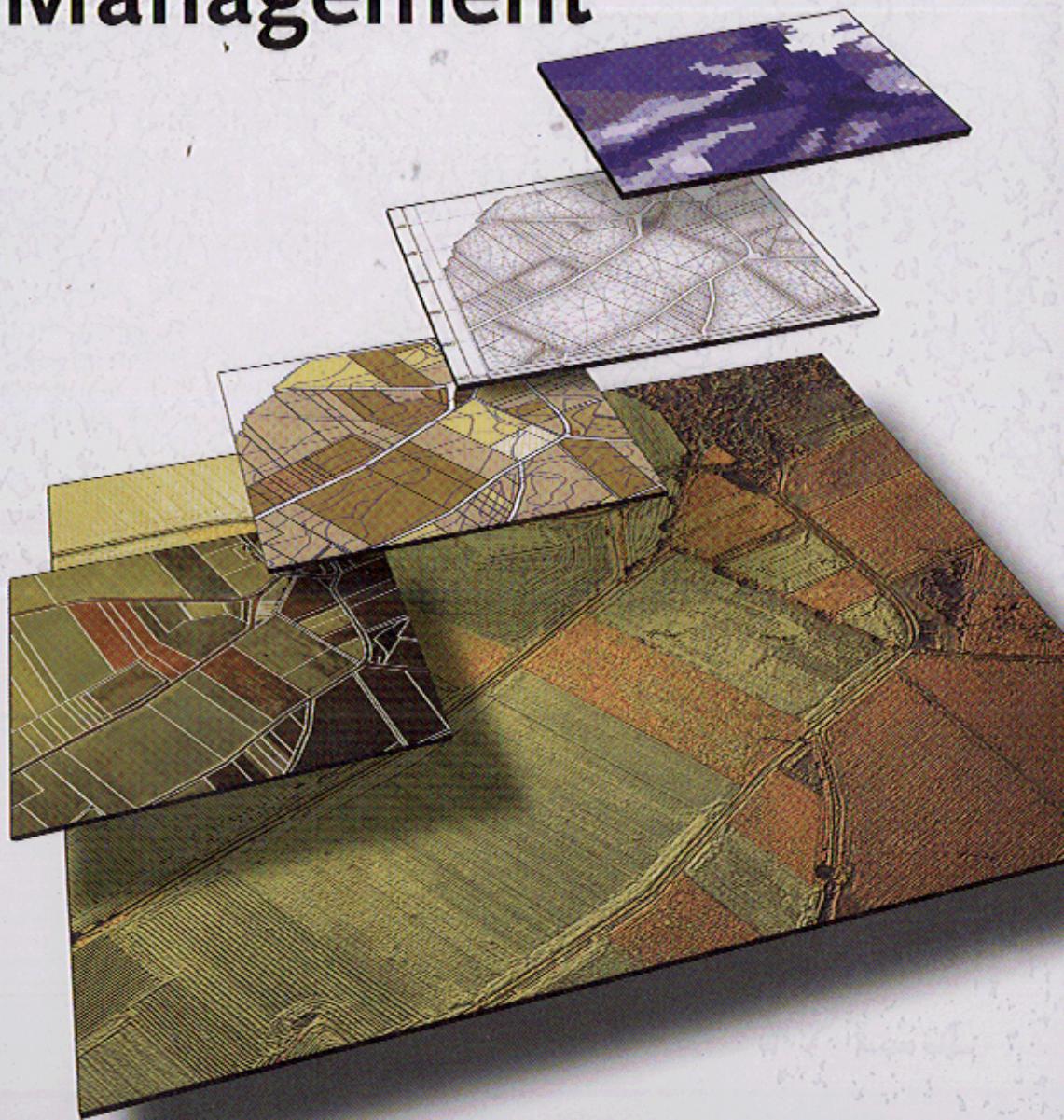


Ralf Seppelt

WILEY-VCH

Computer-Based Environmental Management



Contents

<i>Foreword</i>	v
<i>Acknowledgments</i>	vii
<i>Introduction</i>	xvii

Part I Setting the Scene: Diversity of Environmental Modeling

<i>1 From Conceptual Modeling to Computer Simulations</i>	1
<i>1.1 Introduction</i>	1
<i>1.2 The Modeling Process</i>	3
<i>1.2.1 System Analysis: Conceptual Models</i>	3
<i>1.2.2 Properties: Granularity, Extent and Scale</i>	7
<i>1.2.3 Toolbox and Language: Mathematical Models</i>	10
<i>1.2.4 Results: Computer Models</i>	12
<i>1.3 Model Analysis</i>	14
<i>1.3.1 Verification, Validation and Calibration</i>	14
<i>1.3.2 Intrinsic Verification and Predictive Power</i>	15
<i>1.3.3 Uncertainty</i>	17
<i>1.3.4 Categories and Classifications</i>	18

1.4	<i>Linking Real World Data and Models</i>	21
1.4.1	<i>Regionalization: Applications to Investigation Sites and Spatial Validity</i>	21
1.4.2	<i>Parameter Estimation</i>	23
1.5	<i>Modeling Languages and Development Platforms</i>	24
1.5.1	<i>Overview</i>	24
1.5.2	<i>Mathematical Languages</i>	25
1.5.3	<i>Generic Tools for Model Development</i>	27
1.5.4	<i>Conceptual Modeling Tools</i>	28
1.5.5	<i>Modeling and Programming Environments</i>	29
1.5.6	<i>Numerical Mathematics</i>	30
1.6	<i>Summary</i>	33
2	<i>Environmental Models: Dynamic Processes</i>	35
2.1	<i>Introduction</i>	35
2.2	<i>First Trophic Level: Primary Producers</i>	35
2.2.1	<i>Crop Growth</i>	36
