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DATA INTEGRATION ISSUES FOR A FARM GIS-BASED SPATIAL DECISION SUPPORT SYSTEM

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DATA INTEGRATION ISSUES FOR A FARM GIS-BASED SPATIAL DECISION SUPPORT SYSTEM

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ABSTRACT

Farming has a unique role to play in shaping the landscape and enhancing our environment. In recent years, the industry has declined and no longer makes a significant contribution to the national economy. The impact of animal diseases such as BSE and Foot and Mouth has reduced consumer confidence in the quality of food produced. The UK Government, through the introduction of funding schemes, is aiding the recovery of the industry by encouraging farmers to diversify their farming enterprise. One option is the conversion from intensive to organic farming practices, a decision that involves a high level of risk and uncertainty. This research proposes a role for GIS as a decision support tool for a farm manager exploring the options for organic conversion.

Where data is captured and held in multiple applications, the GIS-based Spatial Decision Support System (SDSS) must integrate data and models. The use of the GIS must be intuitive, allowing the farm manager to explore different scenarios for land allocation effectively. The interface must allow the amendment of input parameters and present the results from each scenario in a clear, understandable format. This functionality raises important data handling issues that are investigated through the development of a prototype GIS.

The identification and assessment of relevant datasets and the seamless integration of data are fundamental to the design of the GIS. Metadata, adhering to international guidelines, are identified as the chief means for discovering, exploring and acquiring spatial datasets from diverse sources. An assessment of the quality and accuracy of the data is essential if they are to be the basis for decision support. Interoperability issues are discussed and suggestions are proposed for the successful integration of data and models for the SDSS through the GIS interface. By providing a visual medium in which alternative strategies can be evaluated, the GIS will enhance the quality of the final decision made by the farm manager.

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- Nigel Smith, agricultural lecturer.

Finally, thanks must go to Mike, for never doubting that I would finish this work.

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LIST OF ACRONYMS

ASCII	American Standard Code for Information Interchange
AGI	Association for Geographic Information
AHP	Analytical Hierarchy Process
API	Application-programming interface
BSE	Bovine Spongiform Encepholitis
CAP	Common Agricultural Policy
CCTA	Central Computer and Telecommunication Agency
CEN	Comité Européen de Normalisation
CLIPS	C Language Integrated Production System
CORBA	Common Object Request Broker
COM	Common Object Model
CSDGM	Content Standards for Digital Geospatial Metadata
CSV	Comma Separated Variable
DBMS	Database Management System
DCMI	Dublin Core Metadata Initiative
DCOM	Distributed Common Object Model
DCP	Distributed computing platform
DEFRA	Department for the Environment, Food and Rural Affairs
DNF	Digital National Framework
DSS	Decision Support System
DXF	Drawing Exchange Format
e-GIF	e-Government Interoperability Framework
e-GMF	e-Government Metadata Framework
e-GMS	e-Government Metadata Standard
EA	Environment Agency
ERDP	England Rural Development Programme
ESA	Environmentally Sensitive Area
ESRI	Environmental Systems Research Institute
ETeMII	European Territorial Management Information Infrastructure
FAO	Food and Agriculture Organisation of the United Nations
FGDC	United States Federal Geographic Data Committee
GICSS	Geographic Information Charter Standard Statement

GIS	Geographical Information System
GPS	Global Positioning System
HCI	Human-Computer Interaction
HTML	Hypertext Markup Language
IACS	Integrated Administration and Control System
IDSS	Integrated Decision Support System
IGGI	Intra-governmental Group on Geographic Information
ISO	International Organisation for Standardization
KBS	Knowledge-based System
LADSS	Land Allocation Decision Support System
LEIGIS	Land Evaluation using an Intelligent Geographical Information System
LP	Linear Programming
MAFF	Ministry of Agriculture, Fisheries and Food
MAGIC	Multi-Agency Geographic Information for the Countryside
MBMS	Model Base Management System
MIF	MapInfo Interchange Format
NASA	National Aeronautics and Space Administration
NESPAL	National Environmentally Sound Production Agriculture Laboratory
NGDF	National Geospatial Data Framework
NTF	National (or Neutral) Transfer Format
OCIS	Organic Conversion Information Service
ODBC	Open Database Connectivity
OFS	Organic Farming Scheme
OGC	Open GIS Consortium
OLE	Object Linking and Embedding
OS	Ordnance Survey
PC	Personal Computer
RDF	Resource Description Framework
RMSE	Root Mean Squared Error
ROW	Rights of Way
SAIF	Spatial Archive and Interchange Format
SDSS	Spatial Decision Support System
SDTS	Spatial Data Transfer Standard
SLC	System Life Cycle

SQL	Structured Query Language
SSSI	Sites of Special Scientific Interest
TOID	Topographic Identifier
UK	United Kingdom
UKROFS	United Kingdom Register of Organic Food Standards
US	United States
WGS	Woodland Grant Scheme
WIMP	Windows, Icons, Menus and Pointing devices
VBA	Visual basic for Applications
VRT	Variable Rate Technology
XML	eXtendable Markup Language

1 INTRODUCTION

1.1 Overview

This research investigates data integration issues relating to the use of GIS as a decision support tool for a farm manager. To make sound decisions for future land use, a farm manager relies on existing farm records and maps and his/her expert knowledge. The availability of funding for the development of environmental schemes may also influence these final decisions. As the data used is clearly spatial in nature, the research develops a role for GIS as the core component of a spatial decision support system for the farm manager.

In the current climate of agricultural decline, farmers and farm managers are encouraged by the Government to diversify and consider alternative land use options. Newton Rigg Farm, as part of the estate owned by the University of Central Lancashire in Cumbria, operates as a commercial enterprise, as well as a teaching resource for students following land-based courses. The Farm Estates Committee regularly reviews the financial position of the farm and in August 1999 commissioned a feasibility study to consider organic conversion at Newton Rigg (Minter 1999). Following this a decision was made to convert part of the farm to the organic production of beef and sheep. This mix would ensure that the University still attracted students wishing to learn intensive farming techniques but also provided a facility to study traditional farming methods relying on natural methods of soil management and animal husbandry. Though computer applications are under development at the University of Wales and the Scottish Agricultural College to assist in organic conversion planning, this research concentrates on a typical farm manager with little computer expertise. By investigating the data and analysis that inform the farm manager's decision of what fields and enterprises to convert, and the requirements for organic certification, an evaluation of the potential use of GIS is possible.

1.2 Approach

The potential analysis of the underlying datasets by the farm manager considering organic conversion raises key issues for the GIS, including:

1. the transfer of map data from paper to digital format;
2. the integration of digital data in different formats;
3. the access to metadata describing data and methods of data handling;
4. the seamless interoperability between systems;
5. the usability of the system by non-GIS users.

By concentrating on these issues, a methodology is developed to evaluate the effectiveness of GIS as a decision support tool. Theoretical concepts relating to spatial decision support systems, metadata, interoperability and developing international standards are investigated. A pilot study is undertaken to determine, using the process-driven approach, the data and functional requirements of the GIS; and a prototype GIS is built to apply and evaluate the theoretical concepts discussed. Financial limitations required the GIS to be implemented using software already available within the organisation. The evaluation of the GIS relies on the usability of the system as seen by the farm manager and other potential users.

