1

Introduction

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1.1 THE CHALLENGE

The environment is key to sustaining human economic activity and well-being, for without a healthy environment, human quality of life is reduced. Most people would agree that there are also many reasons to protect the environment for its own inherent worth, and especially to leave a legacy of fully functioning natural resources. Sustainable land management refers to the activities of humans and implies that activity will continue in perpetuity. It is a term that attempts to balance the often conflicting ideals of economic growth and maintaining environmental quality and viability.

There are three interacting components required for successful natural resource and environmental management, namely policy, participation and information (Figure 1.1). These factors are especially critical in less developed countries, where infrastructure is often rudimentary. The balance between these three components, and their influence on management, will depend on the management problem, as well as the infrastructure and the social, economic and cultural traditions of the country.

Sustainable land use and development is based on two critical factors. Firstly, national, regional and local policy and leadership, which may be asserted through diverse mechanisms including legislation, policy documents, imposing sanctions, introducing incentives (reduced tax, subsidies, etc.), motivation to contribute to development and so on. Policy tools are necessary to encourage farmers and other natural resource managers to make good use of natural resources, and organize management in a sustainable manner. Policy may also be used to define protection areas. Secondly, sustainable land use requires the participation by, and benefits to, local people (farmers, managers, land owners, stakeholders). If the local people benefit directly (through an improved standard of living, better environment, gender equality, etc.) then they will contribute positively to the policy settings. In addition, an active non-governmental organization network is often effective in maintaining accountability.

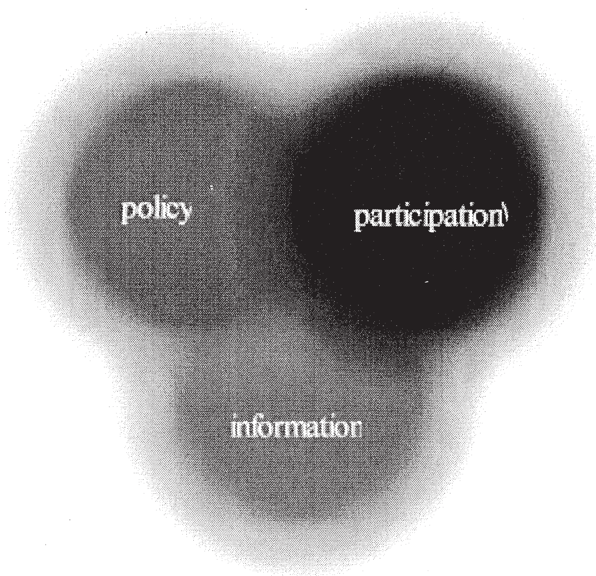

Figure 1.1: Ingredients necessary for a successful geographic information system (GIS) for environmental management project – policy, participation and information.

These elements require the provision of timely, accurate and detailed information on land resources as well as changes in the land resource. This spatial information is provided, and applied through, a geographic information system (GIS) and remote sensing. Better spatial information and maps leads to improved planning and decision making at all levels and scales, and hopefully generates harmony between production and conservation across a landscape.

This book is focused on information, and specifically on how spatial information may be used for environmental modelling and management. There are also examples and discussion in the following chapters of how the geographical information is used for policy, as well as for participation and planning. Thus, the book emphasizes environmental models, and specifically how these models have been extrapolated in space and time in order to develop policy and ultimately assist managers of the environment.

1.2 MOTIVATION TO WRITE THIS BOOK

The genesis for this book was a one week commercial short course developed at ITC (International Institute for Aerospace Survey and Earth Sciences) for participants from around the world. It was an opportunity for a diverse group of lecturers to present the current state of knowledge in their field of expertise, and to share and comment on developments in related fields. The participants and lecturers came from all regions of the World (Europe, Africa, Asia, the Pacific, and the Americas) (Table 1.1). The participants could be broadly categorized as mid-career professionals, some occupying senior management positions in both private and government organizations. All were concerned with the management and implementation of GIS and remote sensing, and specifically how environmental models can be put to work for environmental management. Their excellent feedback at the end of the course allowed us to write a short chapter on perceived trends and bottlenecks in the field of GIS and environmental modelling.

Table 1.1: Participants and lecturers in the short course.

