Preface (Preview Draft)

It is May of 2009 as this book goes into production. This month's news papers are filled with stories of complicated and challenging problems. We read about rapid climate change and the dangerous changes that await us if we do not reduce greenhouse gas emissions substantially. We read about the increasing deaths from swine flu, and we are warned to prepare for a possible pandemic. There are many stories about the boom and bust in real-estate, and we are told to brace for more bankruptcies before the market recovers. These stories leave us wondering about the underlying causes of the problems and confused over which policies could lead to improved behavior in the future.

Understanding Dynamic Complexity

Climate change, pandemics, and boom and bust in real-estate are complex dynamics which challenge our understanding. We are unable to anticipate the dynamic consequences of policies adopted today, especially when there are long delays between our actions and the system's reactions. Our understanding is also limited by the complexity of the feedback processes that control system behavior. Our actions may be partially erased by the system's internal responses, and the system's apparent resistance to our interventions is confusing. Sorting out the effects of delays and multiple feedbacks is beyond our cognitive abilities, so we look to the past for lessons. But how are we to interpret past patterns in climate change, pandemics and boom/bust cycles? Our understanding of these historical dynamics is limited by the same complexities that make it difficult to think about the future. There are many interpretations of past behavior, and we are left with limited understanding of both the past trends and the current problems.

Premise of the Book

This book is based on the premise that modeling can help us build our understanding of complex problems like those appearing in the news headlines. We build a mathematical model to capture the key interrelationships, and we conduct simulations to see the dynamic pattern. Our cognitive abilities are limited, so we should expect some surprises in the simulations. Indeed, the simulations may turn out to be the very opposite of what we expected. Policies thought to make the system better may make it worse than before. Policies thought to produce winners and losers may turn out to deliver win-win results in the long run. These surprises are the key to improved understanding.

Examples from Many Disciplines

The methods described in this book have been used in a wide range of environmental and business problems, including the problems of climate change (chapter 23), epidemics (chapter 8) and boom/bust in real-estate (chapter 19). The methods are explained in introductory chapters and then illustrated with applications to serious problems of the environment. In each case, the problem arises from the way humans interact with the environment. The examples in this book are organized around fundamental patterns such as exponential growth and oscillations. A panel of six fundamental shapes appears throughout the book. These panels remind us of the premise of systems modeling: the combination of stocks, flows and feedbacks that explains a dynamic pattern in one system could help us explain the same pattern in our system.

This book demonstrates the transferability of systems ideas across many disciplines. You'll see cycles in housing markets and cycles in predator-prey populations. We will simulate the recovery of threatened water basins and threatened fish populations. And we'll learn about the homeostatic tendencies in physiological systems and in the climate system. These examples are complimented by a diverse collection of examples on the book's website. The BWeb applications deal with anthropology, ecology, economics, genetics, geomorphology, hydrology, limnology, regional planning, and resource exploration.

Interdisciplinary Modeling

The major environmental challenges of our time are inherently interdisciplinary. Models can help us understand the challenges if they follow the feedback effects that interconnect the environmental, social and economic systems into a tightly coupled system. This book explains the feedback perspective and the system dynamics method of modeling and simulation. System dynamics is valued for the clarity of representation of the stocks and flows and the feedback processes that control the flows. The approach provides a common language that can be understood by scientists from many disciplines, so it is especially useful in interdisciplinary modeling. System dynamics is also ideally suited for participatory modeling, and it has become a common platform for co-operative modeling of environmental systems.

Modeling the Environment provides opportunities to practice with models in your own discipline and in related disciplines. The best way to begin is to build and verify the models in the book. Then try the exercises at the end of each chapter and on the BWeb. A good way to solidify your understanding is to expand and improve one of the models. If you are studying in a one-semester class (i.e. 15 weeks), there should be time to practice with one of the interdisciplinary models. They illustrate the insights that can emerge when contributions from several disciplines are incorporated in a single, highly interconnected model.

Who Should Learn to Model?

Modeling the Environment is suitable for classes from high school to graduate school, and it is suitable for use in a traditional classroom, in distance delivery classes, and in the many hybrid combinations of instruction. The target audience for the previous edition was college students in undergraduate classes in environmental science and regional planning. But the receptive audience has proved to be far larger. Readers of the previous edition ranged from students in Junior High School to retired business executives. Many readers were able to master the concepts and software without organized instruction. Most readers learn more in groups, especially if you meet together to practice with the modeling software.

Decades of teaching have taught me that students see modeling differently than when I was a student. Their questions have opened my eyes to different perspectives on the use of models. The 2nd edition introduces a student point of view in the form of *questions from Joe*. Think of Joe as a hypothetical student who asks questions that I have often heard in my own classroom. His questions and my responses will help you broaden your own understanding and to appreciate what others may be thinking about modeling.