1.3 Research Objectives

The overall aim of this research is to prove that GIS can be used as the key component of a farm spatial decision support system (SDSS). The objectives in achieving this aim are:

- identify the important data integration issues that must be addressed and to propose practical solutions;
- define the role for GIS as a decision support tool for the farm manager;
- investigate and review current, and appropriate, theoretical and developmental work relating to spatial decision support systems and data integration issues;
- develop the GIS functionality required for this application by establishing the data handling and analytical requirements of the GIS;

2

- implement a pilot study through the development of a prototype GIS, applying important theoretical concepts;

- evaluate the effectiveness of using GIS as a decision support tool.

1.4   Expected Outcomes

In achieving the objectives described in section 1.3, the research will demonstrate that data and data handling issues must be resolved if a GIS is to act as an effective decision support tool for land use allocation. The relevance of metadata in raising the users' awareness of useful datasets, their quality and accuracy will be established for this particular project. The interoperability requirements will lead to the design of user interfaces that permit the transfer of data from current and historic datasets between applications used by the farm manager.

The analysis performed by the farm manager will lead to a specification for the GIS. A working prototype will be developed from this specification and evaluated by the farm manager and other interested users. Weaknesses that are identified in the prototype will guide the direction of future research.

1.5   Organisation of the Thesis

The thesis is organised as follows: chapter 2 discusses the current agricultural climate and the decisions facing the farming community if the industry is to survive. The Government has introduced a plethora of initiatives with associated funding to encourage diversification and alternative land uses. Out of these, the Organic Farming Scheme is selected as the focus of this research and a role for GIS to integrate, analyse and present spatial data is introduced. Chapter 3 summarises the theoretical concepts of spatial decision support systems (SDSS) with GIS as the key component. Current applications of SDSS within Agriculture and existing research in the domain are described. Chapter 4 defines the broad requirements for a farm GIS based decision support tool designed to assist the farm manager planning for organic conversion. These requirements are the basis for the specification of the prototype GIS. Chapter 5 raises the data integration issues that must be addressed if GIS is to meet the specification. Metadata, interoperability and the current work on establishing

international standards are discussed in detail and the implications for the design of the prototype are considered. Chapter 6 describes how each requirement was realised in the development of the prototype. The GIS is evaluated against these requirements initially and the farm manager and other potential users provide an assessment of the usability of the system. Chapter 7 concludes with a summary of what has been achieved in this research and points to future areas of work.

2.1   Introduction

Over the last 50 years there has been a steady decline in the contribution which agriculture makes to the national economy. As part of a highly subsidised industry, the farming community is subjected to many pressures. Farm incomes and profitability are low at a time when consumers are demanding good value, high quality food. Recent animal diseases such as Classical Swine Fever, BSE, Foot and Mouth Disease have led to calls for safer and more traceable food. Years of intensive production have resulted in environmental damage, for example the loss of hedgerows and farmland wildlife (DEFRA 2002a). The Government has responded to these crises by developing *The Food and Farming Strategy* to stimulate change in the industry, aiming for good environmental management and the provision of good quality assured food (DEFRA 2002b). This chapter provides an overview of the recent Government activities including the establishment of the Curry Commission and the England Rural Development Programme (ERDP).

The proposal by the farm manager at Newton Rigg to convert some area of land to organic methods led to an investigation of the Organic Farming Scheme (OFS). The documentation and requirements of the OFS are detailed, with a description of the help available for those considering the transition from traditional farming methods. Current research into direct support for the farm manager is summarised.

A role for GIS as a decision support tool is introduced. The farm manager is required to draw on his/her expert knowledge to make decisions about the allocation of land for organic conversion. The factors involved are diverse but, as the data is spatial in nature, it may be displayed and analysed in a GIS. By presenting information and displaying alternative solutions for the farm manager to explore, the GIS may be the core component of a spatial decision support system.

2.2 Government Initiatives

2.2.1 The Curry Commission Report

In 2001 the Government instigated the Policy Commission on the Future of Farming and Food with the remit to *"advise the Government on how we can create a sustainable, competitive and diverse farming and food sector which contributes to a thriving and sustainable rural economy, advances environmental, economic, health and animal welfare goals, and is consistent with the Government's aims for Common Agricultural Policy (CAP) reform, enlargement of the EU and increased trade liberalisation"* (DEFRA 2002a). The final report (the Curry Commission report) proposed a new vision and a set of recommendations to arrest the general decline in the farming industry and to recover from the impact of Classical Swine Fever, BSE and Foot and Mouth Disease.

The Food and Farming strategy builds on the recommendations of the Curry report, introducing new funding (£500m) to address economic, environmental and social sustainable development (DEFRA 2002b). Key proposals of the strategy include: support schemes to assist business activities, reconnecting the food chain with its customers; investment for environmental schemes; and improved regulation on a whole-farm basis.

2.2.2 The England Rural Development Programme (ERDP)

The ERDP was established to assist farmers to *"become more competitive, diverse, flexible and environmentally responsible"* (DEFRA 2003). Amongst the schemes included within the ERDP are The Countryside Stewardship Scheme, The Farm Woodland Scheme and The Organic Farming Scheme. Through such schemes the ERDP will release £1.6bn over the next seven years to farmers for environmental protection and improvement and rural development.

The farming community is thus presented with a wide range of funding schemes and must make an assessment as to the most effective land use options. The linkage of GIS with the current Integrated Administration and Control System (IACS) was

recommended in the Curry report, as a means to producing the whole farm audit. However, its potential as a decision-support tool was not recognised.

2.2.3 The Organic Farming Scheme

Demand for organic produce is growing steadily in the UK and European Community. Through the Organic Farming Scheme (OFS), the government is encouraging farmers to consider converting to organic production to meet this market whilst recognising the contribution such methods can make to environmentally sensitive farming. The key elements of an organic farming system are (Organic Farming Centre for Wales 2002):

- the avoidance of artificial fertilisers and pesticides;

- the use of crop rotations to maintain fertility and control weeds, pests and disease;

- the recycling of nutrients in the form of manures to maintain soil fertility.

There are many factors that contribute to meet these key components, the complexity of which may be seen in the mind map (Figure 2.1) devised by the farm manager in the initial consideration of the conversion to organic farming. As the data is spatial in nature, it may be displayed and analysed in a GIS, implying a role for GIS as a decision support tool (Garton & Car 2000).

In the UK, standards for organic farming are regulated by The United Kingdom Register of Organic Food Standards (UKROFS). Farmers may only sell "organic" produce if it has been certified by an organisation approved by UKROFS. To gain certification the farm manager must provide a written conversion plan that includes detailed cropping plans, rotations, an animal health management plan and budgets. The conversion process itself involves a two-year period in which the land is converted to organic status. The conversion must be carefully monitored and records maintained to ensure organic accreditation (Newton 1995). Although the OFS offers grants to assist with the conversion there are severe penalties if the conversion process is abandoned. Farmers are encouraged to seek expert advice before submitting an application to the scheme.

SHEEP Breeds/Distance
Mkt? Resistance
Lamb late - summer grazing

Closed flock breeding policy
Eg Lleyn, Colbred, Clun forest

Pasteurelloris
Clostridial disease
Report/ www - Discuss

ANTHELMINTICS

P101 Health Control
Flumeth:
Cyromin Delta methrop

DISEASE
CONTROL
(3yr rotation)

Clean grazing
BOOKLET

6t/hhead silage
beef/winter

60% DM Fresh
green food (org)
40% DM - core

FEEDING
REGIME

ENVIRON
CONSERVATION
Marion - ELM

PRG Timothy
Green

SOWING

50-60%
cover
4-5 kg/ha

Grazing
Spp?