Region	Number of participants and lecturers
Africa	10
Asia	6
Americas	4
Europe	14
Oceania	3

The other motivation for writing this edited volume is that there are few books that bring together case studies, theory and applications of GIS and environmental modelling in one volume. Even though we attempt to present the state of the art, GIS and remote sensing is continuing to develop quickly, so some elements of the book may rapidly become dated.

This book is aimed at GIS and remote sensing professionals. We anticipate it will also be of interest to university students, either as the basis of short courses, or as a semester course on the environmental application of GIS or remote sensing. The book complements texts on the introduction to GIS (e.g. Burrough 1986; Burrough and McDonnell 1993), management of GIS (e.g. Aronoff 1989; Huxhold and Levinsohn 1995), the application of GIS (e.g. Heit and Shortreid, 1991), advanced data structures (e.g. Laurini and Thompson 1992; Van Oosterom 1993) and an earlier book on environmental modelling with GIS (Goodchild *et al.* 1993).

1.3 WHAT IS ENVIRONMENTAL MODELLING AND HOW CAN GIS AND REMOTE SENSING HELP IN ENVIRONMENTAL MODELLING?

A model is an abstraction or simplification of reality (Odum 1975; Jeffers 1978; Duerr *et al.* 1979). When models are applied to the environment, it is anticipated that insights about the physical, biological or socio-economic system may be derived. Models may also allow prediction and simulation of future conditions, both in space and in time. The reason to build models is to understand, and ultimately manage, a sustainable system.

As introduced in section 1.1, sustainable development has been defined in many ways; in fact there are 67 different definitions listed in the 'Introduction to natural resource management' module taught at ITC (McCall, per comm.). Interestingly, none mention GIS and remote sensing as being tools necessary for sustainable development. Sustainable development is a term that attempts to balance the often conflicting ideals of economic growth while maintaining environmental quality and viability. As such, sustainability implies maintaining components of the natural environment over time (such as biological diversity, water quality, preventing soil degradation), while simultaneously maintaining (or improving) human welfare (e.g. provision of food, housing, sanitation, etc.).

In any definition of sustainability, a key element is change; for example, Fresco and Kroonenberg (1992) define sustainability as the "...dynamic equilibrium between input and output". In other words, they emphasize that dynamic equilibrium implies change and that in order for a land system to be sustainable, its potential for production should not decrease (in other words the definition allows for reversible damage). This type of definition is most applicable when considering agricultural production systems, but may also be generalized to the management of natural areas. A broader definition of sustainability includes the persistence of all components of the biosphere, even those with no apparent benefit to society, and relates particularly towards maintaining natural ecosystems. Other definitions emphasize increasing the welfare of people (specifically the poor at the 'grassroots' level) while minimizing environmental damage (Barbier 1987), which has a socio-economic bias. The necessary transition to renewable resources, is emphasised by Goodland and Ledec (1987) who state that renewable resources should be used in a way which does not degrade them, and that non-renewable resources should be used so that they allow an orderly societal transition to renewable energy sources.

That changes continually occur at many spatial (e.g. global, regional, local) and temporal (e.g. ice ages, deforestation, fire) scales is obvious to any observer. For example, change may occur in the species occupying a site, amount of nitrate in ground water, or crop yield from a field. Change may also occur to human welfare indices such as health or education. To assess whether such changes are sustainable is a non-trivial problem. Possibly the advantage of the debate about sustainable development is that the long-term capacity of the earth to maintain human life through a healthy and properly functioning global ecosystem is now a normal political goal.

Many alternative definitions of GIS have been suggested, but a simple definition is that a GIS is a computer-based system for the capture, storage, retrieval, analysis and display of spatial data. GIS are differentiated from other spatially related systems by their analytical capacity, thus making it possible to perform modelling operations on the spatial data (see Box 1.1). The spatial data in GIS databases are predominately generated from remote sensing through the direct import of images and classified images, but also through the generation of conventional maps (e.g. topographic maps) using photogrammetry. Thus remote sensing is an integral part of GIS, and GIS is impossible without remote sensing. Remote sensing data, such as satellite images and aerial photos allow us to map the variation in terrain properties, such as vegetation, water, and geology, both in space and time. Satellite images give a synoptic overview and provide very useful environmental information for a wide range of scales, from entire continents to details of a metre.

