SYSTEMS APPROACH TO MANAGEMENT OF DISASTERS

Methods and Applications

Slobodan P. Simonović
SYSTEMS APPROACH TO MANAGEMENT OF DISASTERS
... The weakest thing in the world
Overcomes the strongest thing in the world
What doesn’t exist finds room where there’s none
Wordless instruction
Effortless help
Few in the world can match this.

Lao Tzu (6th century BC)
*Tao Te Ching (verse 43)*

... To understand all this, it is necessary that we should learn to look at things from a new point of view.

D.T. Suzuki (1870–1966)
*Living by Zen*

... The truly noble and resolved spirit raises itself, and becomes more conspicuous in times of disaster and ill-fortune.

Plutarch (46 AD – 120 AD)
*Lives, Eumenes*
SYSTEMS APPROACH
TO MANAGEMENT
OF DISASTERS

Methods and Applications

Slobodan P. Simonović
To Tanja, Dijana, and Damjan
Contents

List of Figures and Tables xiii
About the Author xix
Foreword xxi
Preface xxv
List of Acronyms and Abbreviations xxxiii

I MANAGEMENT OF DISASTERS 1

1 Introduction 3

1.1 Issues in Management of Disasters—Personal Experience 6
1.1.1 Red River Flooding 6
1.1.2 “Red River Flood of the Century,” Manitoba, Canada 9
1.2 Tools for Management of Disasters—Two New Paradigms 19
1.2.1 The Complexity Paradigm 21
1.2.2 The Uncertainty Paradigm 24
1.3 Conclusions 26

References 27
Exercises 29

2 Integrated Disaster Management 30

2.1 Definition 30
2.2 Integrated Disaster Management Activities 31
2.2.1 Mitigation 31
2.2.2 Preparedness 39
2.2.3 Response 40
2.2.4 Recovery 40
2.3 Disaster Management in Canada—Brief Overview 41
2.3.1 Emergency Management Act 42
2.3.2 National Disaster Mitigation Strategy 42
2.3.3 Joint Emergency Preparedness Program 43
2.3.4 Emergency Response 44
CONTENTS

2.3.5 The Role of Federal Government in Disaster Recovery 45
2.4 Decision Making and Integrated Disaster Management 46
  2.4.1 Individual Decision Making 47
  2.4.2 Decision Making in Organizations 47
  2.4.3 Decision Making in Government 47
2.5 Systems View of Integrated Disaster Management 48

References 49
Exercises 50

II SYSTEMS ANALYSIS FOR INTEGRATED MANAGEMENT OF DISASTERS 51

3 Systems Thinking and Integrated Disaster Management 53
  3.1 System Definitions 54
    3.1.1 What is a System? 55
    3.1.2 Systems Thinking 56
    3.1.3 Systems Analysis 59
    3.1.4 The Systems Approach 60
    3.1.5 Systems “Engineering” 60
    3.1.6 Feedback 61
    3.1.7 Mathematical Modeling 66
    3.1.8 A Classification of Systems 68
    3.1.9 A Classification of Mathematical Models 70
  3.2 Systems View of Integrated Disaster Management 70
    3.2.1 A Systems Typology in Integrated Disaster Management 71
    3.2.2 Systems View of Disaster Management 73
    3.2.3 Systems View of Disaster Management Activities 76
  3.3 System Formulation Examples 77
    3.3.1 Dynamics of Epidemics 78
    3.3.2 Shortest Supply Route 80
    3.3.3 Resources Allocation 81

References 82
Exercises 83

4 Introduction to Methods and Tools for a Systems Approach to Management of Disaster 85
  4.1 Simulation 85
  4.2 System Dynamics Simulation 89
  4.3 Optimization 92
  4.4 Multiobjective Analysis 95
  4.5 Disaster Risk Management 97
CONTENTS

3.5.1 Sources of Uncertainty 98
3.5.2 Conceptual Risk Definitions 100
3.5.3 Probabilistic Approach 102
3.5.4 A Fuzzy Set Approach 103

