

Contents

<i>Preface</i>	<i>page xv</i>
1 Introduction	1
1.1 Roots	1
1.2 Sustainability Science	4
1.3 Sustainable Development Is About Quality of Life	7
1.4 Guidelines for the Reader	9
Appendix 1.1 United Nations Decade of Education for Sustainable Development	12
2 The System Dynamics Perspective	14
2.1 Introduction	14
2.2 The World Car System	15
2.3 System Dynamics: The Basics	22
2.3.1 What Is a System?	22
2.3.2 Stocks and Flows	24
2.3.3 Feedback Loops	28
2.3.4 An Illustrative Simulation Experiment	33
2.4 System Dynamics Modelling	35
2.4.1 The Rules of the Game	35
2.4.2 Archetypes	40
2.4.3 An Example: Modelling Car and Public Transport Use	43
2.5 Structure, Space and Time	46
2.6 Summary Points	47
Appendix 2.1 Integral-Differential Calculus	50
3 In Search of Sustainability: Past Civilisations	54
3.1 Introduction	54
3.2 The Beginnings: Two Environmental Tales	56
3.2.1 The Hohokam People in Arizona	56
3.2.2 Easter Island	57
3.3 Emerging Social Complexity: State Formation	60
3.3.1 Early Mesopotamia: Urban Centres and Their Elites	60

3.3.2	Egypt: The Nile and Its Rhythms	61
3.3.3	South Asia: The Indus-Sarasvati Civilisation	63
3.3.4	The Aegean and Mesoamerica: The Role of Ecological Diversity	64
3.4	Empires	66
3.4.1	The Roman Empire	66
3.4.2	Other Empires: China, India and Russia	72
3.5	Mechanisms, Theories and Models	75
3.5.1	Mechanisms	75
3.5.2	Theories and Models	78
3.6	Summary Points	81
4	The World in the Past 300 Years: The Great Acceleration	84
4.1	Introduction	84
4.2	The World in the Last Three Centuries	84
4.2.1	Accelerating Growth: Population and Economic Activity	84
4.2.2	Social-Cultural Changes	93
4.3	Accelerating Impacts: The Natural Environment	96
4.3.1	The Source Side	96
4.3.2	The Sink Side	100
4.3.3	Experiencing Change	102
4.4	Earth System Analysis: Regimes and Syndromes	104
4.4.1	Social-Ecological Regimes	104
4.4.2	Syndromes and Archetypes	109
4.5	Summary Points	114
5	Sustainability: Concerns, Definitions, Indicators	117
5.1	Introduction	117
5.2	Global Change: The Scientific Worldview	117
5.2.1	The Scientific Worldview: Earth	117
5.2.2	The Scientific Worldview: Life	118
5.2.3	The Scientific Worldview: Society	120
5.3	Rising Concerns	122
5.3.1	Early Concerns: Managing Common Inheritance	122
5.3.2	The Environmental Movement	123
5.3.3	Our Common Future?	125
5.4	The Notion of Sustainable Development	129
5.4.1	Prelude: Categories of Goods and Services	129
5.4.2	Interpretations and Definitions	133
5.5	An Indicator Framework for Sustainable Development	136
5.5.1	From Principle to Action: Indicators	136
5.5.2	A Sustainable Development Indicator System (SDIS)	138
5.5.3	Quality-of-Life-Oriented and Aggregate SD-Indicators	139
5.6	Summary Points	142
6	Quality of Life: On Values, Knowledge and Worldviews	146
6.1	Introduction	146

