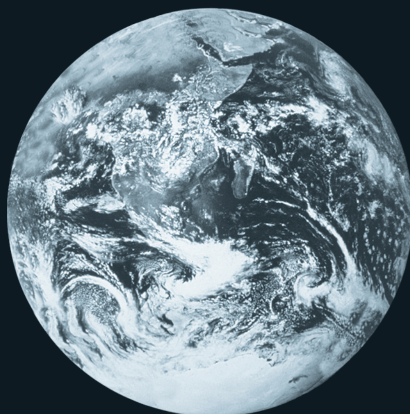
Resource Management Information Systems: Remote Sensing, GIS and Modelling

SECOND EDITION



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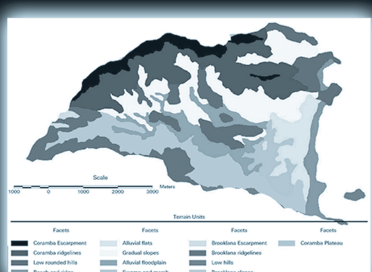

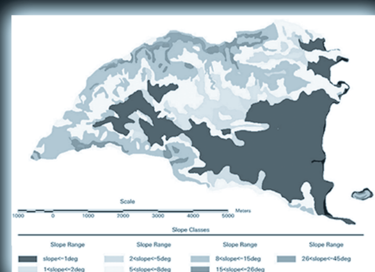

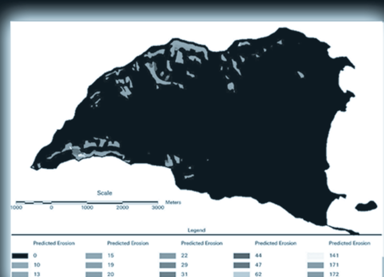

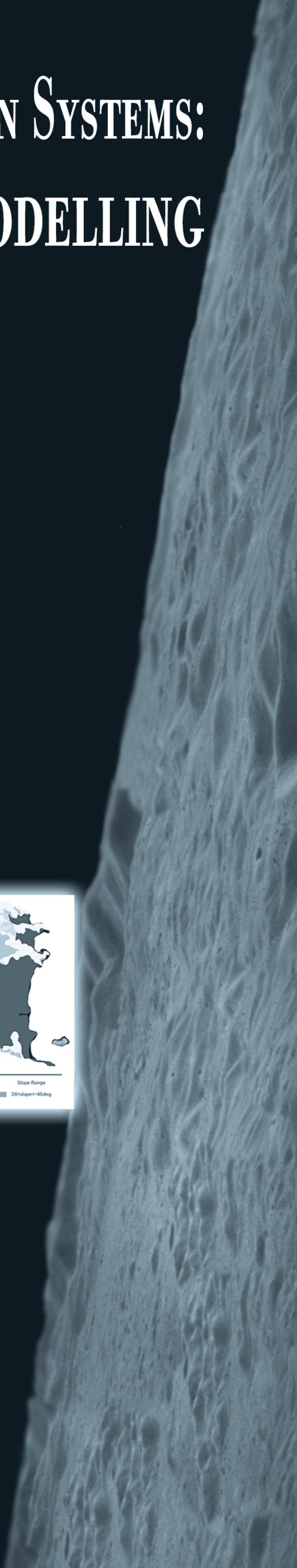

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Second Edition

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Keith R. McCloy

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To Anny.
And to
Sarah, Sophia and Simon,
With love and appreciation

Preface

The purpose of this book is to provide the reader with the knowledge and skills necessary to design, build, implement, operate and use spatial resource management information systems for the management of the physical resources of a region. Spatial resource management information systems are based on the technologies of remote sensing, geographic information systems and modelling. The integration of these technologies with appropriate field data provides the basis of these systems. Accordingly, this book provides the reader with the skills necessary to use these technologies in a spatial context, and provides the reader with the skills to integrate them into, and then to operate, such information systems.

This book is the second edition of a text by the same author, *Resource Management Information Systems: Process and Practice*. That title reflected the end goals of the material given in the book, but did not reflect the contents of the book, which are the material necessary to reach this end goal. The new title, *Resource Management Information Systems: Remote Sensing, GIS and Modelling in Resource Management*, better reflects the contents of the book, and hence the end goal. This edition offers extensive revisions of the material offered in most chapters of the book, reflecting the rapidly evolving nature of the technologies that underlay the management tools needed for the management of spatial resources. The authors believe that this edition reflects the current status of these technologies and their evolving role in the management of spatial resources.

The management of the physical resources of a region is increasingly becoming a balance between the competing needs to both optimise productivity and to meet community demands for the maintenance of resources. The competition for scarce resources is driving the need for better management information systems designed to provide decision support tools to resource managers. One such tool is spatial resource information systems. This type of decision support system can be used to support the management of a farm or park, through regional management to global resource management. They have the characteristic of providing up-to-date spatially extensive yet consistent information on aspects of the resources of interest to the manager. There are many issues where such spatial decision support systems become crucial including dealing with most forms of environmental degradation and pollution since the source of the damage or pollution is separated in time and space from the effects. There are many situations where productivity gains can also be made from the use of spatial information systems, such as the case where agricultural industries collaborate in the construction of harvesting, processing and packaging factories and where there are advantages to be gained from the careful scheduling of the harvest so as to minimise waiting time and storage costs after harvest and to minimise the deterioration of produce prior to processing and packaging. As there becomes increasing competition for the use of scarce land resources, the potential for conflict increases. Resource managers will face an increasing need to resolve such conflicts and spatial decision support tools are critical in providing resource managers with this type of support.

In providing a text that is meant for resource managers, or for those closely connected to the management of resources, it has been necessary to think very carefully about the level of depth and breadth that should be covered as well as the theoretical and practical treatment that should be given to the material in the book. Some readers will want to go further in the study of these topics; the treatment has also been designed so as to provide sufficient foundations for them to do so. Thus, some mathematical treatment is included for some of the more important methods, but the reader should be able to understand the use of the material and its implementation without getting into too much mathematical development if that is his or her wish. In addition, it was recognised that a book like this cannot do justice to its task without some real data to deal with. Accordingly, the text contains a CD that includes data, notes on applications and various Web addresses so that the interested reader can access software to analyse the data in various ways. The CD holds text material to guide the user through the application material and in that sense it stands on its own. But it is meant to be used as an adjunct to the learning that is done by reading the text. Many software systems also provide learning material, and this material is also worth using.

There are a number of different software systems that can be used in the analysis of spatial data. What is needed are software systems that seamlessly include image processing, GIS, modelling and statistical tools and decision support tools. Of the various software systems around only IDRISI has implemented a conscious plan to do this, and they should be complimented for having this vision. I look forward to seeing other systems going down a similar route in the future. All software systems involved in the spatial analysis of data are different and thus cater for different needs. No system is best for everyone. Accordingly, no one system is recommended in this text. By the time that you get to the end of this text, you should know what to look for in selecting a software system to meet your needs.

The importance of information in the management of resources, and the importance of having sets of information of equivalent resolution, timeliness and accuracy for the different managers so as to minimise conflicts arising out of differences in perception of the nature of the problem, cannot be overestimated. These spatial resource management types of information are an important component in meeting these needs. Thus, this text is an important resource for all of those concerned with the management of physical resources, including those involved in agriculture, forestry, marine and aquatic resources, environmental science, landuse planning, valuation, engineering and geography.

A number of people have assisted in the preparation of this book and their assistance is greatly appreciated. Professors Steven De Jong, David Atkinson and Henning Skriver as well as Drs. Jurgen Boehner, Thomas Selige, Niels Broge and James Toledano have all very carefully reviewed various chapters and provided greatly appreciated comments and corrections. Dr. Susanne Kickner has gone much further and contributed valuable sections to the Chapter 6 on GIS. The support of the publishers has been greatly appreciated. Very special thanks must go to Anny for her support throughout the revision of this text.

Keith McCloy
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Denmark

Authors

Keith R. McCloy is a specialist in remote sensing, GIS and modelling, with over 30 years of experience in conducting research into, teaching, developing applications and using remote sensing, GIS and modelling for the management of renewable resources. He has a degree in surveying and a Ph.D. in geography, working 18 years in academia, 13 years in a research environment and 4 years in an operational environment, all focussing on the use of remote sensing, GIS and modelling in resource management. He is currently a senior scientist (remote sensing) with the Danish Institute for Agricultural Sciences.

During his career, he has implemented a number of operational applications in Australia, some of which continue to this day, developed postgraduates course programs in The Philippines and Australia, and developed a number of image analysis tools and techniques in classification, estimation and time series analysis of image data. This textbook reflects his belief in the need for the types of information provided by these spatial technologies, and the importance of integrating them for the best management of renewable resources.

Susanne Kickner graduated from the University of Salzburg in geography and gained her Ph.D. in nature science from the Technical University Karlsruhe in 1998. Her thesis was titled "Cognition, attitude and behaviour — a study of individual traffic behaviour in Karlsruhe." Since then she has focused on the use of geographic information systems for regional and site analyses for a variety of resource management purposes. Until 2004 she was scientific assistant at the Department of Economic Geography of the University of Göttingen, and is currently self-employed as an adviser to businesses as a GIS expert on spatial-economic questions.

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List of Tables

2.1 Metric Units of Distance 32
2.2 F-number, Ratio of Aperture Area to Focal Length and Relative Size 76
2.3 Relationship Among Lens Cone Type, FOV and Focal Length for Aerial Cameras 89
2.4 The Common Radar Wavebands, Their Wavelength Ranges and Frequencies 98
2.5 Factors that Affect the Effective Backscatter Cross-Section Area per Unit Area 103
2.6 The Dielectric Properties of Some Materials, with Most at 3×10^9 Hz 107
2.7 Characteristics of Selected Aircraft-Based Imaging Spectrometers 112
3.1 Typical Map Scales and Some of their Geometric Characteristics 140
3.2 The Emissivities of Common Materials in the 8 to 13.3 m Waveband 155
3.3 Standard Mapping Scales and Coverages 164
4.1 The Advantages and Disadvantages of Visual Interpretation and Digital Image Processing 173
4.2 Mean, Covariance and Correlation Arrays for Four Cover Types as Acquired Using the Three Scanners, Thematic Mapper, SPOT XS and MOS-1 186
4.3 Map, Adjusted Co-ordinates and Residuals in X and Y (Metres) after Rectification of an Image 208
4.4 Typical Rectified Pixel Sizes for Different Sensors 209
4.5 In-Flight Calibration Constants for Landsat TM 4 216
4.6 Typical 16 Level Grey Tone and Colour Lookup Tables 224
4.7 Summary of Image Statistics Used to Create a Principal Components Transformation ... 231
4.8 The Principal Components Transformation Parameters and the Contribution of the Variance to Each of the Components 231
4.9 Contribution of Components to the Variance in the Data 231
4.10 Pixel Values for Vertical Lines, Their Distance from the Centre and their Relationship to the Basic Wavelength 238
4.11 The Input Values, Activation and Output Value for a Simple Two-Channel Artificial Neural Network 280
4.12 Hierarchy of Classes That May be Used for Hierarchical Classification, and Working Towards the Development of Classification Criteria at Each Level to Guide the Development of the Classifier 282
4.13 Additive Seasonal Adjustment of Three Seasonal Cycles for a Pixel in a Temporal Sequence of Monthly Image Data 300
4.14 Proportional Seasonal Adjustment of Three Seasonal Cycles for a Pixel in a Temporal Sequence of Monthly Image Data 301
5.1 Irradiance Observations at Orange on 15 June 1986, Estimated Irradiance Values by the Use of a Sine Curve, and the Residuals 318
5.2 A Set of 31 Observations of Temperature and Elevation used to Compute a Linear Regression Fitting the Data by Means of Least Squares 328
5.3 Probability of Scoring No Errors in Samples of Varying Sizes from a Population with a Probability, p, of Real Errors in Each Pixel. Stepped Line Indicates Approximate 0.05 Probability Level 340

5.4 Probability of Scoring Errors in Samples of Varying Sizes from a Population with Real Errors of 15%, that is an Interpretation Accuracy of 85%. Stepped Line Indicates Approximate 0.05 Probability Level ... 341
5.5 Probability of Scoring Errors in Samples of Varying Sizes from a Population with Real Errors of 10%, that is an Interpretation Accuracy of 90%. Stepped Line Indicates Approximate 0.05 Probability Level ... 341
5.6 Probability of Scoring Errors in Samples of Varying Sizes from a Population with Real Errors of 5%, that is an Interpretation Accuracy of 95%. Stepped Line Indicates Approximate 0.05 Probability Level ... 342
5.7 Cross-Tabulation of Field Classification Against Image Classification as Total Counts .. 345
5.8 Proportional Cross-Tabulations of the Data in Table 5.7 ... 345
5.9 Comparison of the Pixel Counts for the Combinations of Classes in Two Classification Theme Files in Which One File is from Image Processing and One is Derived from Field Data ... 348
5.10 The Proportions of the Total Population for the Data in Table 5.9(c) ... 349
5.11 Accuracies (Black) and Errors of Omission (Gray) from the Data Given in Table 5.9(c). ... 350
5.12 The Errors of Commission are Shown in the Grey Areas, for the Data Given in Table 5.9(c) ... 351
5.13 Variances Associated with the Classification Accuracies and the Errors of Omission 351
6.1 Possible Fields in an Attribute File Describing Important Aspects of the Ownership of Each Land Parcel ... 356
6.2 Contents of Two Interlinked Relational Database Files ... 362
6.3 Spatial Features and Typical Examples of Their Use ... 369
6.4 Relationship between Scale, Pixel Size, Map Coverage Area and the Number of Pixels in the Image ... 372
6.5 Typical 16 Level Grey Tone and Colour Lookup Tables ... 375
6.6 Typical Tasks Conducted in Routine Vector GIS Analysis ... 389
6.7 Conditional Operators Used in Most GIS Systems ... 389
6.8 Results of the Application of the Boolean Operators ... 390
6.9 Some Municipalities in the GIS Municipal Layer, with their Attribute Information ... 390
6.10 Data Records Selected as a Result of the Query Above ... 390
6.11 Data Records Selected as a Result of the Second Query ... 391
6.12 Typical Questions That Can Be Addressed by Selection by Location in Vector GIS Analysis ... 391
6.13 The Grain Size of the Different Categories of Soil Material ... 438
6.14 Values of x_j^m, x_j^{m-1} and x_j^{m-2} Expected for the m Values Used and the Distances of One Cell, 10 Cells and 10 Cells from the Start of the Slope ... 439
6.15 The Vegetal Cover Factor and Cultural Techniques (C Factor) for West Africa ... 440
6.16 C Factor Values for Undisturbed Land in the United States ... 440
6.17 Erosion Control Practice, P ... 441
6.18 The Hierarchy of Regulating Feedback Mechanisms in an Aquatic Environment (Jørgensen and Bendoricchio, 2001) ... 442
7.1 Relationships between Various Parameters Occurring in the Suits Model, Canopy Parameters and the K–M Theory Parameters ... 488
7.2 The Suits Model Parameters for the Two Simple Canopies Used in Chapter 2 ... 490
7.3 The Contributions to Canopy Reflectance in Direction θ_o ... 490
7.4 Typical Parameter Values Used for the Li Kernels ... 497
7.5 Zadoks Growth Stages for Winter Wheat, Depicted Diagrammatically in Figure 7.25 ... 512
8.1 Relationship Between Management Category and the Attributes of the Information Required for Management Purposes ... 526

