veb sites, or publication of programs and of data. No form of dissemination s discounted, and prospective authors are invited to suggest whatever primary orm of publication and support material they think is appropriate.

The editorial board

The monograph series is supported by an editorial board. Every monograph proposal is sent to all members of the board which includes Ralf Bill, Antonio Camara, Joseph Ferreira, Pip Forer, Andrew Frank, Gail Kucera, Peter van Oostrom and Enrico Puppo. These people have been invited for their experience in the field, of monograph writing, and their geographic and subject diversity. With particular monographs members may also be involved later in the process.

Future submissions

Anyone who is interested in preparing a research monograph should contact either of the editors. Advice on how to proceed will be available from them, and is treated on a case by case basis.

For now we hope that you will find this, the first in the series, a worthwhile addition to your GIS bookshelf, and that you may be inspired to submit one too.

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Foreword

It is a great honour to be asked to write this brief foreword to Gerard Heuvelink's monograph. As Gerard notes in his Preface, the monograph is the culmination of a decade of work, and it brings together and extends results that have been published in a number of forms over that period. Gerard has made an outstanding contribution to the field over that period, and his work is far and away the best and most comprehensive attempt to formalise and offer solutions to the difficult problem of error propagation in GIS. Publication of this monograph is very timely, as it makes all of this work accessible in one source, and brings it to the attention of a wide and multidisciplinary audience in a format that is both rigorous and relatively easy to implement.

Error propagation in GIS may appear to the uninitiated as an obscure, abstruse topic within a relatively obscure field – so why is it so important, and why does it deserve attention in the form of this monograph? Aren't computers accurate, and isn't everything that emerges from them perfectly true? We have made great progress in the past decade or so in extending computer applications into the domain of the vague and imprecise, and computers are now used to help make decisions under conditions of uncertainty; computers armed with tools such as the World Wide Web are far from the exact number-crunchers that defined the computing world of thirty years ago. But in the case of geographic information the problem of unreasonable expectations is made worse by two additional factors. First, uncertainty is endemic in geographic information, since it is virtually impossible to record and represent the true complexity of the Earth's surface in digital form. But perhaps more important is the fact that the previous technology – in this case, the paper map – was also guilty of an exaggerated sense of its own precision. Somehow, we have grown used to the idea of precisely drawn contours on topographic maps, and precise boundaries on soil maps, even though we know on reflec-

tion or closer examination that their true accuracy is much lower. Somehow we accept this pretence of accuracy, and have developed a technology of geographic information systems that takes and analyses that map information at face value, without questioning its true accuracy. We are only now coming to realise that much of what passes for accurate analysis in GIS is in fact highly uncertain, and that decisions and regulations that depend on analysis can be flawed. Pity the poor GIS analyst required to defend in court the results of a GIS analysis that did not adequately reflect the uncertainty in its data, against a clever and well-informed lawyer. The only answer is a new generation of accuracy-aware GIS, using the techniques and following the examples discussed in this monograph.

Gerard uses the term 'error' in the statistical sense of variation, and explains why the problem is rather more general than the term might imply. It is important to realise that the methods discussed here can be applied not only to the problem of error in measurement, but also to the uncertainties introduced by inadequate definitions, excessively coarse scale, insufficient samples, and many other sources. The definition of accuracy used here – the "difference between reality and our representation of reality" – contains that all-important word 'our'. If 'we' are not all of one mind – if different observers might make slightly different maps of the soils in the same area – the variation that results is a form of error in the sense of this monograph.

Error analysis in GIS would be much easier if map-making were more like scientific measurement; for example, if a digital elevation model (DEM) were actually built by going out in the field and measuring directly the elevation at each point in the DEM's grid. In reality, the construction of a geographic database is often a complex process involving many different people, different sets of measurements, stages of interpretation and manipulation that more or less completely confound the relationship between original measurements and final database contents. The process is often undocumented, and only in rare circumstances is it possible to develop a formal analysis of error. Moreover, the response of the environment to uncertain inputs is often highly nonlinear. A small error or uncertainty in a digital elevation model can make a dramatic difference to the calculation of the area visible from a point, or the geometry of a drainage network. The net result is that our intuitive understanding of the connection between uncertain input and uncertain output of an analysis or a model is extremely limited. It can be close to impossible to guess how much impact a given input uncertainty will have, without the aid of error propagation methods.

So what next, and where do we go from here? Gerard's monograph includes many tools, and the means to implement them is available in packages like ADAM. It includes excellent examples of the use of the methods in classic GIS analyses. It is important to note, however, that while GIS and environmental modelling overlap, they are not the same, and that the methods are potentially applicable to a much wider domain. Finite-element methods

are often used for modelling environmental systems without reference to GIS; and for modelling in spaces that are not normally thought of as geographic. The tools would be much more widely accessible if they could be incorporated into the mainstream commercial GISs, and into software environments that are also commonly used to support environmental modelling, such as the statistical and mathematical packages. Hopefully, this work will also stimulate further research on the other forms of geographic data, particularly discrete object representations, and the particular uncertainties to which they are subject.

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