White v Red
Clover

Grazing leys +
GRASSLAND MGT

Hand
Pull

Red - Conservation
Extra care!

Set Aside!

Undersow clover
with cereal

GRAZING

STOCKING RATE
1.6-2.0 LU/ha
90% conventional
p93 Handbook

MAY lambing? - outdoors
3 months role MAFF - OFS
(HELPLINE) 0117927707

Bio Dynamic
Ag. Assoc

ORG. F.G

Org. food +
feeds

APPLIC FEE
LICENSING
FEES, REGS

CERTIFYING
BODIES

SOIL ASSOC

Conversion
planning

ELM FARM
RESEARCH

SAC
FIELD RECORDS
+ HISTORIES

ALL fields
SLURRY 14-20 m³/ha

SOIL MANAGEMENT - FYM 10.30 t/ha
- spring - grazing

Waste management p25 report

BUILDINGS
P136 Handbook

SOIL ANALYSIS - ELM FRC 01488 658298
pH6 (most phosphate available)

CROP ROTATIONS – Marley on land
eligible for AAP (£242/ha)

Stubble turnip p52,54 handbook -
After grass, wheat, barley, oats

ROUNDUP!!!!!!!!!

Rotation of long + short term leys
+ breakcrops - fodder crop
cereals

WEED & PEST CONTROL
Chain harrowing in spring

Thistles - cutting
Docks Topping

Grazing - Avoid poaching
- compaction
- overuse of slurry
- topping/bastard
fallow

ORGANIC
CONVERSION
PLAN

Bill Grayson
Bank House Farm
Lancs. Beef + sheep

Terry Prince, Beechenhill farm
Derbyshire. Dairy + sheep

1 - INTERNAL PARASITE RESISTANCE
2 - TARGET MARKET

Figure 2.1 Farm Manager's Mind Map (*with permission from Nigel Smith, Cumbria Campus, Newton Rigg*)

2.3 Support for Farmers

"The decision to convert all or part of a farm requires a high level of commitment on the part of the farmer or manager if it is to succeed. In particular, the decision to convert carries with it a high element of risk and uncertainty as far as the financial viability of the farm is concerned, and this is compounded by the current lack of detailed information and advice"

Nicholas Lampkin (1990), p.526

In 1999 the Ministry of Agriculture, Fisheries and Food (MAFF) initiated the Organic Conversion Information Service (OCIS) as part of the Government's commitment to promote organic farming (MAFF 1999). OCIS helps farmers examine the organic option and to make an informed decision on whether it is worthwhile to convert to organic methods. The service includes an information pack, an "Organic Helpline" and free advisory visits. An individual farmer may also request 1½ days of free consultancy time to give more detailed advice on conversion. These visits are undertaken by staff at the Organic Advisory Service based at the Elm Farm Research Centre. Figure 2.2 summarises the stages leading to organic status. At the inception of this study, the Elm Farm Research Centre indicated that GIS is not currently used in discussions with farmers.
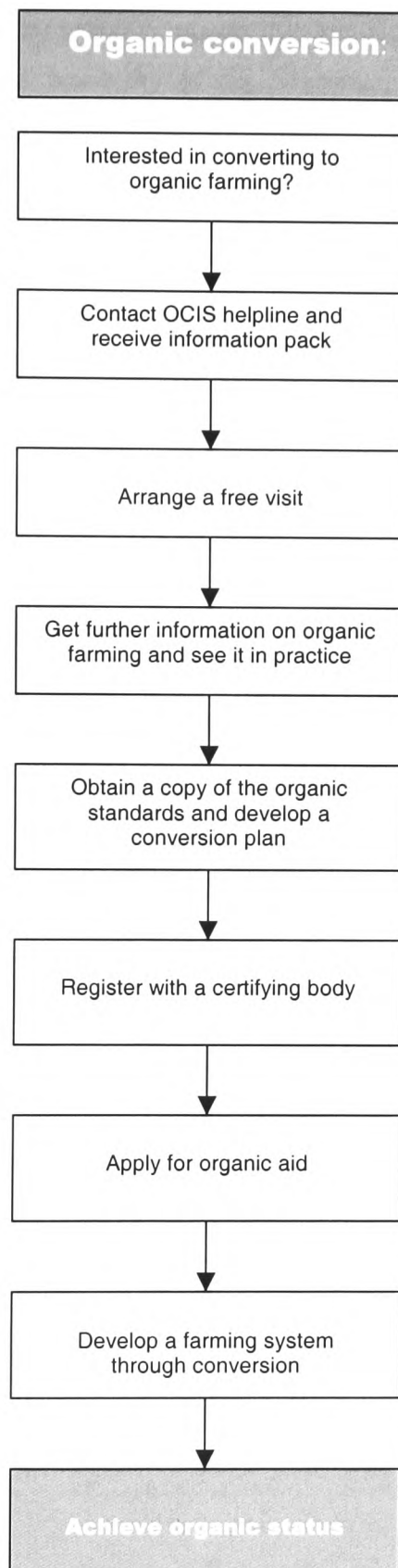
Figure 2.2 Stages in achieving organic status (*Source*: Organic Farming Centre for Wales 2002)

Although OCIS provide information about the certification process, there is no assistance in assessing the feasibility of the conversion. Research at The Welsh Institute of Rural Studies at the University of Aberystwyth has led to the development of OrgPlan, a computer programme aimed at farmers and advisors assisting with the planning of an organic conversion (Padel et al. 2002). The programme consists of a standard enterprise database, a report builder and an advisory section. Conversion scenarios are explored for technical and financial feasibility by producing financial reports (cash flow budget and profit and loss account), which are either printed or exported to a spreadsheet for further manipulation. It is recognised that a map enables farmland to be visualised more effectively but there are no plans to incorporate GIS into the package.

A prototype integrated modelling system is under development by researchers at the Scottish Agricultural College. The Integrated Decision Support System (IDSS) incorporates "GIS, biophysical models and socio-economic models of the farming goals" (Julian et al. 2002). The model uses Linear Programming (LP) techniques and has a profit maximising objective. The GIS within the prototype has two roles: to manage and integrate geo-referenced data relating to the farm; and to visualise the output from the LP model. The developers acknowledge many enhancements to the prototype are required before it could be deployed as a decision support tool but, if properly constructed, feel a spatial modelling system would lead to an informed decision by allowing alternative options to be simulated.

Both OrgPlan and IDSS integrate data from standard enterprise databases, farm management records, farm management handbooks and other organic farming literature. Access to data is seen as crucial to good decision-making. The ability to integrate data from a range of sources is clearly a key function of the GIS at the centre of a spatial decision support system.

2.4 Summary

The Government, recognising that farming as an industry is in decline, established the Curry Commission to review the future of farming and food. In response to the Curry report, schemes designed to assist in the recovery of the rural economy have been

promoted through the England Rural Development Programme. As a result, the farming community is faced with a complex array of funding schemes from which to choose a way forward. The potential conversion of land to organic status in this case study provided an opportunity to explore one scheme, the Organic Farming Scheme. The documentation and requirements of the OFS were introduced in this chapter and the help available to farmers from the Organic Conversion Information Service was described. Although practical advice relating to certification is offered, there is no assessment of the feasibility of the conversion.