4.6 Computer Support: Decision Support Systems 106

References 109
Exercises 111

III IMPLEMENTATION OF SYSTEMS ANALYSIS TO MANAGEMENT OF DISASTERS 113

5 Simulation 115

5.1 Definitions 115
5.2 System Dynamics Simulation 116
  5.2.1 Introduction 116
  5.2.2 System Structure and Patterns of Behavior 117
5.3 System Dynamics Simulation Modeling Process 126
  5.3.1 Causal Loop Diagram 127
  5.3.2 Stock and Flow Diagram 131
  5.3.3 Generic Principles of System Dynamics Simulation Modeling 133
  5.3.4 Numerical Simulation 137
  5.3.5 Policy Design and Evaluation—Model Use 141
5.4 System Dynamics Simulation Modeling Examples 141
  5.4.1 A Simple Flu Epidemic Model 142
  5.4.2 A More Complex Flu Epidemic Model with Recovery 146
5.5 An Example of Disaster Management Simulation—Flood Evacuation Simulation Model 152
  5.5.1 Introduction 152
  5.5.2 Human Behavior During Disasters 153
  5.5.3 A System Dynamics Simulation Model 154
  5.5.4 Application of the Evacuation Model to the Analyses of Flood Emergency Procedures in the Red River Basin, Manitoba, Canada 162
  5.5.5 Conclusions 171

References 172
Exercises 172

6 Optimization 175

6.1 Linear Programming 178
  6.1.1 Formulation of Linear Optimization Models 178
CONTENTS

6.1.2 Algebraic Representations of Linear Optimization Models 182

6.2 The Simplex Method for Solving Linear Programs 186
   6.2.1 Completeness of the Simplex Algorithm 190
   6.2.2 The Big M Method 193

6.3 Duality in LP 196
   6.3.1 Sensitivity Analysis 198

6.4 Special Types of LP Problems—Transportation Problem 202
   6.4.1 Formulation of the Transportation Problem 202
   6.4.2 Solution of the Transportation Problem 207

6.5 Special Types of LP Problems—Network Problems 213
   6.5.1 The Shortest Path Problem 217
   6.5.2 The Minimum Spanning Tree Problem 219
   6.5.3 The Maximum Flow Problem 223

6.6 An Example of Disaster Management Optimization—The Optimal Placement of Casualty Evacuation Assets 229
   6.6.1 Introduction 229
   6.6.2 The OPTEVAC Model 230
   6.6.3 A Casualty Evacuation Example 231
   6.6.4 Summary 234

References 234
Exercises 235

7 Multiobjective Analysis 242

7.1 Introduction 243
   7.1.1 Toward Operational Framework for Multiobjective Analysis 243
   7.1.2 An Illustrative Example 244

7.2 Multiobjective Analysis Methodology 249
   7.2.1 Change of Concept 251
   7.2.2 Nondominated Solutions 251
   7.2.3 Participation of Decision Makers 254
   7.2.4 Classification of Multiobjective Techniques 255
   7.2.5 Disaster Management Applications 259

7.3 The Weighting Method 263

7.4 The Compromise Programming Method 268
   7.4.1 Compromise Programming 268
   7.4.2 Some Practical Recommendations 273
   7.4.3 The COMPRO Computer Program 273

7.5 An Example of Disaster Management Multiobjective Analysis—Selection of Flood Management Alternative 274
List of Figures and Tables

Figures

1.1 Great natural disasters 1950–2007, number of events (after Munich Re, NatCatSERVICE, 2008). 4
1.4 Red River basin. 7
1.5 Schematic illustration of the complexity paradigm. 22
1.6 Schematic illustration of the uncertainty paradigm. 25
2.1 The Venn diagram of integrated disaster management. 31
3.1 Schematic presentation of a system definition. 55
3.2 Looking for problem solution (high leverage). 59
3.3 Schematic presentation of (a) an open and (b) a closed system. 62
3.4 A feedback loop. 64
3.5 Positive (a) and negative (b) feedback loop. 64
3.6 Negative feedback loop representing rewards of volunteering activity. 65
3.7 Causal structure of a simple model of an epidemic. 78
4.1 Sources of uncertainty. 99
5.1 (a) Positive feedback loop; (b) system behavior. 118
5.2 (a) Negative feedback loop; (b) system behavior. 119
5.3 An evacuation planning example. 119
5.4 Evacuation flow diagram. 120
5.5 Constant evacuation flow rate. 121
LIST OF FIGURES AND TABLES