Your Mathematical Background

Joe's first question is the one I have heard most often at the start of a new class:

Do I need to learn calculus before I can learn to model?

This question is often asked by students who have not taken calculus or who have forgotten calculus from years ago. Some students find mathematics abstract and difficult to understand. They sometimes tell me that modeling is for others to learn. Many students will have a good command of calculus, and they ask if *Modeling the Environment* is their opportunity to put calculus to work on environmental problems.

Calculus may be the first thing on a student's mind, but it is not central to this book. *Modeling the Environment* was written for readers with a wide range of mathematical backgrounds. There is a growing need for modeling projects that help a group of individuals learn together. These projects benefit from experts in several disciplines, from agency staff and from the stakeholders with first-hand knowledge of the system. This book is written with these individuals in mind. I believe everyone can learn to model, and this book minimizes the mathematical hurdles that block many individuals from trying to do so.

Computer simulation is definitely a form of quantitative analysis, so you need some knowledge of mathematics, and you must be willing to think about the numbers and their units of measure. You probably learned about units in high school, and it is useful to review what you learned (appendix A). It's also helpful to check the units in the equilibrium diagrams (chapter 6). The equilibrium diagrams are also a good way to build your familiarity with the numerical values in your model. I also assume you have learned about graphs. This knowledge is important as there are hundreds of graphs in the book. Be sure to study the graphs carefully, paying particular attention to the vertical scales. And take the time to think of the best combination of variables and scales when you create your own graphs.

I also assume that you have learned introductory algebra. This knowledge is crucial since the models use algebra to explain the flows. I believe we should aim for clarity, and the clearest models are those whose algebraic equations can be guessed by simple inspection. We should select variable names that are commonly recognized, and we should be able to write the equations with a combination of add, subtract, multiply or divide. This book aims for clarity in every chapter, and it commits to "friendly" algebra. Indeed, there are only a few instances where the algebraic equations go beyond add, subtract, multiply or divide.

This book does not require training in calculus, differential equations, partial differential equations, statistical analysis, or computer programming. Knowledge of these topics is not required, nor is it crucial to your ability to put modeling to use. The crucial requirement is your knowledge of the feedback processes in your system. The models in this book are constructed in a visual manner on the computer. You'll use your knowledge to select the proper combination of stocks, flows and feedbacks. The tedious job of generating the simulation results is left to the computer. Your challenge is to use the simulation results to build understanding of your dynamic problem.

Website Support for Instructors

Many teachers tell me that they are teaching modeling for the first time, and the first thing they need is access to the figures in the book. You will find these on the book's website. The BWeb provides exercises beyond those at the end of each chapter. There are also exercise collections in fields from anthropology to resource exploration. Instructors may register at the BWeb, and you will be given access to the answers for the exercises.

Many of the models in the book can be constructed in a step by step manner from the description in the chapter. Copies of these models are available to instructors on the BWeb. Some of the models are described in general terms, so readers cannot build them on their own. These models are available to both students and instructors on the BWeb. Case information is also available for both students and instructors. The materials on Mono Lake, the Tucannon salmon population and the Idagon river simulator are the most extensive as of 2009.

Stella and Vensim programs are undergoing continual improvements, and the BWeb is a good way to keep pace with the improving software. There will be typos and other errors in the book, and the BWeb will provide a list of the errors. Check the list if something is erroneous, and the error may have been reported by a previous reader. If not, report the error and we'll add it to the list. I also welcome comments on the exercises and the answer pages. The website will grow over time, and your feedback will help it grow in useful directions.

Instructors' Ideas from the 1st Edition

The new edition benefits from ten years of experience by instructors using the 1st edition. Indeed, many of the best exercises in the 2nd edition grew out of the good work by previous instructors and their students. Instructors have also shared their ways of teaching with me, and I have realigned the chapters to take advantage of their experiences.

Many teachers wonder about the mix of time to be spent learning modeling methods and learning modeling software. The Stella and Vensim programs have become more versatile and easier to learn. Both programs come with excellent, on-line documentation, so the majority of this book is devoted to general concepts, modeling methods and illustrative applications. However, I believe it is useful for some step-by-step instruction on the software. Several chapters have been written as if you are following along on your own computer. This approach is taken in chapter 2, in chapter 14 and in the "read and verify" portion of chapter 16.

An important benefit from a decade of teaching is the identification of technical problems in model formulation. These are pitfalls, i.e., concealed dangers for the unwary modeler. Chapter 17 describes some of the most common pitfalls identified from conversations with a wide range of instructors, students and practitioners. Each pitfall is illustrated with a simple model and its problematical behavior. Alternative formulations are presented to show how to avoid the problem.