List of Figures

1.1 The relationship of management levels, the types of information used and the activities conducted by management. 16
2.1 The components of a remote sensing project based on image data acquired using reflected solar radiation. Some sensors use other forms of radiation as will be discussed in this chapter, but the conceptual structure shown in the figure remain essentially the same. 28
2.2 The sine wave and its parameters of wavelength, λ and amplitude, *A*. 31
2.3 Energy emitted by blackbody with parameters of wavelength, λ and amplitude, *A*. .. 32
2.4 The effect of emissivity on the energy radiated by a surface at a temperature of 313K (40°C), showing the energy radiated for surfaces with emissivities of 1.0, 0.8, 0.5 and 0.2. 33
2.5 Radiant intensity from a point source. 34
2.6 Radiance into an extended source area, *A*. 35
2.7 Solar irradiance before and after transmission through Earth's atmosphere, with atmospheric absorption, for the sun at the zenith (from Lintz, and Simonett, D.S. (Eds), 1976. *Remote Sensing of Environment*, Addison-Wesley, Reading, M.A. With permission). 35
2.8 Atmospheric transmissivity, common absorption bands, and the spectral ranges of selected remote sensing systems (from Sabins, F.F., 1987. With permission). 36
2.9 Transmission of solar irradiance through the atmosphere to the sensor. 40
2.10 Schematic diagram of the construction of a spectrometer, consisting of an optical system, aperture, filter unit, detectors, amplifier and recorder. 45
2.11 The wedge prism filter unit. 46
2.12 The transmission spectrum of selected gelatine filters, Haze filter 3,12 — Yellow, 25 — Red and 89A — Deep red (from Kodak. With permission). 47
2.13 The relative quantium efficiency of modern (CCD) as used in spectrometers and cameras. 48
2.14 Specular Reflection in accordance with Snell's Law and Lambertian reflectance. 50
2.15 Hemispherical, directional and bi-directional reflectance. 51
2.16 The bi-directional reflectance function (BRDF) of a recently ploughed bare field at 25° solar elevation for 662 nm wavelength (from Asrar, G. (Ed.), 1989. *Theory and Applications of Optical Remote Sensing*, John Wiley & Sons, New York. With permission). 52
2.17 The bi-directional reflectance function of a sand shinnery oak rangelands community at 31° solar zenith angle at = 662 nm (from Asrar, G. (Ed.), 1989. *Theory and Applications of Optical Remote Sensing*, John Wiley & Sons, New York. With permission). 53
2.18 The bi-directional reflectance function of a sand shinnery oak rangelands community at 31° solar zenith angle at = 826 nm (from Asrar, G. (Ed.), 1989. *Theory and Applications of Optical Remote Sensing*, John Wiley & Sons, New York. With permission). 54
2.19 The absorption characteristics of pure water. 55

2.20 The reflectance of pure water (a), and the effects of sediments (b) and chlorophyll (c) on the reflectance of water. 55
2.21 Representative spectra for the reflectance of soils with (a) minimally altered (fibric), (b) partially altered (ferric) and (c) fully decomposed (sapric) organic matter (from Stoner, E.R. and Baumgardner, M.F., 1981. *Soil Science of America Journal*, 45, 1161–1165. With permission). 56
2.22 Changes in reflectance of a typical soil with changes in moisture content. 57
2.23 Reflectance spectra of surface samples of five mineral soils; (a) organic dominated (high organic content, moderately fine texture), (b) minimally altered (low organic and iron content), (c) iron altered (low organic and medium iron content), (d) organic affected (high organic content and moderately coarse texture) and (e) iron dominated (high iron content with fine texture) (from Stoner, E.R. and Baumgardner, M.F., 1981. *Soil Science of America Journal*, 45, 1161–1165. With permission). 57
2.24 Cross-sections through typical C3 and C4 leaves, showing the arrangement of the upper and lower epidermis, containing the stomata, and the mesophyll consisting of palisade and spongy mesophyll cells, airspaces, and the veins. 59
2.25 Cross-section of a C3 grass leaf. 59
2.26 Cross-section of a C4 grass leaf. 60
2.27 Specific absorption versus frequency and wavelength of the principal plant pigments and liquid water (from Gates, D.M., 1965. *Applied Optics*, 4, 11–20. With permission). 60
2.28 The spectral absorption of green (a) and albina (b) leaves of a *Hedera helix* plant (from Gates, D.M., 1965. *Applied Optics*, 4, 11–20. With permission). 61
2.29 Laboratory spectrophotometric reflectances measures over the waveband 500 nm 2500 nm for the leaves of dorsiventral — oleander and six succulent and four nonsucculent species (Gausman et al. 1978a). 61
2.30 The reflectance, transmittance and absorptance of *Populus deltoides* leaves, being moderately thin and light coloured, *Nerium oleander* a thick green leaf, *Raphilolepis ovata* a thick dark green lead and four selected desert succulent plants (from Gates, D.M., 1965. *Applied Optics*, 4, 11–20. With permission). 62
2.31 Reflectance spectra of four plant genera differing in plant leaf structural or mesophyl arrangement, being dorsiventra — (a) oleander and (b) hyacinth and isolateral — (c) eucalyptus and (d) compact (from Gaussman et al, 1970. *Technical Monograph* no. 4, Texas A&M University, College Station, Texas. With permission). 63
2.32 Evolution of the spectral reflectance of a Quercus alba leaf during the growing season for the dates shown in the figure (from Gates, D.M., 1965. *Applied Optics*, 4, 11–20. With permission). 63
2.33 The reflectance of corn leaves for each increase in stack thickness by one leaf, up to a thickness of six leaves. 64
2.34 Change in crop canopy reflectance with changes in LAI and percent cover (from Bauer, M.E., Daughtry, C.S.T. and Vanderbelt, V.C., 1981. *AgRISTARS Technical Report SR-P7-04187*, Purdue University, West Lafeyette, IN. With permission). 65
2.35 The reflectance characteristics of the upper and lower surfaces of wheat leaves (from Schutt et al, 1984. *International Journal of Remote Sensing*, 5, 95–102. With permission). 65
2.36 Laboratory spectrophotometrically measured reflecatnces of dead leaves and bare soils for six crop species, (a) avocado, (b) sugarcane, (c) citrus, (d) corn, (e) cotton and (f) sorghum (from Gausman et al., 1976. *Journal of Rio Grande Valley Horticultural Society* 30, 103–107. With permission). 67
2.37 The geometry of energy interactions in vertical and horizontal canopies. 68

2.38 The relectance of selected *Eucalyptus* sp. plants (from O'Niel, A., 1990. *Personal communication*. With permission)........ 70
2.39 Polar co-ordinate system used in the observation of bi-directional reflectance functions........ 71
2.40 Relationship between an object and its image in a perfect camera that exactly obeys the principles of the Central Perspective Projection........ 73
2.41 Shutter efficiency. The hatched rectangular figure represents ideal shutter action, open in zero time, stay completely open, close in zero time. The shaded figure shows the actural shutter aperture........ 76
2.42 Construction of a typical film framing camera. 77
2.43 Spectral sensitivity curves for two common one layer emulsion films. 79
2.44 Spectral sensitivity curves for three layer colour (a) and colour IR (b) films. 79
2.45 Cross section through a colour film emulsion showing the emulsion layers. 80
2.46 Typical transmission curves for (a) cut-off and (b) band filters........ 80
2.47 Determination of the FF as the ratio of the area under the film curve, as normally exposed, over the area under the curve with the filter (a) and the responsivity versus wavelength for several typical photon detectors (b)........ 81
2.48 The quantum efficiency of tow digital camera CCD arrays........ 82
2.49 The OTF for a panchromatic film derived from the use of four sources sine wave signals and their response signals. 83
2.50 Tilted (oblique) and vertical photographs........ 84
2.51 Typical layout of an aerial sortie, with flight lines of photography by 60–80% and with sidelap between the photographs in the different flight lines of 10–20%........ 85
2.52 The effects of height differences on position in an aerial photograph........ 86
2.53 Height displacements for a point in an overlapping pair of aerial photographs........ 88
2.54 Relationship between cameras of different cone angles........ 88
2.55 A typical scanner construction and its relationship to the surface being sensed. 90
2.56 The object space scanning unit. 90
2.57 The rotating conical mirror scanning unit. 91
2.58 Diagram illustrating of the construction of a typical thermal scanner unit. 92
2.59 Geometric relations in a scanline........ 93
2.60 Stepping of satellite scanner data due to Earth rotation. 94
2.61 Displacements due to earth curvature and height displacements and the geometric relationships used to solve this problem. 95
2.62 Schematic layout of a pushbroom scanner. 96
2.63 Geometry of a side looking imaging radar. 98
2.64 The approximated antenna pattern for side looking radar. 99
2.65 Resolution constraints on radar image data (a) real aperture radar, and (b) synthetic aperture radar. 100
2.66 Concept of synthetic large antenna represented by the observation of individual rays from that antenna by individual actual antennas........ 100
2.67 Incorpration of Doppler shift into the construction of SAR image data........ 101
2.68 The effects of topographic heights on radar imagery........ 102
2.69 Backscattering cross-section angular distribution for incident radiation at angle of incidence, θ, as a function of facet size, L. 104
2.70 The corner reflector effect in two and three dimensions. 105
2.71 Polarisation of a sine wave. Normal radiation in the direction AB will have its sine wave at all orientations about the line AB. Polarised light has its radiation at the one orientation. In this figure the radiation is polarised in the vertical or Y direction........ 109
2.72 Reflection of a radar signal in a forest. 110

2.73 Typical radar responses from a softwood forest with low, moderate and high density tree cover. 110
2.74 Tethering of a ballon under steady and fluctuating conditions. 114
2.75 The effect of differences between aircraft heading and direction of flight on photography. 115
2.76 The effect of sudden changes in roll rotation on scanner imagery. 116
2.77 Creation of hotspots due primarily to the lack of shadowing in the surface at this direction and partly to refraction around an aircraft. 117
2.78 The forces acting on a satelite. 118
3.1 Cross-section of the human eye showing the major components that affect vision. 125
3.2 The rods and cones in the human eye. 127
3.3 Binocular vision and displacements in those images due to the eyebase during observation. 128
3.4 Viewing in epipolar planes. 128
3.5 The co-ordinate system used for viewing and associated x- and y-parallaxes. 129
3.6 The lens or pocket stereoscope. 130
3.7 The mirror stereoscope. 131
3.8 Construction of a stereo-triplet. 133
3.9 The principle of the floating mark. 134
3.10 Magnitude of displacements due to height differences. 136
3.11 Derivation of the parallax bar formula. 137
3.12 The theoretical basis of the anharmonic ratio. 142
3.13 The paper strip method of transferring detail. 143
3.14 Construction of projective nets between four corner points on an aerial photograph and a map. 143
3.15 Proportional dividers. 144
3.16 The chromaticity triangle. 145
3.17 Typical diurnal variations in temperature for different types of surface. 156
3.18 The parameters of the World Geodetic System (WGS), 1984 spheroid, showing its semi-major and semi-minor axes values. The flattening of the spheroid, $f = (a - b)/a = 1/298.257223563$. 158
3.19 The conic projection. 159
3.20 The cylindrical projection. 160
3.21 Three common alternative forms of azimuthal map projection. 160
3.22 The gnomic projection with axis in the equator and nadir point in South America. 161
3.23 The stereographic projection using the same axis and nadir point as for the gnomic projection. 161
3.24 The orthographic projection using the same axis and nadir point as for the other two projections. 162
3.25 Ratio of the three standard alternative ways of deriving projected distances to the arc distance when projecting from a sphere onto a plane. 162
3.26 Construction of the transverse mercator projection. 163
3.27 The contents of a map sheet. 164
3.28 Geographic co-ordinates of latitude and longitude around the globe. 165
3.29 The CCS of two axes at right angles, distances measured along these axes, and bearings measured relative to one of the axes. 166
3.30 Part of a topographic map and three profiles from the map. 167
3.31 The compass resection. 168
3.32 The characteristics of contours. 168
4.1 Histogram of an image as displayed in Idrisi. The display shows the range of values in the image, the mean value and the standard deviation. 179

4.2 The cumulative histogram for the histogram shown in Figure 4.1, as displayed in Idrisi. 180
4.3 A Scattergram of Red (x-axis) versus Near-IR (y-axis) for the same image for which the Near-IR histogram is shown in Figure 4.1, as displayed in Idrisi image processing software. 181
4.4 Probability distributions for three different sets of observational data, (a) skewed unimodal, (b) normal unimodal and (c) leptokurtic unimodal. 181
4.5 The Standard Normal Distribution, $N(0, 1)$. 183
4.6 Diagrammatic illustration of the shapes of the normal distribution at one standard deviation for populations in two variables, with different correlations between the parameters. Figure 4.3 illustrates the distribution of actual data in two wavebands for a specific sensor at a specific site on a specific day. Such data, representing many cover types, rarely exhibits the circular or elliptical shapes discussed here. 185
4.7 A line of 13 pixels and their response values. 191
4.8 Autocorrelation and variogram functions for the data in Figure 4.7. 192
4.9 Typical shapes that can be expected for autocorrelation and variogram functions derived from remotely sensed data. 192
4.10 A set of data values and its component sinusoidal values. 193
4.11 The frequency domain showing the power spectrum. 194
4.12 A simple example of the relationships between an image and the ground, typical of a camera in both directions, and of scanners in one direction, but not the other direction. 205
4.13 Errors in the x and y directions when the sensor orientation is at a bearing to these axes. 206
4.14 Plot of residuals after least squares adjustment and given in Table 4.3. The plot scale for the residuals is much larger than the plot scale for the control points. A pattern in the magnitude and direction of these residuals would be of concern to the analyst. 208
4.15 Relationship between the source pixels in the image data and the rectified pixels. 209
4.16 Relationship between the source pixels and the rectified pixels in the bi-linear interpolation. 210
4.17 The $\sin(\pi \times x)/\pi \times x$ and cubic convolution filters. 211
4.18 The interpolation axes for cubic convolution resampling. 212
4.19 Relationships in using the cubic convolution interpolation equation. 212
4.20 Distribution of 9 and 25 ground control points for image rectification. 214
4.21 Pixel tones and their relationship to ground detail. 214
4.22 Distribution of residuals due to an error in the location of one control point. 215
4.23 Relationship between solar elevation and energy incident on the target area. 217
4.24 Sensing in three narrow wavebands to estimate the moisture content of the atmosphere. 221
4.25 The Idrisi prompt window for the display of an image. 223
4.26 Linear enhancement of the data shown in Figure 4.1. 225
4.27 Logarithmic response function of the human eye. 227
4.28 Typical piecewise linear stretch for data, showing the seven linear enhancements used for different subsets of the data. 228
4.29 Histogram equalisation of the same data as has been used in the other enhancement transformations (Figure 4.26 and Figure 4.28). 229
4.30 The principal components transformation. 230
4.31 The tasselled cap concept (formulated by Kauth, R.J. and Thomas, G.S., *Proceedings, Symposium on Machine Processing of Remotely Sensed Data*, Purdue University, West Lafayette, Indiana, USA. With Permission) 1976. 232