5.6 Quantity time graph: (a) the number of people in shelter A for every point in time and (b) the number of people for an evacuation rate of 10, 20, and 30 [people/day]. 121

5.7 Evacuation rate volume graph. 122

5.8 Evacuation problem data. 123

5.9 General patterns of system behavior. 124

5.10 Causal loop diagram for “filling a temporary storage tank with water.” 128

5.11 A causal diagram of the evacuation planning system. 130

5.12 Stock and flow diagramming notation. 132

5.13 Example stock and flow diagrams. 135

5.14 Tent city growth: (a) causal diagram and (b) stock and flow diagram. 136

5.15 Flood-protection infrastructure depreciation: (a) causal diagram and (b) stock and flow diagram. 137

5.16 Volunteering team’s performance in the field: (a) causal diagram and (b) stock and flow diagram. 137

5.17 Hydraulic metaphor for stock and flow diagram. 138

5.18 Causal diagram of a simple flu epidemic model. 142

5.19 Stock and flow diagram of a simple flu epidemic model. 143

5.20 Vensim equations of the flu epidemic model. 144

5.21 Results of flu epidemic model simulations. 145

5.22 Causal diagram of an epidemic model with recovery. 146

5.23 Stock and flow diagram of an epidemic model with recovery. 146

5.24 Vensim equations of the flu epidemic model with recovery. 148

5.25 Epidemic simulation—infected, \( F_{IR} \), and recovery, \( F_{RR} \), rates. 149

5.26 Epidemic simulation—susceptible, \( S_{FP} \), infectious, \( I_{FP} \), and recovered, \( R_{FP} \), populations. 150

5.27 Epidemic dynamics. 151

5.28 Conceptual framework of a behavioral model for evacuation planning. 155

5.29 Causal diagram of a behavioral model for evacuation planning. 156

5.30 A graphical relationship between \( Flooding\_Factor \) and \( Upstream\_Community\_Flooded \). 160

5.31 Evacuation model interface. 162
LIST OF FIGURES AND TABLES

5.32 Sensitivity analysis of Warning consistency. 165
5.33 Sensitivity analysis of Timing of order. 165
5.34 Sensitivity analysis of Coherence of community. 166
5.35 Sensitivity analysis of Upstream community flooding. 167
5.36 Sensitivity analysis of Mail effect. 168
5.37 Sensitivity analysis of Visit effect. 168
5.38 Model simulation results for different scenarios: (a) MEMO scenario, (b) RESIDENTS scenario, (c) GOOD scenario, and (d) BEST scenario. 171
6.1 Possible values of \((x_1, x_2)\) allowed by \(x_1 \geq 0, x_2 \geq 0\) and \(x_1 \geq 4\). 180
6.2 Possible values of \((x_1, x_2)\). 181
6.3 Value of \((x_1, x_2)\) that maximizes \(3x_1 + 5x_2\). 182
6.4 Linear program solutions: (a) unique optimal solution, (b) alternate optimal solution, (c) infeasible solution, and (d) unbounded optimal solution. 185
6.5 Corner point solutions for SIMON D&W problem. 192
6.6 Format of transportation simplex tableau. 207
6.7 Initial basic feasible solution from northwest corner rule. 209
6.8 Completed initial transportation simplex tableau. 211
6.9 Chain reaction caused by increasing the entering basic variable \(x_{25}\). 212
6.10 Change in the basic feasible solution. 213
6.11 Complete set of transportation simplex tableaux for the postdisaster water distribution problem. 214
6.12 The road system for the prototype example. 215
6.13 Example of a directed network. 217
6.14 Illustration of the spanning tree concept for the prototype problem: (a) not a spanning tree, (b) not a spanning tree, and (c) a spanning tree. 220
6.15 Minimum spanning tree for the prototype problem. 221
6.16 Minimum spanning tree for the prototype problem. 222
6.17 Minimum spanning tree for the prototype problem. 222
6.18 Minimum spanning tree for the prototype problem. 222
6.19 Minimum spanning tree for the prototype problem. 223
LIST OF FIGURES AND TABLES