2.2.2	<i>Temporal Patterns of Annual Plants</i>	37
2.2.3	<i>Nitrogen Uptake</i>	38
2.2.4	<i>Interspecific Competition: Weeds and Weed Control</i>	39
2.3	<i>Parameter Estimation (Part I)</i>	39
2.3.1	<i>Experimental Design of Field Experiments</i>	40
2.3.2	<i>Application of Algorithms</i>	41
2.3.3	<i>Parameters of Crop Growth</i>	43
2.3.4	<i>Competition Models</i>	46
2.3.5	<i>Results</i>	49
2.4	<i>Abiotic Environment: Water and Matter Dynamics</i>	50
2.4.1	<i>Nutrient Cycle: Detritus</i>	51
2.4.2	<i>Xenobiotica Fate: Agrochemicals</i>	52
2.5	<i>Parameter Estimation (Part II)</i>	53
2.5.1	<i>Laboratory Experiments</i>	54
2.5.2	<i>Results</i>	54
2.6	<i>Higher Trophic Levels: Consumers or Pest Infestation</i>	55
2.6.1	<i>Continuous Population Dynamics</i>	55
2.6.2	<i>Age-structured Populations</i>	57
2.6.3	<i>Types of Population Dynamic Models</i>	60
2.7	<i>Model Integration: Generic Agroecosystem Model</i>	62
2.8	<i>Summary</i>	65

3	<i>Environmental Models: Spatial Interactions</i>	67
3.1	<i>Spatial References in Environmental Models</i>	67
3.1.1	<i>Spatial Scales and Model Support</i>	67
3.1.2	<i>Models for Spatial Data Structures</i>	70
3.1.3	<i>Spatial Patterns</i>	72
3.2	<i>Aggregated Spatially Explicit Models</i>	73
3.2.1	<i>Abiotic Processes</i>	73
3.2.2	<i>Biotic Processes</i>	76
3.3	<i>Integrating Spatially Explicit Models</i>	85
3.3.1	<i>Regionalization of Site Models</i>	85
3.3.2	<i>Cellular Automata</i>	89
3.3.3	<i>Generic Landscape Models</i>	91
3.4	<i>Discussion</i>	94