Two research projects into organic farming support, both offering mechanisms to explore the financial implications of conversion, were identified. The prototype Integrated Decision Support System incorporates GIS, which manages the data relating to the farm and provides visual output from the underlying model.

This chapter has identified GIS, with its ability to display and analyse spatial data, as a decision support tool for the farm manager. The integration of data from standard enterprise databases and farm management records provides a major challenge to the design of the GIS.

3 SPATIAL DECISION SUPPORT SYSTEMS AND GIS

3.1 Introduction

Good decision-making relies on having access to relevant and appropriate information (Sauter 1997). Decision support systems (DSS) are computer-based systems that assist the decision-maker, particularly where problems are ill defined and it is not obvious what information is needed or what modelling tools would be useful. By integrating and organising data from a range of sources and incorporating internal models, a DSS allows the decision-maker to explore the impact of choices and finally to make an informed decision. Increasingly many organisations, including business and government, are using GIS as a decision support tool (Grimshaw 2000). When it is recognised that spatial information is an essential factor in formulating a decision, incorporating GIS into a DSS leads to the development of a spatial decision support system (SDSS). Honea et al. (1990) stress that, despite technological advances, GIS should be *part* of a DSS and that the requirements of the DSS should drive the design and development of a GIS, not vice versa.

Densham (1991) provides a number of reasons why GIS fail when designed as a DSS, including restricted analytical modelling facilities and the absence of expert knowledge in the subject area. However, Heywood & Carver (1994) introduce the concept of using GIS as a medium to explore and visualise ideas and it is this strength that may be exploited in the decision-making process, presenting information and displaying alternative solutions for consideration by the decision-maker.

This chapter includes a discussion of the decision-making process, describing an iterative approach to problem solving. The characteristics of SDSS are defined and the limitations of GIS as a SDSS are presented. The application of SDSS in precision farming is described, and the current research into integrating GIS and expert systems for land allocation and evaluation is explored. The role of GIS as a component within a SDSS for a farm manager is defined, based on an architecture originally proposed by Armstrong, Densham and Rushton (Densham 1991).

3.2 The Decision-Making Process

A decision may be defined as a specific commitment to action, often with an associated commitment of resources (Janssen 1992). Research into the decision making process (Simon 1960) has led to the acceptance of three major components (Figure 3.1): *intelligence*, in which the problem(s) are identified, *design* in which alternative solutions are considered, and *choice*, in which the solution is selected. The three stages are not always sequential. Indeed, as new information becomes available during the process, it may be necessary to revisit stages in order to collect more information or refine the design (Malczewski 1999).
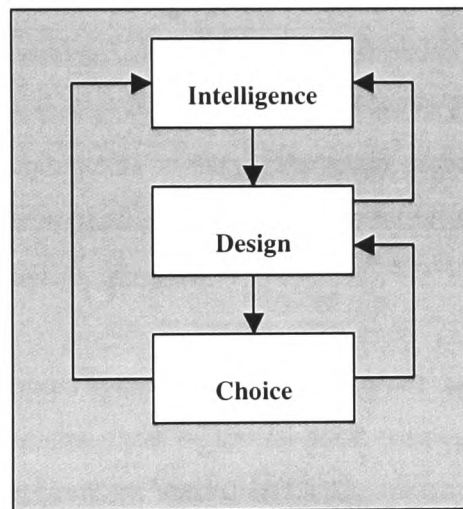
Figure 3.1 Three-phase decision-making process (*Source*: Malczewski 1999, p.75)

The decision-making process may be iterative. A decision-maker, a farm manager for example, may revise his/her decisions due to new information, e.g. a higher premium may be made available by the government for beef production. A decision support system (DSS) will assist the decision-maker involved in this process. Such a DSS can be defined as a computer-based system that incorporates both data and models and offers support by improving the efficiency with which decisions are made (Sprague and Carlson 1982, Grimshaw 2000). In simple terms, the DSS must assist the decision-maker by allowing him/her to retrieve relevant information. It should allow for exploring alternatives easily through the use of models built into the DSS and present

the results in an appropriate format. The DSS will not make the decision but instead, will enhance the quality of the decision made.

## 3.3 GIS and Spatial Decision Support Systems

The important requirements of a DSS are that it must access data from a variety of sources and facilitate the development and evaluation of potential solutions produced through appropriate models (Sauter 1997). Densham (1991) (after Geoffrion 1983) develops these broad functions of a DSS into six distinguishing characteristics:

1. DSS are most useful where problems are ill defined or poorly specified.
2. DSS include a graphic user interface (GUI) designed to be user-friendly.
3. DSS allow the user to access both data and models in a flexible environment.
4. DSS generate a series of decision alternatives using internal models.
5. DSS are easily adaptable as the user's needs evolve.
6. DSS are interactive and permit the user to refine a decision through iterations in the decision-making process.

A spatial decision support system (SDSS) must share all the above characteristics but, in addition, must allow the input of spatial data, support complex spatial relations and structures, include functions for spatial and geographical analysis and provide output in map or other format (Densham 1991). The components of a SDSS are thus identified as database management system (DBMS), a model base management system (MBMS), display and report generators and a user interface that integrates all modules and handles interaction with the user (Figure 3.2). The arrows represent data flows between the decision-maker and the individual components of the SDSS. The decision-maker arrives at a decision following an iterative process in which solutions generated by the SDSS are evaluated and refined.

The design of the user interface is crucial and both graphical and tabular interactions are required. For example, the user may wish to modify the parameters for the analytical models in tabular or graphical format and to view the output from the model in a graphical format. Densham (1991) introduces the terms *objective space*, in which the