6.20 Minimum spanning tree for the prototype problem. 223
6.21 Limits on the number of trips per day for the prototype problem. 224
6.22 The residual network for the prototype problem after iteration 1. 226
6.23 The residual network for the prototype problem after iteration 2. 226
6.24 The residual network for the prototype problem after iteration 4. 227
6.25 The residual network for the prototype problem after iteration 6. 227
6.26 The residual network for the prototype problem after iteration 7. 227
6.27 Optimal solution for the prototype problem. 228
6.28 A minimum cut for the prototype problem. 228
6.29 A simple input screen to the OPTIVEC model showing rescue operation nodes and medical treatment facilities. 231
7.1 Existing conditions (after Novoa and Halff, 1977). 245
7.2 Park Greenway—North (after Novoa and Halff, 1977). 248
7.3 Park Greenway—South (after Novoa and Halff, 1977). 248
7.4 Feasible region of a multiobjective problem presented in the objective space. 252
7.5 Classification of feasible multiobjective alternative solutions. 253
7.6 The feasible region and the nondominated set in the decision space. 267
7.7 The feasible region and the nondominated set in the objective space. 268
7.8 Illustration of compromise solutions. 269

Tables
1.1 Red River Floods in m³/sec (after IJC, 1997) 8
3.1 Input Data for the Resources Allocation Problem 81
5.1 Input Data for the Evacuation Problem 123
6.1 Input Data for Prototype Problem—Capacity Used per Unit Production Rate 179
6.2 Simplex Tableau for the SIMON D&W Example 2 Problem 188
6.3 Simplex Tableau for the Modified SIMON D&W Problem 191
6.4 Simplex Tableau for the SIMON D&W Problem with Equality Constraint 195
6.5 Relationship between Primal and Dual Problems 197
LIST OF FIGURES AND TABLES

6.6 Cost and Requirements Table for the Transportation Problem 203

6.7 Input Data for the Emergency Water Distribution Problem 205

6.8 Input Data for the Emergency Water Distribution Problem without Minimum Needs 206

6.9 Input Data for the Emergency Water Distribution Problem without Minimum Needs 206

6.10 Shortest Path Problem Solution for the Example 10 218

6.11 Data for the Casualty Evacuation Example 232

7.1 Evaluation of Alternative Plans 250

7.2 Payoff Matrix 257

7.3 Available Data for Emergency Water Supply Example 265

7.4 Pairs of Weights and Associated Nondominated Solutions 267

7.5 Nondominated Solutions 272

7.6 Scaled Nondominated Solutions 272

7.7 Final Compromise Solutions 273

7.8 Payoff Matrix for Floodplane Management Example 275

7.9 The Compromise Set of Solutions (Iteration 1) 276

7.10 The Compromise Set of Solutions (Iteration 2) 276

7.11 The Compromise Set of Solutions (Iteration 3) 277

7.12 The Best Compromise Solution 278

7.13 Alternative Weight Sets 278

7.14 The Most Robust Solution 279
About the Author

Slobodan P. Simonović was born and raised in Belgrade, Yugoslavia. He obtained his undergraduate degree in civil engineering (water resources division) from the University of Belgrade in 1974. By joining the interdisciplinary master’s degree program at the University of Belgrade, he was able to direct his education further into the application of formal systems theory to water resources systems management. His MSc included training in formal systems theory from the Department of Electrical Engineering and in water resources engineering from the Department of Civil Engineering. He graduated in 1976.

From 1974 until 1978, he worked as a researcher for the Jaroslav Cerni Institute for Water Resources Development in Belgrade. In 1978, he continued his graduate education at the University of California in Davis, where he obtained his PhD in engineering in 1981. Until 1986, he worked as consulting engineer for the large international consulting company Energoproject in Belgrade. In 1986, he moved to Canada and joined the Department of Civil Engineering at the University of Manitoba in Winnipeg. He was professor in the department until 1996, when he became the Director of the Natural Resources Institute, an interdisciplinary graduate program in natural resources management at the University of Manitoba.

