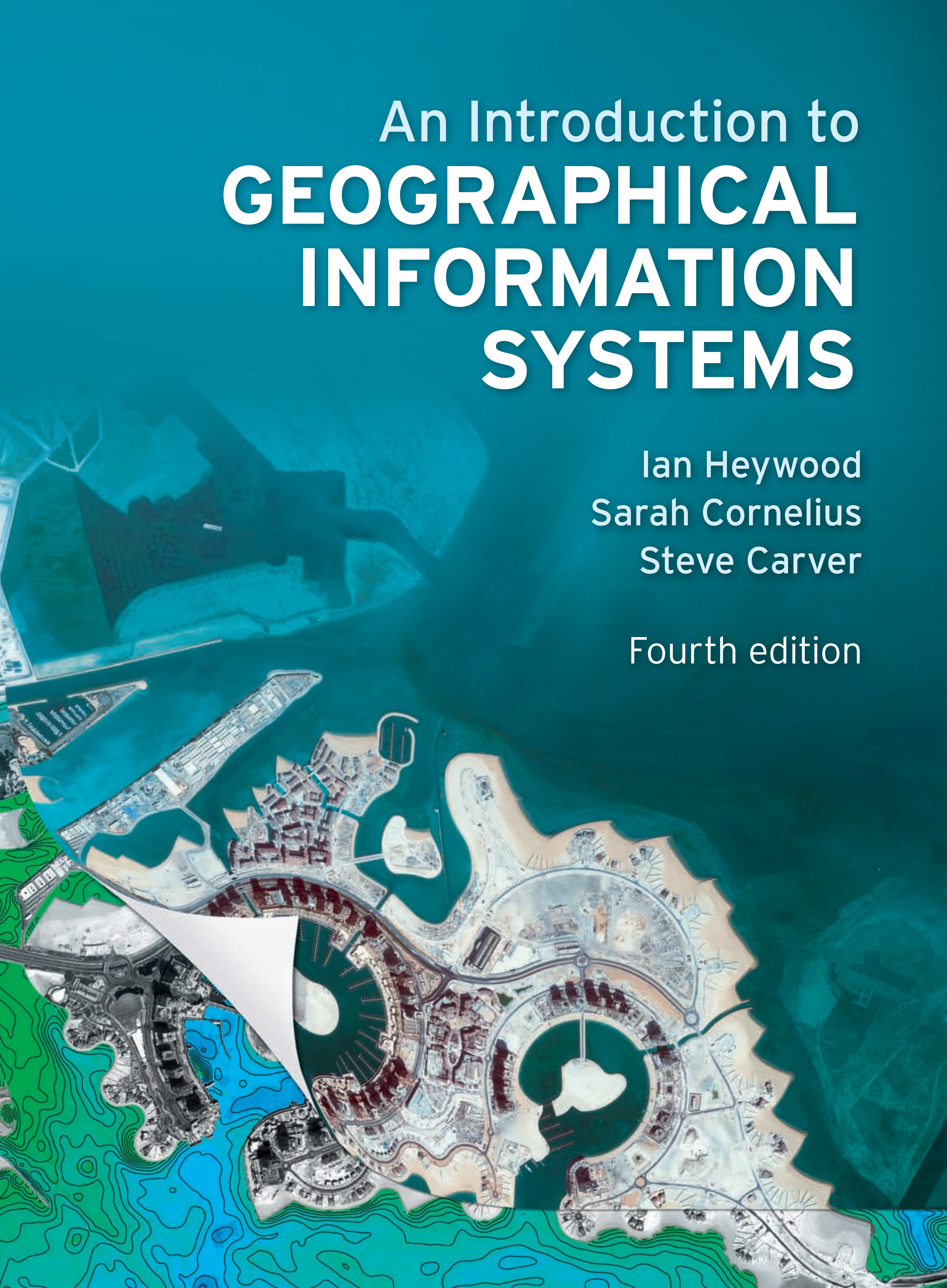

An Introduction to GEOGRAPHICAL INFORMATION SYSTEMS

Ian Heywood
Sarah Cornelius
Steve Carver

Fourth edition

An Introduction to
GEOGRAPHICAL INFORMATION SYSTEMS

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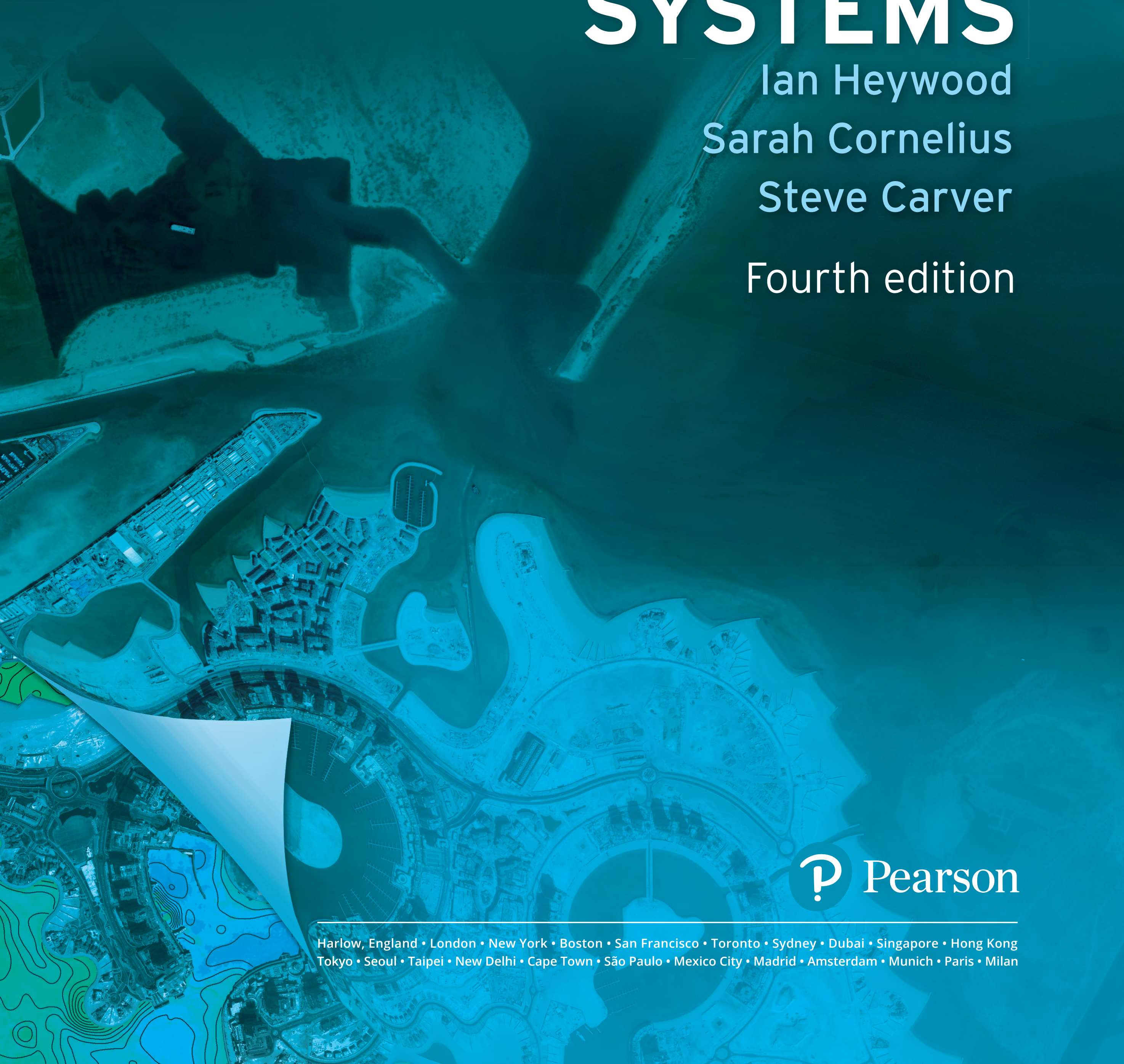

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Brief contents

Contents

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- Instructor's Manual including lecture outlines and practical exercises
- PowerPoint slides containing the artwork and images from the text

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- Online help and support to assist with website usage and troubleshooting

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Preface

HOW THIS BOOK IS WRITTEN

Your encounters with GIS to date may be similar to those of a Martian arriving on Earth and being faced with a motor car. Imagine a Martian coming to Earth and stumbling across a motor car showroom. Very soon he (or she) has heard of a 'car' and may even have seen a few glossy brochures. Perhaps you are in the same position. You have heard of the term GIS, maybe even seen one or two demonstrations or the paper output they produce.

Developing the analogy of the Martian and the car leads us to a dilemma. There are two approaches to explaining to the Martian what the car is and how it works. The first method is a bottom-up approach. This involves taking the car apart into its component pieces and explaining what each part does. Gradually, we put the pieces back together so that by the time we have reassembled the car we have a good appreciation of how the car works in theory. However, we may still have little idea about how to use it or what to do with it in practice.

The second method, the top-down approach, starts by providing several examples of what the car is used for and why. Perhaps we take it for a test run, and then explore how the different components of the car work together to produce an end result. If this approach is adopted, we may never be able to build a car engine, but we will have a clear appreciation of how, when, why and where a car could be used. In addition, if we explore the subject in sufficient technical detail we will know how to choose one car in preference to another or when to switch on the lights rather than the windscreen wipers.

We feel that the same two methods can be used to inform you about GIS. Since we believe you are reading this book not because you want to write your own GIS software, but because you wish to develop a better appreciation of GIS, the approach adopted is similar to the top-down method. We focus on the practical application of GIS technology and, where necessary and appropriate, take a more detailed look at how it works. In a book of this size it is impossible for us to explain and describe every aspect of GIS. Therefore, we concentrate on those areas that enable you to make sense of the application of GIS, understand the theories upon which it is based and appreciate how to set up and implement your own GIS project.

THE FOURTH EDITION

The fourth edition has been expanded to cover the latest advances in GIS including Web and mobile applications of GIS. The case studies, written by academics, professionals, teachers and research students to help illustrate the many ways in which GIS is being used around the world, have been updated and several new ones added to this fourth edition.

Many of the changes and corrections have been made in response to suggestions made by reviewers, and from lecturers and teachers using the book. Many, many thanks to all of you who commented on the first, second and third editions.

With rapid developments in GIS over recent years, the chapter on the future of GIS which was written for the earlier editions of the book had become outdated. Thus, one of the major changes for the fourth edition has been to restructure and rewrite Chapters 9 and 13. Much of what we predicted might happen to GIS in earlier editions of the book is now reality and these events are captured in an expanded Chapter 9, which looks at the development of GIS from a historical perspective. In Chapter 13 we offer comments on where GIS is now and on some of the likely future challenges. We also invite you to formulate your own predictions for the future of GIS and encourage you to share these with us via the website for the book.