4.32 Typical response values in broad red/near IR waveband space for the common cover types and the shape of typical broadband vegetation indices. 234
4.33 Illustration of the “linear method” (Guyot G. and Barret, F. *Proceedings of the 4th International Colloquium on Spectral Signature of Objects in Remote Sensing*, Aussois, France, January 18–22, 1988 (ESA SP-287, April 1988), pp. 279–286. With Permission) 1988. 236
4.34 Image of a sine wave. 237
4.35 Fourier power spectrum of the image shown in Figure 4.34. 237
4.36 A 5 × 5 window of pixels and their image values. 240
4.37 Response profiles through an edge and a road, their first and second derivatives. 243
4.38 The local co-ordinate system used in computation of texture. 244
4.39 The filter shapes and crispness determinations typically used in filtering frequency domain data based on image data. 246
4.40 A typical variogram and its components. 248
4.41 Sinusoidal and arch variograms derived from imagery dominated by repetitive linear features in the landscape or from long sequences of image data that is dominated by the cyclic seasonal growth of vegetation. 249
4.42 Sinusoidal features in image data, their orientation to the image pixels and lines and the frequency of the features. 250
4.43 Types of boundaries that can be met in image data, being (a) mixtures of adjacent field cover types, (b) a different linear feature between the fields and (c) areas of mixed cover type. 251
4.44 Typical average local variance (ALV) functions for two cover types. 253
4.45 Average local variance functions for the two images shown in Photograph 4.2. 254
4.46 Colour assignment over time using the temporal enhancement. 256
4.47 Construction of temporal distance images relative to each of the three cover types A, B and C. 257
4.48 Mixture of two cover types in a pixel. 258
4.49 The response characteristics of ten lakes in Western Victoria (Australia), illustrating the linear change in response that can occur across certain landcovers. 258
4.50 The domain of the linear end member algorithm for three end members in three-dimensional space. The end member response locations are at A, B and C, defining the vertices of the triangle. The relationship between the end members and proportions is shown in the figure. 260
4.51 Probability distributions that an animal is either species A or B from its measured weight, with errors of classification (a) and (b) for the decision surface set at $W = 23.684$. 266
4.52 Probability distribution for a second sample of animals from the population sampled to construct the probability distributions in Figure 4.51. 268
4.53 The probability distribution and decision surfaces for three classes in two dimensions for the minimum distance classifier. 271
4.54 The maximum likelihood classifier for three classes in two dimensions showing the decisions surfaces for these three classes and the capacity to set a threshold or limit to the classification so as to reject wild pixels. 277
4.55 The architecture of a typical artificial neural network classifier consisting of input neurons, two hidden layers of synapses and the output neuron. 279
4.56 Two threshold functions used to transform the activation to output values at a synapse. 280
4.57 The data space and the decision surface for a simple two channel, single hidden layer ANN. 281
4.58 Minimise the within class spread and maximise the between-class distances. 288

4.59 Typical relationship between FPAR and NDVI. 293
4.60 Typical relationship between GLAI and RVI for various crop types. 293
4.61 Relationship between NDVI and RVI. 294
4.62 The interpolation between field data to create contour maps or estimate digital elevation and for other types of surface modelling. 295
4.63 The concept of a hypercube of image data. 296
4.64 The additive seasonal adjustment of the data in Table 4.13. 300
4.65 The proportional seasonal adjustment of the data in Table 4.14. 301
4.66 Comparison of a reference sine wave with a second sine wave. (a) the various source signals for the comparison, (b) the comparison of each signal with the reference signal. 304
5.1 Interpolated graph of irradiance from regular irradiance observations taken throughout one day. 317
5.2 Typical reflectance characteristics of Halon powder (from Grove et al., 1992 *Jet Propulsion Laboratory Publication 92-2*, Pasadena, CA. With permission). 320
5.3 Radiance, irradiance and reflectance curves for a red waveband recorded throughout the day, for a Lambertian Halon target, and curves of the ratios of (NIR/red) radiance and reflectance values using the same field data set for red and NIR wavebands. 321
5.4 Distribution of data required to develop a model to estimate GLAI and BLAI for pastures from spectral data. 323
5.5 Calculation of the area covered by an instrument of specified IFOV at distance, d from the target. 323
5.6 The relative area of a pixel at different look angles and different FOV values. 324
5.7 A set of observational data and a linear regression line fitted to the data. 327
5.8 The non-linear relationship between two sets of variables (a) and their transformation into a linear relationship by transforming one of the datasets (b). 328
5.9 Data values, linear regression and confidence limits. 329
5.10 Typical relationship between GLAI and the normalised difference vegetation index (NDVI) (courtesy of Wolfgang Buermann, Boston University). 330
5.11 Relationship between sampling fraction, cost of field data collection and accuracy. 337
5.12 Sampling for a pixel in scanner data. 338
5.13 Ratio of the field sample area to image sample size for different numbers of pixels in the image samples, for different rectification accuracies (different s/d values). 339
5.14 (a) Classification of an image, (b) field data map and (c) cross-tabulation of the two classifications. Black = pasture, dark grey = water, light grey = cropping and white = forest. 344
5.15 Accuracies and errors of omission and commission in relation to the one class. 350
6.1 Layers of data on attributes of the environment that may be used in addressing some specific questions in resource management. 356
6.2 The components of a geographic information system. 359
6.3 A spatial file containing the key attribute to a database of soil attributes. 361
6.4 Typical faults at digitising. 364
6.5 Digitisation of data on a video screen showing the relationship between the screen pixels, the feature to be digitised (grey) and the stored digitised data (black). The figure may be considered to be misleading since the digitising is always done at the finest spatial resolution that can be achieved on the screen. Even if the pixels are magnified so that they look like those depicted in this figure, the digitising will appear to be a continuous curve since the set of (x, y) co-ordinates that are stored at the finest achievable screen resolution. What is depicted in the figure is how the digitising would appear if it is digitised at one scale and then subsequently greatly magnified. 365
6.6 The spatial data and its databases that provide topology in the GIS. 367

6.7 The relationship between a location on the earth's surface and the satellites being used to fix its location using GPS. Only three satellites are depicted, whereas at least four should be observable before taking observations of location. The satellite ephemeris is the satellite orbit characteristics. The three distances between the satellites are calculated using the calculated ephemeris data and the three distances to the ground stations are observed prior to calculation. 371
6.8 Quad tree and run length encoding techniques for spatial data compression. 373
6.9 The interactive window used in Idrisi to enable the operator to define what layer is to be displayed, the type of file and the lookup table to be used, if appropriate. 376
6.10 Flowcharts illustrating the steps taken to combine layers using logical combinatorial techniques. 377
6.11 The Idrisi window for the construction of logical expressions. 379
6.12 Local (x, y) co-ordinates and pixel values to solve for gradient, and rate of change in gradient. 381
6.13 Templates that can be used to compute gradients in the X and Y directions using Equation (6.7). 383
6.14 Pixels used to compute the cost value associated with pixels in different positions. .. 384
6.15 The normal distribution (a) and skewed normal distribution (b). 387
6.16 Selecting lines that are crossed by lines either in the same or in different layers of the GIS. 392
6.17 Selecting points that are within a certain distance to lines. 393
6.18 Selecting areas that are completely within other areas. 393
6.19 Selecting areas that completely contain other areas. 394
6.20 Selecting lines which touch the boundary of lines in another layer. 394
6.21 Selecting areas with identical geometry as areas in another layer. 395
6.22 Example for the function DISSOLVE. 395
6.23 Examples of intersections. 396
6.24 The UNION operation in vector GIS. 397
6.25 The IDENTITY operation in vector GIS. 398
6.26 Examples of the application of the ERASE function. 398
6.27 Examples of UPDATE. 399
6.28 Examples of CLIP. 399
6.29 Examples of a line buffer with different buffer distances and a polygon buffer with the same distance around all forests. 400
6.30 Example file structure for three projects; Biodiversity Investigation (BIOD) in Watershed #2, Soil Mapping (SOIL) in both watersheds and Landuse and LULA in both watersheds. 402
6.31 The window provided in Idrisi to window into an image file. 403
6.32 Application of the Dijkstra algorithm for finding the shortest route from A to F. 406
6.33 Example for allocation of doctors services in a township area. 407
6.34 Example of a location–allocation solution to the provision of medical services in a town. 408
6.35 The map algebra window in the Idrisi software for numerical analyses. 410
6.36 The modelling window in Imagine showing some of the graphical script language ikons and the flow directions for processing. 411
6.37 The Imagine function definition window used to create the function to be used in the model being constructed in Figure 6.38. 412
6.38 Flow chart for the computation of FPAR image using the Imagine script language. .. 414
6.39 A network of data points and two triangulations of them; Delaunay triangulation (left) and non-Delaunay triangulation (right) showing how other points fall within a circle containing the three points of some triangles. 415

6.40 Distribution of spot heights used to create a digital terrain model, and estimated grid cell values using linear interpolation within triangles of points. 417
6.41 The semi-variogram and its elements. 419
6.42 Transect one-dimensional variogram taken from the two-dimensional variogram depicted in Photograph 6.1. 420
6.43 Examples of three of the variogram models in which the nugget variance is 4, the sill variance is 19 and the range is 120. 421
6.44 Example relationship between four known points, ($z_1, \ldots, z_4$) and the unknown point to be interpolated, z_0. 423
6.45 Block Kriging to find the average value within a block or pixel area. 424
6.46 The Idrisi window for cross-tabulation of two layers. 425
6.47 The dominating influences on a falling object: gravity and air resistance. 428
6.48 The world of Boids. 431
6.49 A map of two values in an attribute (left-hand side) and the derived statistical information using four different ways of partitioning the area into four equal sized sub-areas on the right-hand side. 433
6.50 A typical S shaped plot of area-level correlation coefficients against individual-level coefficients. 434
6.51 Average annual values of the rainfall erosivity factor, R, for the United States. 437
6.52 Nomograph for determining the soil erodibility factor, K, for U.S. mainland soils. 437
6.53 The normal distribution and the 10% tail. 445
6.54 The normal distribution and the probability of the classification accuracy being satisfactory for more than 95% of the time. 445
6.55 A normally distributed data value, d is $N(50, 10)$ in relation to set bounds of $a = 20$ and $b = 60$. 448
6.56 Supplementary information that should be placed on a map for the assistance of the user. 452
6.57 Tools for the construction of a map sheet as supplied by Imagine. 453
7.1 The components of the Earth's energy budget. 457
7.2 Temporal winter wheat crop growth curves for 16 different fertiliser treatments on the same sandy-loam soil in Denmark, and the dates of application of fertiliser. 462
7.3 The reflectance of winter wheat over different soil backgrounds at an LAI of 3.2. The graphs illustrate the impact of the soil background on reflectance in the NIR, at even high LAI values, whereas there is negligible effect in the visible part of the spectrum. Figure supplied by Dr. Niels Broge. 467
7.4 Average local variance functions for two distinct landcover conditions, derived from 0.4 m resolution colour orthophotographs, with the individual band ALVAR functions shown in the figure. 468
7.5 Temporal RVI profiles for seven different nutrient applications to winter wheat, varying from 200 kg/ha at the first application date early in the season to no application, and no applications at the two typical subsequent application dates in Denmark. 468
7.6 Geometrical relationships in the BRDF. 469
7.7 Simulated effect of variations of atmospheric moisture content on the sensed signal from a crop canopy with LAI = 3.4 at the top of the atmosphere, due to three different levels of water vapour. The curves have been calculated using a mid latitude summer atmospheric model for the atmospheric constituents. 470
7.8 The spatial distributions that can be found in a canopy. 472
7.9 The rays contain multiple reflections within each layer and the stack reflectance and transmittance is the summation of all of the individual components. 476

7.10 The average transmissivity of a dielectric plane surface, $t_{av}(\alpha, n)$ as a function of the refractive index, n, and the incidence angle, a. 477
7.11 The refractive index of typical leaf material and water as a function of wavelength. 478
7.12 A computer generated depiction of a leaf structure used for ray tracing. 479
7.13 Tendency of the epidermal cells to focus the incoming radiation on the chloroplasts. 480
7.14 The Walthal Empirical Canopy Reflectance model. 482
7.15 The turbid medium concept in canopy modelling, depicted for a single layer canopy. 483
7.16 The co-ordinate systems, layers and fluxes that are used in the Suits canopy reflectance model. 486
7.17 A leaf element and its horizontal and vertical cross-section areas 487
7.18 Geometric-optical models use a distribution of geometric shapes to represent the canopy. 491
7.19 The types of paths that can be taken by a ray traversing through a canopy. 492
7.20 Comparison between the concepts that form the basis of the radiative transport and the radiosity models. 494
7.21 Ellipsoidal shapes and their dimensions. 496
7.22 RVI versus GLAI plot for a winter wheat trial in Denmark, using field-based reflectance data for the derivation of the RVI values, for a variety of nutrient application trials, and for the crop prior to flowering. All the trials were on the same soil colour, and for the same variety of winter wheat. 496
7.23 The steps in the classification of rice by incorporation of agronomic knowledge into the classification process. 508
7.24 Incorporation of farmer data into the classification process. 509
7.25 Zadoks stage 13 of a seedling, three leaves unfolded. 511
7.26 The Zadoks stages in the growth of winter wheat. 511
7.27 Crop calendars for wheat in the vicinity of three towns in New South Wales — Moree (26°S), Parkes (29°S) and Barham (31°S) indicating the influence of temperature on crop phenology. 513
7.28 Crop calendars from three different cereal crops at the same location near Parkes (NSW) (29°S). 514
7.29 Crop calendars for spring and winter wheat, each at two locations in China. 514
7.30 Sequential flowering and simultaneous fruiting in related species of *Shorea* during a year with gregarious flowering. 515
7.31 Canopy development, flowering and fruiting of the dominant chaparral shrubs in California. 515
7.32 The GLAI temporal profile for winter wheat grown in Germany under conditions of adequate fertiliser and irrigation, indicating the optimum growth that can be expected for Winter Wheat, as estimated using the Daisy crop growth model 516
7.33 Temporal RVI profiles for winter wheat in Denmark, with an envelope curve indicating optimum growth and the differences between them, derived from field observed data. The vertical axis indicates values in ratio vegetation index. The data has been acquired in the field using field-based instruments. The discrepancy between the two curves at about days 26 and 32 are due to water on the leaves of the plants, and at day 42 is due to moisture stress. 516
8.1 Management levels relating to planning, control and information in (a) relation of managerial position to the time spent in planning and control, and (b) relation of managerial position to the summarisation of information. 526
8.2 A view of the relationship between electronic data processing, management information systems and decision support systems. 532
8.3 Types of decisions. 534

8.4 The IDRISI interface for multi-criteria evaluation. 537
8.5 The decision space in multi-criteria evaluation. 538
8.6 The IDRISI user interface for ordered weighted average MCE. 539
8.7 Decision surfaces in situations of conflict. 540
8.8 Classification versus actual conditions — errors of omission and commission. 545

List of Photographs

2.1 A modern wild RC30 film mapping camera to acquire large format (23 × 23 cm^2) images that are suitable for topographic mapping, geologic and many other interpretation tasks set on its aircraft mount and its associated navigation sight........ 77
2.2 (a) The USAAF 1951 bar target designed to determine the resolution characteristics of aerial photographs and (b) the IEEE Resolution Chart designed to test camera performance. 82
2.3 The DIAS 7915 hyperspectral scanner as installed in an aircraft. The DIAS scanner, constructed at the German Aerospace Center, contains 79 wavebands of data for each pixel. 105
2.4 The corner reflectors used by the Danish Technical University (photograph supplied by Dr. Henning Skriver. With permission). 106
4.1 A source airborne scanner image of an agricultural site, its frequency power spectrum, the filtered power spectrum and the derived image by inversion of the filtered power spectrum. 247
4.2 The images used to derive the ALV functions shown in Figure 4.43. 254
6.1 A two dimensional variogram derived from image data and the location of the transect depicted in Figure 6.42. The origin for the variogram is the top right hand corner. 420

Contents

Chapter 1
Introduction 1
1.1 Goals of this Book 1
1.2 Current Status of Resources 2
1.2.1 Ozone Hole 2
1.2.2 Water-Borne Soil Erosion 3
1.2.3 Loss of Biodiversity 5
1.3 Impact of Resource Degradation 7
1.4 Nature of Resource Degradation 10
1.5 Nature of Resource Management 12
1.5.1 Strategic Management 12
1.5.2 Process or Regional Management 13
1.5.3 Operational Management 15
1.5.4 Relationship between These Levels of Management 15
1.6 Nature of Regional Resource Management Information Systems 16
1.7 Geographic Information in Resource Management 20
1.8 Structure of this Book 24
Reference 25