user interacts with the model based system, and *map space*, in which the output from the model is represented as a cartographic display.
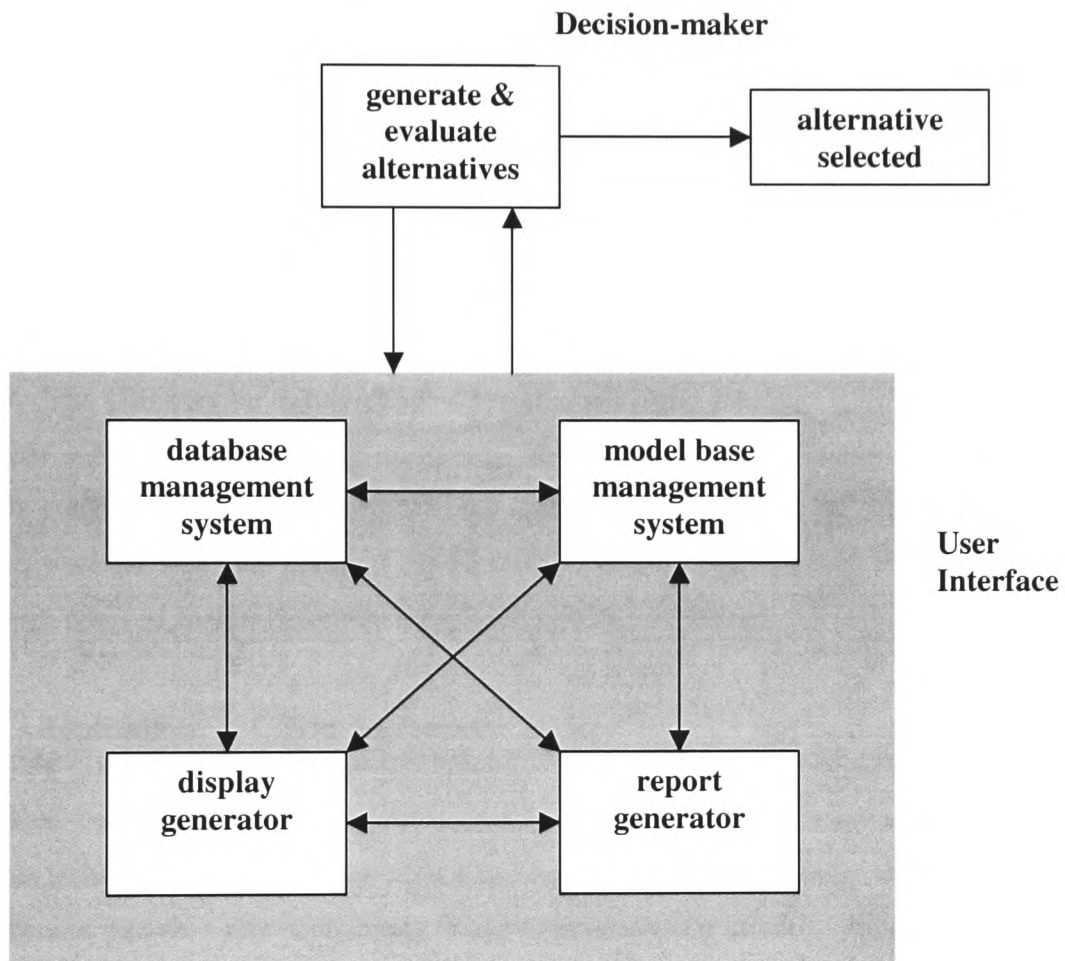
Figure 3.2 A proposed architecture for a SDSS

(*Source*: Densham 1991 p.408, after Armstrong, Densham and Rushton 1986)

Although used to present information that may ultimately lead to a decision, a GIS does not strictly comply with the requirements of a DSS as defined by Geoffrion (1983). Heywood & Carver (1994), after Densham (1991) summarise the failures in GIS as: "

1   *the lack of appropriate database management tools;*

2   *restricted analytical modelling capabilities;*

3   *limited graphical displays;*

4   *poor report generation systems;*

5   *lack of inclusion of expert knowledge;*

Though some applications, Idrisi for example, include tools for multi-criteria analysis and friction surface calculations (Eastman 2002), the statistical functions offered by most GIS software are limited. The ability to link a GIS with other applications such as spreadsheet software addresses this limitation and strengthens the potential for statistical analysis and providing both tabular and graphical output as required.

GIS, with the ability to integrate, analyse and present data in a highly visual format such as a map, can be an extremely valuable tool for those involved in decision-making. When coupled with other modelling software, GIS can become the key component of a SDSS. The GIS may be tightly coupled to other software, that is, the linkage between different software is completely transparent to the user. Alternatively, if the GIS is loosely coupled to modelling software, the user may have to translate the output from one software environment before it can be used in another (Heywood et al. 1998). The approach adopted will be determined by the expertise of the user.

3.4   Applications of GIS in Agriculture

As a land-based industry, agriculture is an area that is benefiting from the introduction of new technologies: global positioning systems (GPS), GIS, remote sensing, online sensors and variable rate technology (VRT) (Grenzdorffer 2000). When combined, these technologies assist land management from the local farm field level to the global level, by collecting and processing data quickly and cheaply, providing data for crop yield and pollution models and producing maps and reports for specific purposes (Wilson 1999). This section introduces the use of GIS for precision farming, the development of the NESPAL precision farming decision support system and examines current research in the area of decision support within agriculture generally.

3.4.1 Precision Farming

Even before the outbreak of Foot and Mouth disease in 2001, the farming industry in the UK acknowledged that agriculture was in severe recession (Abel 2000). Precision farming is seen as an important technology for the farmer wishing to achieve higher yields and improved crop margins. The objectives of a land manager may vary from optimising financial returns through to minimising chemical inputs and improving the environmental quality. By directing the application of seed, fertiliser, pesticide and water at sub field level (Usery et al. 1995), precision farming can assist in meeting these objectives.

The overall aim of precision farming is to collect spatially referenced data using GPS, GIS and remote sensing techniques, perform spatial analysis and assist decision-making and apply variable rate treatment (Wilson 1999). Figure 3.3 illustrates GIS as a central hub of the precision farming decision support system developed by the National Environmentally Sound Production Agriculture Laboratory (NESPAL) in Georgia, USA. Essentially, data is collected from control points in the field whose locations are measured to less than 1.0 metre using differential GPS. These location data are available in all GIS layers so that the correct treatment is applied at the correct site.
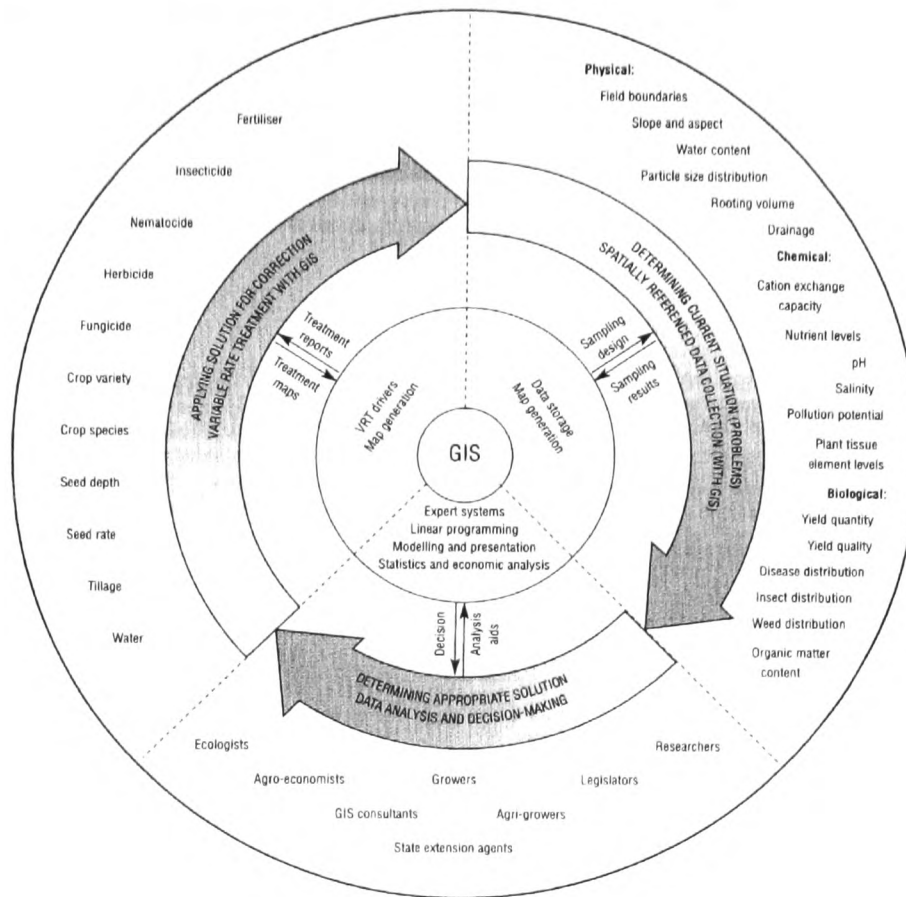
Figure 3.3 The components of the NESPAL precision farming decision support system with a GIS as a central hub and GPS as the correlating base for geographical reference. (*Source*: Wilson 1999 pp981)