HOW TO USE THIS BOOK

There are three ways to use this book:

1 Browse through the text, consider the chapter headings, and review the learning outcomes

at the start of each chapter. Supplemented by reading Chapter 1 this will give you a quick tour through the world of GIS and highlight some of the important issues and concepts. If you wish you can explore specific topics further using the boxes, case studies and the companion website.

2 A better way to approach the text is to read the book chapter by chapter. This will allow you to discover the ideas presented and develop an understanding at your own pace. To assist you we have included learning outcomes at the start of each chapter, reflection boxes within each chapter, and revision questions and pointers for further study at the end of each chapter. The reflection boxes can be found at the end of major sections of text to encourage you to pause and reflect on key issues and themes. They may ask you to think beyond the text itself and about the role of GIS in your studies, your work and the world around you. The revision questions are provided to encourage you to examine and revisit the major themes and issues introduced in each chapter and reinforce your learning. Further study sections at the end of each chapter have two parts; suggestions for further reading including full references and bibliographic details, and suggestions for activities you can do yourself either on the Web, on paper or using a GIS package if you have one available. A selection of weblinks is also provided at the end of each chapter to help you explore online materials and information resources.

3 The third way to use this book is as a reference source. You might wish to delve into those sections that you feel are relevant at a particular time. Perhaps you can read the appropriate chapter to supplement a course you are following. There is a comprehensive index and glossary at the back of the text and pointers to further sources of information. We have tried to reference only readily available published material. References to other additional information sources on the Internet can be found on the website for the book. These lists of further sources are by no means comprehensive, but are offered as a starting point. We suggest that you also consult library and online sources for more up-to-date materials.

BEFORE YOU START

You could not drive a car without an understanding of the road network or road signs. Similarly, a full understanding of GIS requires some computing background, particularly in topics like operating systems and file management. This book assumes basic familiarity with PC computing. Anyone who has any experience of word processing, spreadsheets, databases or mapping packages, should be able to apply that knowledge in a GIS context. The typical first-year undergraduate IT course offered in subject areas like geography, biology, business studies or geology is sufficient for you to cope with the ideas presented in this book. We assume that you are familiar with terms such as hardware and software, the Internet and the major components of a computer: for example, monitor, keyboard, hard disk drive, CD-ROM drive, processor and memory. We make no other assumptions – this book is written to be accessible to students of GIS from any professional or academic background: from archaeology, through biology, business studies, computing, demography, environmental management, forestry, geography, history … and on to zoology.

If you want to become a GIS expert, you will need to be comfortable with more advanced computing issues, and will have to expand your computing background to include skills in such areas as programming and networks. These issues are beyond the scope of this book, but we hope to provide you with a valuable head start and many pointers as to where to continue your journey.

A book cannot substitute for hands-on experience in a subject area as practical as GIS. Therefore, for a fuller appreciation of GIS we encourage you to enroll on a course that offers practical experience of GIS, or to find a system to use in your own time. There are a number of excellent GIS 'courses' now available electronically and reference has been made to these on the website for the book.

HOW THIS BOOK IS STRUCTURED

The book is organized into 13 chapters in two parts. The first part of the book deals with GIS theory and concepts. After an introductory scene-setting chapter, that also introduces four case studies that are used throughout the book, important topics like spatial data, database theory, analysis operations and output are all examined. In the second part of the book we have focused on a selection of GIS 'issues' – the development of GIS, data quality, organizational issues and project management. There are, of course, other issues we could have considered, but those selected reflect many of the key themes of current interest, and areas important for anyone undertaking practical work in GIS. The book ends with a postscript on the future of GIS which sets out a challenge for you to help us explore what the future for GIS might hold. Each chapter has been carefully structured to link together into a unified whole, but can be read in isolation. There are several common elements to each chapter to help you get the most from the book. These are:

- Introduction and list of learning outcomes.
- Boxes providing additional detail on theory and practice.
- Full colour maps, diagrams, tables and photographs.
- Illustrated case studies with further details of issues and applications in GIS.
- Reflection questions and activities.
- Conclusions including revision questions.
- Pointers to further study including references to additional reading and activities.
- Web links.

In summary, the chapters are:

PART 1: FUNDAMENTALS OF GIS

Chapter 1: What is GIS?

This chapter provides an overview of GIS. It examines what GIS is, what it can do and, in brief, how it works. The chapter starts by looking at the types of generic questions GIS can answer and expands on these with reference to a series of case studies which are then used throughout the rest of the book. GIS is then defined, and a range of issues and ideas associated with its use identified. Much of the material introduced in this chapter will be covered in more detail later in the book.

Chapter 2: Spatial data

This chapter looks at the distinction between data and information and identifies the three main dimensions of data (temporal, thematic and spatial). The main characteristics of spatial data are described. A review of how the traditional map-making process shapes these characteristics is presented. The three basic spatial entity types (points, lines and areas), which form the basic building blocks of most GIS applications, are introduced. Maps and a range of other sources of spatial data are reviewed.

Chapter 3: Spatial data modelling

How do you model spatial form in the computer? This chapter considers in detail how the basic spatial entities (points, lines and areas) can be represented using two different approaches: raster and vector. Two other entity types that allow the modelling of more complex spatial features (networks and surfaces) are introduced. Finally, modelling of three- and four-dimensional spatial data is reviewed.

Chapter 4: Database management

This chapter introduces the methods available for handling attribute data in GIS. The need for formal methods for database management is discussed. The principles and implementation of a relational database model are considered in detail, since this model is the most frequently used in current GIS. Database options for large-scale users are presented, including the use of centralized and distributed database systems. Finally, a brief introduction to the object-oriented approach to database management is provided.

Chapter 5: Data input and editing

This chapter gives an overview of the process of creating an integrated GIS. It takes us from source data through data encoding, to editing and on to manipulatory operations such as re-projection, transformation, and rubber sheeting. The chapter provides examples of how these processes are carried out, and highlights issues pertinent to the successful implementation of a GIS application.

Chapter 6: Data analysis

Methods for making measurements and performing queries in GIS are introduced in this chapter. Proximity, neighbourhood and reclassification functions are outlined, then methods for integrating data using overlay functions explained. Interpolation techniques (used for the prediction of data at unknown locations) are introduced and the analysis of surfaces and networks considered. Finally, analysis of quantitative data is reviewed.

Chapter 7: Analytical modelling in GIS

This chapter provides a summary of process models before considering how they can be implemented in GIS. These models are then approached from an applications perspective, and three examples are examined: physical process models; human process models and decision-making models. To conclude, the chapter considers some of the advantages and disadvantages of using GIS to construct spatial process models.

Chapter 8: Output: from new maps to enhanced decisions

An understanding of the basic principles of map design is essential for the effective communication of information and ideas in map form. In addition, an understanding of the complexity of the map design process helps appreciation of the power of maps as a visualization tool. This chapter considers the advantages and disadvantages of cartographic and non-cartographic output. In the conclusion to this chapter there is a brief discussion of the role of GIS output in supporting decision making.

PART 2: ISSUES IN GIS

Chapter 9: The development of computer methods for handling of spatial data

This chapter considers how GIS have developed to their current state. The methods of handling spatial data that were used before computers were available are examined. These give an insight into what we require computers to do, and how they can help (or hinder) existing practice. Computer methods for handling spatial data existed before GIS, so these are reviewed, then developments in GIS are discussed together with developments in a selection of complementary disciplines. The chapter does not attempt to present a comprehensive history of GIS but aims to give some context for the systems and concepts we work with today.

Chapter 10: Data quality issues

The terms used for data errors and quality are explained at the beginning of this chapter, since the first step to solving problems is to be able to recognize and describe them. The remainder of the chapter outlines the types and sources of errors in GIS to help you identify and deal with problems at the appropriate stage of a GIS project. Techniques for modelling and managing errors are also considered.

Chapter 11: Human and organizational issues

This chapter takes us away from relatively small-scale research-type applications of GIS, where one user can be in control from start to finish, and takes a look at some of the issues surrounding larger-scale commercial and business applications. In utilities, local government, commerce and consultancy, GIS must serve the needs of a wide range of users, and should fit seamlessly and effectively into the information-technology strategy and decision-making culture of the organization. In this chapter we examine the users of GIS and their needs; GIS education; how to justify investment in GIS; how to select and implement a system, and the organizational changes that may result.

Chapter 12: GIS project design and management

How do we understand a problem for which a GIS solution is being sought? Two methods are introduced in this chapter: constructing a rich picture and a root definition. The method for constructing a GIS data model is then discussed. Here a distinction is made between the conceptual data model and its physical implementation in the computer. A closer look at the various project management approaches and techniques and tools available for the implementation of a GIS project follow. Potential implementation problems, tools for managing risk and tips for project evaluation are also considered. To conclude, a checklist is provided to help with the design and implementation of your own GIS project. A case study is used to illustrate the approach throughout the chapter.

Chapter 13: The future of GIS

Who knows what the future for GIS will hold? So much has happened since the first edition of this book was published in 1998 and we revisit some of our earlier predictions for GIS in this chapter. Some of the challenges which remain for data, for technology and for applications are also considered. We provide some 'stories from the future' to stimulate your own thoughts on what the future for GIS might be, and invite you to contribute your own ideas via the website for the book.

IN SUMMARY

We hope that after you have read this book, you will have the knowledge and enthusiasm to start applying GIS in the context of your own course, discipline or organization. Whilst the text will not have taught you how to drive a specific GIS product, we hope that it will give you an appreciation of the concepts on which GIS are based, the methods they use and the applications to which they can be put. In addition, the book should give you an appreciation of some of the difficulties and considerations associated with setting up any GIS project. We hope you enjoy the book!

Note

In common with Bonham-Carter (1995) we have found it convenient to use the abbreviation GIS in a number of ways:

- to refer to a single system (e.g. a GIS software package that illustrates this is...)
- to refer to several or all geographical information systems (e.g. there are many GIS that...)
- to refer to the field of geographical information systems (e.g. GIS has a long history), and
- to refer to the technology (e.g. the GIS answer would be...).