Chapter 2
Physical Principles of Remote Sensing 27
2.1 Introduction 27
2.2 Electromagnetic Radiation 31
2.2.1 Nature of Electromagnetic Radiation 31
2.2.2 Radiometric Terms and Definitions 34
2.2.3 Energy Radiated by the Sun and the Earth 35
2.2.4 Effects of the Atmosphere 36
2.2.5 Correction of Remotely Sensed Data for Attenuation through the Atmosphere 40
2.2.5.1 Atmospheric Correction Using Field Data 42
2.2.5.2 Atmospheric Correction Using Numerical Atmospheric Models 43
2.2.6 Measurement of Radiance and Irradiance 44
2.2.6.1 Collecting Optics 45
2.2.6.2 Filter Unit 45
2.2.6.3 Detectors 46
2.2.6.4 Output Device 47
2.3 Interaction of Radiation with Matter 48
2.3.1 Nature of Reflectance 48
2.3.1.1 Reflectance within the Boundary Layer 49
2.3.2 Reflectance of Water Surfaces 54
2.3.3 Reflectance Characteristics of Soils 55

2.3.4 Reflectance of Vegetation 58
2.3.5 Reflectance Characteristics of Green Leaves 62
2.3.6 Reflectance Characteristics of Dead Leaves 66
2.3.7 Vegetative Canopy Reflectance 66
2.3.8 Bi-Directional Reflectance Distribution Function of Surfaces 71
2.4 Passive Sensing Systems 72
2.4.1 The Camera 74
2.4.1.1 Lens Cone 74
2.4.1.2 Magazine or Digital Back 75
2.4.1.3 Camera Body 76
2.4.1.4 Suspension Mount 76
2.4.1.5 Light Sensitive Cell Arrays 81
2.4.1.6 Measurement of Resolution in Image Data 81
2.4.2 Acquisition of Aerial Photography with a Framing Camera 84
2.4.2.1 Effects of Height Differences on an Aerial Photograph 87
2.4.2.2 Types of Lens Cones 88
2.4.3 The Scanner 89
2.4.4 The Moving Mirror Scanner 89
2.4.4.1 Resolution of Scanner Data 91
2.4.4.2 Thermal Scanner Data 92
2.4.4.3 Sources of Error in Oscillating Mirror Scanner Imagery 92
2.4.5 Pushbroom Scanners 96
2.5 Active Sensing Systems 97
2.5.1 Introduction 97
2.5.2 The Geometry of Radar Systems 98
2.5.2.1 Resolution of Radar Data 99
2.5.2.2 Effect of Height Displacements 101
2.5.3 The Attenuation and Scattering of Radar in the Atmosphere 102
2.5.4 The Information Content of Radar Imagery 102
2.5.4.1 Surface Roughness and Slope 103
2.5.4.2 Inhomogeneity 106
2.5.4.3 Dielectric Properties 107
2.5.4.4 Resonance-Sized Objects 108
2.5.4.5 Wavelength 108
2.5.4.6 Polarisation 108
2.5.5 Radar Interferometry 109
2.5.6 Summary 111
2.6 Hyperspectral Image Data 111
2.6.1 Definition 111
2.6.2 Applications of Hyperspectral Image Data 112
2.7 Hypertemporal Image Data 112
2.7.1 Introduction 112
2.8 Platforms 113
2.8.1 Terrestrial Platforms 113
2.8.2 Balloon 114
2.8.3 Helicopter or Boat 114
2.8.4 Manned and Unmanned Aircraft 114
2.8.4.1 Hot Spots 116
2.8.5 Planning an Aerial Sortie 116
2.8.6 Satellite Platform 117
2.9 Satellite Sensor Systems 119

Additional Reading 119
References 120

Chapter 3
Visual Interpretation and Map Reading 123
3.1 Overview 123
3.1.1 Remotely Sensed Data and Visual Interpretation 123
3.1.2 Effects of Height Differences on Remotely Sensed Images 124
3.2 Stereoscopy 124
3.2.1 Introduction 124
3.2.2 Monocular Vision 125
3.2.3 Binocular Vision 126
3.2.4 Binocular Perception of Colour 128
3.2.5 General Principles of Stereoscopic Vision 129
3.2.6 Methods of Stereoscopic Viewing 130
3.2.7 Physical Methods of Separation Using Stereoscopes 130
3.2.8 Viewing with a Stereoscope 131
3.2.9 Optical Methods of Separation 132
3.2.9.1 Coloured Anaglyph 132
3.2.9.2 Polarising Filters 133
3.2.10 Construction of a Stereo-Triplet 133
3.3 Measuring Height Differences in a Stereoscopic Pair of Photographs 134
3.3.1 Principle of the Floating Mark 134
3.3.2 Parallax Bar 135
3.3.3 Vertical Exaggeration 135
3.3.4 Displacements due to Height Differences in an Aerial Photograph 135
3.3.5 Derivation of the Parallax Bar Formulae 136
3.3.6 Characteristics of the Parallax Bar Equation 138
3.4 Planimetric Measurements on Aerial Photographs 139
3.4.1 Introduction 139
3.4.2 Determination of Scale 139
3.4.3 Measurement of Distances 140
3.4.3.1 Graduated Rule or Scale 140
3.4.3.2 Paper Strip 140
3.4.3.3 Length of String 140
3.4.3.4 Odometer 140
3.4.4 Measurement of Areas 141
3.4.4.1 Dot Grid 141
3.4.4.2 Digitiser 141
3.4.5 Transfer of Planimetric Detail by the Use of the Anharmonic Ratio 141
3.4.5.1 Paper Strip Method 142
3.4.5.2 Projective Nets 142
3.4.6 Proportional Dividers 143
3.5 Perception of Colour 144
3.6 Principles of Photographic Interpretation 146
3.6.1 Introduction 146
3.6.2 Levels of Interpretation 147
3.6.2.1 Image Reading 147
3.6.2.2 Image Analysis 147
3.6.2.3 Image Interpretation 147

3.6.3 Principles of Object Recognition ... 148
3.6.3.1 Size ... 148
3.6.3.2 Shape ... 148
3.6.3.3 Shadow ... 148
3.6.3.4 Colour or Tone ... 149
3.6.3.5 Pattern and Texture ... 150
3.6.4 Interpretation Strategies ... 150
3.6.4.1 Location and Association ... 150
3.6.4.2 Temporal Change ... 150
3.6.4.3 Convergence of Evidence ... 151
3.6.5 Interpretation Procedure ... 151
3.7 Visual Interpretation of Images ... 152
3.7.1 Visual Interpretation of Thermal Image Data ... 154
3.7.2 Visual Interpretation of Radar Image Data ... 155
3.8 Maps and Map Reading ... 157
3.8.1 Map Projections ... 157
3.8.1.1 Definition of the Mathematical Shape of the Portion of the Earth ... 157
3.8.1.2 Specify How the Curved Surface of the Earth is to be Unfolded onto a Flat Sheet ... 158
3.8.2 Mapping Systems and Map Types ... 163
3.8.3 Map Co-ordinates and Bearings ... 165
3.8.4 Establishing One's Location on a Map ... 167
3.8.5 Map Reading on a Topographic Map ... 168
3.8.6 Terrain Classification ... 170
Further Reading ... 171
References ... 171

Chapter 4
Image Processing ... 173
4.1 Overview ... 173
4.1.1 Pre-Processing ... 174
4.1.2 Enhancement ... 175
4.1.3 Classification ... 175
4.1.4 Estimation ... 176
4.1.5 Temporal Analysis ... 177
4.2 Statistical Considerations ... 179
4.2.1 Probability Density Functions ... 180
4.2.1.1 Binomial Distribution ... 182
4.2.1.2 Normal Distribution ... 182
4.2.2 Correlation ... 183
4.2.3 Statistical Characteristics of Satellite Scanner Data ... 185
4.2.4 Measures of Distance ... 189
4.2.5 Shannon's Sampling Theorem ... 190
4.2.6 Autocorrelation and Variograms ... 191
4.2.7 Frequency Domain ... 193
4.2.7.1 Scaling ... 196
4.2.7.2 Shifting ... 196
4.2.7.3 Convolution ... 196
4.2.8 Least Squares Method of Fitting ... 196
4.3 Pre-Processing of Image Data ... 201
4.3.1 Introduction ... 201

4.3.2 Rectification ... 203
4.3.2.1 Theoretical Basis for Rectification ... 203
4.3.2.2 Correction for Systematic Errors ... 204
4.3.2.3 Fitting Image Data to Ground Control ... 206
4.3.2.4 Resampling the Image Data ... 209
4.3.2.5 Windowing and Mosaicing ... 212
4.3.2.6 Rectification in Practice ... 213
4.3.3 Radiometric Calibration ... 215
4.3.4 Atmospheric Correction ... 216
4.3.4.1 Use of a Linear Model for Atmospheric Correction ... 218
4.3.4.2 Atmospheric Correction Using Atmospheric Models ... 220
4.4 The Enhancement of Image Data ... 221
4.4.1 Radiometric Enhancement ... 221
4.4.1.1 Display of an Image ... 222
4.4.1.2 Pseudo-Colour Density Slice ... 223
4.4.1.3 Linear Enhancement ... 224
4.4.1.4 Non-Linear Enhancements ... 226
4.4.1.5 Piecewise Linear Stretch ... 227
4.4.1.6 Histogram Equalisation ... 228
4.4.2 Spectral Enhancements ... 228
4.4.2.1 Ratioing ... 229
4.4.2.2 Orthogonal Transformations ... 230
4.4.2.3 Vegetation Indices ... 233
4.4.2.4 Fourier Transformation ... 236
4.4.3 Spatial Transformations of Image Data ... 238
4.4.3.1 Measurement of Texture ... 239
4.4.3.2 Edge Detection ... 242
4.4.3.3 Removal of Regular Noise in Image Data ... 246
4.4.3.4 Analysis of Spatial Correlation: The Variogram ... 247
4.4.3.5 Image Segmentation ... 249
4.4.3.6 Object Patterns and Object Sizes: The ALV Function ... 252
4.4.4 Temporal Enhancements ... 255
4.4.4.1 Temporal Enhancement ... 256
4.4.4.2 Principal Components ... 256
4.4.4.3 Temporal Distance Images ... 256
4.4.4.4 Fourier Analysis of Hypertemporal Data ... 257
4.5 Analysis of Mixtures or End Member Analysis ... 258
4.5.1 Linear End Member Model ... 259
4.5.2 Characteristics of the Linear End Member Model ... 263
4.5.3 Identification of End Members ... 264
4.5.4 Implementation of the Linear End Member Algorithm ... 265
4.6 Image Classification ... 265
4.6.1 Principles of Classification ... 265
4.6.2 Discriminant Function Classifiers ... 270
4.6.2.1 Development of the Maximum Likelihood Classifier ... 271
4.6.2.2 Summary ... 275
4.6.2.3 Characteristics of the Discriminant Function Family of Classifiers ... 275
4.6.2.4 Implementation of the Maximum Likelihood Classifier ... 276
4.6.3 Fuzzy Classifiers ... 277
4.6.4 Neural Network Classifiers ... 278

4.6.5 Hierarchical Classifiers 281
4.6.6 Classification Strategies 282
4.6.6.1 Types of Classes 283
4.6.6.2 Selecting Classes and Classifiers 283
4.6.6.3 Improving Interclass Discriminability 284
4.6.6.4 Cost Minimisation 285
4.6.6.5 Field Data in Classification 286
4.6.6.6 Use of Different Classification Strategies 286
4.7 Clustering 288
4.7.1 Clustering Criteria 288
4.7.1.1 Minimisation of the Variance 288
4.7.1.2 Maximise the Divergence 290
4.7.2 Clustering of Training Data 290
4.7.3 Strategies for Clustering 290
4.7.3.1 Reduction of the Cluster Distributions 290
4.7.3.2 Increase of the Between-Cluster Distances 291
4.8 Estimation 291
4.8.1 Introduction 291
4.8.2 Development of Regression Estimation Models 292
4.8.3 Application of Regression Estimation Models 292
4.8.4 Development of Interpolation Estimation Models 294
4.8.5 Estimation Based on Physical Models 295
4.9 Analysis of Hyper-Spectral Image Data 296
4.9.1 Introduction 296
4.9.2 Vegetation Mapping 296
4.9.3 Fitting of Spectra 297
4.10 Analysis of Dynamic Processes 297
4.10.1 Introduction 297
4.10.2 Time Series Analysis of Image Data 299
4.10.2.1 Removal of the Seasonality 299
4.10.2.2 Analysis 301
4.10.3 Comparison of Two Time Series 303
4.10.4 Analysis of Spatio-Temporal Dynamic Processes 305
4.11 Summary 305
Further Reading 307
References 307

Chapter 5
Use of Field Data 309
5.1 The Purpose of Field Data 309
5.1.1 Definition and Description of Field Data 309
5.1.2 Role and Types of Field Data 310
5.1.3 Accuracy and Reliability 313
5.2 Collection of Field Spectral Data 315
5.2.1 Purpose of Collecting Field Spectral Data 315
5.2.2 Measurement of Field Spectral Data 315
5.2.2.1 Method 1: The Direct Measurement of Reflectance 316
5.2.2.2 Measurement of Reflectance Factors 318
5.2.3 Considerations in Collecting Field Spectral Data 320
5.2.3.1 Need for Representative Data 320
5.2.3.2 Need for Lambertian Control Surfaces 320

5.2.3.3 Effect of Non-Lambertian Surfaces on Reflectance 320
5.2.3.4 Impact of Clouds on Measurement of Reflectance 321
5.2.4 Collection of Other Data With Spectral Data 322
5.2.4.1 Ability of Spectral Data to Estimate Selected Physical Parameters 322
5.2.4.2 Need for Representative Physical and Spectral Data 322
5.2.4.3 Impact of Variations in Canopy Reflectance on Derived Models 325
5.2.4.4 Implementation of Models in Airborne and Space Borne Systems 326
5.2.5 Construction of Models from a Set of Related Spectral and Field Data 326
5.3 Use of Field Data in Visual Interpretation 330
5.3.1 Identification 330
5.3.2 Interpretation 331
5.3.2.1 *CLASS A* Errors or Errors of Non-Identification 332
5.3.2.2 *CLASS B* Errors or Errors of Mis-Identification 332
5.3.2.3 *CLASS C* Errors or Errors of Mis-Interpretation 332
5.3.2.4 *CLASS D* Errors or Errors of Non-Interpretation 332
5.4 Use of Field Data in the Classification of Digital Image Data 333
5.4.1 Classification with the Normal Classifiers 333
5.4.1.1 Classification Then Verification 333
5.4.1.2 Field Data Collection Then Classification 334
5.4.2 Classification Using the Mixture Model 335
5.4.2.1 Verify That the Class Data Occupy a Linear Domain 335
5.4.2.2 Assist in Defining Node Response Values 335
5.5 Stratified Random Sampling Method 335
5.5.1 Delineation of Strata 336
5.5.2 Determination of the Sampling Fraction and the Number of Samples 336
5.5.3 Selection of Samples 342
5.5.4 Measurement of Samples 344
5.6 Accuracy Assessment 345
5.6.1 Role of Accuracy Assessment 345
5.6.1.1 Relevance 346
5.6.1.2 Representative of the Population 346
5.6.1.3 Easily Understood and Usable 346
5.6.1.4 Can be Related to Other Information 346
5.6.2 Comparison of Field Data with Classification Results 347
5.6.2.1 Classification Accuracy 347
5.6.2.2 Accuracy of Identifying Production Units 352
5.6.2.3 Boundary and Area Accuracy Assessment 353
5.6.3 Use of Field Data in Estimation 353
5.7 Summary 353
Further Reading 354
References 354