6.2	Quality of Life and Values	146
6.2.1	Needs and the Quality of Life	146
6.2.2	Capabilities and Satisfiers	149
6.2.3	Values and Their Measurement	152
6.3	The Cultural Theory	155
6.3.1	Stories from the Himalayas and Bali	155
6.3.2	Four Perspectives	158
6.4	Worldviews: Ways to See the World	164
6.4.1	Values and Beliefs: Four Worldviews	164
6.4.2	Worldviews in History	168
6.4.3	Mechanisms of Social Change	172
6.5	Worldviews in Action	174
6.6	Summary Points	176
7	Energy Fundamentals	179
7.1	Introduction: The Essential Resource	179
7.2	Basic Energy Science: Thermodynamics	184
7.2.1	Classical Thermodynamics: The First and Second Law	184
7.2.2	Energy Quality: The Potential to Do Work	190
7.2.3	Energy Forms	194
7.3	Movement in Space and Time: Mechanics	195
7.4	Stories	201
7.4.1	Fuel-Efficient Stoves for People in Darfur	201
7.4.2	The South Nyírség Bioenergy Project	202
7.5	Energy Conversion	203
7.5.1	Elementary Processes	203
7.5.2	The Energy System	206
7.6	Energy Futures	208
7.7	Summary Points	210
	Appendix 7.1 The Steady-State Mass-Energy Equation	213
8	On Knowledge and Models	215
8.1	Introduction	215
8.2	Models in the Natural Sciences	216
8.2.1	The Scientific Method	216
8.2.2	Models and the Modelling Process	219
8.3	Strong and Weak Knowledge	221
8.4	Complexity	227
8.5	Metamodels and Organising Concepts	232
8.6	Science in the Age of Complexity	238
8.7	Summary Points	240
	Appendix 8.1 A Brief History of Complex Systems Science	242
9	Land and Nature	244
9.1	Introduction	244
9.2	Earth: Soil Climate Vegetation Maps	245
9.3	Stories	253

9.3.1	Forest Fires	253
9.3.2	Biodiversity in South America: The Trésor Project	254
9.3.3	Mining in Papua New Guinea	255
9.4	Land Cover Change and Degradation	256
9.5	Ecosystem Dynamics: Population Ecology	262
9.5.1	Population Ecology: Logistic Growth	262
9.5.2	Population Models: Prey-Predator Dynamics	265
9.6	Food Webs: The Stocks and Flows in Ecosystems	272
9.6.1	Food Webs and Their Representations	272
9.6.2	Stability and Resilience	274
9.7	Catastrophic Change in Ecosystems	277
9.8	Biodiversity and Ecosystem Services	283
9.9	Nature and Sustainable Development	288
9.10	Summary Points	291
	Appendix 9.1 Prey-Predator Models and Stability Analysis	293
	Appendix 9.2 Catastrophic Change and Bifurcations	294
10	Human Populations and Human Behaviour	296
10.1	Introduction: The Image of Man	296
10.2	Demography: Human Population Dynamics	299
10.2.1	Modelling Population	299
10.2.2	Driving Forces	303
10.3	Evolution: Our Biological Roots	308
10.4	<i>Homo Economicus</i> and Its Critics	312
10.4.1	Consumers and Producers	312
10.4.2	Games, Dilemmas and Cooperation	314
10.5	Simulating Human Behaviour	320
10.5.1	Introduction	320
10.5.2	Cellular Automata Models	321
10.5.3	Interaction: Networks	325
10.5.4	Multi-Agent Simulation: Behavioural Variety	329
10.6	Summary Points	332
	Appendix 10.1 Models of Economic Decision Making	334
	Appendix 10.2 Replicator Dynamics	336
	Appendix 10.3 Network or Graph Theory	336
11	Agro-Food Systems	339
11.1	Introduction: The Human Habitat	339
11.1.1	Land and People	339
11.1.2	Anthromes	341
11.2	Agricultural Systems	344
11.2.1	Agro-Food Systems in the World	344
11.2.2	Food: Needs and Consumption	347
11.2.3	Food: Resources and Potential Supply	348
11.2.4	More Food: Can It Be Supplied Sustainably?	349
11.3	Stories from the Real World	357
11.3.1	Nomads in Mongolia	357
11.3.2	Can and Should Rural France Be Saved?	358