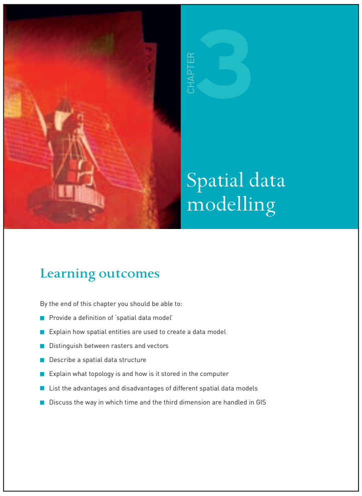
Trade marks

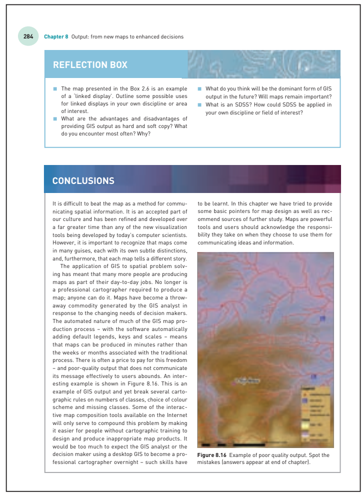
Mention of commercial products does not constitute an endorsement, or, indeed, a refutation of these products. The products are simply referred to as illustrations of different approaches or concepts, and to help the reader relate to the practical world of GIS.

Ian Heywood, Sarah Cornelius and Steve Carver

Guided tour

Navigation and setting the scene





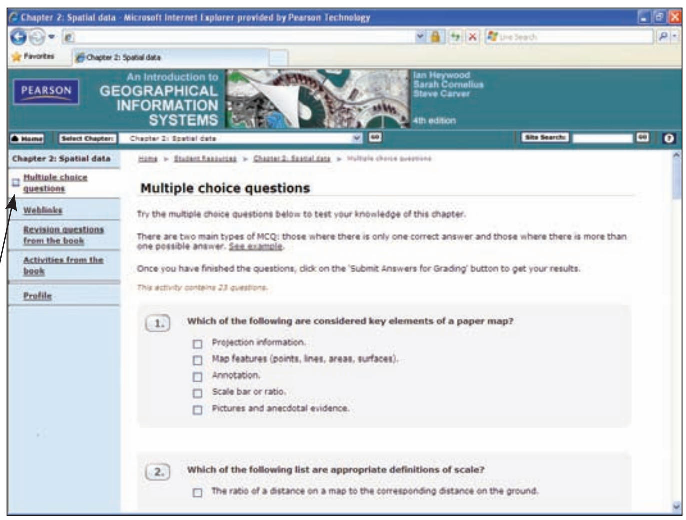
Learning outcomes show what you'll gain from reading the chapter.

Introduction maps out the principal themes and content for the chapter.

Conclusions recall and highlight the key issues.

Reflection, testing and practice

Reflection box encourages you to ponder key issues or think further.

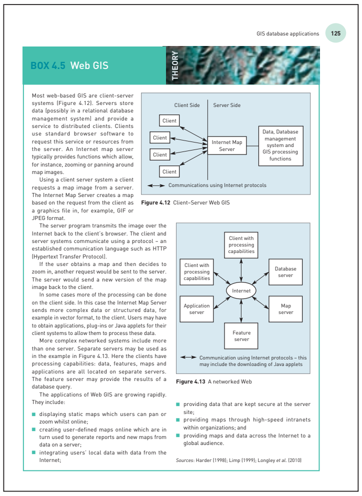


End of chapter revision questions help revisit and test the main themes.

Datasets on the website linked to the Happy Valley case study provide an opportunity for practice and application using simulated data.

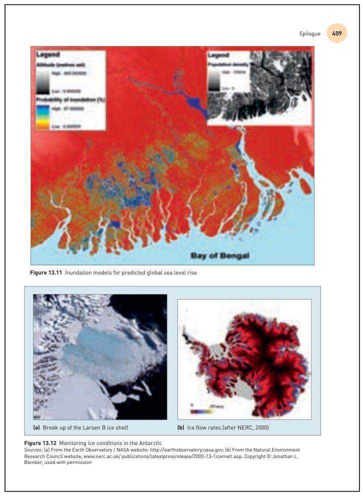
Multiple choice questions on the website permit self-testing of basic understanding and help to build confidence.

Aiding your understanding

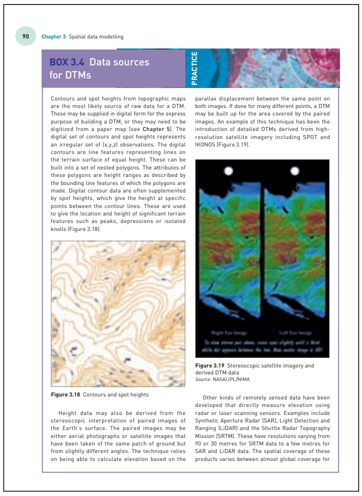


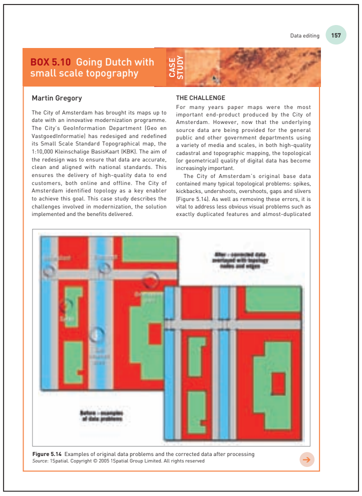
Theory boxes help explain the thinking or technology behind a topic, issue or practice.

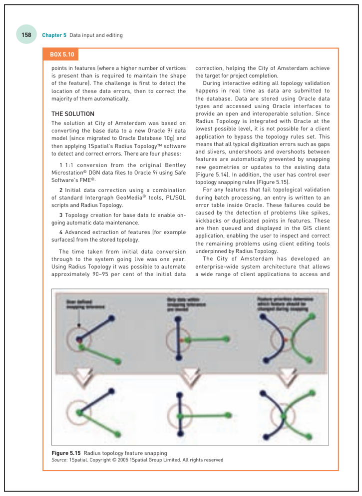
Visual presentation of material shows GIS at work in exciting ways and helps demonstrate GIS in action.



Applying GIS in the real world



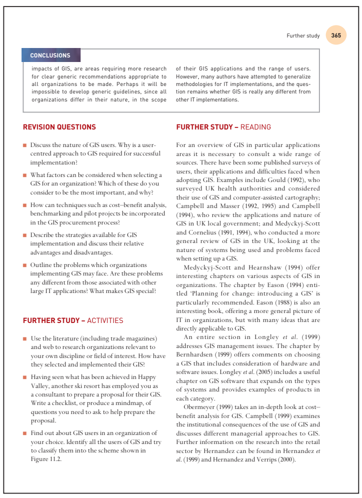




Practice boxes give detailed examples of GIS being used in the real world.

Multi-disciplinary case studies show how GIS principles and technology are used in multiple ways, by different people, and across a range of industries.

Further study



End of chapter activities and revision questions for self-study or discussion encourage the application and practice of knowledge and research beyond the textbook.

Reading and Web Links help you investigate key topics of further interest.

Case studies

Case study		Location								Sector										
		Any	UK	Europe	Africa	Asia	Remote areas	Australia	North America	Tourism	Environmental planning	Commercial planning	Transport planning	Planning	Social/public sector	Business	Hazard assessment	Local government	Environmental Mgmt.	Urban planning
1.1	Questions GIS could answer in Happy Valley *Steve Carver, University of Leeds and Sarah Cornelius, University of Aberdeen*	✗								✓										
1.2	Issues raised by the nuclear waste case study *Steve Carver, University of Leeds and Sarah Cornelius, University of Aberdeen*	✗									✓									
1.3	Issues raised by the Zdarske Vrchy case study *Steve Carver, University of Leeds and Sarah Cornelius, University of Aberdeen*			✗							✓									
1.4	Issues raised by the house-hunting case study *Steve Carver, University of Leeds and Sarah Cornelius, University of Aberdeen*	✗										✓								
2.6	Integrating data with GIS: • Mapping the UK's railways, *Peter Robson*, *Network Rail* • Solving crime in Salford City, *Paul Coward*, *Salford GIS Ltd*		✗										✓							
2.8	High-resolution data solutions to complex modelling problems *Stuart Lane, Durham University and Joe Holden, Leeds University*	✗																	✓	
3.8	Monitoring coastal change with GIS *Jonathan Raper, City University, London*	✗																	✓	
4.4	Encroachments on public land in Accra, Ghana *Isaac Bonsu Karikari, Millennium Development Authority, Ghana*				✗									✓						
4.6	Delivering census interaction data: WICID *John Stillwell, University of Leeds*		✗												✓					
5.2	Business process outsourcing and the Indian GIS industry *Ankur Das, India*					✗										✓				
5.4	OpenStreetMap *Tim Waters, Geospacial consultant, Leeds*		✗																	
5.5	Terrestial laser scanning *Jeff Warburton, University of Durham*	✗																		
5.6	Fireguard: Using GIS and remote sensing for fire management *Jim Hogg, University of Leeds*			✗													✓			
5.10	Going Dutch with small scale topography *Martin Gregory, 1Spatial*			✗														✓		
5.11	Ordnance Survey (OS) data collection – from plan to MasterMap *Paul Corcoran, Ordnance Survey*		✗												✓					
5.12	An integrated GIS for Happy Valley *Steve Carver, University of Leeds and Sarah Cornelius, University of Aberdeen*	✗								✓										
6.1	Data analysis in Happy Valley *Steve Carver, University of Leeds and Sarah Cornelius, University of Aberdeen*	✗								✓										
6.3	Modelling remoteness in mountain areas *Steve Carver and Steffen Fritz, University of Leeds*						✗				✓									
6.5	Siting a nuclear waste repository *Steve Carver, University of Leeds and Sarah Cornelius, University of Aberdeen*	✗								✓										
6.6	Raster analysis of the nuclear waste siting example *Steve Carver, University of Leeds and Sarah Cornelius, University of Aberdeen*	✗									✓									