Chapter 6

Geographic Information Systems 355
6.1 Introduction to Geographic Information Systems 355
6.2 Data Input 360
6.2.1 Databases and Attribute Data 360

6.2.2 Creation of Spatial GIS Layers by Digitising from an Existing Map or Image ... 363
6.2.2.1 Manual Digitising on a Viewing Screen ... 365
6.2.2.2 Manual Digitising by Use of a Tablet or Table ... 366
6.2.2.3 Scan Digitising ... 369
6.2.3 Field Collected Data and Observations ... 370
6.2.4 Information from Image Data ... 372
6.2.4.1 Quadtree Data Structures ... 373
6.2.4.2 Run Length Encoding ... 373
6.3 Simple Raster Data Analysis in a GIS ... 373
6.3.1 Displaying Data ... 374
6.3.1.1 Name of the Layer ... 374
6.3.1.2 Type of Data to be Displayed ... 374
6.3.1.3 Colour Table to be Used ... 375
6.3.1.4 Scale of the Display and/or the Portion of the Whole Layer That is to be Displayed ... 376
6.3.2 Overlaying Layers of Data on the Screen ... 376
6.3.3 Combining Layers, Numerically and Logically ... 377
6.3.4 Filtering and Neighbourhood Analyses ... 381
6.3.5 Distances, Cost Surfaces, Least Cost Pathways and Contextual Analysis ... 383
6.3.5.1 Least Cost Pathways ... 385
6.3.5.2 Context Operators ... 385
6.3.6 Statistical Analysis ... 386
6.4 Vector GIS Data Analysis Functions (Susanne Kickner) ... 388
6.4.1 Selection ... 388
6.4.1.1 Selecting by Attribute ... 389
6.4.1.2 Selecting by Location ... 391
6.4.2 Dividing and Joining Areas ... 394
6.4.3 Types of Spatial Overlay ... 395
6.4.3.1 Intersection ... 396
6.4.3.2 Union ... 397
6.4.3.3 Identity ... 397
6.4.3.4 Erase ... 397
6.4.3.5 Update ... 398
6.4.3.6 Clip ... 399
6.4.4 Proximity Analysis ... 399
6.4.4.1 Near ... 400
6.4.4.2 Buffer Creation ... 400
6.5 Data Management in a GIS ... 400
6.6 Advanced Analysis Techniques in a Vector GIS — Network Modelling (Susanne Kickner) ... 403
6.6.1 Topology in a Network ... 404
6.6.2 Address Geocoding ... 405
6.6.3 Path Finding in Vector GIS ... 405
6.6.4 Location–Allocation ... 407
6.6.5 Gravity Models ... 408
6.7 Advanced Raster Analysis Techniques in a GIS ... 409
6.7.1 Geostatistics ... 409
6.7.2 Map Algebra and Script Languages ... 410
6.7.2.1 Compute an NDVI Image ... 413
6.7.2.2 Compute an FPAR Image ... 413

6.7.3 Surface Analysis ... 414
6.7.3.1 Linear Interpolation Using Triangulated Irregular Networks ... 415
6.7.3.2 Curve Fitting ... 417
6.7.3.3 Kriging ... 418
6.7.4 Analyses of Cross-Tabulation Tables ... 425
6.7.5 Clump Analysis ... 426
6.7.6 Zonal Analysis ... 426
6.8 Modelling in a GIS ... 426
6.8.1 What is Modelling? ... 426
6.8.1.1 Cellular Automata ... 430
6.8.1.2 Agent-Based Models ... 430
6.8.2 Modifiable Areal Unit Problem ... 432
6.8.3 Measures of Global and Local Homogeneity/Heterogeneity ... 435
6.8.4 An Example of a "Top-Down," Regression Based Model — The Universal Soil Loss Equation ... 435
6.8.5 Modelling of Ecological Systems ... 441
6.9 Uncertainty in GIS Analysis ... 443
6.9.1 Errors within a Layer and Error Statements ... 444
6.9.2 Propagation of Error in Combining Layers ... 446
6.9.2.1 Propagation of Error in Numerical Analysis ... 446
6.9.2.2 Propagation of Error in Logical Operations ... 448
6.9.3 Sensitivity Analyses ... 449
6.9.4 Decision Making under Uncertainty ... 450
6.9.4.1 Bayes ... 451
6.9.4.2 Dempster–Shafer ... 451
6.10 Presentation in a GIS ... 451
6.11 Three-Dimensional GIS ... 453
Additional Reading ... 453
References ... 454

Chapter 7
The Analysis and Interpretation of Vegetation ... 455
7.1 Introduction ... 455
7.1.1 Energy Budget ... 456
7.1.2 Hydrologic Cycle ... 458
7.1.3 Carbon Cycle ... 458
7.1.4 Nutrient Budgets ... 459
7.2 Regional Vegetation Mapping and Monitoring ... 463
7.2.1 Landcover ... 464
7.2.2 Estimation ... 465
7.3 Signatures of Vegetation ... 465
7.3.1 Spectral Signatures (λ) ... 466
7.3.2 Spatial Signatures (x, y, z) ... 467
7.3.3 Temporal Signatures (t) ... 467
7.3.4 Angular Signatures ... 469
7.3.5 Polarisation Signatures ... 469
7.4 Modelling Canopy Reflectance ... 470
7.4.1 Introduction ... 470
7.4.2 Leaf Reflectance Models ... 475
7.4.2.1 Plate Models ... 475
7.4.2.2 Ray Tracing Models ... 479

7.4.3 Canopy Reflectance Models ... 480
7.4.4 Empirical Models ... 481
7.4.5 Turbid Medium Models ... 481
7.4.5.1 Theoretical Basis for These Models ... 481
7.4.5.2 Suits Model ... 486
7.4.6 Geometric-Optic (GO) Models ... 491
7.4.7 Ray Tracing Models ... 492
7.4.8 Radiosity or Computer Graphics Based Models ... 493
7.4.9 Linear Semi-Empirical Approximations to the Physical Models ... 493
7.5 Estimation of Vegetation Parameters and Status ... 497
7.5.1 Introduction ... 497
7.5.2 Regression Models ... 498
7.5.3 Empirical Interpolation ... 500
7.5.4 Inversion of Canopy Reflectance Models ... 500
7.5.4.1 Linearisation for Least Squares ... 502
7.5.4.2 Levenberg–Marquandt (L–M) Method of Solution ... 503
7.5.5 Estimation Based on Linear Approximations to the CR Models ... 505
7.6 Classification of Vegetation ... 505
7.6.1 Incorporation of Environmental Knowledge into the Classification Process ... 507
7.6.2 Incorporation of Environmental Data into the Classification Process ... 508
7.7 Analysis of Vegetation Phenology ... 509
7.7.1 Germination ... 510
7.7.2 Seedling Stage ... 510
7.7.3 Tillering ... 510
7.7.4 Stem Elongation ... 510
7.7.5 Booting Stage ... 510
7.7.6 Heading Stage ... 510
7.7.7 Flowering or Anthesis Stage ... 511
7.7.8 Milk Stage ... 511
7.7.9 Dough Development Stage ... 512
7.7.10 Ripening Stage ... 512
7.8 Concluding Remarks ... 517
Additional Reading ... 518
References ... 518

Chapter 8
The Management of Spatial Resources and Decision Support ... 521
8.1 Introduction ... 521
8.2 Nature of Management of Rural Physical Resources ... 523
8.2.1 Introduction ... 523
8.2.2 Levels of Management ... 523
8.2.2.1 Strategic Management ... 523
8.2.2.2 Regional ... 524
8.2.2.3 Operational ... 525
8.2.3 Role of Remote Sensing and GIS in Resource Management ... 527
8.2.3.1 Strategic Management ... 527
8.2.3.2 Regional Management ... 527
8.2.3.3 Operational Management ... 528
8.3 Process of Decision Making in Resource Management ... 529
8.3.1 Selecting an Appropriate Model of Events ... 529
8.3.2 Parameterise the Model ... 529

8.3.3 Identify Decision Choices ... 530
8.3.4 Making the Choice ... 530
8.3.5 Types of Models and Decisions ... 530
8.4 Decision Support Systems and Their Role in Decision Making ... 531
8.4.1 Definitions ... 533
8.4.2 Multi-Criteria Evaluation ... 535
8.4.3 Multi-Objective Evaluation ... 539
8.4.3.1 Legal Issues in the Use of Data and Information ... 540
8.4.4 Use of Data Supplied by a Third Party for Use by the Analyst ... 541
8.4.4.1 Copyright ... 542
8.4.4.2 Legal Protection of Databases ... 542
8.4.4.3 Patents ... 543
8.4.5 Protection of Confidentiality of Data about Third Parties ... 543
8.4.6 Use of Information Derived from the Analysis of Data ... 544
8.5 Other Project Management Tools ... 546
8.6 Concluding Remarks ... 546
Further Reading ... 547
References ... 547

1 Introduction

1.1 THE GOALS OF THIS BOOK

There is clear, readily accepted evidence of resource degradation in many parts of the globe, and there are many other examples of claimed resource degradation that have yet to receive general acceptance. What are the cause or causes of this degradation? The underlying causes are to do with the shear level of pressure that is being placed on the resources of the globe by the combination of the number of people, their expectations in terms of goods and services and our technical capacity to utilise those resources to meet this demand. The level of degradation is also to do with our levels of consumption and wastage associated with production, distribution and sale of products. Some of this degradation results from inappropriate land use practices both in the use of the land for appropriate purposes and the use of inappropriate practices on the land. Thus, lands with steep slopes continue to be used for cropping even though extensive erosion results, and even moderately sloped land is cultivated with furrows down the slope by some farmers, again exacerbating the soil erosion problem. Our land use allocations and the practices adopted on those lands continue to be the major factors in exacerbating land degradation. It follows that improved land allocation and improved land using practices will significantly reduce land degradation. Changing land allocations and land using practices are management activities and so the way that we manage our rural lands is a major factor in the fight to reduce land degradation and to strive to achieve the goal of sustainable land using practices.

The title of this book was chosen to convey its dominant theme: *to understand the role of, as well as to develop and use, spatial information systems for the proper management of physical resources*. There are a number of critical components to such Resource Management Systems including remote sensing, geographic information systems (GIS), modelling resource management and decision support. This text covers the principles and practices associated with these components as well as their integration into a system so as to emphasise the holistic way in which the management of resources is going to evolve, if we are to achieve the twin goals of maximising productivity and maintaining the resource base.

In some way these physical resources may be managed adequately using current tools and techniques; however, this is rarely the case if the second criterion of resource maintenance is adopted. How much does resource degradation have to do with resource management? Does our method of management, the quality of that management, the nature of the resource management tools and how they are used to influence the level of resource degradation? This chapter explores some of these issues:

- Exploring the status of physical resources, specifically, “Is there a reason to be concerned?”
- Moving on to the reasons why this situation exists, or “What is the nature of this concern?”
- Considering which types of these concerns can be addressed by the use of better management tools or techniques, or “How can better tools and techniques help deal with these issues?”
- Addressing the question of how can resource management use these tools and techniques, or “What are the characteristics of resource management that may be part of the problem and how can these tools and techniques address some of these imitations?”

The chapter then moves on to consider the nature of the information that is required for good resource management, and how geographic information fits into this role. It finishes with a description of how the book is structured to assist the reader in understanding the need and role of Resource Management

Information Systems (RMIS) and then in developing the skills that they need to meet the goal of developing and implementing these systems.

1.2 THE CURRENT STATUS OF RESOURCES

There is widespread recognition that the finite resources that constitute the Earth — its soils and land covers, its oceans and its atmosphere — are being consumed at such alarming rates that they have already become or will become seriously depleted in the foreseeable future. While at the same time, we are also producing wastes faster than they can be absorbed and broken down by the natural ecosystems upon which we depend, and that supply many of the resources we use. There are many examples of this situation and current responses to them. Three of them will be considered here.

1.2.1 The Ozone Hole

One of the most notable examples of degradation and response at the global level concerns the identification and response to the existence of the ozone hole. The British Antarctic Survey first noticed the dramatic losses of ozone over the Antarctic in the 1970s. When the first instruments were set up to take accurate readings of the ozone levels over the Antarctic in 1985, the readings were so low that the scientists thought that there must be something wrong with their instruments. They sent them back to be replaced, and it was only when the replacement instruments gave similar readings that the results were accepted.

Ozone forms a layer in the stratosphere that is naturally thinnest at the equator and thickest over the poles. It is formed when ultraviolet light from the sun strikes the atmosphere. Some of the ultraviolet light strikes oxygen molecules in the atmosphere, splitting them into two oxygen atoms.

$$O_2 \triangleright O + O$$

The oxygen atoms are unstable in the atmosphere and will quickly combine with other chemicals that they come in contact with. They are most likely to either combine with another oxygen atom, thereby just reversing the equation, or to combine with an oxygen molecule to form ozone.

$$O + O_2 \rightarrow O_3$$

Ozone absorbs ultraviolet light and so the ozone in the atmosphere filters out most of the ultraviolet light before it reaches the surface of the Earth. All plants and animals are vulnerable to high levels of ultraviolet light, and so the absence of ozone will create very dangerous conditions for all plants and animals. The dramatic reductions in ozone that were occurring were soon recognised as being a serious threat to life on Earth. As a consequence, global agreement on a response was achieved at the Montreal Accords in 1987 that planned to halve the production of the offending chemicals the were causing the loss of ozone by 2000. In fact this commitment has been exceeded with most countries stopping production of the chemicals, except for minor medical needs, by 1995. Currently, it is expected that the ozone hole will have disappeared by about 2045.

Man-made chemicals that contain chlorine or bromine can, when released into the atmosphere and under certain conditions, decompose releasing the chlorine or bromine that reacts with the ozone to form oxygen. These atmospheric conditions are much more likely to occur over the Antarctic continent than other parts of the globe and hence the appearance of the ozone hole over Antarctica.

It could be said that the ozone issue has been a successful environmental fight. However, it was a very simple fight; there was an obvious culprit, the solution was clearly identifiable and those dependent on this industry were sufficiently small in number so that stopping production did not have significant economic implications for national budgets.

Most environmental issues are not this clear cut. There are often a number of causes. Some of those causes are man induced and some may be due to natural processes. It is often difficult to identify all the actions by man and the natural processes which are contributing to the degradation, particularly where the degradation is due, at least in part, to complex loop and interconnection mechanisms. As a consequence it is often difficult to identify all the culprits and allocate responsibility. There are often a number of potential solutions, many of which are partially or even totally in conflict, either amongst themselves or with solutions to other issues. Finally, it is often the case that some of the interested parties have a large investment, of one form or another, that may be at risk of being lost or degraded depending on the solutions that are adopted. When this occurs, then the economic implications need to be taken into account in developing a solution.

1.2.2 Water-Borne Soil Erosion

The basic principles of water-borne soil erosion are conceptually well understood by most land managers. Rainfall, hitting the Earth's surface either directly or as drops from leaves, tends to dislodge small amounts of soil from the surface and mobilise them into the surface flow. The rain accumulates into runoff, and this water tends to both carry the water-borne sediment down slope, as well as collecting more sediment from the soil surface. The size, density and volume of soil particles that are dislodged from the soil surface and then carried away in the surface water depend on the energy in the water droplets in the rain and in the surface flow. By far, the greatest impact is due to the droplets hitting the surface of the Earth, hence the greatest single factor in dislodging and mobilising soil particles is the impact of the rain on the surface. The effect of this energy is reduced by vegetation and any other matter that absorbs most of the impact energy of the rain that it intercepts, so that vegetative cover and mulch are important factors in reducing soil erosion. The energy in the surface water affects the capacity of the flow to carry the particles away from the site of displacement. As the volume and the velocity of the water increase, the capacity of the water to hold the sediment increases. The net result is an increasing load of sediment being carried by the water as its volume and/or velocity increases. Once the water starts to loose energy, most typically when it starts to slow down as the slope decreases or it is resisted by denser vegetation, it will loose the capacity to carry sediment. The heavier sediments, such as gravel and sand, are deposited first, followed by the finer sediments such as clay and silt.

