2.3 Radiation 336
    8.1.2.4 Combining Heat Transfer Processes 341
  8.1.3 Windows and Air Exchange 344
    8.1.3.1 Windows 344
    8.1.3.2 Air Exchange 345
  8.1.4 Heating and Cooling Efficiency 349
8.2 Energy Demand in Buildings 351
  8.2.1 Degree Days 351
  8.2.2 Compactness and Shape Factor 355
  8.2.3 Building Energy Demand Trends 356
8.3 Building Design and Technology Recommendations 359
  8.3.1 Better Designs 359
    8.3.1.1 Size 360
    8.3.1.2 Compactness 360
    8.3.1.3 Orientation 360
    8.3.1.4 Shading 361
  8.3.2 Technologies 363
    8.3.2.1 Turning Off and Down Equipment 364
    8.3.2.2 Sealing Leaks 364
    8.3.2.3 Windows 364
    8.3.2.4 Insulation 364
    8.3.2.5 Reflecting Material/Paint 364
    8.3.2.6 White-Blue-Green Roof 364
9 Solid Waste 383

9.1 Fundamentals of Solid Waste Management 386
  9.1.1 History 387
  9.1.2 Definition of Solid Waste and Solid Waste Management 391
  9.1.3 Physical, Chemical, and Biological Properties of Solid Waste 401
    9.1.3.1 Physical Properties 401
    9.1.3.2 Chemical Properties 405
    9.1.3.3 Biological Properties 409

9.2 Solid Waste Generation and Composition 411
  9.2.1 Solid Waste Audit 413
  9.2.2 Solid Waste Trends and Composition 417
  9.2.3 Solid Waste Composition by Sector 426

9.3 Solid Waste Disposal 432
  9.3.1 Solid Waste Separation and Processing 434
  9.3.2 Solid Waste Transformation 437
    9.3.2.1 Reuse 437
    9.3.2.2 Recycle 438
    9.3.2.3 Recover 442
  9.3.3 Solid Waste Disposal 442
    9.3.3.1 Incineration 442
    9.3.3.2 Sanitary Landfill 445

9.4 Conclusion 449
Problem Set 451
Notes 457
References 459
III Urban Metabolism and Novel Approaches 461

10 Urban Metabolism and Infrastructure Integration 463

10.1 Urban Metabolism 465
  10.1.1 Materials 469
  10.1.2 Food 475
  10.1.3 Energy 475
  10.1.4 Water 479

10.2 Infrastructure Interdependencies 485
  10.2.1 Transport 487
  10.2.2 Water 492
  10.2.3 Utility 494
  10.2.4 Electricity 495
  10.2.5 Telecom 496
  10.2.6 Solid Waste 498
  10.2.7 Buildings 499

10.3 Integrating and Decentralizing Urban Infrastructure Systems 500
  10.3.1 The Design Patterns of Infrastructure 502
  10.3.2 Integration-Decentralization Matrix 504

10.4 Conclusion 510

Problem Set 512
Notes 518
References 520

11 Science of Cities and Machine Learning 523

11.1 The Science of Cities 525
  11.1.1 Complexity Science 525
  11.1.2 Scaling Laws in Cities 528
  11.1.3 Zipf’s Law 532
  11.1.4 Simple Population Models 536
  11.1.5 Network Science 540

11.2 Machine Learning 551
  11.2.1 Basic Concepts of Machine Learning 552
  11.2.2 K-means Clustering 556
  11.2.3 Decision Tree Learning 558
  11.2.4 Neural Networks 564

11.3 Conclusion 568

Problem Set 572
Notes 579
References 582
12 Conclusion  585

12.1 Three Paradigm-Shifting Changes  587
   12.1.1 Smart Cities  588
   12.1.2 The Rise of New Materials  590
   12.1.3 Organizational Change  594

12.2 Final Thoughts and the Four-Step Urban Infrastructure Design Process  598

Problem Set  600
Notes  601
References  602

Appendix  605
   A. Tables  605
   B. Moody Diagram  611
   C. Level-of-Service Diagram  612
   D. Equation Sheet  614

Index  629