Case study		Location: Any	UK	Europe	Africa	Asia	Remote areas	Australia	North America	Sector: Tourism	Environmental	Environmental planning	Commercial planning	Transport planning	Planning	Social/public sector	Business	Hazard assessment	Local government	Environmental Mgmt.	Urban planning
6.9	Identifying mountains with GIS *Jo Wood, City University, London*	✗									✓										
6.10	Wind farm visibility in Cape Bridgewater, Australia *Ian Bishop, University of Melbourne*							✗				✓									
7.1	The development of a snow cover model for Happy Valley *Steve Carver, University of Leeds and Sarah Cornelius, University of Aberdeen*	✗								✓											
7.3	Using GIS to help manage air quality through estimating emissions of atmospheric pollutants *Sarah Lindley, University of Manchester*		✗																	✓	
7.5	GIS-enabled retail sales forecasting *Tony Hernandez, Ryerson University*								✗								✓				
7.8	Fuzzy GIS and the fear of crime *Andrew Evans, University of Leeds*		✗													✓					
8.2	Retail geovisualization: 3D and animation for retail decision support *Tony Hernandez, Ryerson University*	✗															✓				
8.4	Virtual London *Michael Batty, University College London*		✗																		✓
8.5	Happy Valley Internet GIS *Steve Carver, University of Leeds and Sarah Cornelius, University of Aberdeen*	✗								✓											
8.7	Public participation GIS *Richard Kingston, University of Manchester*		✗												✓						
8.8	MapAction: a personal view *Chris Ewing, MapAction*	✗															✓				
9.1	Developments in computer cartography *Steve Carver, University of Leeds and Sarah Cornelius, University of Aberdeen*	✗																			
9.2	CGIS: an early GIS *Steve Carver, University of Leeds and Sarah Cornelius, University of Aberdeen*								✗												
9.4	CORINE: an international multi-agency GIS project *Steve Carver, University of Leeds and Sarah Cornelius, University of Aberdeen*			✗																	
10.7	Viewshed analysis in archaelogy *Graham McElearney, University of Sheffield*	✗									✓										
10.8	Uncertainty and terrain data in ice-sheet modelling *Ross Purves and Felix Hebeler, University of Zurich*								✗		✓										
10.10	Errors in the nuclear waste case study *Steve Carver, University of Leeds and Sarah Cornelius, University of Aberdeen*	✗																			
11.6	A problematic implementation *Steve Carver, University of Leeds and Sarah Cornelius, University of Aberdeen*		✗																		
13.3	The Culloden Battlefield Guide *Steve Bone, Consultant*		✗																		

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During the production of four editions of this book many, many people have helped with support, advice and ideas both directly and indirectly. We have taken the opportunity here to thank some of those who have helped, but we recognize that we have omitted many others who deserve appreciation.

For help with the text of the first edition we should thank Steve Wise and an anonymous reviewer who made constructive comments on early drafts. Tony Hernandez, Chris Higgins, Derek Reeve, David Medyckyj-Scott and Tony Heywood are also thanked for reading drafts of various sections. Help with the diagrams, plates and cartoons and word processing came from Gustav Dobrinski, Bruce Carlisle, Simon Kenton and Tracey McKenna.

All of the case studies used in the book are the result of the work of teams of researchers and academics. Stan Openshaw and Martin Charlton were involved with the original radioactive waste siting study. Jim Petch, Eva Pauknerova, Ian Downey, Mike Beswick and Christine Warr worked on the Zdarske Vrchy study. The initial ideas for the House Hunting game came from a team that included James Oliver and Steve Tomlinson. This last case study was made available by the GeographyCAL initiative based at the University of Leicester following additional input and support from Roy Alexander, John McKewan and John Castleford. In particular, we would like to thank the many people who have given their time freely to write and update the case studies you see in this fourth edition. These people – friends, colleagues, associates and students who have worked with us on GIS projects – have allowed us to pass on the richness and variety of GIS applications across the globe. They are all introduced in the author bibliographies.

Many other individuals have supported our work on this book – Helen Carver, Thomas Blaschke and Manuela Bruckler deserve special mention. In addition, the Universities of Leeds, Aberdeen and Salzburg, the Manchester Metropolitan University and the Vrije Universiteit Amsterdam have allowed us to use their resources to help compile the materials.

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Ian Heywood, Sarah Cornelius and Steve Carver

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Abbreviations and acronyms

1:1	One-to-one relationship
1:M	One-to-many relationship
2.5D	Two-and-a-half-dimensional
2D	Two-dimensional
3D	Three-dimensional
4D	Four-dimensional
AGI	Association for Geographical Information (UK)
AI	Artificial Intelligence
AM/FM	Automated Mapping/Facilities Management
BGS	British Geological Survey
BS	British Standard
BSU	Basic Spatial Unit
CAD	Computer-aided Design
CAL	Computer-aided Learning
CASE	Computer-assisted Software Engineering
CCTV	Closed-circuit Television
CD-ROM	Compact Disc – Read Only Memory
CEN	Comité Européen de Normalisation (European Standards Commission)
CGIS	Canadian Geographic Information System
CORINE	Coordinated Information on the European Environment
CoRWM	Committee on Radioactive Waste Management
CRT	Cathode Ray Tube
CUS	Census Use Study (USA)
DBMS	Database Management System
DEM	Digital Elevation Model
DIGEST	Digital Geographic Information Exchange Standards
DNF	Digital National Framework
DoE	Department of the Environment (UK)
DOS	Disk Operating System
dpi	Dots Per Inch
DSS	Decision Support System
DTM	Digital Terrain Model
DXF	Data Exchange Format
EAM	Entity Attribute Modelling
ED	Enumeration District (UK)
EDA	Exploratory Data Analysis
EDM	Electronic Distance Metering
ESMI	European Spatial Meta-information system
ESRC	Economic and Social Research Council (UK)
ESRI	Environmental Systems Research Institute
ETHICS	Effective Technical and Human Implementation of Computer-based Systems
EUROGI	European Umbrella Organization for Geographical Information
GAM	Geographical Analysis Machine
GBF-DIME	Geographical Base File, Dual Independent Map Encoding
GDF	Geographic Data File
GeoTIFF	Geographic Tagged Image Format File
GIS	Geographical Information System
GISc	Geographic Information Science
GLONASS	Global Orbiting Navigation Satellite System
GML	Geography Markup Language
GPS	Global Positioning Systems
GUI	Graphical User Interface
HTTP	Hypertext Transfer Protocol
IAEA	International Atomic Energy Authority
ID	Identifier
IS	Information System
ISO	International Standards Organization
IT	Information Technology
LAN	Local Area Network
LBS	Location-based Services
LCD	Liquid Crystal Display
LiDAR	Light Detection and Ranging
M:N	Many-to-many relationship
MAUP	Modifiable Areal Unit Problem
MCE	Multi-criteria Evaluation
MEGRIN	Multipurpose European Ground Related Information Network
MSS	Multispectral Scanner
NAVSTAR	Navigation System with Time and Ranging
NCDCDS	National Commitee on Digital Cartographic Data Standards (USA)

NCGIA	National Center for Geographic Information and Analysis (USA)
NDA	Nuclear Decommissioning Authority (UK)
NERC	Natural Environmental Research Council (UK)
NGO	Non-governmental Organization
NII	Nuclear Installations Inspectorate (UK)
NIMBY	Not In My Back Yard
NIREX	Nuclear Industry Radioactive Waste Executive (UK)
NGDC	National Geospatial Data Clearinghouse
NJUG	National Joint Utilities Group (UK)
NTF	National Transfer Format (UK)
NTF	Neutral Transfer Format (UK)
NTS	National Trust fo Scotland
NWW	North West Water plc
OA	Output Area (UK Census of Population)
OCR	Optical Character Recognition
OGC	Open GIS Consortium
OGIS	Open Geodata Interoperability Standards
OO	Object-oriented
OS	Ordnance Survey (UK)
OSM	Open Street Map
OSOCC	On-site Operations Co-ordination Centre
PC	Personal Computer
PDA	Personal Data Assistant
PDF	Portable Document Format
PNG	Portable Network Graphics
PERT	Program Evaluation and Review Technique
PHP	Hypertext Preprocessor
PLSS	Public Land Survey System (USA)
PPGIS	Public Participation GIS
PRINCE2	Projects IN Controlled Environments
RAD	Rapid Application Development
REGIS	Regional Geographic Information Systems Project (Australia)
RINEX	Receiver Independent Exchange Format
RRL	Regional Research Laboratory (UK)
SDLC	Systems Development Life Cycle
SDSS	Spatial Decision Support System
SDTS	Spatial Data Transfer Standard
SLC	System Life Cycle
SPOT	Système pour l'Observation de la Terre
SQL	Standard Query Language (or Structured Query Language)
SSA	Soft Systems Analysis
SSADM	Structured Systems Analysis and Design
SWOT	Strengths, Weaknesses, Opportunities, Threats
TCP/IP	Transmission Control Protocol/ Internet Protocol
TIGER	Topologically Integrated Geographic Encoding Reference File (USA)
TIN	Triangulated Irregular Network
TLS	Terrestrial Laser Scanner
TM	Thematic Mapper
TV	Television
URL	Uniform Resource Locator
UK	United Kingdom
UN	United Nations
UNDAC	United Nations Disaster Assessment Team
URISA	Urban and Regional Information Systems Association (USA)
USA	United States of America
UTM	Univeral Transverse Mercator
VIP	Very Important Point
VR	Virtual Reality
VRML	Virtual Reality Modelling Language
WALTER	Terrestrial Database for Wales
WAP	Wireless Application Protocol
WAAS	Wide Area Augmentation System
WWW	World Wide Web
XML	Extensible Markup Language
ZVI	Zone of Visual Influence