Research undertaken by Usery et al. (1995) indicated that GIS software such as ARC/INFO, Idrisi and MapInfo was difficult to use directly for precision farming, containing too many functions and lacking some essential functions. In designing a GIS for precision farming, software developers must meet a number of challenges: farmers may not have skills in spatial data handling; digital information such as soil maps may not be available; hardware components, including job controllers and on-board computers in the tractor cab have already been developed in the industry and must be supported by the GIS (Grenzdorffer 2000). This has led to the development of specialised applications that perform some spatial analysis (distance and area calculations, Boolean overlays, buffering and reclassification) though statistical tools such as multivariate analysis are omitted. Figure 3.4 summarises the special requirements for a precision farming GIS: a simple interface for communication with

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the farmer; the collection and integration of digital data relating to site locations (GPS, soil and yield maps, for example); spatial analysis tools; and output including maps (yield and nutrient balance, for example), reports for grant submissions and site specific control of farming machinery. In addition the GIS is required to manage the links to other software used by the farmer or consultant.
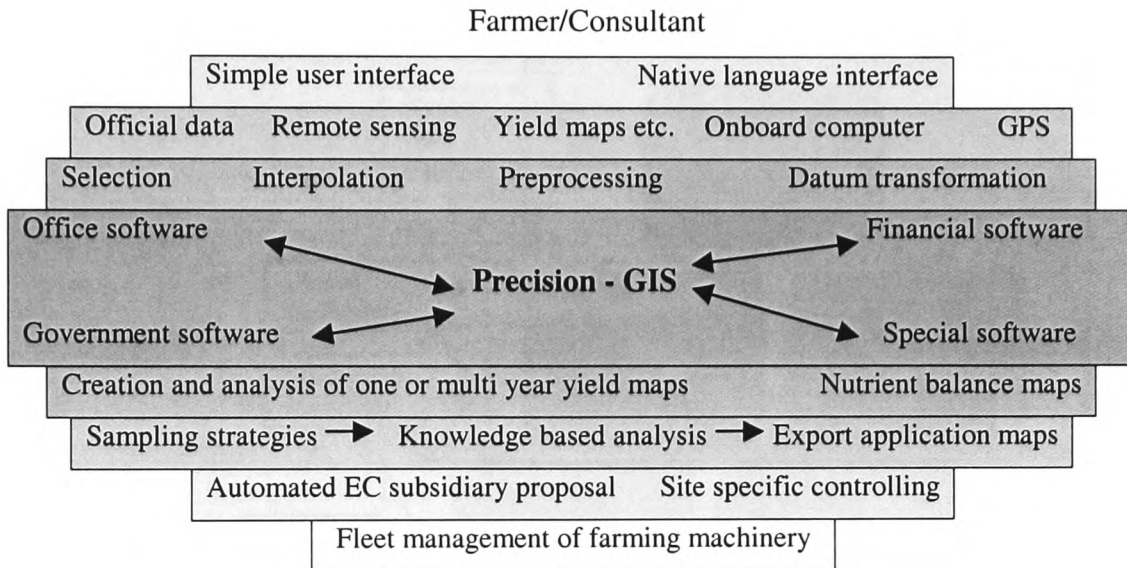
**Figure 3.4** Special requirements for a precision farming GIS

(*Source*: Grenzdorffer 2000 p14)

3.4.2 Spatial Decision Support Systems and Land Use Management

SDSS in land use planning help determine how land should be allocated to existing land parcels to meet certain objectives. In agriculture, land use planning generally involves the allocation of crops and is subject to constraints such as soil characteristics, crop rotation patterns and financial incentives (Sharifi 1993). The problem is seen as multi-objective.

Researchers at the Macaulay Land Use Research Institute have developed a Land Allocation Decision Support System (LADSS) that supports strategic, farm-scale, land use planning. Within LADSS, the land manager specifies certain objectives, the system generates possible combinations of land uses and allows the manager to evaluate the financial, social and environmental consequences (Matthews et al. 1999). The land manager may then refine the objectives after the evaluation. Figure 3.5 presents the five

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components of LADSS and its iterative approach: a GIS; land use modules; impact assessment modules; a graphical user interface; and land use planning tools. LADSS clearly demonstrates the role of GIS as a component within a SDSS. The GIS provides facilities for spatial data handling and visualisation. Bridging software is required between the GIS and the knowledge based system and models within LADSS.
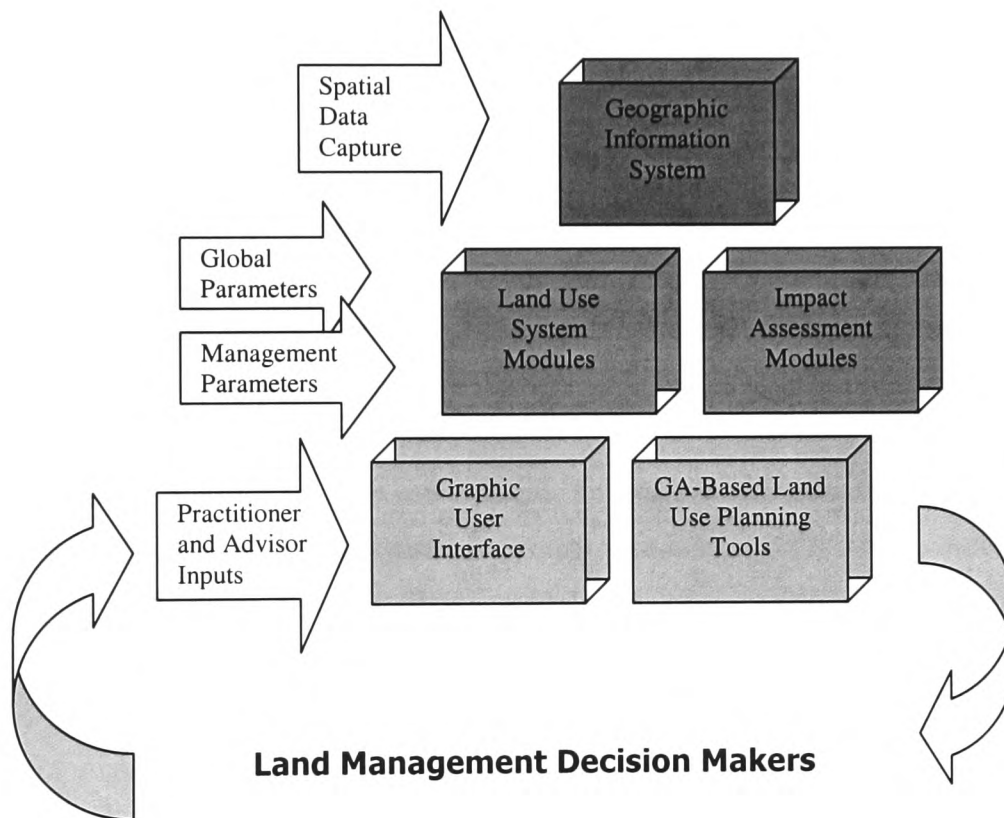
Figure 3.5 LADSS components (*Source*: Matthews et al. 1999)

Research is currently in progress in which expert systems and GIS technologies are integrated to assist in the implementation of a land suitability evaluation model. In this work, Kalogirou (2002) argues that land evaluation has two components, a physical and an economic evaluation. The physical evaluation produces a score for cultivation based on the Food and Agriculture Organisation of the United Nations (FAO) land classification for crops (FAO 1976), data describing a land parcel in terms of its soil properties and its environmental characteristics. The economic evaluation selects the highest expected income from calculations of expected income for all possible types of cultivation. The software that has been developed to perform the evaluation is named

Land Evaluation using an Intelligent Geographical Information System (LEIGIS). The role of GIS within LEIGIS is to provide functions for managing spatial data and visualising results whilst the expert system has been implemented in CLIPS, the C Language Integrated Production System developed by NASA (Zhu et al. 2001).