In 2000, Dr Simonović moved to London, Ontario, where he became professor at the Department of Civil and Environmental Engineering and an engineering research chair of the Institute for Catastrophic Loss Reduction at the University of Western Ontario.

Dr Simonović teaches courses in civil engineering and water resources systems. He still actively works for national and international professional organizations (the Canadian Society of Civil Engineers, Canadian Water Resources Association, International Association of Hydrological Sciences, and International Hydrologic Program of UNESCO). He has received a number of awards for excellence in teaching, research and outreach, and has been invited to present special courses for practicing water resources engineers in many countries. He currently serves as associate editor of four water resources journals, and participates actively in the organization of national and international meetings. He has more than 350 professional publications.

Dr Simonović’s primary research interest focuses on the application of a systems approach to, and the development of decision support tools for, the management of complex water and environmental systems. Most of his work is related to the integration of risk, reliability, uncertainty, simulation, and optimization in hydrology and water resources management. He has undertaken applied research projects that integrate mathematical modeling, database management, geographical information...
ABOUT THE AUTHOR

systems, and intelligent interface development into decision support tools for water resources decision makers. Most of his research is conducted through the Facility for Intelligent Decision Support (FIDS) at the University of Western Ontario.

His subject expertise focuses on systems modeling, risk and reliability, water resources and environmental systems analysis, computer-based decision support systems development, and water resources education and training. Particular topical areas of expertise are reservoirs, flood control, hydropower energy, operational hydrology, and climate change.
Foreword

Alleluia! This is not a conventional way in which to begin a Foreword, but in this case, it is justified. Slobodan Simonović has produced a book that is a bold and vital step toward revising, even revolutionizing, our approach to disaster management. This helps in the movement toward the establishment of a recognized professional domain with appropriate theory, methods, and a community of practice. It is long overdue. At the same time, it has to be said that Slobodan’s effort is not the first, and nor will it be the last. It gives a big push in the right direction. It should be widely read and widely used by students and professionals.

The problem of disasters and their management has proved to be highly intractable. The frequency and magnitude of disasters are growing worldwide. Scientific knowledge of the natural forces in the earth’s crust and in the atmosphere that initiate disaster events has expanded enormously in the last 50 years. So has our capacity to predict, to make accurate forecasts, and to issue warnings. Also our knowledge of where extreme events are more likely to occur, and of the available measures for mitigation (or what the climate change community refers to as “adaptation”), has grown significantly. We have the scientific understanding, the technology, and the wealth to be able to mitigate disasters much more effectively. But instead things continue to get worse at an apparently accelerating rate.

The international community of scientists and policymakers has known this for a long time. The decade of the 1990s was designated by the United Nations as the International Decade for Natural Disaster Reduction. Since 2000, a new UN coordinating body—the International Strategy for Disaster Reduction—has been leading the global effort to contain disaster losses. And yet the losses continue to climb at an accelerating rate.

There are many ideas and theories of why this continues to happen. Common to them is a recognition that we have failed to effectively use and apply internationally, at the national level, and in many communities the knowledge we have. At the same time, it is recognized that we do not adequately understand the causes of this persistent failure. Slobodan Simonović’s book is based on the idea that part of the explanation at least is that we have not properly integrated the knowledge and methods available to us. Our disaster management is still too highly fragmented into the stovepipes and silos of different disciplines, areas of expertise, and administration. It remains bedeviled by reliance on short-term emergency response and myopic short-term thinking. Simonović argues cogently for the use of a systems approach, and much of what he writes is a demonstration and a set of guides and instructions on how to develop and apply such an approach, incorporating optimization, simulation,
and multiple-objective analysis. Each chapter is accompanied by a set of exercises intended for student use.