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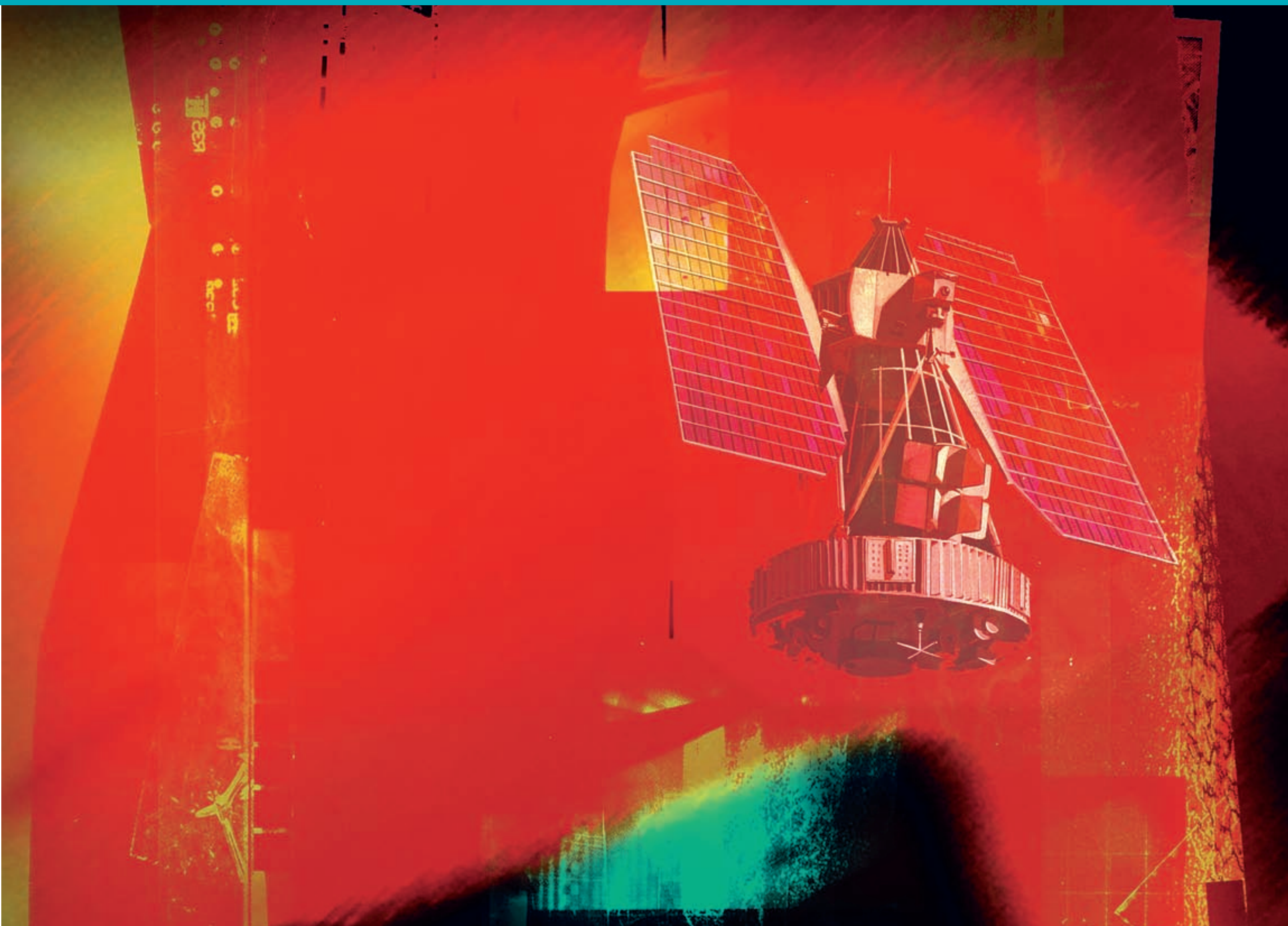
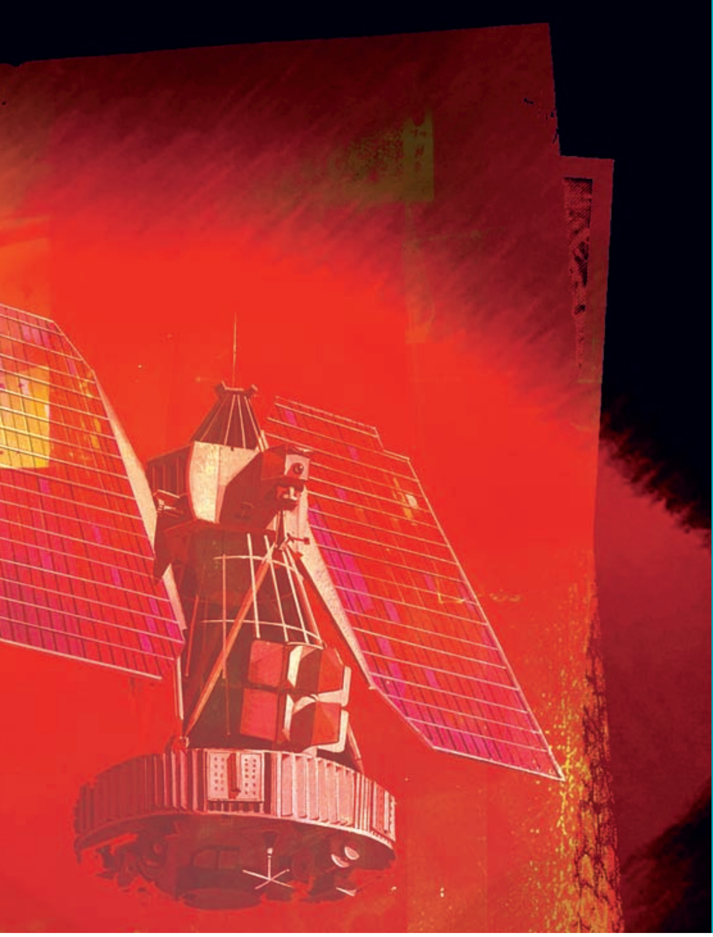
PART 1

Fundamentals of GIS





CHAPTER 1

What is GIS?

Learning outcomes

By the end of this chapter you should be able to:

- Explain what GIS is
- Give examples of the applications of GIS
- Outline the characteristics of GIS
- Describe how the real world is represented in GIS
- Provide examples of the analysis GIS can perform
- Know where to find more information about GIS

INTRODUCTION

Every day you ask questions with a spatial component. Whether you are at work, studying or at leisure you probably ask spatial questions. Many of these questions you answer for yourself without reference to a map or a GIS, but both of these tools could help. GIS has particular value when you need to answer questions about location, patterns, trends and conditions such as those below:

- *Location*. Where is the nearest bookshop? Where are stone age settlements located in Europe? Where are areas of forestry in which Norwegian Spruce trees can be found?
- *Patterns*. Where do high concentrations of students live in this city? What is the flow of traffic along this motorway? What is the distribution of crime incidents in London?
- *Trends*. How are patterns of retailing changing in response to the development of out-of-town superstores? Where have glaciers retreated in the European Alps? Where have changes to the population of polar bears occurred?
- *Conditions*. Where can I find holiday accommodation that is within 1 km of a wind surfing beach and accessible by public transport? Where is there flat land within 500 m of a major highway? Where are there over 100,000 potential customers within a 5-mile radius of a railway station?
- *Implications*. If I move to a new home in this location, how far will I be from the office, gym or coffee shop? If we build a new theme park here, what will be the effect on traffic flows? What would be the time saving if we delivered our parcels using this route, rather than an alternative?

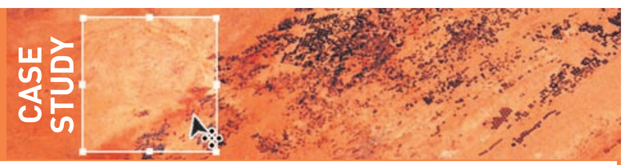
This chapter provides an overview of GIS. It examines what GIS is, what it can do and, in brief, how it works. We begin with a look at the types of generic questions GIS can answer and expand on these with reference to case studies. GIS is then defined, and a range of issues and ideas associated with its use identified. Much of the material introduced in this chapter will be covered in more detail later in the book, and pointers to the appropriate sections are provided. If we return to the car analogy introduced in the Preface, this is where you find out what exactly a car is, why it is useful and what you need to know to make it work.

The generic questions that a GIS can help to answer can be summarized as:

- Where are particular features found?
- What geographical patterns exist?
- Where have changes occurred over a given period?
- Where do certain conditions apply?
- What will the spatial implications be if an organization takes certain action?

Box 1.1 provides examples of problems that can be addressed by asking these types of questions in an imaginary ski resort called Happy Valley.

BOX 1.1 Questions GIS could answer in Happy Valley



The Happy Valley GIS has been established to help the ski resort's managers improve the quality of the ski experience for visitors. The examples below are only a few of the situations in which asking a spatial question can help with the management of Happy Valley. You will find many other examples throughout the rest of this book.

1 *Where are particular features found?* When skiers visit Happy Valley they need to know where all the visitor facilities are located. To help, the Happy Valley GIS is used to produce maps of the ski area. Visitors can also ask direct questions about the location of facilities using 'touch screen' computerized information points located in shops and cafes throughout the ski resort. These information points provide skiers with a customized map showing them how to find the facilities they require.

2 *What geographical patterns exist?* Over the last few ski seasons there have been a number of accidents involving skiers. All these incidents

BOX 1.1

have been located and entered into the GIS. The Happy Valley management team is trying to establish whether there is any common theme or spatial pattern to the accidents. Do accidents of a certain type occur only on specific ski pistes, at certain points on a ski piste such as the lift stations, or at particular times of day? So far one accident black spot has been identified where an advanced ski run cuts across a slope used by beginners, just below a mountain restaurant.

Figure 1.1 Facilities in Happy Valley ski resort

3 *Where have changes occurred over a given time period?* In Happy Valley avalanches present a danger to skiers who wish to venture off the groomed ski pistes. The management team and the ski patrol use the GIS to build up a picture of snow cover throughout the area. This is done by regularly recording snow depth, surface temperature, snow water content and snow strength at a number of locations. A study of the geographical changes in these parameters helps the management team prepare avalanche forecasts for different locations in Happy Valley.

4 *Where do certain conditions apply?* Every day, during the winter season, the Happy Valley management team provides information on which ski pistes are open. Since this depends on the snow cover, avalanche danger and wind strength, data on these factors are regularly added to the GIS from reports provided by the ski patrols and local weather service. The warden can use this information and the GIS to help identify which runs should be opened or closed.

5 *What will the spatial implications be if an organization takes certain action?* The access road to Happy Valley is now too narrow for the number of skiers visiting the area. A plan is being prepared for widening the road. However, any road-widening scheme will have impacts on a local nature reserve as well as surrounding farm land. The Happy Valley GIS is being used to establish the amount of land that is likely to be affected under different road-widening schemes.

Datasets and activities relating to the Happy Valley Case Study can be found online at **www.pearsoned.co.uk/heywood**

Figure 1.2 Avalanche!
Source: Richard Armstrong

If you have a geographical background you may be asking what is new about these generic questions. Are these not the questions that geographers have been contemplating and answering for centuries? In part they are, though in many cases geographers and others using spatial data have been unable to find answers to their questions because of the volume of data required and a lack of time and techniques available to process these data. The following examples of GIS applications are used to illustrate the capabilities of GIS as a tool for geographical analysis. All involve the manipulation of data in ways that would be difficult or impossible by hand, and each illustrates different issues associated with the application of GIS.

Searching for sites

Searching for the optimum location to put something is a task performed by individuals and organizations on a regular basis. The task may be to find a site for a new retail outlet, a new oil terminal or a new airport. Sometimes the task is more demanding than others, involving searches through large numbers of maps and related documents.