3.4.3 Transportable Agricultural Decision Support Systems

An area of research into agricultural DSS, undertaken by Jacucci et al. (1996), explores the portability of agricultural DSS between different locations. The aim of developing transportable DSS is to construct a system that can be widely used. The researchers propose a conceptual framework (Table 3.1) in which four aspects are identified: the general implementation of the DSS; user interaction; data management; and models. This is in agreement with the architecture proposed by Densham (1991). Public domain tools are used to implement a DSS that is transportable and emphasis is placed on a user interface that is easy to use. Data management issues are raised in accessing different sources of data and automatic data conversions. The adaptability of agricultural models is considered as the DSS is transported from one region to another. This research is important as it identifies access to diverse data sources using different access methods as a key factor in the development of the DSS.

Table 3.1 Aspects of the conceptual framework for developing transportable DSSs

(Source: Jacucci et al. 1996)

| CONCEPTUAL FRAMEWORK FOR DEVELOPING TRANSPORTABLE DSS			
General Implementation Aspects	User Interaction Aspects	Data Management Aspects	Model Aspects
Public Domain Tools	Graphical User Interface (GUI)	Multiple Access Methods	Flexible Models
Portable Tools	Multiple Speaking Languages	Automatic Data Conversion	Model Adaptation Component
Structured Programming	User Specific Decision Scenarios	Data Management Utilities	

3.4.4 Web-based Decision Support

With the development of the Web, information is now widely available to users who are able to access centralised resources from home, work, libraries and other Internet access points. The Internet offers many GIS facilities including, for example, access to teaching and learning material, information location tools such as geolibraries and low cost data transfer (Longley et al. 2001). Within the field of environmental management, research is underway to develop web-based tools that will assist land managers in deriving policies for sustainable native vegetation management. Vegman, a prototype Web-based information system allows decision-makers to weight multiple objectives as part of their analysis (Zhu et al. 2001). The system uses JavaAHP, a Web-based decision analysis tool that implements the Analytical Hierarchy Process as a multi-criteria decision-making methodology. The use of Web technology to disseminate information between different systems through a well-designed user interface and hyperlinks is clearly a solution in addressing compatibility between computer platforms. The whole area of interoperability is discussed in detail in chapter 5 of this study.

3.5   Development of a Prototype GIS as a Farm Decision Support Tool

Section 3.4 provided an overview of the current SDSS applications and research found within the agricultural and environmental sectors. In the studies described, GIS lies at the centre of the SDSS, playing a key role in handling user queries through an intuitive interface, integrating data and models and providing output in appropriate formats. Though a GIS has limited modelling capabilities (Densham 1991), it has been presented as a powerful component of a SDSS. This section justifies the proposed development of a prototype GIS as a farm decision support tool.

A farm manager making decisions relating to land allocation clearly relies on data that has a spatial nature. Location, extent and properties of land parcels (e.g. soil type and composition) are important factors when deciding how to utilise the land to meet specific objectives. Figure 3.6 develops the SDSS architecture proposed in Figure 3.2 and illustrates how a GIS, situated within a DSS, can act as a support tool for the farm manager (Garton & Taylor 2001).
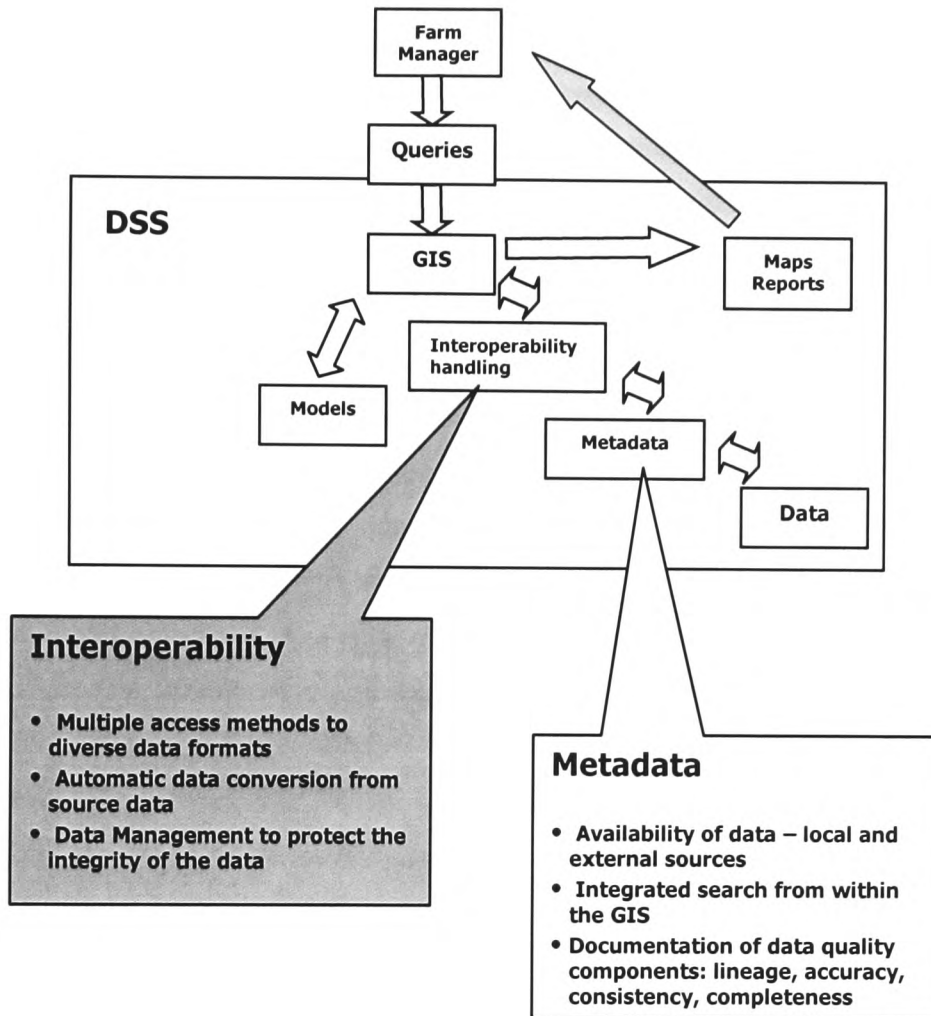
Figure 3.6 Data Issues within a SDSS for the farm manager
(Garton & Taylor 2001)

The integration of the GIS within the DSS agrees with the approach proposed by Fedra (1996). The farm manager generates a query that is passed into the GIS. The GIS locates the data required for the query and transfers the data into the modelling facility. The results of the analysis are presented to the manager in a suitable format, a report or a map. This process may lead to further refinement of the query until, after a number of iterations, an acceptable option is reached (Garton & Car 2000).