Slobodan has substantial experience in the application of systems analysis in the water resources management field. More recently he has been heavily involved in disaster risk management in Canada, especially the flood risks in Winnipeg, Manitoba, and so has turned his attention to the development of a systems approach to disaster management. Although the book may have special relevance to Canadians, its message and its contents are universal. Human response to disasters has long been dominated by humanitarian relief and rehabilitation and emergency preparedness. The trend toward addressing the multiple and complex causes of rising disaster losses has been underway for some time. The book is a further reinforcement of this trend. Slobodan Simonović is modest about his contribution. He recognizes that there is need to further strengthen and broaden the approach presented here. He specifically recognizes the need to incorporate the increased risks associated with climate change and to deepen our understanding of the dimensions of population growth and migration and community-level resilience. He also recognizes the need for better treatment of uncertainty. In sum, we are observing the slow and steady emergence of a new profession—that of disaster risk management. Slobodan Simonović’s book is a vital contribution to the foundations and practice of this field.

IAN BURTON, PhD, FRSC
Emeritus Professor, University of Toronto
Scientist Emeritus, Meteorological Service of Canada

This must be the first book ever published on systems analysis approach to disaster management. It is timely and precious. The author must be congratulated, appreciated, and encouraged for his further lead in this increasingly important subject.

The author has long experiences of applying systems analyses technology in the field of water resources management. In this book, his vast knowledge on systems analyses has been reintegrated into disaster management, specifically on systems dynamics simulation, linear programming, and multiobjective analyses. Concrete examples such as simulation of evacuation procedures, optimal placement of evacuation assets, and selection of flood protection alternatives, illustrated from the author’s practical experiences, are quite valuable. The evacuation simulation in Chapter 5 drew my special attention as it shows how to analyze the effects of “warning methods and mode of evacuation order dissemination,” a very important practical question in emergency response.

The author humbly says that they are still rather simple, but all the examples would certainly serve for mind broadening and refreshing of practitioners who are facing complicated problems in everyday disaster management. This book eloquently demonstrates how remarkable systems thinking might be in sustainable management of a complex system with “equity, efficiency, and integrity.”

The author has long and diverse experiences of witnessing flood disasters and consulting with municipal flood disaster management agencies in countries such as Serbia, Canada, China, and Egypt. In particular, his experience of “Flood of the
Century” of the Red River in 1997 in Manitoba made him extensively engage in the International Joint Commission (IJC). The causes and effects of this great flood are vividly described in Chapter 1. This experience, I believe, has become the basis of his compiling this book.

At UNESCO-ICHARM (International Center for Water Hazard and Risk Management), Tsukuba, Japan, we have a graduate program on water-related disaster management. Students are practical engineers in the water field. I am glad to see Chapters 2 and 3 of this book introducing concepts of integrated approach and systems approach, which best suit those who start learning disaster management, and for students interested in systems tools, the CD-ROM that goes with the book illustrates the principles with numerical examples.

I hope this book will be used by many students and practitioners in disaster management to step ahead for better integrated disaster management in societies at risk.

KUNIYOSHI TAKEUCHI, Ph.D.,
Director, International Center for Water Hazard and Risk Management under the auspices of UNESCO (ICHARM)
Tsukuba, Japan
Preface

I am one of the lucky few who have the opportunity to work all their professional life in an area that they enjoy. The most enjoyable activity for me is to integrate the knowledge from different fields into an approach for solving complex problems. My work has brought me into contact with many great people, responsible professionals, talented engineers, capable managers, and dedicated politicians. In my capacity as an academic I have also had an opportunity to work with the abundant young talent that continues to feed the workforce. I learned a lot from all these people. I learned many things about the profession, I learned a lot about different cultures, and most importantly, I learned about life. Thank you.

My interest in natural disasters as one would expect grew from my main area of expertise—water resources systems management. From early days of my professional carrier I was involved with floods and flood management, first from the engineering point of view and then later from the management point of view. Flood problems along Morava, Sava, and Danube rivers in my country of origin—Serbia—were among the first professional challenges I had to deal with, after graduation. In 1997, I was teaching at the University of Manitoba and living in Winnipeg. That was the year of the “Flood of the Century.” The governments of Canada and the United States have agreed that steps must be taken to reduce the impact of future flooding on the Red River. In June 1997, they asked the International Joint Commission (IJC) to analyze the causes and effects of the Red River flood of that year. The IJC appointed the International Red River Basin Task Force to examine a range of alternatives to prevent or reduce future flood damage. I was appointed to the task force and the following experience changed my life.