The previous decade has seen important advances in system dynamics applications. The growth in participatory modeling is especially encouraging (as explained in chapters 13 and 24). The continued use of system dynamics in interdisciplinary applications is also promising. I believe interdisciplinary models have the greatest potential for profound insights, and I have made interdisciplinary modeling the theme of the book.

There have also been important advances in software and advanced methods. The past decade has seen the development of a wide range of icon-based software for stock-and-flow modeling (appendix C). Recent advances in the analysis of uncertainty intervals and the search for key inputs is now within reach of the broad community of modelers (appendix D). The past decade has also seen improved capability to incorporate short-term dynamics within system dynamics models of long-term trends (appendices E and F). And recent software developments have improved the capability for spatial display of the inputs and outputs of system dynamics models (appendix G).

Author's Perspective

One of my favorite teachers urged all her students to reflect on their theories of how environmental systems work. She argued that these theories dominate the way we think -- they shape the questions we ask, the people we listen to, the models we build, the data we seek and the policies we advocate. She urged all students to give voice to their underlying theories so that teams of students would be more aware of where their teammates were coming from. This was good advice when I was a student, and it is good advice now as I hand this book off to you.

My thinking about environmental systems has been strongly influenced by the ideas published by Jay Forrester and his colleagues at the Sloan School of Management at MIT. Their view of systems and the value of computer simulation underlie much of what you will read in this book. System dynamics has been tremendously useful in my own research and consultancies, and I am impressed by the influential work of many system dynamics practitioners. The method is immensely useful, and we need well-trained people to put it to use on the serious environmental problems of our time.

My thinking on environmental systems was shaped at an earlier age by the text on *Biology* by Garrett Hardin. His thoughts on *homeostasis* made a deep impression that holds sway to this day. His view of the *homeostatic plateau* is sketched in Fig. 10.1. You can see his influence on several of the cases in this book from the summary in Table 10.1.

My own thinking on systems has come to focus more and more on the role of delays. This is probably the cumulative result of policy studies in which the ability to simulate the effect of delays emerged as the key to improved understanding. Delays play a prominent role in this book, as you will see in chapter 15 (salmon life cycle delay), chapter 18 (oscillations), chapter 19 (delays in real-estate construction), chapter 22 (delays in DDT degradation) and chapter 23 (delays in the effective removal of CO_2 from the atmosphere).

Looking back to an earlier age, I was probably primed to think about delays by a driving test as a teenager. The test was organized by my father on a snowy day in our desert town. (We lived east of the Sierra Nevada, a land of little rain and snow.) My friends and I were learning to drive, and our parents advised us to be careful driving on the slick streets. My father could see that the advice was not getting through to teenagers filled with talk about horsepower and engine size. So he had us drive our cars to the school parking lot which was set up with rubber barrels in a course requiring a few turns and some braking. The test looked simple enough until the first teenager put his parents' car into a skid that took out two barrels. The rest of us laughed at his error and wondered if he had heard the advice to "be careful." I concluded that my friend was either not listening or not paying attention to the barrels during the test drive. Each of my friends approached the course with confidence, and each of them quickly lost control, sending the barrels flying across the parking lot. I was the last to take the test, so I had the benefit of learning from my friends' failures. I took the wheel expecting to steer through the obstacle course at a somewhat slower speed without any problems. You can probably guess what actually happened – I went into a skid after the first barrel and wiped out the remainder of the course.

We were all embarrassed by our driving, and I was particularly embarrassed since I failed to learn from my friends. What I remember most is the superficial explanations of my friends' failures. I simply wrote off their experience as something that would not happen to me. The driving test showed that all of us had grossly underestimated the long delay to change a car's direction when the tires have less frictional grip on the surface. We all grossly misjudged the slow speed to drive cars safely on a slippery surface. My father said nothing at the conclusion of the test. But, like Oscar Wilde, he was probably thinking that *experience is one thing you can't get for nothing*.

I tell this driving-test story to dramatize the importance of delays and the difficulty of learning their importance. The driving test reminds us that putting general advice (i.e., "be careful") to good use is extremely difficult. And it reminds us that we do not necessarily learn from previous failures. However, computer simulation modeling can help us overcome the learning obstacles. The existence of a single delay in a key feedback loop may be the confounding factor which makes a system's behavior confusing. System dynamics models are ideally suited to simulate the role of delays. We should strive for realistic models that reveal the system's dynamic problem. Then we should design the models to allow participants to experience the effect of delays through interactive simulation. If we do this work well, we can help to build understanding of environmental systems.

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I close with words of appreciation to my family, first to my father who helped me to see the world, and to my mother who helped me reflect on what I saw. And warmest thanks to Amanda and Emilee, two daughters with the unfailing ability to brighten the day and challenge the mind. And to Amy, still my wife and best friend after all these years, thanks for your love, your support and your sense of what is important.