Radioactive waste is waste material that contains levels of ionizing radiation considered harmful to health. It is produced by the nuclear industry, nuclear power generation, weapons manufacture, medical and research establishments (Figure 1.3). Radioactive waste is categorized according to the level of radiation emitted and the length of time for which it will be radioactive. Careful management is required, and ultimately governments and the nuclear industry have to find appropriate disposal options. Over the last 20 years finding a suitable site for the disposal of radioactive waste in the UK has become a sensitive and important issue. The Nuclear Decommissioning Authority (NDA, formerly known as NIREX – the Nuclear Industry Radioactive Waste Executive) is the UK organization with responsibility

(a) (b) (c) (d)

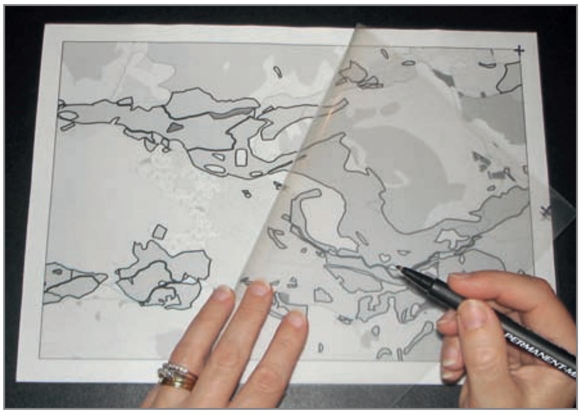
Figure 1.3 A nuclear power station (a) and nuclear waste containers (b, c and d)
Sources: (a) Courtesy of author; (b) Jeff T. Green Getty Images; (c,d) British Nuclear Fuels Ltd

Figure 1.4 Anti-nuclear protestors
Source: Stefan Rousseau/Press Association Images

for the identification of suitable radioactive waste disposal sites. Advice on what to do with the UK's radioactive waste is provided by the Committee on Radioactive Waste Management (CoRWM). The NDA has the task of interpreting current government radioactive waste policy and siting guidelines and presenting possible sites at public inquiries. One of the problems for NDA is the lack of comprehensive and coherent guidelines for the identification of suitable sites. Another is that radioactive waste is a strong political issue because nobody wants a disposal facility in their neighbourhood and protests against potential sites are common (Figure 1.4). However, NDA is expected to show that it has followed a rational procedure for site identification (Department of the Environment, 1985). Hydrology, population distribution and accessibility are examples of important siting factors, but how such factors should be interpreted is left up to NDA. Where, therefore, should NDA site a nuclear waste repository?

NIREX (the NDA's predecessor) used a pen-and-paper approach to sieve through large numbers of paper maps containing data about geology, land use, land ownership, protected areas, population and other relevant factors. Areas of interest were traced from these maps by hand, then the tracings were overlaid to identify areas where conditions overlapped. NIREX is not the only organization that has searched for sites using these techniques. This was a standard approach employed in the siting of a wide range of activities including shopping centres, roads and offices (Figure 1.5). The method is time-consuming and means that it is impossible to perform the analysis for more than a few different siting criteria. The best sites are often missed. GIS techniques offer an alternative approach, allowing quick remodelling for slight changes in siting criteria, and produce results as maps eminently suitable for presentation at public inquiries.

Openshaw *et al.* (1989) first demonstrated the use of GIS for nuclear waste repository siting, and their method is summarized in Figure 1.6. They established a number of data layers, each containing data for a separate siting criterion (for example, geology, transport networks, nature conservation areas and population statistics). These were converted from paper to digital format by digitizing (this technique is explained in **Chapter 5**), or acquired from existing digital sources such as the UK Census of Population. These data layers were then processed so that they represented specific siting criteria. The geology layer was refined so that only those areas with suitable geology remained; the transport layer altered so that only those areas close to major routes were identified; and the nature conservation layer processed to show protected areas where no development is permitted. The population layer was analysed so that areas with high population densities were removed. The four data layers are shown in Figure 1.7.



(a) Step one

(b) Step two

(c) Step three

Figure 1.5 Tracing paper overlay

GIS software was then used to combine these new data layers with additional layers of information representing other siting criteria. The final result was a map showing the locations where all the specified siting criteria were satisfied and, thus, a number of locations suitable for the siting of a nuclear waste repository. The advantage of using the GIS to perform this task was that the siting criteria could be altered and the procedure repeated with relative ease. Examples for several siting scenarios are shown in Figure 1.8. These illustrate how changes in siting criteria influence the geographical distribution of potential sites.

This example shows how a GIS approach allows comparative re-evaluation and testing of data and conditions. In this way the decision maker can evaluate options in a detailed and scientific manner. The work of Openshaw *et al*. (1989) also illustrates three other important issues associated with the use of GIS: the problem of errors in spatial data sets; the difficulty in establishing criteria for abstract spatial concepts; and the potential value of using GIS to communicate ideas (Box 1.2).

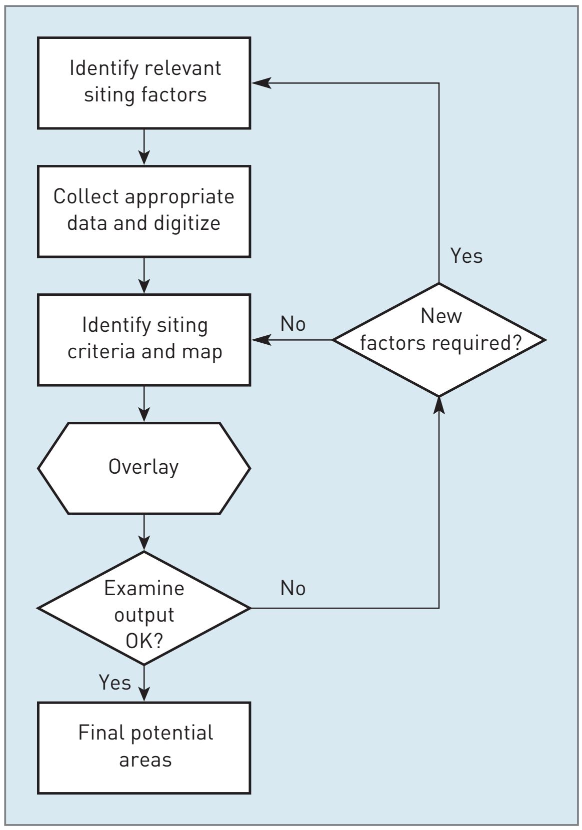
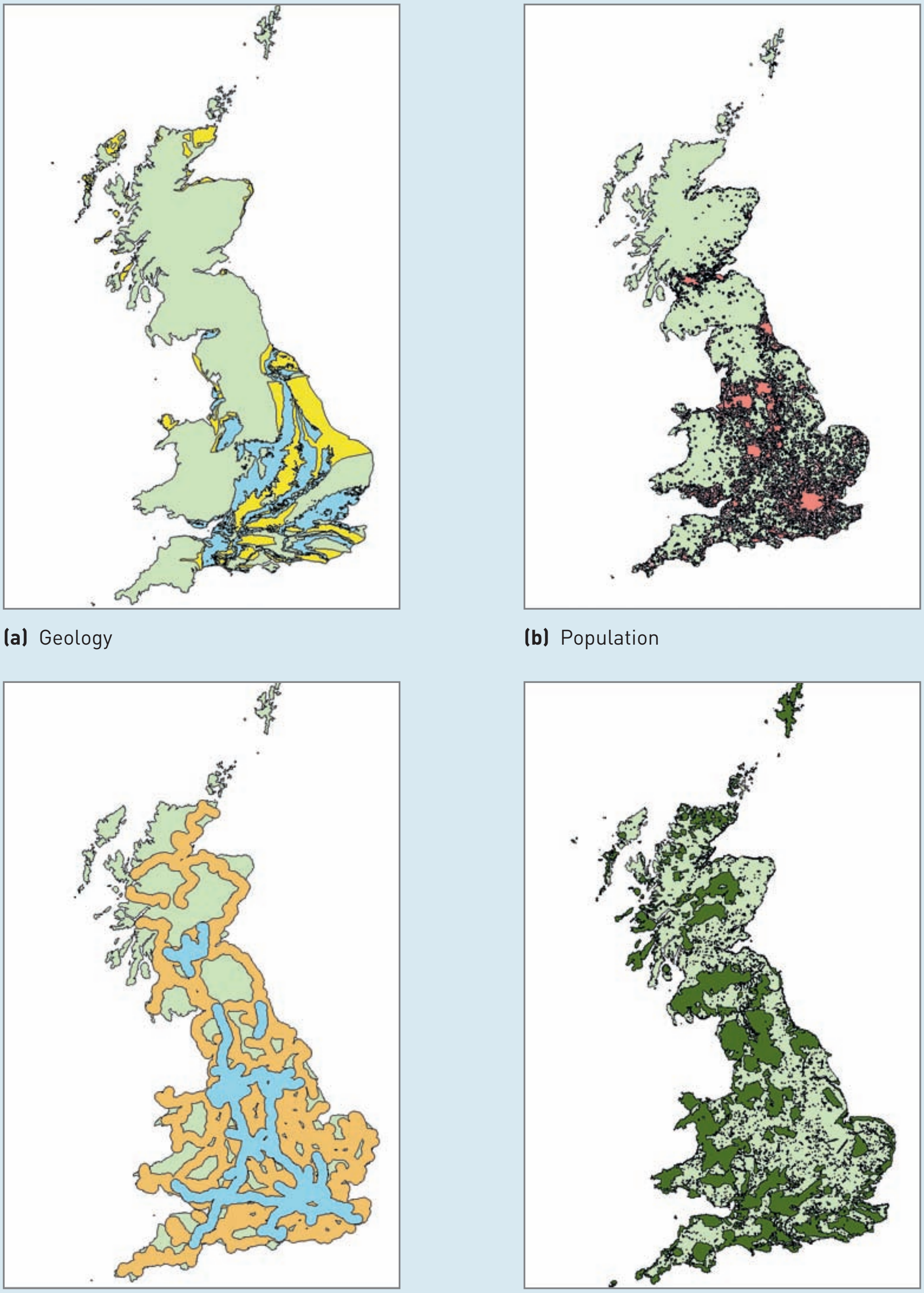


Figure 1.6 Using GIS for siting a NDA waste site
Source: Adapted from Openshaw *et al*. (1989)



