

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

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

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