11.4	Land Use and Cover Change	359
11.4.1	Land Use Changes and Its Causes	359
11.4.2	Modelling Land Use and Cover Change	360
11.5	Towards a Global Industrial Agro-Food System	363
11.5.1	Diversity in Transition	363
11.5.2	The Global Agro-Food System	366
11.5.3	Markets, Scale and Innovations As Driving Forces	369
11.6	Perspectives on Food and Agriculture	372
11.7	Summary Points	375
	Appendix 11.1 Income and Price Elasticity	377
12	Renewable Resources: Water, Fish and Forest	379
12.1	Introduction: Lakeland	379
12.2	Renewable Resources	384
12.2.1	Renewable Resource Use: An Archetypical Model	384
12.2.2	Model Extensions and Management Principles	387
12.3	Water Resources	391
12.3.1	Water Availability and Use	391
12.3.2	Water for Irrigation: A Case Study and a Model	398
12.4	Stories	400
12.4.1	The Canadian Fish Drama	400
12.4.2	European Union Fisheries Policy in Senegal	400
12.5	Fisheries and Forests	401
12.5.1	World Fisheries	401
12.5.2	Fisheries Models: Strategies and Interactions	404
12.5.3	Fisheries Models: Behavioural Variety	408
12.5.4	World Forests	412
12.6	Interactive Modelling for Sustainable Livelihood	414
12.7	Perspectives on Water, Fish and Forest	416
12.8	Summary Points	417
	Appendix 12.1 The Simple Population and Renewable Resource Model	421
	Appendix 12.2 Resource Use in the Simple Model	421
	Appendix 12.3 Modelling Different Harvesting Strategies	422
	Appendix 12.4 The Geonamica Software	423
13	Non-Renewable Resources: The Industrial Economy	425
13.1	Introduction: The Industrial Regime	425
13.2	Non-Renewable Resource Chains: Extraction	427
13.2.1	Biogeochemical Element Cycles	427
13.2.2	Classification	430
13.2.3	Availability, Exploration and Extraction: Two Models	431
13.3	Elementary Resource Economics	436
13.3.1	Supply Cost Curves	436
13.3.2	Innovation: The Learning-By-Doing Mechanism	439
13.3.3	Optimal Depletion: The Resource Curse and Resource Security	442
13.4	Stories	445

13.4.1	Oil and Power	445
13.4.2	The Promise of Gold: Tambogrande	446
13.5	Resource Chains: Material Use and Efficiency	447
13.5.1	Assessment Methods	447
13.5.2	Dematerialisation: The Intensity-of-Use Hypothesis	449
13.5.3	Richer and Cleaner?	453
13.6	Stories	455
13.6.1	Pearl River Estuary, China	455
13.6.2	Water As a Commodity: Ban on Bottled Water in an Australian Town	455
13.6.3	Organotin Compounds As Antifouling Agents	456
13.7	The Sink Side: Environment and the Industrial Economy	457
13.7.1	Resource Chains: The Sink Side	457
13.7.2	Enduring Environmental Problems	459
13.7.3	Persistent Chemicals	463
13.8	Perspectives on the Industrial Economy	465
13.9	Summary Points	466
	Appendix 13.1 The Crustal Abundance Geostatistical (CAG) Model	469
	Appendix 13.2 The Logistic Growth Life Cycle Model	471
14	Towards a Sustainable Economy?	472
14.1	Introduction	472
14.1.1	An Archetypical Model	472
14.1.2	Substitutability, Technology and Optimality	477
14.2	Theories of Economic Growth	479
14.2.1	Classical Theories	479
14.2.2	Economic Growth Theory	481
14.2.3	The Role of Technology, Learning and Behaviour	485
14.3	Source and Sink Constraints in the Economy	492
14.3.1	Structural Economics: The Input-Output Formalism	492
14.3.2	Resource Efficiency and Pollution Abatement: Economic Mechanisms	496
14.4	Economic Growth and Sustainable Development	501
14.4.1	GDP and the Need for a Better Indicator	501
14.4.2	Beyond Models: Welcome to the Real World	503
14.5	Summary Points	507
	Appendix 14.1 A Simple Behaviour Model of Saving	511
	Appendix 14.2 Evolutionary Models of Producers and Consumers	511
	Appendix 14.3 Input-Output Tables	512
	Appendix 14.4 Gross Domestic Product	514
15	Outlook on Futures	516
15.1	Introduction	516
15.2	Outlooks	517
15.2.1	Sustainable Futures: Urban, Rural, Global	517
15.2.2	The Scenario Approach	519
15.2.3	Sustainable Development in a Scenario Frame	521

15.3 Scenarios for a Sustainable World	522
15.3.1 Four Stories	522
15.3.2 Growth within Limits . . .	526
15.3.3 . . . But Is It Sustainable?	529
15.4 An Agenda for Sustainability Science	533
<i>Glossary</i>	537
<i>References</i>	561
<i>Index</i>	585