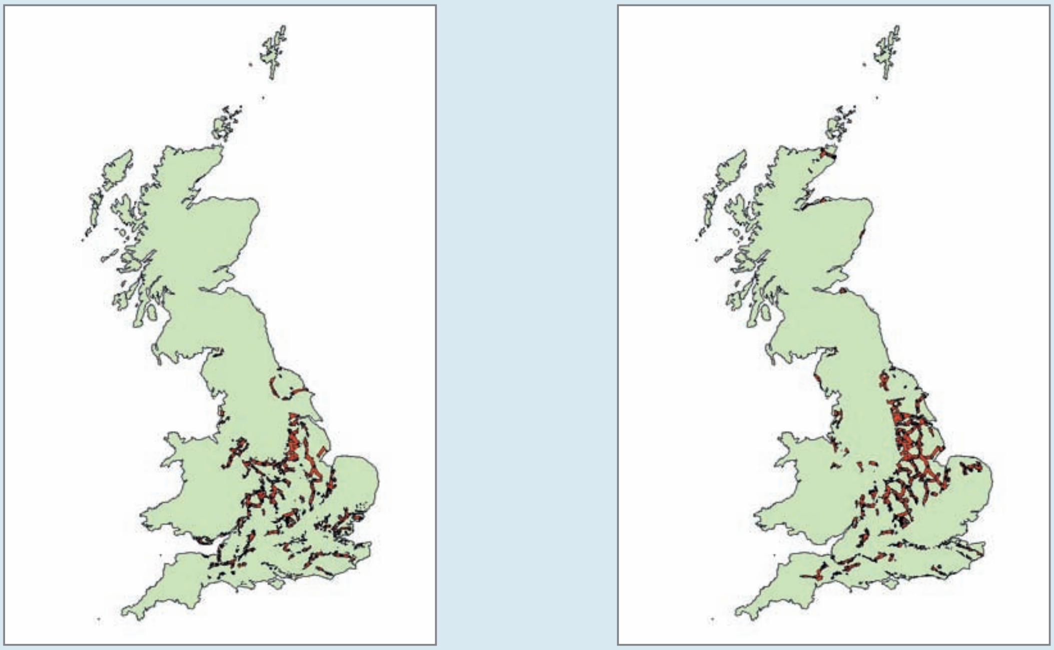
(a) Geology

(b) Population

(c) Transport

(d) Conservation criterion

Figure 1.7 Radioactive waste case study: geology, population, transport and conservation criteria maps;
Sources: (a) British Geological Survey. © NERC, IPR/71-39C reproduced by permission; (b) Office for National Statistics; (c) Ordnance Survey; (d) Joint Nature Conservation Committee, www.jncc.gov.uk

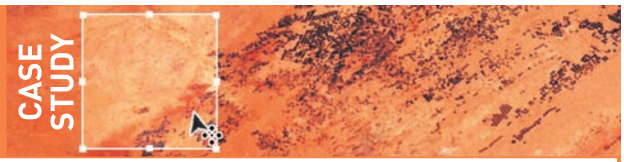


(a) Near-surface disposal in surface clay geology

(b) Deep disposal in suitable deep geology

Figure 1.8 Radioactive waste case study (a and b): results from different siting scenarios

BOX 1.2 Issues raised by the nuclear waste case study



- *Errors in source data*, such as those introduced during the conversion of data to digital form, may have a significant effect on the GIS site-searching process. Mistakes in capturing areas of appropriate geology from paper maps may lead to inappropriate waste repository sites being identified, because areas on the ground will have different geological properties from those recorded in the GIS. Errors in spatial data sets and the associated issues of data quality are discussed in detail in **Chapter 10**.
- The GIS site-searching process relies on the translation of *abstract* (or '*fuzzy*') concepts such as 'near to' and 'far from' into precise conditions that can be mapped. This can be a problem. How do you create a map that shows all the geographical zones 'far from' a centre of population? The only method is to make an arbitrary decision about what sort of distance (for example, 10, 20 or 30 km) 'far from' represents. In some cases rules may be applied to guide this process, but in others the numerical representation of a criterion may depend upon the preferences of the person responsible for choosing and implementing the criterion.
- *GIS output* can be used to inform public participation in the decision-making process. A series of maps could be used to illustrate why a particular geographical location has been identified as a suitable site for the disposal of radioactive waste. However, the issues raised above – data quality and the problems of creating spatial criteria for abstract concepts – suggest that output from GIS should be viewed with caution. Just because a map is computer-generated does not mean that the picture it presents is correct. More on this issue can be found in **Chapter 8**.

Evaluating land use planning

Virtually every country in the world has areas of natural beauty and conservation value that are managed and protected in the public interest. Those managing these areas face the problem of balancing human activities (such as farming, industry and tourism) with the natural elements of the landscape (such as climate, flora and fauna) in order to maintain the special landscape character without exploitation or stagnation.

The protected area of Zdarske Vrchy, in the Bohemian–Moravian highlands of the Czech Republic (Figure 1.9), is an example of an area that has suffered as a result of ill-considered state control. Unregulated farming, tourism and industrial activities have placed the landscape under severe pressure. Czech scientists and environmental managers have relied on traditional mapping and statistical techniques to monitor, evaluate and predict the consequences of this exploitation. However, with change in the political administration of the country came scientists and managers who were looking not only into a policy of sustainable development for Zdarske Vrchy, but also at GIS as a tool to help with policy formulation (Petch *et al.*, 1995).

GIS is seen as a tool to bring together disparate data and information about the character and activities that take place in the Zdarske Vrchy region. Data from maps, aerial photographs, satellite images, ecological field projects, pollution monitoring programmes, socio-economic surveys and tourism studies have been mapped and overlaid to identify areas of compatibility and conflict.

Figure 1.9 Zdarske Vrchy

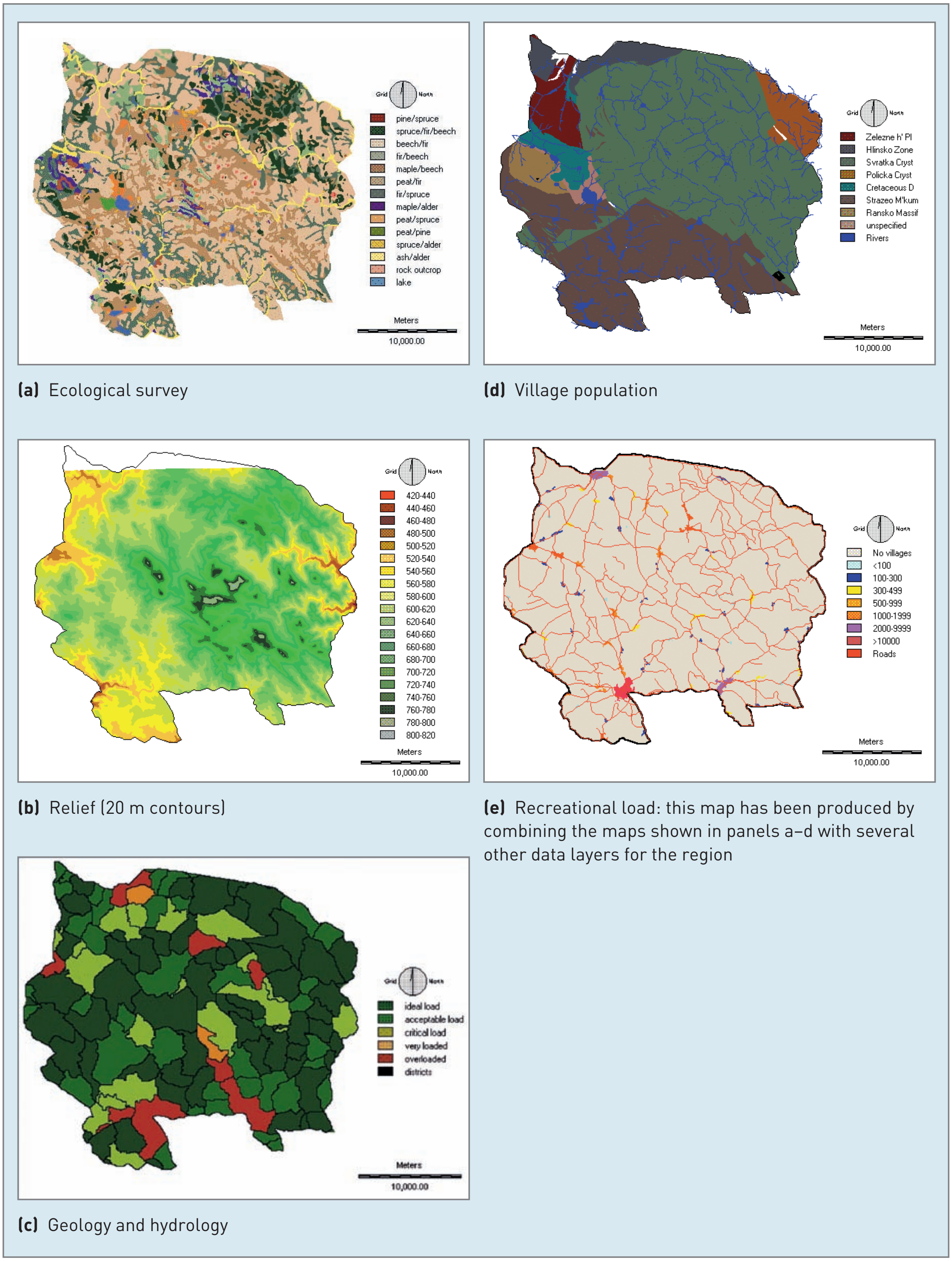
In this context GIS permits scientists and managers in Zdarske Vrchy to interact with their data and ask questions such as:

- What will be the long-term consequences of continuing recreational activity for the landscape? (Figure 1.10)
- Where will damage from acid rain occur if a particular industrial plant continues to operate?
- Where is the best location for the re-introduction of certain bird species?
- Where should landscape conservation zones be established?

(after Downey *et al.*, 1991, Downey *et al.*, 1992 and Petch *et al.*, 1995).

One application of GIS in Zdarske Vrchy has been to identify areas of the landscape for conservation. Traditionally, water storage in the region has relied on the use of natural water reservoirs such as peat wetlands and old river meanders (Petch *et al.*, 1995). Current land-use practices, in particular forestry and farming, are resulting in the gradual disappearance of these features. The consequences of these changes have been localized droughts and floods in areas further downstream. In turn, these changes have brought about a reduction in plant species and wildlife habitats. Managers in the Zdarske Vrchy region wanted to identify conservation zones to protect the remaining natural water reservoirs as well as to identify those areas where it may be possible to restore the water retention character of the landscape. To do this, they needed to establish the characteristics of the landscape that determine whether or not a particular location is likely to retain water. Specialists in hydrology, geology and ecology were consulted to identify a range of important criteria describing:

- the type of soil and its water retention ability;
- the character of the topography (for example, presence or absence of hollows or hills);
- the type of land use, as certain agricultural practices exploit the water retention capacity of the landscape; and
- the presence or absence of human-enhanced water drainage channels.