Despite this well-established understanding of the process, water-borne soil erosion still continues at a very high rate. The International Soil Reference and Information Centre (http://www.isric.nl/) in Holland conducted a global mapping of soil degradation in 1991 and concluded that water-borne soil erosion is the single most important factor affecting the soils of the globe. They estimated that 56% of the global soil degradation was due to soil erosion. It has been estimated that 200 years of farming in the United States has meant that most of the lands in the United States (http://www.seafriends.org.nz/enviro/soil/erosion.htm) have had 25–75% of the topsoil lost. Some have lost so much as to be unproductive. They have further estimated that soil formation takes place at about 25 mm every 1000 years or about 0.6 tons/ha/year. This compares to the 10–40 tons/ha/year that is lost from the so-called sustainable agricultural production systems that do not use soil tillage at all, the amount depending on the soil slope. Clearly agriculture, in all the forms currently practised, causes levels of soil erosion that are not sustainable in the long term.

One of the problems with soil erosion is that it appears to be happening very slowly. The effects may be difficult to see over a period of 30 years or so. This slowness is exacerbated by the way that the application of fertiliser tends to mask the impacts of soil erosion on productivity. Thus, farmers, faced with a competitive market situation, unable to see the significant impact of erosion and having this impact masked by the use of fertiliser, are often reluctant to take appropriate remedial and preventative actions. Soil erosion has always occurred. It is part of the natural weathering processes that wear down landforms as they are created. What is critical is the significantly higher rates of soil erosion that have been introduced by agriculture and other land using activities.

It should be pointed out that this amount of soil may be lost, but some of it is recovered as deposits on flood plains and some of it ends up as nutrients in the sea. The deposits on flood plains may well be more productive than the areas that lost the soil, due to our capacity to irrigate flood plains at lower costs than most other areas, the suitability of flood plains for agriculture and the concentration of fertile soils in the flood plains. But only a small percentage of that which is caught in this way can be used for agriculture since most of the alluvium is too deep to be of use. The sediment that goes into the sea provides nutrients to the coastal zone, but again, too much of it can destroy many forms of marine life, as well as being buried under subsequent layers of silt.

Even though the processes of soil erosion have been well understood for more than 50 years, soil erosion is clearly a continuing source of soil degradation. Why is this the case? Are the problems technical, economic, social or political? In the sense that agricultural research has not found an alternative to cultivation that is sustainable and is acceptable to most farmers around the globe, the problem is technical. That the process is slow so that the farmers are only partially aware of the scale of the problem, and how its impact varies considerably with management practices, primarily because of the differences in landcover with the different practices, the problem is technical. There are alternatives to cultivation including no-tillage cultivation and stepping away from the monoculture ethic that dominates agriculture. But neither alternative has been widely adopted because they are, for many situations more expensive than cultivation. So, in this sense the problem is economic and political.

Sustainable means that the process to which it refers can be continued in the same way and at the same level into the foreseeable future. Sustainable agriculture has been defined (Ikerd, 1990), as resource conserving, socially supportive, commercially competitive and environmentally sound. Sustainable agriculture thus has three main foci:

- Ecological sustainability
- Economically sound
- Socially supportive

Ecological Sustainability. This requires that it be resource conserving, in harmony with the environmental processes that operate in the area and maintains biodiversity. If it is resource conserving then it will be at lower economic and environmental cost, it will not result in wastes that cannot be used and consumed within the ecological cycles that are in operation and it will not remove resources permanently from the environment. If it is in harmony then the processes involved in production are harmonised with the ecological processes in the environment and the wastes become part of the food chain in a way that contributes to those ecological processes. If it supports biodiversity then it supports the maintenance of a rich complexity of life.

Economic viability. Capitalism has been shown to be a good, but incomplete or inadequate mechanism for the conduct of normal trading business in our society. Its strengths include its resource conserving nature, its independence of political power and its traceability through society. It tends to be resource conserving because all resources have a cost and one of the main goals of capitalist processes is to minimise the costs of production. Independence of political power means that the market is freer of political manipulation and corruption than most alternative systems that have been tried. Its traceability means that efficient and equitable taxation systems can be established that ensure that all members of society can carry their correct proportion of the taxation burden and it provides the basis of accurate quantifiable information on cash flows throughout society that can form the basis of more sound financial management than is possible without this information.

However, it is inadequate because it does not adequately value resources that are not owned by individuals or by organisations in the commercial system (the problem of the commons), it does not take into account future implications of proposed or actual actions and often it does not properly address the costs and benefits of an action to parties outside of the trading, particularly where the relationship between these parties and the trading has non-commercial aspects.

One of the fundamental characteristics of capitalism is its need to grow. The bottom line for every business is to show that it has grown over the last reporting period. Yet we are striving towards sustainable land using practices and systems. The need to find a balance between the aggressive growth goals of capitalism on the one hand and the goals of balance and continuity implicit in sustainability on the other is one of the big challenges that our society is facing.

Socially supportive. Sustainable systems should treat all livings things with reasonable respect and care. Animals should not be kept or slaughtered under conditions that are cruel in any way. Sustainable practices should not be ethically or morally reprehensible. Thus, many practices in agriculture that cause pain and anguish to the animals do not have a place in sustainable agricultural systems.

1.2.3 Loss of Biodiversity

The third aspect of modern resource management to which I wish to refer is biodiversity. Diversity is defined as the variety of conditions that can exist within the object of attention. High diversity means great variety. The biological scientific community currently recognises three types of biodiversity: habitat, genetic and species (http://www.defenders.org/).

Habitat diversity refers to the variety of places where life exists — coral reefs, old-growth forests in the Pacific Northwest, tall grass prairie, coastal wetlands and many others. Each broad type of habitat is the home for numerous species, many of which are utterly dependent on that habitat. When a type of habitat is reduced in extent or disappears, a vast number of species are placed under pressure and may disappear.

Genetic diversity is the variety in the genetic pool of the species, and this is related to the number of populations that exist in the species. Species live in population clusters. Generally, the individuals in one population will breed with another individual in the same population, simply because of the distance between populations, although they can, and will mate with individuals in other populations. Populations only diverge into different species when individuals will no longer mate across the population boundaries, because of genetic differences between the individuals. The genetic diversity within a species is primarily the variety of populations that comprises it. Species reduced to a single population (like the California condor) generally contain less genetic diversity than those consisting of many populations. Song sparrows, found over much of North America, occur in numerous populations and thus maintain considerable genetic diversity within the species.

Species diversity refers to the diversity of species that exist. Thus, one can consider the species diversity within a habitat, a continent or the globe. There are about one and a half million identified and classified species on Earth, but we know that many unnamed species exist. It is estimated that the total number of species is probably between 5 and 15 million. Most of the evidence for numerous unnamed species comes from studies of insects in tropical forests: when the canopy of a tropical tree is fumigated and all the dead insects are collected, large numbers of hitherto unknown insects are frequently collected.

Species are categorised as *variety: species: genus: family: order: class: phylum: kingdom*. Thus the categories for humans are

Species	Homo sapiens
Genus	Homo
Family	Hominidae (Man and apes)
Order	Primates
Class	Mammalia
Phylum	Chordata (vertebrates)
Kingdom	Animal

The relatively small percentage of the species that are actually known, estimated to be between 10 and 30% of the total number of species, means that it is impossible to accurately estimate the decimation that is actually occurring. Biologists estimate that about 20% of the birds species have become extinct over the last 2000 years and that about 11% of the remaining known 9040 species are threatened with extinction. But these estimates cannot start to take into account the vast majority of species that we do not know about. Since these species are unknown, they are likely to be animals of very small size, to be either in very small populations or to exist in small numbers, or to exist in unique habitats such as the deep ocean. Some of these conditions mean that many of these unknown species could be very vulnerable, particularly those that exist in small numbers and live in unique habitats if these habitats are limited in scope, as many of them will be. As a consequence, the extinction rate among the unknown species may well be higher than amongst the known species.

In 1992 the World Resources Institute (http://www.wri.org/index.html) proposed that there are seven causes for the loss of biodiversity:

1. Population growth
2. Increased resource consumption
3. Ignorance of species and ecosystems
4. Poorly conceived policies and poor resource management
5. Global trading systems
6. Inequities in resource distribution
7. Low valuation of biodiversity in economic systems

What are the implications of loss of biodiversity? Whilst it is far from clear what all of the implications are, and the significance of these impacts, some are understood:

1. *Higher levels of Ecological instability*. The lower the biodiversity in an area, the more vulnerable the area is to predation or attack by invasive plants or animals, and the less likely that the area can adapt to these attacks and to changes in environmental conditions. Areas of low biodiversity are agricultural cropping areas and cities, where, in both cases, the environment is dominated by one species. The presence of large numbers of a species in one location is attractive to other species that can use that species for food, as a host, or for some other reason. This is clearly shown in the responses of specific insect populations to the existence of monocultures in their vicinity that are beneficial to them in some way. Nature, of itself, promotes or encourages biodiversity, as can be seen by the growth of biodiversity after mass species destructions in the past. But man, with his significant capacity to influence the biosphere, is often inhibiting this process.
2. *The loss of species of benefit to man*, including the possibility of new drugs and medicines, and better food sources.

It is generally accepted that high levels of biodiversity usually indicate complex ecological systems. Complex ecological systems contain species that overlap in the domains of influence, so that the destruction of one species leaves others that can step in, albeit at not quite the same level of efficiency and effectiveness. Thus, complex ecological systems with high levels of biodiversity represent systems that are capable of high levels of adaptation to and absorption of forces of change. Such systems are inherently stable over a wide range of conditions of the forcing functions that are affecting that ecological system. However, even such stable systems will degrade and eventually collapse if the level of force applied to the ecological system exceeds that capacity for absorption of the ecological system for long enough. Any debate on biodiversity adequacy or inadequacy must therefore hinge on the sustainable level of adaptation of the system. The sustainable level of adaptation does not imply no change, and so it allows for changes in the species composition of an ecological system, but it does imply that these changes are occurring through sustainable adaptation and not due to unsustainable destruction of species.

Monocultures are ecological systems with very low biodiversity. Stability is only maintained in man-made monocultures by the application of significant levels of resources in the form of insecticides, herbicides and physical management. Agriculture and forestry are thus major factors in reducing biodiversity, but they are not the only factors. Many other activities of man affect the biodiversity of an area. Hunting and the introduction of new species also affect biodiversity, certainly in the short term, but whether they do in the long term depends very much on the nature of the environments being dealt with and the other pressures being exerted on those environments. The Australian Aboriginals are thought to have introduced both fire and the dog into Australia. They used both in their hunting of animals for food, clothing, utensils and shelter. Both had a significant impact on the ecology on the Australian environment, however, the rate of impact was not too great for the communities to adapt, although it may have been too great for specific species to adjust and they have subsequently become extinct. This is the fundamental difference between the impact of the Aboriginals and white man on the Australian environment. In the former case the impact was not too large for the environment to adapt and change, even though some species could not adapt and became extinct in the process. In the latter case the level of pressure is far too high for the environment to adapt in the time available.

Thus, evaluation of the significance for the loss of biodiversity can be very complex. There are usually a variety of causes, where these causes can vary in significance over time and space, and there are usually a variety of solutions, where the more obvious solutions that may include reestablishment of the status quo prior to the impact, may not be the best solution, nor even viable. Often the solutions will be in conflict, so consideration and choice between solutions involve taking into account the impacts on others who are not directly involved in the processes being considered.

There are many forms of resource degradation, with only three being briefly considered here. All of them are, in some way, created or exacerbated by man. Often there are multiple causes where the influence of a cause on the degradation can vary spatially and temporally. It is often difficult to properly assess all the causes of degradation and their relative significance. The impact of degradation usually occurs at different locations and times to the initiation of the degradation. Degradation thus often affects different communities to those causing the degradation. It can thus be difficult to evaluate the effects of degradation on an individual or a community. Finally, the proposed solutions can have impacts on both these groups, as well as other groups in society, where these impacts may not be exactly in proportion to their involvement with the degradation. Thus, the development of solutions that are satisfactory within society can also be very difficult and complex.

The range, level of severity and ongoing nature of many forms of degradation indicate that there is a significant cause for concern. With many, but not all forms of degradation, the basic principles underlying the degradation are well understood. However, the interdependencies between the degradation and the broader environment are often not well understood, just as the detailed understanding that is often necessary for good management is often not yet available.

1.3 THE IMPACT OF RESOURCE DEGRADATION

As resources decline, more resources, albeit of different kinds are used to maintain production. There are many examples of this process. In agriculture and forestry, if production declines, then more fertiliser, herbicide or pesticides are used, depending on the cause of the loss in productivity. In mining, when the ore becomes very deep, or of low quality, then production can only be maintained by the use of bigger machines, longer lines of production or more miners, or combinations of all three. As these inputs increase, so do the costs of production. However, if the resulting production is the same, then this means that productivity decreases, where productivity is defined as the amount of output for one unit of input.

Increasing inputs often masks the decline in production, so that the decline in productivity may not be obvious outside of the units of production. Even within the units of production, the decline may be gradual over time and may be masked by changes in management practices. As a consequence the implications of declining productivity are often very subtle, and may be well advanced before these implications are well understood. However, the units of production that are suffering degradation continue to suffer declining productivity relative to units of production that are not suffering a degrading resource base. This means that the units of production with a degrading resource base are becoming poorer compared to those not affected. They are becoming poorer in two ways:

- *Reduced wealth or loss of assets*. Low or declining productivity is reflected in the budgets of the affected units of production. As a result these units of production cannot sell their resource base at the same value as those units with higher productivity. This means that these units of production have a low or declining capital asset base, reducing the wealth of the owner, and reducing their capacity to borrow money, using the asset base as security.
- *Reduced income*. Lower productivity reduces the profit margins and hence the income. A lower income reduces the investment capacity of the business, further exacerbating the problem.

The same principles apply to the nation as to the individual unit of production within the nation, but the effects have historically been quite different. When a unit of production declines, then the owners become progressively poorer until such time as the unit is sold. Historically, with nations, when one became weak (or poor), then it becomes vulnerable to forced takeover or invasion. The degradation will have reduced national productivity. The ruling class are usually in the best position to resist this loss in productivity, shifting the burden for carrying it onto the poorer members of society. The result is a growing disparity between the rich and the poor, with the percentage of those in poverty increasing, and the level of poverty declining. This leads to frustration, anger and desperation when conditions become very bad. This weakening of the fabric of society, on top of the weakening economic conditions, makes the country vulnerable to internal or external takeover. This is one of the various causes for revolution or invasion.

History has shown that degradation of the resource base of a society can be a cause of the decline of that society. The Mayan society was a flourishing society in the central Yucatan Peninsular of Mexico from about 400 A.D. until about 900 A.D. At about this time the society suffered a serious and permanent decline. There is no evidence of massive destruction by invasion, as is the case with the Aztec civilisation in the valley of Mexico City. It is known that the Mayan civilisation was very dependent on irrigated agriculture. The Yucatan Peninsular is a limestone formation, so that the limestone would have allowed rainfall to permeate through the stone and away from the topsoil. Areas with these characteristics will have limited agricultural capacity without irrigation if rainfall is insufficient to maintain soil moisture in the root zone. However, the water that has drained down to the water table is accessible across most of the Yucatan Peninsula through bores since it is not too deep to remove in this way. The water is thus stored, ready for use for irrigation and for human and animal consumption. The same characteristic that makes the area unsuitable for non-irrigated agriculture makes it very suitable for irrigated agriculture. However, such limestone systems can have another disadvantage. If the surface water is polluted for some reason, then this pollution is readily carried down into the water table. If the groundwater becomes polluted then it cannot be used for any activity where the pollution in the water has a deleterious effect.