My work has taken me all over the world. I have had an opportunity to see the water problems in the developed and developing world, in small villages and large urban centers. Projects I have been involved with range in scale from the local to the international. I have discussed the flooding issues with farmers of the Sihu area in China as well as the Minister for Irrigation and Water Resources of Egypt. I hope that my professional expertise continues to contribute to the solution of some of these problems. It definitely inspires me to continue to work with greater effort and more dedication.

For more than 30 years of personal research, consulting, teaching, involvement in policy, implementation of projects, and presentation of experiences through the pages of many professional journals, I have worked hard to raise the awareness of the importance of interdisciplinary approach to the solution of complex problems. The main thrust of my work is the use of systems approach in dealing with complexity.
PREFACE

I have accumulated tremendous experience over the years. In that time I realized that there is an opportunity to contribute to the area of disaster management by transferring some of the knowledge and experience from the implementation of the systems thinking and systems tools to various steps of the disaster management cycle. Writing this book offered me a moment of reflection, and it elaborates on lessons learned from the past to develop ideas for the future.

The main goal of this book is to introduce the systems approach to the disaster management community as an alternative approach that can provide support for interdisciplinary activities involved in the management of disasters. The systems approach draws on the fields of operations research and economics to create skills in solving complex management problems. The field of operations research evolved from its origins during the Second World War, and the area known as mathematical programming found wide application as a means to simulate and optimize complex design and operational problems in many fields (of natural, social and health sciences and engineering). A primary emphasis of systems analysis in disaster management as I see it is on providing an improved basis for decision making. A large number of analytical, computer-based tools, from simulation and optimization to multiobjective analysis, are available for formulating, analyzing, and solving disaster management problems.

Large and more frequent disasters in last few decades have brought a remarkable transformation of attitude by the disaster management community toward integration of economic, social and environmental concerns related to disasters, and of action to deal with them.

The early period of hazards research was characterized by taking knowledge from various fields of science and engineering that is applicable to natural and related technological hazards and using it in disaster management. The most significant contribution in the last 10 years is a fundamental shift in the character of how the citizens, communities, governments, and businesses conduct themselves in relation to the natural environment they occupy. Pressures from a growing population and the associated needs for food production and rapid urbanization contribute to an exponential increase in human and material losses from natural and technological disasters.

Disaster management being divided among disciplinary boundaries has faced an uphill battle with the regulatory approaches that are used in many countries around the world. They have not been conducive to the integrative character of the systems approach that is inherent in simulation and optimization management models. Fortunately, recent trends in regulation include consideration of the entire region under threat, explicit consideration of all costs and benefits, elaboration of a large number of alternatives to reduce the damages, and the greater participation of all stakeholders in decision making. Systems approaches based on simulation, optimization, and multiobjective analyses have great potential for providing appropriate support for effective disaster management in this emerging context.

In 1987, with the publication of the Brundtland Commission’s report Our Common Future, decision making in many fields began to be influenced by a sustainability paradigm. It can safely be assumed that sustainability is now the major unifying concept promoted, accepted, and discussed by governments throughout most of the
world. The original report introduced the concept of sustainable development as “the ability to meet the needs of the present without compromising the needs of future generations”. This concept as applied to contemporary hazards mitigation aims at implementing approaches that could result in disaster-resilient communities.

Applying the principles of sustainability to disaster decision making requires major changes in the objectives on which decisions are based, and an understanding of the complicated interrelationships between existing ecological, economic, and social factors. The broadest objectives for achieving sustainability are equity, economic efficiency, and environmental integrity. In addition, sustainable decision making regarding natural hazards faces the challenge of time; that is, it must identify and account for long-term consequences.