(a) Ecological survey

(d) Village population

(b) Relief (20 m contours)

(e) Recreational load: this map has been produced by combining the maps shown in panels a–d with several other data layers for the region

(c) Geology and hydrology

Figure 1.10 GIS landscape assessment data layers: Zdarske Vrchy

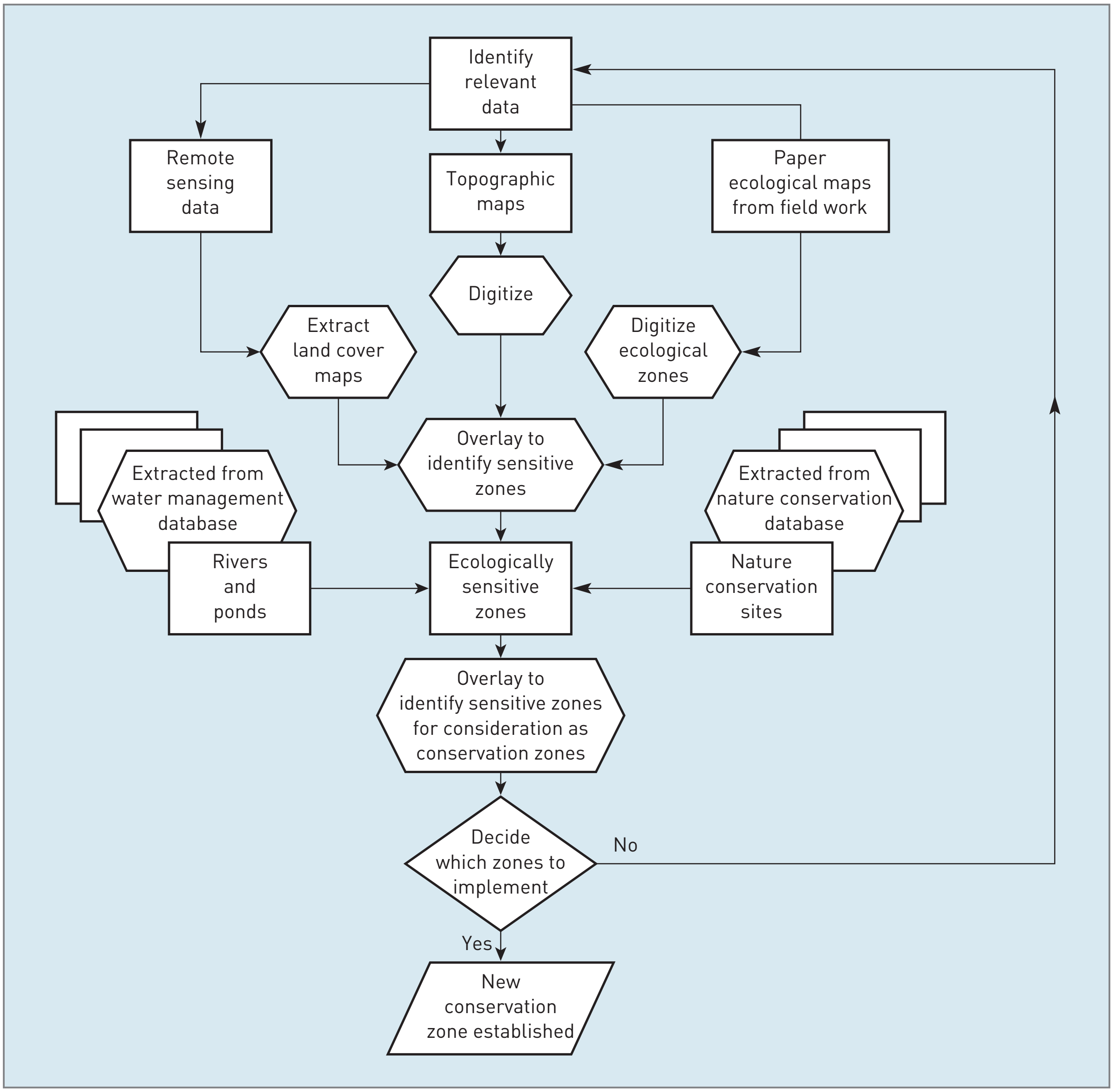


Figure 1.11 Using GIS for identifying conservation zones in Zdarske Vrchy
Source: Adapted from Petch *et al.* (1995)

GIS professionals were then asked to find appropriate sources of spatial data that could be used to represent these criteria. A range of sources was identified including:

- paper maps (for soil type and geology);
- contour maps (for topography);
- ecological field maps (for drainage conditions); and
- remote sensing (for land use).

These data were acquired and entered into the GIS. The hydrologists, ecologists and geologists were then asked how each of the criteria (land use, topography, soil type and drainage) might interact to influence the retention capacity of the landscape at a particular location. First, the scientists used the GIS to look at the relationship of the criteria they had identified in areas where natural water reservoirs were still in existence. This involved adding more data to the GIS about the location of existing water retention zones. These data came from the regional water authorities as paper maps. The relationship between the geographical distribution of the various landscape characteristics at these locations was then used to develop a model. This model allowed the managers of the Zdarske Vrchy region to predict which other areas could be restored as natural water reservoirs. The next stage was to check which of these areas were located in existing conservation zones, as it was easier to change existing conservation regulations than to set up new conservation areas. Figure 1.11 summarizes the method used and shows how the GIS was used to integrate data from a range of different sources. Figure 1.11 also shows how these data were overlain with additional data about existing water retention zones and existing conservation areas to identify potential new conservation sites.

The Zdarske Vrchy project shows how GIS can be used to bring together data from a wide variety of sources to help address a range of environmental management problems. This use of GIS is not unique to environmental planning in Eastern Europe and is being practised by environmental managers all over the world. In addition, the Zdarske Vrchy project reveals a number of other important issues associated with the use of GIS. These include the problem of data sources being in different map projections, the value of GIS as a modelling tool and the role for GIS as a participatory problem-solving tool (Box 1.3).

Finding a new home

At some stage in our lives, most of us will need to look for a new home. Perhaps because of a new job, or a change in family circumstances, our accommodation requirements will change and we will have to look for a new place to live. This can be a time-consuming and frustrating task. The requirements of individual family members need to be considered. Do they need to be close to schools, major roads or a railway station? Perhaps they would prefer to be in an area where insurance costs are lower. Maybe they want to be in an urban area to be close to shops and

BOX 1.3 Issues raised by the Zdarske Vrchy case study

- The greatest problem associated with bringing data together for the creation of the Zdarske Vrchy GIS was deciding which *map projection* to adopt as the common frame of reference. Several different projection systems were used by the source maps. A projection system is the method of transformation of data about the surface of the earth on to a flat piece of paper. Because many methods exist which can be used to perform this task, maps drawn for different purposes (and maybe even for the same purpose but at different points in time) may use different projection systems. This does not present any problems as long as the maps are used independently. However, when the user wishes to overlay the data in a GIS, the result can be confusing. Features that exist at the same location on the ground may appear to lie at different geographical positions when viewed on the computer screen. This problem became apparent in the Zdarske Vrchy project when the road network, present on two of the maps, was compared. Map projections are explained in more detail in **Chapter 2**.
- The Zdarske Vrchy case study also shows how GIS can be used to create models of environmental processes with maps used as the building blocks for the model. The topic of *modelling and GIS* is returned to in **Chapters 6 and 7**.
- Bringing people together to search for a solution to a common problem is often difficult. Different specialists will have different ideas about the problem. For example, an ecologist might recommend one approach, an engineer a second and an economist a third. The Zdarske Vrchy project showed how, through the use of GIS, the common medium of the map could be used as a tool to help experts from different backgrounds exchange ideas and compare possible solutions. The idea that GIS can be used as a *participatory problem-solving tool* has also received considerable attention from the GIS research community (Carver *et al.*, 1997) and often involves the use of web-based mapping tools. **Chapter 7** considers this topic in more detail.

their place of work. To find a new home acceptable to all the family a decision support system (software to help you make a decision) may be appropriate. GIS can act in this role.

Much of the data needed to help answer the questions posed above can be gathered and converted into a format for integration in GIS. Heywood *et al.* (1995) have successfully completed this exercise and created a house-hunting decision support system. To find a suitable home, participants were first required to decide which of a series of factors (insurance costs, proximity to schools, railways and roads, urban areas) were important in their decision making. These factors were allocated weights and scores reflecting their importance. Constraints, areas where a new home would not be suitable under any conditions, were also identified. Constraints excluded certain areas from the analysis altogether; for example, participants could decide that they did not wish to live within 500 m of a major road.

Once the weighting process had been completed, the data selected were combined in a GIS using a multi-criteria modelling technique. This technique will be explored in more detail in **Chapter 7**, but, in brief, the data layers were combined using weightings, so that the layer with the highest weight had the most influence on the result. The resulting maps were used to help target the house-hunting process. The method is summarized in Figures 1.12 and 1.13.

Locations of houses that were for sale were plotted over the top of the suitable areas identified, and ranked according to the number of criteria which they meet. If further details of these houses were available in computerized form, they were accessed by pointing at the map to find out: for instance, how many bedrooms they had, or whether they had a garden. To achieve this, the information on the map (locations of properties) was linked with a database of house features. This type of data is often referred to as 'attribute' data. Attribute data and database concepts are considered in detail in **Chapter 4**.

There are examples of software developed to perform similar tasks, including Wigwam in the UK (Anon., no date) and GeoData in the USA (Esri, 1995). These systems have been designed to make it possible for a home buyer to visit an estate agent, explain the type of house and neighbourhood they prefer, and come away with a map showing the locations of houses for sale which meet their requirements. These products bring help to the home buyer deciding where to look for a new home in an unfamiliar area. GIS in this context is a decision support system. Online applications such as upmystreet.com and Google Street View also allow users to search for properties and explore the characteristics of the area in which they are found.

The house-hunting example shows how GIS can be used to link databases with similar types of data. This improves the speed and efficiency with which an appropriate location can be found. In this respect, it is a similar application to the NDA case study discussed earlier. However, it differs from the NDA example in that a large part of the search process may be carried out using the attributes associated with a spatial feature. In the case of the house-hunting example, these may be the number of bedrooms a property has or its price. Heywood *et al.* (1995) raise other issues associated with the use of GIS as a decision support tool. These are the problem of different GIS software products giving different results, the problem of defining search criteria and the human constraints on the decision-making process (Box 1.4).

The examples above are not enough to illustrate the range of applications and problems that GIS can be used to address. Even when a problem cannot be solved entirely using GIS, there may be the potential for some GIS input to aid the decision-making process. Table 1.1 offers additional pointers to further examples of GIS use by local government, defence agencies, utility companies, commerce and business.