Whilst the actual reasons for the decline are not known, historians have ruled out the conventional ones of warfare and invasion. It seems reasonable to suggest that the Mayan society declined and then collapsed because of some form of environmental and institutional degradation, where these may well have been related. The irrigated agricultural system may have collapsed because of the inability of the Mayan society to maintain the monocultures on which their agriculture was based. Alternatively, the groundwater may have become polluted in ways that were harmful to the crops, to the people of society or to both. Either of these situations could have brought on institutional decline, which may have resulted in a decline in maintenance of the irrigation system, contributing to further declines in the production base of society.

The ancient societies of the Mesopotamian valleys were also dependent on irrigated agriculture. Extensive areas in these valleys are now salinised in the root zone or at the surface. If irrigation caused excessive salinisation in the root zone or on the surface, then the resulting decline may have been a factor in the decline and fall of these societies. When these lands started to become salinised, their productivity may have started to decline.

Most soils contain some sodic salts, and all plants can accept some sodic salts in their water. Many animals, including man, need some salt in their diet. Soils that have been beneath the sea can contain more sodic salt from this source. Another source of sodic salt is the atmosphere. When water is evaporated from the sea, some salt is carried aloft in this process. This salt is then carried on by the wind, and will eventually fall back to Earth. If it falls on the land, then it is deposited on the surface. Sodic salts are highly soluble, and so rainfall will dissolve the salt and carry it down into the soil. Some of it will be deposited within the soil layers, and some will end up in the groundwater. Eventually, a balance is achieved between the salt being deposited, the amount that is held in the soil profile and the amount that is being lost from transport within the groundwater or removal from the overland water flow. The higher the rainfall and the lower the evaporation in the area, the lower the amount of salt that is retained in the soil profiles in this balance and vice versa. As the level of salt increases, it favours species that are salt tolerant; as it increases further even these species cannot tolerate the levels of salt, and all vegetation dies.

Irrigation usually deposits water into the groundwater, because more water is applied than is used by the plants. This particularly applies to flood irrigation because of the difficulty fine tuning water allocations by means of flood irrigation, and to permanently flooded irrigation as is used with rice. In these situations the groundwater level rises, mobilising the salt in the soil horizons that have been saturated, making the groundwater more saline. If the groundwater approaches or breaks the surface, then this salt is carried into the root zone and to the surface. If there is sufficient salt in the groundwater, then the result is toxic levels of salt in the root zone and on the surface. This process may well have happened in Mesopotamia.

Currently, there are no realistic methods available for the removal of salt from the soil horizon of salinised soils other than for the relatively slow process of the natural flushing of the salt out of the soil horizons by rainwater. Clearly, this process is much faster in areas of high rainfall and low evapo-transpiration than it is in areas of low rainfall and high evapo-transpiration. It is no surprise that most of the salinisation problems are in those parts of the globe that experience low rainfall and high evapo-transpiration, such as Australia and Mesopotamia.

There are, of course, major differences between conditions as they now apply and those that were applied in earlier times. These differences take three forms. The first is the shear numbers of people right around the globe, and the pressure that this applies to the natural resources of the globe. Whereas with fewer people, there is the possibility of leaving some of the land to lie fallow for long periods, as the numbers increase, so the opportunities to leave the fallow land deceases. Thus, land has less and less opportunity to be left unused and for it to recover during this period. Population densities would have been as high, or higher, in some areas in the past than what they are now. However in the past, if these areas could not sustain their population, then the opportunity existed to migrate to other, less populous areas. This would have been the basis of some of the mass migrations in the past. However, this safety valve mechanism no longer exists since there are few areas that are significantly under-populated. This could be one of the reasons for resistance to immigration that exists in some countries around the globe.

The second major dimension is the advent of technologies that enable us to place much greater demands on the land. In both agriculture and forestry the advent of modern machinery has allowed fewer people to plant, manage and harvest larger areas in less time than in the past. Other advances have increased the yield per plant or per area, but with the costs of this being the withdrawal of more resources from the soil. This cost is partially offset by the use of other technologies that allow the application of nutrients to the soil, where these nutrients have been taken from other places around the globe. Still other technologies have improved our mobility, consuming resources in the process and requiring packaging in the case of foodstuffs, where that packaging then ends up as a waste product from our society.

The third major dimension is the advent of modern forms of information dissemination and transmission. Conditions on the land are not now exclusively the knowledge of those directly affected and a small elite who may have been aware of the problem. These conditions are now known throughout the society. One effect of this dissemination of information on the extent and degree of resource degradation is that society as a whole becomes involved in the issue, and society often takes on the responsibility for the maintenance of the resource base of the society. Thus, modern media is an active participant in the process of societies rising concern for and action in relation to the environment. Not only does this have implications for the protection of resources, but also for the way resources are viewed and managed in our society.

1.4 THE NATURE OF RESOURCE DEGRADATION

Resource degradation can be considered at least at two levels — at the process or regional and the local levels.

1. *At the regional or process level.* The region is defined as the area covered by the cause and the effects of the degradation. Most forms of degradation have a cause at one spatial and temporal set of coordinates and the effects are imposed at other spatial and temporal coordinates. Clearly, the size of the region is a function of the spatial extent of the cause and effect coordinates, and the temporal duration is a function of the time that it takes for the processes to occur. Thus, in the first example discussed above, the causes of the ozone hole come from the release of the chemical at all latitudes lower than about 75°, on the basis that there are negligible populations at higher latitudes. The effects are global, but are focused on latitudes higher than 75°. The temporal dimension is continuous due to the nature of the release. Remove the release of gases containing chlorine and bromine into the atmosphere and the hole will gradually disappear.

For water-borne soil erosion, the normal source of the erosion is cultivation within a watershed, and the deposition is within that watershed or the sea. So, watersheds would be reasonable regions to consider for water-borne soil erosion. It should be noted in passing that all other forms of soil degradation including wind-borne soil erosion and chemical pollution of the soil and groundwater cannot usually be dealt within watersheds, since the areas of the process for these other forms of degradation are not the watershed.

The complexity of the issue of biodiversity loss has been discussed above. If individual issues of biodiversity loss are addressed, then the process regions may be a habitat, or a cluster of habitats, where these can vary significantly in size depending on the characteristics of the species of interest. The issue of region of impact depends very much on the migratory patterns of the species of interest and their dependencies.

2. *At the unit of management or the local level.* While most forms of degradation have to be considered at the process or regional level, implementation will have to be at the unit of management or local level. If the process or regional level is smaller than the unit of management level, then the source and the effects of the pollution or degradation are contained within units of management and the individual manager holds the power to both introduce remedies and to reap the benefits. Unfortunately, this is not usually the case. Usually, the cause of the degradation are removed from the jurisdiction that has to deal with the effects, so that the manager who introduces the degradation

may not suffer all, or even some of the consequences of his or her actions. Sometimes the region or process area is larger than an administrative area within a country, or may even cross national boundaries. The difficulties of dealing with this situation has meant that many forms of degradation have taken a long time to be accepted by all parties, and then a solution found that is acceptable to all parties.

The community concern for natural resources and consequent pressure to implement sustainable practices requires responses at a number of levels:

- *The adoption of more sustainable tools, techniques and practices* at the field or the farm. Clearly significant savings in degradation can occur with the adoption of more resource conserving practices. However these, on their own, are likely to be insufficient, particularly if they are costly relative to the alternatives. It has, for example, been estimated (http://www.seafriends.org.nz/enviro/soil/erosion.htm) that no tillage agriculture still incurs losses of 10 to 40 tons/ha/year of soil compared to the 0.6 tons/ha/year of soil creation in the United States. This represents the technological component of the solution.
- *Placing more realistic values on many resources* and recognising both the fragility of the environment and its transitory nature. Many of our attitudes to natural resources arise from assumptions about their permanence and pervasiveness, neither of which is correct under the levels of resource use and demand that is occurring with current population and technology pressures. This represents the attitudinal component of the solution.
- *Improving the way we allocate and use resources* in a region so as to provide the most sustainable use of resources as possible within the region. Thus, some areas are suitable for some activities, and less suitable for other activities. A simple case is that tillage should not be practised on steep slopes, and not even on slight slopes with downhill furrows. So, practices that are acceptable under certain conditions are not acceptable under other conditions. In addition, the degraded resources from one unit of production may well be a valued input for another unit, and so these units need to be managed in a symbiotic manner. This is the resource management component of the solution.

A system designed to sustainably manage the physical resources of an area has to function at the regional or process level, yet be capable of providing information at the local level so as to contribute to local resource management decisions. Such a system needs to cover the spatial extent of the region and derive and supply information at a resolution that can be used at the local level. The nature of the process region has been discussed. Clearly, their extent varies with the issue being addressed. Such areas will usually be different to the areas of local government, even if local government is structured so as to have boundaries that are compatible with the more common forms of resource degradation. Fortunately, these differences do not cause significant problems if the resource management system is based on GIS as these systems can easily join together sets of information and then repartition that information into new areas. Thus, geographic information can be structured so that it is stored in a way that is readily manageable and understood by all users, and it can then be readily merged and partitioned into new areas of interest from a point of view of resource management. It is likely that the most effective way to store digital geographic data is in the form of map sheet layers, that can then be readily merged to cover the extent of the area of interest, and that area masked out from the map data outside the area, so that all the analysis deals just with the information within the area of interest.

Since resource management typically occurs at the field level, those dealing with the process regions need to supply information at the field level, and of sufficient accuracy for it to be of use at the local management level. For example, information on landuse, may supply one landuse class for a field, but the bounds of the field, and the area of the field, will need to be supplied at much higher resolution and accuracy.

1.5 THE NATURE OF RESOURCE MANAGEMENT

Once upon a time, a long time ago, or so it seems these days, resource management was very simple. It meant simply the management of resources so as to make the best return on your investment. To put it more simply, it meant making the largest possible profit from the resources that you had at your disposal. This was how it would have been stated in those days. This is not to say that the average landowner did not care about the resources that he was using; quite the contrary most landowners cared quite a lot. But the stated aims were to maximise profit. The unstated aims usually included maintaining the farm or the resource for future generations of their family. But something has happened over the last 50 years or so to change that perspective, in fact to turn that perspective on its head.

I can still remember, when, in Australia, a farmer would view his farm as his castle. When he got home he was away from, safe from, protected from all those pernicious things that the average farmer typically considered plagued those who live in cities — to many people, no privacy, controlled by too many rules, told what to do by too many people, in a few words, no freedom. When the farmer got home he could forget all those details and he was free to just get on with his struggle against nature and the markets to "make a quid."

But no longer do farmers; at least in Australia and Denmark, think that way. No longer does a farmer view the farm as his castle to which he could flee from the complexities of modern living. These days farmers think much more like most other people making a living in a society — they have to deal with intrusions into their life, with more rules on what they can and cannot do, with the need to supply more information to diverse bureaucracies, all of which have some form of life or death hold over them. So, now many of them do not view their farm as their own, but rather as a business in which they have a major stake, even though their children may not do so.

These attitudes have changed in a revolutionary way since the middle of the 20th century. This change in attitudes has largely come about due to an increasingly wider societal recognition that we are consuming increasingly large quantities on non-renewable resources, and creating significant pollution in the process. This recognition has been brought about primarily by the revolution in information and communication that has occurred since the middle of the 20th century. This revolution has provided stronger evidence of the effects of societies on the environment on the one hand, and enabled pressure groups to more rapidly and extensively mobilise support for action against significant environmental damage and impact.

Increasingly, resource managers cannot ignore the environmental and sustainability implications of their actions, and this trend will increase as the information tools available to resource managers, and society, provide more up to date and accurate information on the environmental and sustainability implications of management actions. Thus, society is now becoming much more involved in the way all resources are being managed, and this involvement will increase.

Given this trend, there is a need to understand the nature of resource management, so as to ensure that the tools available to the resource manager, and to the society, are the best that can be built, in terms of their usability and economy. To design and develop such tools requires that we first analyse the nature of resource management, the information that resource managers require for the management of resources, how the decisions get implemented and finally how to best support such a process.

All resource management can be seen to fit into one of three broad categories, which I will call strategic, process or regional and local management.

1.5.1 Strategic Management

> Strategic planning is defined as planning the future directions for the corporation through establishing the corporations long-term objectives and mobilising its resources so as to achieve these objectives.

Developing corporate objectives or goals will normally do this, establishing the structure appropriate to the achievement of these goals, and then setting the goals of the units within the corporation. This type of activity is the primary concern of the board of directors and senior managers.

Strategic planning activities are concerned with the environments (physical, economic, social and political) within which the corporation operates. It involves assessing how these may change in the future, the potential impact of these changes on the corporation, and how the corporation needs to respond and operate under evolving conditions. *Strategic planning requires extensive information about environments that are external to the corporation.* Strategic planning, in considering these external environments, will need to consider many factors over which the corporation has no control, and many of which are quite unpredictable since the corporation will usually have incomplete information on the factors and their environments. *Strategic planning requires the use of models that can accommodate the impact of unexpected and unpredictable factors. It generally requires the use of unstructured models.*

Generally, the information that is used in strategic planning will be of low spatial resolution, generalised and qualitative because of the way that the information is to be used, and the extensive range of information that has to be considered.

Typical information used in strategic planning includes:

1. Statistical information as collected by central Statistical Bureaus providing national and regional level information on different aspects of the society and the economy. Remote sensing and GIS can improve the collection and accuracy of this information by providing sampling strata appropriate to the information being collected, and in some cases by the actual collection of the sampled information itself.
2. Broad-scale monitoring information as collected by satellite at the global and regional level. Remote sensing with field data is the basis of most of these monitoring programmes, such as with weather prediction.
3. Institutional information as collected from documents and publications including economic, social and political information about the institution and its relationships with other institutions, including governments.

1.5.2 Process or Regional Management

Process or regional management is concerned with translating strategic plans and programmes into action plans whilst ensuring the maintenance or improvement of the productivity of the units of production in the region.

Strategic policies and programmes will often include implementation of environmental and social policies. Such policies may have to do with the sustainability of production systems, maintenance of biodiversity and social equity. As has been discussed earlier, the sources of degradation are often removed spatially and temporally from the effects. A major component of process management is to ameliorate the effects of degradation. Often the best way to achieve this, and ensure the long-term viability of the resource base is to reduce degradation at the source. One of the main foci of resource management at the process level will thus be to reduce the degradation of resources.

Regional management is also concerned with optimising productivity within the corporation or region. It will achieve these goals by influencing all the units of production. Regional management is not concerned with the over arching focus of strategic planning, but with a more direct focus on the corporation as a whole, and its interactions with its immediate environment.

Regional management is concerned with more localised external and internal information on all aspects of the physical, economic and sociological environments within which the corporation operates.

Regional management is concerned with predicting future effects of proposed actions so as to assess decision options for the region or corporation. This prediction must come from the use of quantitative models of processes, requiring quantitative information to drive these models. The resolution of the information must be compatible with assessing the impacts of decisions on the individual units of production. The resolution required in this information is a function of the size of the local management units.

> Regional management requires that the quantitative and qualitative information that it uses has a resolution sufficient to provide information about, or within, the smallest units of management within the corporation.