To make disaster management decisions designed to produce sustainable disaster-resilient, communities also calls for a change in procedural policies and implementation. If the choice is to select projects with this outcome, it will require major changes in both substantive and procedural policies. Sustainability is an integrating process. It encompasses technology, ecology, and the social and political infrastructure of society. It is not a state that may ever be reached completely. It is, however, one for which the disaster management community and decision makers strive.

The evolution of disaster management is occurring in the context of rapid technological change. In the same period that brought us the systems approach, environmental awareness, and sustainability, we were exposed to the dynamic development of computer hardware and software systems. The power of the large mainframe computers of the early 1970s is now exceeded many times over by the average laptop computer. The computer has moved out of data processing, through the user’s office and into knowledge processing. Whether it takes the form of a laptop personal computer or a desktop multiprocessor workstation is not important. The important point is that the computer acts as a partner for more effective decision making.

Systems can be defined as a collection of various structural and nonstructural elements that are connected and organized in such a way as to achieve some specific objective through the control and distribution of material resources, energy, and information. The systems approach is a paradigm concerned with systems and interrelationships among their components. Today, more than ever, we face the need for appropriate tools that can assist in dealing with difficulties introduced by the increase in the complexity of disaster management problems, consideration of environmental impacts and the introduction of the principles of sustainability. The systems approach is one such tool. It uses rigorous methods to help determine the preferred plans and designs for complex, often large-scale systems. It combines knowledge of the available analytic tools, an understanding of when each is appropriate, and a skill in applying them to practical problems. It is both mathematical and intuitive, as is all disaster management cycle of hazard mitigation, preparation, emergency/event/crisis management, and recovery.

Despite many efforts, systems thinking is in a less secure position in the social sciences than it was 30 years ago. Many theorists still write it off as another version of functionalism, discredited in their eyes because of its inability to deal with the subtlety and dynamics of organizational processes and, in particular, power and
PREFACE

Conflict. Practitioners continue to see the approach as too theoretical to be helpful with their everyday concerns. Progress there might have been but the full potential of systems ideas still remains to be realized.

The aim of this book is directly related to the current state of systems thinking as an approach within the social and specially disaster management sciences. Its purpose is to offer systems thinking as a coherent approach to inquiry and disaster problem management so that it can again occupy a role at the leading edge of development in the applied disciplines. With this book I would like to contribute to the change of disaster management practice and respond to a clear need to redefine the education of disaster management professionals and increase their abilities to (a) work in an interdisciplinary environment; (b) develop a new framework for hazard mitigation, preparation, emergency/event/crisis management, and recovery that will take into consideration current complex socioeconomic conditions; and (c) provide the context for disaster management in conditions of uncertainty.

The main objectives of this book are to introduce the systems approach as the theoretical background for modern disaster management, and to focus on three main sets of tools: simulation, optimization, and multiobjective analysis. At the same time, this book will allow me to reflect on the past 30 years of practicing and teaching water resources systems management. The process of reflection unlocks theory from practice in one field, brings to the surface insights gained from experience, and offers a framework for uncovering many hidden aspects of applying a theoretical approach in the search for a solution of practical problems in other areas. Insights gained from reflection can then be used to elaborate and present a theoretical approach in a different way, which I hope will prove more understandable to the students of the discipline and more acceptable to the practicing disaster managers. Therefore, my sincere hope is that this book will be able to serve multiple communities: as a text for teaching systems analysis and as a guide for the application of a systems approach to disaster management.

The text presented in this book is supported by a number of computer programs that can be used in applying the theory presented here to the solution of real-world problems.

THE ORGANIZATION OF THE BOOK

This book is organized into 4 parts and 8 chapters. Part I provides an introductory discussion and sets the scene. In Chapter 1, there is a brief overview of my personal experience, which provided my motivation for writing this book. I then define the main terms used in integrated disaster management in Chapter 2.

Part II is devoted to the introduction of the systems theory, mathematical formalization, and classification of methods. The material presented in this section should be of practical relevance during the process of formulating a disaster management problem as a systems problem and selecting an appropriate tool for the solution of the problem. In Chapter 3, I focus on systems thinking as a philosophical background of the systems approach and then I formally introduce the systems approach, define systems terms,