Editors John Wainwright and Mark Mulligan

Second Edition

Environmental Modelling

Finding Simplicity in Complexity

WILEY-BLACKWELL

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Visit the website for:

- Figures and Tables from the book

To Betty and John, for past and present inspiration, and Xavier and Lourenço for the future. (JW)

To my parents, David and Filomena, who taught (and teach) me so much and Sophia, Charlie and Olive who are very good at coping with all these whirring computers around the place. (MM)

Preface to the Second Edition

Travelling through the UK following the wettest summer on record, one can see the direct and indirect effects of the dynamism of the environment and the responses to change, whether due to global-scale climate or local scale land use. Flood dis and still-inundated fields are the reminders of the dramas of months past. The impacts of such change are felt in many different ways across the globe, both in the moment of the event, or after a period of months or years – such as the expected significant rise of food prices that we are soon to endure. In this context, the aim of this book to understand environmental processes and use models to evaluate their effects remains as strong as ever. In what has been almost a decade since the first edition was assembled, the message of the original chapters remain as strong as ever, but the decade has also seen great advances in conceptual approaches, practical methods and technological advances for modelling. Practical applications of models always need to relate to the people affected by the systems simulated, but what is presented here are examples of the building blocks that can be used to such ends. It is left to the modeller to ensure that these blocks are put together in a robust but societally relevant manner.

In putting this second edition together, we realized very quickly that in wanting to provide more of a basic introduction to modelling, the structure was becoming very unwieldy. Therefore, we decided to take most of the original chapter 2 and develop it into a companion volume (or prequel, if you prefer) – *Building Environmental Models: A Primer on Simplifying Complexity* – which should appear in the next year or so. Some chapters from the original edition have been removed or rewritten and integrated into others to make way for chapters reflecting new developments and themes. We extend our warmest thanks to all of the authors for their collaboration and co-operation in this process. Discussions with, and inspirations from them all continue to inspire and inform our own work.

The basis of the book remains the work we both carried out in the Environmental Monitoring and Modelling Research Group in the Department of Geography, King's College London. Since the first edition, its original leader and our mentor, John Thornes, has sadly passed away, but we hope his work (see chapter 24) will remain an inspiration to environmental scientists for many years to come. Alan Dykes is now leading the production of an edited volume in his honour to show his legacy more fully. Also since the first edition, JW has become more peripatetic, which has provided an opportunity to try out ideas and materials on students in Sheffield, Strasbourg and Durham. We thank them all, as well as those from King's throughout the last two decades or so. The last word again goes to the apparently infinite patience of our editors at Wiley-Blackwell – Fiona Seymour and Lucy Sayer – in bringing this project to a successful conclusion.

John Wainwright and Mark Mulligan
Durham and London
October 2012

Preface to the First Edition

Attempting to understand the world around us has been a fascination for millennia. It is said to be part of the human condition. The development of the numerical models, which are largely the focus of this book, is a logical development of earlier descriptive tools used to analyse the environment such as drawings, classifications and maps. Models should be seen as a complement to other techniques used to arrive at an understanding, and they also, we believe uniquely, provide an important means of testing our understanding. This understanding is never complete, as we will see in many examples in the following pages. This statement is meant to be realistic rather than critical. By maintaining a healthy scepticism about our results and continuing to test and re-evaluate them, we strive to achieve a progressively better knowledge of the way the world works. Modelling should be carried out alongside field and laboratory studies and cannot exist without them. We would therefore encourage all environmental scientists not to build up artificial barriers between 'modellers' and 'non-modellers'. Such a viewpoint benefits no-one. It may be true that the peculiarities of mathematical notation and technical methods in modelling form a vocabulary which is difficult to penetrate for some but we believe that the fundamental basis of modelling is one which, like fieldwork and laboratory experimentation, can be used by any scientist who, as they would in the field or the laboratory, might work with others, more specialist in a particular technique to break this language barrier.

Complexity is an issue that is gaining much attention in the field of modelling. Some see new ways of tackling the modelling of highly diverse problems (the economy, wars, landscape evolution) within a common framework. Whether this optimism will go the way of other attempts to unify scientific methods remains to be seen. Our approach here has been to present as many ways as possible to deal with environmental complexity, and to encourage readers to make comparisons across these approaches and between different disciplines. If a unified science of the environment does exist, it will only be achieved by working across traditional disciplinary boundaries to find common ways of arriving at simple understandings. Often the simplest tools are the most effective and reliable, as anyone working in the field in remote locations will tell you!

We have tried to avoid the sensationalism of placing the book in the context of any ongoing environmental 'catastrophe'. However, the fact cannot be ignored that many environmental modelling research programmes are funded within the realms of work on potential impacts on the environment, particularly due to anthropic climate and land-use change. Indeed, the modelling approach – and particularly its propensity to be used in forecasting – has done much to bring potential environmental problems to light. It is impossible to say with any certainty as yet whether the alarm has been raised early enough and indeed which alarms are ringing loudest. Many models have been developed to evaluate what the optimal means of human interaction with the environment are, given the conflicting needs of different groups. Unfortunately, in many cases, the results of such models are often used to take environmental exploitation 'to the limit' that the environment will accept, if not beyond. Given the propensity for environments to drift and vary over time and our uncertain knowledge about complex, non-linear systems with threshold behaviour, we would argue that this is clearly not the right approach, and encourage modellers to ensure that their results are not misused. One of the values of modelling, especially within the context of decision-support systems (see Chapter 14) is that non-modellers and indeed non-scientists can use them. They can thus convey the opinion of the scientist and the thrust of scientific knowledge with the scientist *absent*. This gives modellers and scientists contributing to models (potentially) great influence over the decision-making process (where the political constraints to this process are not paramount). With this influence comes a great responsibility for the modeller to ensure that the models used are both accurate and comprehensive in terms of the driving forces and affected factors and that

these models are not applied out of context or in ways for which they were not designed.

This book has developed from our work in environmental modelling as part of the Environmental Monitoring and Modelling Research Group in the Department of Geography, King's College London. It owes a great debt to the supportive research atmosphere we have found there, and not least to John Thornes who initiated the group over a decade ago. We are particularly pleased to be able to include a contribution from him (Chapter 18) relating to his more recent work in modelling land-degradation processes. We would also like to thank Andy Baird (Chapter 3), whose thought-provoking chapter on modelling in his book *Ecohydrology* (co-edited with Wilby) and the workshop from which it was derived provided one of the major stimuli for putting this overview together. Of course, the strength of this book rests on all the contributions, and we would like to thank all of the authors for providing excellent overviews of their work and the state-of-the art in their various fields, some at very short notice. We hope we have been able to do justice to your work. We would also like to thank the numerous individuals who generously gave their time and expertise to assist in the review of the chapters in the book. Roma Beaumont re-drew a number of the figures in her usual cheerful manner. A number of the ideas presented have been tested on our students at King's over the last few years – we would like to thank them all for their inputs. Finally, we would like to thank Keily Larkins and Sally Wilkinson at John Wiley and Sons for bearing with us through the delays and helping out throughout the long process of putting this book together.

John Wainwright and Mark Mulligan
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Contents

PART III MODELS FOR MANAGEMENT, 333

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• Figures and Tables from the book