Part II Integrated Models

4	<i>Multi-paradigm Modeling</i>	99
4.1	<i>Introduction</i>	99
4.2	<i>Fundamental Aspects of Environmental Modeling</i>	100
4.3	<i>Mathematics of Environmental Modeling</i>	102
4.3.1	<i>General Model Equation</i>	102
4.3.2	<i>Integrated Models</i>	103
4.4	<i>Model Documentation and Model Databases</i>	104
4.4.1	<i>Introduction</i>	104
4.4.2	<i>Model Databases</i>	105
4.4.3	<i>Meta-modeling Concepts</i>	107
4.5	<i>Summary and Outlook</i>	110
5	<i>Concepts: Hybrid Petri Nets</i>	111
5.1	<i>Introduction</i>	111
5.1.1	<i>Concepts of Hybrid Model Development</i>	111
5.1.2	<i>Aim and Scope of the Development</i>	112
5.2	<i>Theoretical Background</i>	112
5.2.1	<i>Hybrid Low Level Petri Nets</i>	112
5.2.2	<i>Functional Behavior</i>	114
5.3	<i>Development Platform</i>	115
5.3.1	<i>Overview</i>	115

5.3.2	<i>Meta-modeling Concept</i>	117
5.3.3	<i>Core Simulation Algorithm and Model Analysis</i>	117
5.4	<i>An Ecological Modeling Example</i>	118
5.4.1	<i>Predator–Prey Interactions</i>	118
5.4.2	<i>Event-based Modeling of Predator–Prey Interactions</i>	119
5.4.3	<i>Simulation Results</i>	120
5.4.4	<i>Discussion and Extensions</i>	121
5.5	<i>Concluding Remarks</i>	122
6	<i>Case Studies: Hybrid Systems in Ecology</i>	123
6.1	<i>Introduction</i>	123
6.2	<i>Hybrid Crop Growth Models</i>	123
6.2.1	<i>Modeling of Crop Growth with Dynamically Changing Model Structures</i>	123
6.2.2	<i>Hybrid Petri Net</i>	125
6.2.3	<i>Results</i>	126
6.3	<i>The Galápagos Archipelago and the Blue-winged Grasshopper</i>	128
6.3.1	<i>Meta-population in Island Biogeography</i>	128
6.3.2	<i>Spatially Explicit Hybrid Petri nets</i>	130
6.3.3	<i>Results</i>	131
6.3.4	<i>Comparison</i>	132
6.4	<i>Summary</i>	135
7	<i>Applications: Environmental Impact Assessment</i>	137
7.1	<i>Introduction</i>	137
7.2	<i>Aim and Scope</i>	138
7.3	<i>Methodology</i>	138
7.3.1	<i>Life Cycle Inventory</i>	139
7.3.2	<i>The Link: Environmental Fate Modeling</i>	140
7.3.3	<i>Fuzzy Expert Systems for Impact Assessment</i>	140
7.4	<i>Life Cycle Inventory of the Production Process</i>	143
7.5	<i>Environmental Fate Modeling of NO_x-Emissions</i>	145
7.5.1	<i>Overview</i>	145
7.5.2	<i>Atmospheric Transport Model</i>	146
7.5.3	<i>Process Model</i>	148
7.5.4	<i>Results</i>	150

7.6	<i>Environmental Impact Assessment</i>	151
7.6.1	<i>Soil Acidification</i>	151
7.6.2	<i>Eutrophication</i>	152
7.6.3	<i>Plant Damage</i>	154
7.7	<i>Discussion</i>	154

