# Contents

Preface xv  
Acknowledgments xxi  

## I Urban Contexts and Sustainability  
1 Introduction  
1.1 On the Path to Scenario B  
1.2 Objective: Integrate Infrastructure Networks  
1.3 Why Cities?  
1.4 Civitas  
1.5 Book Outline  
1.6 Measures and Units  
1.7 Missing Topics  
1.8 Conclusion  
Problem Set  
Notes  
References  

## II Sustainability  
2 Defining Sustainability  
2.1 Formal Definition of Sustainability  
2.2 Peak Oil, and Why Fossil Fuels Are Unsustainable  
2.2.1 The Rebound Effect  
2.2.2 Controlling Interdependencies  
2.3 The Triple Bottom Line of Sustainability  
2.4 The IPAT Equation and the Kaya Identity
### 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
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1.2</td>
<td>Flow in Closed Conduits</td>
<td>194</td>
</tr>
<tr>
<td>6.1.2.1</td>
<td>Conservation of Energy</td>
<td>196</td>
</tr>
<tr>
<td>6.1.2.2</td>
<td>Friction Losses</td>
<td>198</td>
</tr>
<tr>
<td>6.1.2.3</td>
<td>Pumps</td>
<td>199</td>
</tr>
<tr>
<td>6.1.2.4</td>
<td>Pipe Networks</td>
<td>200</td>
</tr>
<tr>
<td>6.1.3</td>
<td>Flow in Open Channels</td>
<td>203</td>
</tr>
<tr>
<td>6.1.3.1</td>
<td>The Manning Equation</td>
<td>203</td>
</tr>
<tr>
<td>6.1.3.2</td>
<td>Energy, Critical Flow, and the Froude Number</td>
<td>206</td>
</tr>
<tr>
<td>6.1.4</td>
<td>Groundwater Engineering</td>
<td>208</td>
</tr>
<tr>
<td>6.1.4.1</td>
<td>Groundwater Hydrology</td>
<td>209</td>
</tr>
<tr>
<td>6.1.4.2</td>
<td>Darcy's Law</td>
<td>210</td>
</tr>
<tr>
<td>6.1.4.3</td>
<td>Pumps</td>
<td>210</td>
</tr>
<tr>
<td>6.2</td>
<td>Water Demand</td>
<td>213</td>
</tr>
<tr>
<td>6.2.1</td>
<td>Water Consumption Trends</td>
<td>213</td>
</tr>
<tr>
<td>6.2.2</td>
<td>Water Demand by End Use</td>
<td>215</td>
</tr>
<tr>
<td>6.2.3</td>
<td>Water Demand by Household Size</td>
<td>217</td>
</tr>
<tr>
<td>6.2.4</td>
<td>Water Demand by Hour</td>
<td>217</td>
</tr>
<tr>
<td>6.3</td>
<td>Water and Wastewater Treatment</td>
<td>220</td>
</tr>
<tr>
<td>6.3.1</td>
<td>Water Treatment</td>
<td>220</td>
</tr>
<tr>
<td>6.3.2</td>
<td>Wastewater Treatment</td>
<td>221</td>
</tr>
<tr>
<td>6.4</td>
<td>Stormwater Management</td>
<td>223</td>
</tr>
<tr>
<td>6.4.1</td>
<td>Sewer Systems</td>
<td>223</td>
</tr>
<tr>
<td>6.4.2</td>
<td>Green Infrastructure and Low-Impact Development</td>
<td>226</td>
</tr>
<tr>
<td>6.4.3</td>
<td>Runoff Modeling</td>
<td>229</td>
</tr>
<tr>
<td>6.4.3.1</td>
<td>Rational Method</td>
<td>229</td>
</tr>
<tr>
<td>6.4.3.2</td>
<td>Natural Resources Conservation Service Curve Number Model</td>
<td>232</td>
</tr>
<tr>
<td>6.5</td>
<td>Energy Use in Water</td>
<td>237</td>
</tr>
<tr>
<td>6.6</td>
<td>Conclusion</td>
<td>241</td>
</tr>
<tr>
<td>Problem Set</td>
<td>242</td>
<td></td>
</tr>
<tr>
<td>Notes</td>
<td>248</td>
<td></td>
</tr>
<tr>
<td>References</td>
<td>251</td>
<td></td>
</tr>
</tbody>
</table>

7 **Transport** | 253

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1</td>
<td>Fundamentals of Transport</td>
<td>255</td>
</tr>
<tr>
<td>7.1.1</td>
<td>Traffic Flow Theory</td>
<td>256</td>
</tr>
<tr>
<td>7.1.2</td>
<td>Pedestrian Flow</td>
<td>262</td>
</tr>
<tr>
<td>7.1.3</td>
<td>Public Transit Planning</td>
<td>265</td>
</tr>
<tr>
<td>7.2</td>
<td>Travel Demand</td>
<td>275</td>
</tr>
<tr>
<td>7.2.1</td>
<td>Trips</td>
<td>275</td>
</tr>
<tr>
<td>7.2.2</td>
<td>Distance Traveled</td>
<td>277</td>
</tr>
<tr>
<td>7.2.3</td>
<td>Mode Share</td>
<td>281</td>
</tr>
</tbody>
</table>
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
8.3.2.7 Solar Water Heating 366
8.3.2.8 Solar Photovoltaic 367
8.3.2.9 Vertical Gardens 367
8.3.2.10 Air-Source and Ground-Source Heat Pumps 367
8.3.2.11 District Heating and Cooling 369
8.3.2.12 Technologies and Internal Rate of Return 369
8.3.2.13 Leadership in Energy & Environmental Design Rating 371

8.4 Conclusion 372
Problem Set 373
Notes 379
References 380

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