At present only Australia has attempted to seriously develop this level of resource management. Landcare Australia (http://www.landcareaustralia.com.au/) is the umbrella organisation formed for the many landcare groups that have been established across the country. This concept has taken off in Australia with wide political and financial support. The general modus operandi of a landcare group is that the group itself is community based, with representatives from the major economic and resource using groups in the community. They identify resource degradation issues that are of concern in the community. They access scientific and technical assistance from government, academic and scientific institutions to formulate action plans designed to address the individual degradation issues. They then implement the plan of action. The general method of implementation is to identify the main causes of the problem and then help those managers to find solutions that are less destructive of resources. The community pressure is the main form of influence that such groups have on the actions of individual land managers.

The landcare groups themselves are voluntary organisations, and the members are not paid for their participation. Whilst this approach has gained a very significant level of community support in Australia, it also raises the issue of how will it deal with declining membership should that occur in the future, and it does not properly reflect the costs of this level of management. It may thus work for some considerable time in Australia where the dominant forms of resource degradation of the land are very obvious on the surface. However, the degradation in resources in other areas can be subtler, resulting in declining quality or quantity of the groundwater and slow reductions in the fertility of the soil. Will there be the political and community will, in these situations, to implement this type of system?

An alternate approach could be developed along the lines of a taxation and incentives system. Regional management assesses the costs of production, including the costs of the use of all resources and the costs of the degradation, less the benefits of using degradation coming from other sites and sets a tax on these costs. The goal of such a system would be to provide a financial incentive to local managers to adopt sustainable practices. Such a system will require similar information systems as those properly required in the first approach, but they will be used in a different way. In this approach the information systems would be used to assess the taxation owed by the individual local manager. A significant disadvantage of the taxation approach is the general attitude of the community towards taxation and those responsible for implementing it. The information systems that are developed for such a purpose could, and should, be used to provide advice to individual land managers on the alternatives open to them.

The European Union (EU) is slowly moving towards an incentive form of this approach. The EU decides on the criteria that it will set for environmentally friendly resource use and management, and then provides financial incentives to resource managers to implement methods that abide by these criteria. The rationale behind this approach being that society as a whole requires that the natural resources be used in a sustainable manner, so the society as a whole should pay for the costs of implementation. Such an approach requires that adequate monitoring systems be established so as to verify that the system is not being abused. Information system used to verify claims for incentive payment should be constructed so that they can also be used to support resource management activities and thus have their costs distributed across both the community, in terms of resource maintenance, and resource management in terms of production.

Two broad approaches to the implementation of regional management have been described. Other approaches may evolve or adapt these ideas. However, the information systems required by both approaches are similar, even if they are used in quite different ways. These information systems will need to have the following characteristics:

- *Resolution* in the information content down to the unit of management (the field in agriculture) or better, and to each period or season of management.
- *Accuracy* to be compatible with the information used at the field level by the local manager.
- *Spatially extensive*, so that it covers the area of both cause and effect in relation to the resources being managed.
- *Predictive*, so that it can provide information on the likely effects of proposed actions.
- *Neutral* in its display of information and predictions, so that it cannot be interpreted as being critical of, or negative about, individual resource managers, except in terms of the sustainability of the proposed management.
- *Provides alternatives*, that is to show the costs and benefits of various options that are available to the resource manager. Many agricultural areas use rotation practices, where the high costs of one rotation are offset, to some extent, by mitigation in other rotations. The advice provided needs to cover a period long enough to consider this strategy as part of the advice.

The information used in such systems will need to be of two main forms:

- *Stable information*, or information that does not change during the process being investigated. Such information may include digital elevation models, some soil chemical characteristics, administrative data on field and farm boundaries, and navigation data.
- *Dynamic information*, such as weather data, landuse and land condition data, soil moisture and humus content, and so forth.

1.5.3 Operational Management

> To control and direct the current operations of individual units of production so as to achieve maximum productivity within the constraints and guidelines set by regional action plans and programmes.

Operational control involves the direction of staff in activities directly involved in managing the resources of the unit of production, whether it be a farm, a factory or a shop. Operational control is concerned with day-to-day decisions. It requires quick decisions, often on site, using primarily on site or internal information. It requires models that can be implemented by the manager on site, and that can respond to events as they occur. Information requirements at this level are for high resolution, yet simple, information since the decisions are usually made quickly using empirical models.

1.5.4 Relationship between these Levels of Management

The characteristics of these three levels of resource management and their relationship are discussed in more detail in Chapter 8, and shown in Figure 1.1. The figure is meant to emphasise the differences between the management decisions that are being taken and the information needs of each level of management, yet show that there are very fuzzy boundaries between the levels of management, and that there is an interdependence between these levels of management.

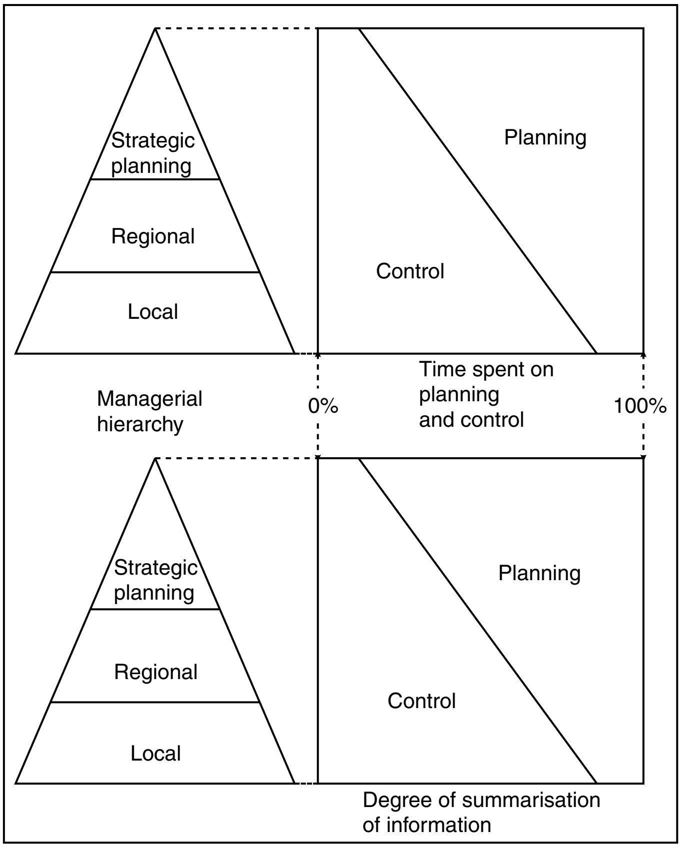

FIGURE 1.1 The relationship of management levels, the types of information used and the activities conducted by management.

Thus, even though the information systems needed at each level of management are quite different, there none the less needs to be an extensive communication among these different levels and there needs to be a consistency in the information provided to and used by each level of management. It is important that the local manager uses, in field management, information that is consistent with the information on the status of that field that is being used by the regional manager, just as it is also important that the information being used by the regional managers is consistent with that used by the policy-makers in establishing the policies that the regional managers will need to implement.

Thus, regional resource management systems need to provide information down to the unit of production, and this information needs to be accurate enough to be consistent with that used by the local resource manager. It also needs to be extensive enough to provide evidence that it is compatible with the information used by policy-makers for the construction and monitoring of the effectiveness of those policies.

1.6 THE NATURE OF REGIONAL RESOURCE MANAGEMENT INFORMATION SYSTEMS

Section 1.5 identified and discussed the three broad levels of resource management that can be found in all countries, albeit with some significant differences in their relative significance and impact. The section showed that the information needs of each form of management are quite different.

It is clear from this discussion that the key level of management in terms of resource sustainability is the regional level. If a form of degradation is to be brought under control, then controlling the degradation has to be done at its source. However, the local resource managers at the source may be unaware of the impact of their actions on other managers, and they may have little incentive to control the degradation if its impacts are exported elsewhere. This is where they need to see themselves as part of a community, where they may have responsibilities towards others in the community, but where the community also has responsibilities towards them. If regional management is to be able to have this impact on the individual resource managers, then they require information systems that provide information down to the individual unit of production, typically the field. If this information is to have credibility with the local managers, then it needs to be accurate enough to be credible to the local manager, it needs to be up to date and it needs to be detailed enough to tell the regional managers about the general conditions in the field. It does not have to be detailed enough to show the local manager how to better manage his field, but detailed enough to show whether his management is having the desired effect.

However, another critical characteristic of regional resource management information systems (RMISs) is that they must contain a predictive capacity. This is not meant to suggest the creation of long-term projections that are the focus of the strategic manager, but rather short-term predictions of the effects of proposed actions. What are the impacts of different forms of regional resource management on the resources over a season? Such predictive information also needs to be of adequate accuracy to earn the respect of the local managers, if they are to take them into account in the development of their resource management plans. The only way to achieve these goals is by the establishment of rigorous, quantitative information systems that contain embedded models and spatial information systems when dealing with spatially distributed resources. An RMIS must also be capable of providing options to the regional managers, that they can suggest for implementation by the local resource managers. Thus, faced with problems arising from current land using practices, the regional and local resource managers can work together to consider alternative management options that are available to the local resource manager.

An important component of these activities have to do with the resolution of conflict. In attempting to resolve conflicts among community desires, as reflected in policies, and local managers, or among local managers in terms of land uses, the first response should be to consider those alternative options that are available to the local managers. It may, for example, be possible to adopt other practices that remove or significantly reduce the causes of the conflict of interest.

The functions of an RMIS are thus to:

1. Be able to *display information on the status of resources* across an area as the basis for information, discussion, decisions and further analysis.
2. Show or *predict the effects of degradation* under different scenarios of variations in weather conditions and management across the area of interest.
3. Show or *predict the effects of different proposed actions* or management decisions, under different scenarios.
4. *Provide option advice* on the options available to the manager, their expected costs and benefits.
5. *Optimise specific criteria*, given constraints on physical conditions, weather, management, legal and economic constraints or conditions.

To be able to implement these functions, an RMIS needs to have the characteristics of:

1. Providing spatial and temporal context across the region of interest for the information being analysed in the system. The RMIS thus needs to be able to analyse and display temporal geographical information.
2. It needs to be able to provide information down to the level of resource management so as to link to the local managers. It thus has to have spatial information that has a resolution

down to the unit of management, or smaller. The unit of management is usually the field in agriculture or forestry, but may be some other form of area for other land using activities.
3. It needs to have a temporal resolution that is also compatible with the local management, so that typically it would need to provide information within the season.
4. It needs to be able to record decisions as a layer that is retained in the system so that it can be subsequently used to influence the analysis tools implemented within the RMIS.
5. The RMIS will require a suite of physical, economical and sociological models, all of which can be implemented individually or together, responding to the data in the system in the construction of predictions based on that data and other parameters as are necessary to drive the models.
6. Provide estimates of the reliability of the derived information.

RMIS are defined as systems that use temporal geographic data and information, with associated ancillary data and information, to derive information required by resource managers in a cost-effective manner.

An RMIS is intended to provide information to regional resource managers, presenting that information in a way that allows the manager to understand the information and its implications so as to construct a tactical knowledge model before making a management decision. An RMIS is therefore a decision support system for the regional resource manager and does not in any way take the actual decision making process away from that manager, nor his responsibilities in the management of resources. Since the RMIS is providing a comprehensive set of relevant information to the manager, it should facilitate the implementation of more timely decisions, and should be accompanied by an improvement in the quality of the decisions made by the manager. However, an RMIS is not a panacea that will relieve the manager of his responsibilities, nor the challenges, in making management decisions.

Since an RMIS is a management decision support system, it is essential that the system interface to the manager be easy for the manager to learn, use and understand. Clearly, the more that this language mimics the language of the manager the more convenient it will be, and so it is important to phase questions in the RMIS in terms used by the resource manager. The current trend in computer interfaces, using the concepts of windows and pointers or a mouse, improves the convenience of the interface, requiring minimum training by those who are not familiar with computers. The RMIS must also communicate its information to the manager in a manner that reflects their concerns and priorities if it is to be of most economic use to those managers. An RMIS is often based on sophisticated technology; it often requires sophisticated technological skills to implement, in consequence the workshop component of an RMIS may contain staff with highly specialised technical skills. Whilst this workshop component must be accessible to the manager, it will not be through the workshop that the manager will communicate with the RMIS. It is more likely that he will communicate directly with the RMIS. In consequence the interface in the RMIS to the manager must be suitable for use by the manager.

An RMIS will consist of at least four parts:

- Input
- Analysis
- Estimation, prediction, option evaluation and optimisation
- Decision support

Input includes acceptance by the system of all of the data and information used by the system to derive management information. These inputs can include aerial photographs, field data, maps and remotely sensed images. The maps can include topographic, property or cadastral (land ownership), geologic, soil, landuse and other relevant maps in either analog or digital forms. If the system is to use analog data then the input is likely to include the facilities necessary to convert analog data into digital data, as well as the facilities necessary to store both the analog and digital data.

Input must also consider error checking and validation of the data that is being entered into the RMIS. The adage, “garbage in, garbage out,” is quite correct. Users may be more nervous about digital data than analog data because they cannot “see” the digital data and hence they cannot assess the quality of the information for themselves, as they can with an analog document. In consequence, if they come across errors in the information given to them by an RMIS then they are likely to be less forgiving of the system; they will place less reliance on the system when making management decisions. The ongoing viability of an RMIS depends on its credibility with its users, and this in turn depends on users understanding the accuracies that they can both expect and are actually getting, in the information provided by the system.

Analysis involves the derivation of raw information from the input data and information, as well as the derivation of management information from the raw information. The derivation of raw information is usually done from the analysis of remotely sensed images, derived from maps or from field data. The derivation of this raw information is likely to be done by image analysis specialists, sometimes using advanced image processing and analysis techniques. Whilst this raw information can be used on its own, it is more frequently used in conjunction with other information. The processing of sets of raw information to derive management information is usually done within a GIS environment. The resource manager or his assistants may derive the management information, so that this is where a user-friendly interface is essential.

One goal of an RMIS would be to create raw information that can be used by a range of different resource managers. Once the raw information is supplied to the individual managers, they integrate it with their other raw information layers to derive the management information that they require. Such an approach minimises the costs of data acquisition and analysis, and spreads this cost across a number of users. It also means that the different managers have consistent information sets in the management of the resources in a region. This is critical when resolving conflicts in resource use or allocation.

Typical types of management information that might be derived using a GIS could be to answer questions of the form, “What fields in County Alpha have been cropped in each of the last four years and what is the average yield of these fields relative to the average for the county,” or “Show me all areas that have been cropped at least twice over the last five years and are within x Km of railhead Beta. What is the area involved in cropping each year and the average production.”

The raw information for both of these questions is the cropping history, yield information and land administration information. The cropping history information can be readily taken from remotely sensed images. The yield information may come from remotely sensed data or from field data in the form of annual returns. The administrative information will have come from digitisation of maps that may be maintained as a digital database. Each layer of raw information described for the above example can be used on its own, but they become capable of being used to provide much more powerful and useful information when they are combined with the other layers of raw information. These same layers can be used to address many other management questions, either on their own or in conjunction with other layers of raw information such as soil or slope information. The manager is the person who is in the best position to define clearly the questions that he wants addressed, he will also want the system to be responsive to his needs; to provide the requested information when required. This component of an RMIS must therefore be very accessible to, and usable by, the resource manager himself.

Estimation and prediction are defined as the extrapolation from data or information on specific resource attributes to derive estimates of those or other attributes by making assumptions about the behaviour of parameters that affect the estimation or prediction. Estimation is the extrapolation from a specific set of attributes to another set at the same time. It thus involves models that estimate the second set of parameters from values given to the model for the parameters in the first set. Prediction