Part III The Big Picture: Environmental Management

8	<i>Scenario Analysis and Optimization</i>	159
8.1	<i>Introduction</i>	159
8.2	<i>Optimization and Environmental Modeling</i>	161
8.2.1	<i>Analytical Treatment and Non-spatial Applications</i>	161
8.2.2	<i>Spatially Explicit Applications</i>	162
8.3	<i>Assessing the Environment Variables</i>	162
8.3.1	<i>Indicators</i>	162
8.3.2	<i>... and Applications for Optimization</i>	166
8.4	<i>General Optimization Task</i>	167
8.4.1	<i>Performance Criteria</i>	167
8.4.2	<i>General Optimization Task</i>	169
8.4.3	<i>Methodology</i>	170
8.5	<i>Discussion</i>	171
9	<i>Prerequisites: Temporal Hierarchies and Spatial Scales</i>	173
9.1	<i>Introduction</i>	173
9.2	<i>Hierarchical Dynamic Programming</i>	174
9.2.1	<i>Introduction</i>	174
9.2.2	<i>Hierarchies and Temporal Scales</i>	176
9.2.3	<i>Program Library</i>	180
9.2.4	<i>Concluding Remarks</i>	182
9.3	<i>Optimization and Spatially Explicit Models</i>	182
9.3.1	<i>Computational Effort</i>	183
9.3.2	<i>Local and Global Performance Criteria</i>	183
9.3.3	<i>Grid Search Strategy on Local Problem</i>	185
9.3.4	<i>Disturbing a Solution: Monte Carlo Simulation</i>	185
9.3.5	<i>Genetic Algorithm Solving the Global Problem</i>	187
9.3.6	<i>Toolbox for Spatially Explicit Optimization</i>	188

9.4 Summary	191
10 Optimum Agroecosystem Management: Temporal Patterns	193
10.1 Introduction	193
10.2 Assessing the State of an Agroecosystem	194
10.2.1 External Cost and Non-measurable Variables	194
10.2.2 Performance Criteria	194
10.2.3 Weighting Schemes	195
10.3 Agricultural Optimum Control Problem	196
10.3.1 Optimization Task	196
10.3.2 Hierarchical Structure of the Problem	197
10.4 Short-term Solutions: Managing a Vegetation Period	198
10.4.1 Optimum Fertilizing Schemes	198
10.4.2 Optimum Pesticide Application Timing	199
10.5 Long-term Solutions: Managing Crop Rotations	201
10.5.1 Nutrient Balance	201
10.5.2 Pest Control	201
10.6 Discussion	202
11 Optimum Agroecosystem Management: Spatial Patterns	207
11.1 Introduction	207
11.1.1 Site-specific Agroecological Modeling	207
11.1.2 Aims, Scope and Region	208
11.2 Optimum Control in Regionalized Models	208
11.2.1 Agroecological Simulation Model	208
11.2.2 Optimization Task	210
11.3 Concept of Optimum Spatial Control	210
11.4 Optimization and Simulation Experiments	213
11.4.1 Types of Spatial Solutions	213
11.4.2 Results	216
11.5 Discussion	217
12 Changing Landscapes: Optimum Landscape Patterns	221
12.1 Introduction	221
12.2 Performance Criteria for Landscape Optimization	223
12.2.1 Economic–Ecologic Assessment	223
12.2.2 Localization of Optimization Problem	225
12.2.3 Multi-criteria Assessment of Ecosystem Functions	226

12.2.4 Numerical Effort	227
12.3 Validation of Concept: Results for Hunting Creek Watershed	228
12.3.1 Local Optimization	228
12.3.2 Monte Carlo Simulations	229
12.3.3 Statistical Analysis	232
12.3.4 Genetic Algorithms	233
12.4 Results of Multi-criteria Optimization	235
12.4.1 General Results for Optimum Land Use Patterns	235
12.4.2 Scenarios of Optimized Land Use Patterns	239
12.5 Climatic Variability and Optimum Land Use Patterns	244
12.6 Multi-scale Analysis of Landscape Patterns	244
12.6.1 Distance Measure of Discrete Maps	246
12.6.2 "Correlation"-analysis of Landscape Patterns	247
12.6.3 Optimization Results on Differing Scales	248
12.7 Summary and Outlook	250
12.7.1 Methodological Aspects	250
12.7.2 Optimization Results as Multi-stage Decision Process	251
12.7.3 Application of Results	251
12.7.4 Patterns and Processes	252
12.7.5 Outlook	253
13 Conclusions, Perspectives and Research Demands	255
13.1 Retrospection	255
13.2 Conclusions	256
13.3 Perspectives	257
References	259
Additional References	279
Web Ressources	279
Copyrights and Sources	279
Quotations	280
Index	281