Box 1.1: Typical questions addressed by a GIS (after Burrough 1986 and Garner 1993).

Location {What is at ....?}
- What house number is at lot X?
- What is the crop type at point Y?

Condition {Where is it .....?}
- Where is all the land zoned for firework factories within 200 m of a suburb?
- Where is the forest within 100 km of a timber mill?

Distribution {What is the distribution/pattern .....?}
- What proportion of *Eucalyptus sieberi* trees occur on ridges?
- What is the average radiation level 5 – 10 km from Chernobyl?

Trend {What has changed ......?}
- What is the decline in wildebeest abundance in the last 20 years in Kenya?
- What is the increase in salt in the Murray River in the last 50 years?

Routing {Which is the best way ....?}
- Which is the shortest distance to a forest fire?
- Which is the fastest route from London to Colchester?

It is because of its analytical capacity that GIS is being increasingly used for decision making, planning and environmental management. GIS and remote sensing have been combined with environmental models for many applications, including for example, monitoring of deforestation, agro-ecological zonation, ozone layer depletion, food early warning systems, monitoring of large atmospheric-oceanic anomalies such as El Nino, climate and weather prediction, ocean mapping and monitoring, wetland degradation, vegetation mapping, soil mapping, natural disaster and hazard assessment and mapping, and land cover maps for input to global climate models. Though developments have been broadly based across many divergent disciplines, there is still much work required to develop GIS models suited to natural resource management, refine techniques, improve the accuracy of output, and demonstrate and implement work in operational systems.

In the mainstream GIS literature there has been growing attention to the need to consider models as an integral part of GIS, and to improve understanding and application of models. The problems inherent in applying GIS (for environmental management) are summarized in Table 1.2, as identified by key papers and books. An obvious trend in Table 1.2 is for technical problems (hardware, software, etc.) in the 1980s to be replaced by organizational issues in the 1990s. Data availability, quality of data, and appropriate models for specific applications appear to be the main issues presently, and are the focus in this book.

Table 1.2: Main problems in implementing GIS, as cited from 1986 to 2001.

Year	Author	Problems in implementing GIS
1986	Burrough	Technical requirements (hardware, software and data structures); cost; expertise; embedding GIS in the organization
1989	Aronoff	Technology; database creation; institutional barriers; expertise
1991	Atenucci *et al.*	Software (data structures, hypermedia, artificial intelligence); hardware (PC performance, mass storage); communications and networking; system implementation
1993	Van Oosterom	Software (data structure)
1995	Huxhold and Levinsohn	Embedding GIS technology in organizations; managing GIS projects
2001	Bregt *et al.*	Data availability and quality; model applicability and development

1.4 CONTENTS OF THE BOOK

The problem of how to classify models was posed by Crane and Goodchild (1993; p 481). In Chapter 2 a taxomony of GIS environmental models is proposed, and examples provided.

As identified in Table 1.2 and in Chapter 12, the availability of spatial data is a major bottleneck for managers wishing to implement GIS for environmental modelling. This important issue is discussed in Chapter 3 for remotely sensed data, and Chapter 4 for GIS data.

In Chapter 5, the application of GIS to global monitoring and environmental models is addressed. This chapter describes the problems and solutions for a number of pressing global issues. The scale changes in Chapter 6 from a global to a regional perspective, where environmental models for vegetation mapping and monitoring are discussed.

The emphasis in Chapter 7 shifts from vegetation models to habitat models in general, with special attention to wildlife habitat models.

The issue of biodiversity, and how geoinformation is used for developing policy about biodiversity, is addressed in Chapter 8.

An important branch of environmental modelling is hydrology; water quantity and quality is a primary determinant of productivity in agricultural as well as environmental systems. The use of GIS and remote sensing in hydrological modelling is discussed in Chapter 9.

Extreme weather events, as well as other natural hazards such as earthquakes, are described in Chapter 10. Techniques developed to model such hazards are presented.

The penultimate chapter (11) shows how geoinformation may be used in environmental impact assessment (EIS) and land use planning. A number of case studies are presented.

Finally in Chapter 12, the feedback from participants and lecturers on problems in the use of GIS and remote sensing for environmental modelling, and possible solutions to these problems is presented.

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