The GIS is required to integrate data, modelling and report generating software and communicate with the farm manager through the user interface. Data may be stored on different computer platforms and in management systems that have their own generic

file format. Issues involving the location of datasets and interoperability between systems are thus raised (Garton & Taylor 2002), as shown in Figure 3.6. Metadata and interoperability are considered of fundamental importance for the location and use of datasets within the SDSS. The development of standards and good practice guidelines for the creation and management of metadata are discussed in chapter 5 section 5.2.5; the current approach to interoperability and proposed solutions for the prototype GIS are considered in chapter 5 sections 5.3 and 5.4.

The model base within the SDSS must provide access to software that the farm manager already finds useful, as well as to other software that will enhance the final decision. Detailed systems analysis will identify the model requirements but it is clear that spreadsheet and spatial analysis software are important. Though the farm manager may have multiple objectives in allocating land use, most decisions are justified financially (Garton & Car 2000). Gross margin calculations are made by the farm manager, offsetting potential income, based on crop yields and grants per hectare of land, against overheads (Powell 1999). When considering the conversion to organic farming, decisions may have to be made to ensure that organic enterprises are not polluted by contact with non-organic practice. This may involve repositioning buildings, analysing access to fields and identifying pollution risks to watercourses. Spatial analysis software modules would assist with this analysis and form part of the model base system within the SDSS.

The farm manager will require output in map format, cropping plans for example, and in tabular format suitable for submission to grant awarding bodies and, in the case of the conversion to organic farming, to accreditation bodies (Minter 1999). Commercial GIS software such as MapInfo and ArcView include Crystal Reports, a sophisticated reporting package that allows the user to define standard reports in addition to generating ad hoc reports (MapInfo 1998a, ESRI 1999)

Users will interact differently with the GIS, depending on the task they wish to tackle and their own level of expertise. The most basic functions relating to data offered by a GIS include facilities to:

- identify appropriate data sets (browsing);
- select spatial objects of interest (querying);

- output graphical and tabular data (displaying and reporting) (Egenhofer & Kuhn 1999).

In developing the GIS as a support tool, the user interface must be tailored for ease of use. Customisation of a GIS package generally involves the modification of the standard graphical user interface and addition of specialised routines (Maguire 1999). High level languages can be used by the developer to customise an application: MapBasic allows the development of programs in MapInfo (MapInfo 1998b) and Avenue scripts can be written to provide extra functionality in ArcView (ESRI 1999). In addition GIS packages now support other programming environments and allow developments in Visual Basic, Visual C++, Delphi and Java (Maguire 1999, ESRI 2003).

The architecture of the prototype GIS has been proposed in this section but the scope and the range of facilities it must offer will only become clear after detailed analysis with the farm manager. The main areas to address have been identified as:

- the location of datasets;
- the interoperability between software applications;
- the specification of models;
- the definition of outputs: maps and reports;
- the level of customisation required.

3.6 Summary

A decision-maker requires a flexible environment in which to explore alternative models before making an informed decision. The decision-making process tends to be iterative, with the results of an iteration feeding into the next. SDSS assist the decision-maker dealing with spatial problems by incorporating a model management system, a database management system, display and report generators and a user interface. Though GIS do not fully meet the characteristics of a DSS, the functions offered within a GIS, when coupled with other modelling software, can form the core of a SDSS.

As a land based industry, agriculture is beginning to exploit new technologies such as GIS, GPS, remote sensing and variable rate treatment. Precision farming, in which land

management can be taken down to sub field level, relies on GIS as its central hub. The GIS integrates the collection of data and the use of modelling software, and directs the application of seed and nutrients using an onboard computer in the tractor cab.

Current research in agricultural and environmental SDSS views GIS as a key component, enhanced by links to more powerful statistical and modelling packages. Developments in the dissemination of information to decision-makers include the transportability of a SDSS between systems and the use of the Web to deliver decision-making tools. Customised interfaces are designed to facilitate ease of use of a SDSS and support the iterative decision-making process.

Recognising GIS as a powerful tool within a SDSS, a revised architecture for a SDSS for a farm manager was proposed in this chapter. GIS is represented as the key decision support tool, integrating data and models and providing output in a variety of formats. Customisation of the GIS interface will ensure the links are transparent to the user. The functionality required of the GIS will be specified following a detailed analysis of user requirements.

4.1   Introduction

GIS was identified as an essential tool at the core of a powerful SDSS designed to assist those making land-based decisions (section 3.3). The role of the GIS is to allow the user to explore alternative solutions through a user-friendly interface by integrating disparate datasets, providing access to relevant models and producing output in an appropriate format. This chapter explores the general requirements for a GIS acting as a support tool for the farm manager initiating the conversion process from traditional farming to organic practices.

The process-driven approach for system development is introduced; in which the output demanded from the system defines essential data sources and the functionality that must be available from the GIS. Together these factors lead to the final specification of the GIS. Three main activities during the conversion process are identified: site selection for conversion; production of conversion plans; and monitoring of the conversion process. The decisions involved and the data required to assist the farm manager in site selection and monitoring are explored. The documentation required by the certifying body (Soil Association 1999) is summarised, establishing the main output required from the GIS.

By studying the tasks performed by the farm manager in this case study the broad requirements for the GIS as a decision support tool are specified. Data issues are raised that are explored in chapter 5. The specific implementation of the requirements in this case study is described in chapter 6.

4.2   The Process-Driven Approach

The process-driven approach to system development examines the functionality required of the GIS, ensuring the design is driven by the user's needs rather than the available technology (Honea et al. 1990). By consulting with the user, the developer will identify the tasks to be performed, the data used and the format preferred for the presentation of information (Frank 1995).

This process will clarify (Figure 4.1):

- the users' requirements (**output**) from the GIS;

- the data needed to provide this information (**input**), what is there and what is missing;

- the functions required to transform the data into information (**functionality**);

and will lead to (Cremers 1995):

- the **specification** of the proposed GIS.
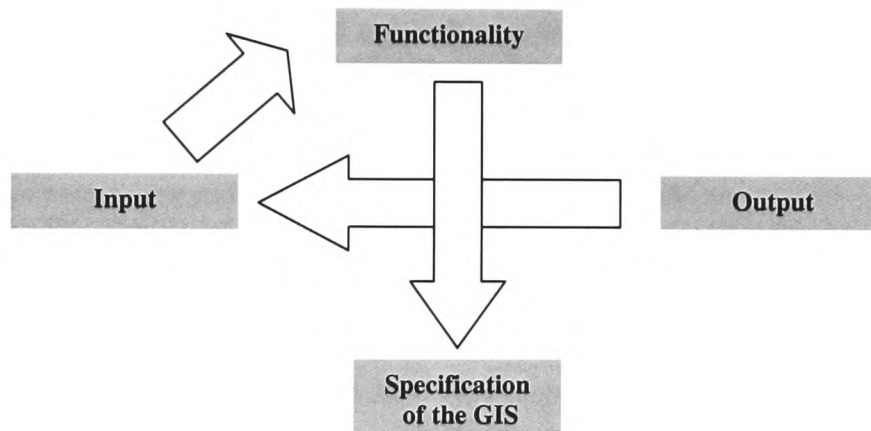
Figure 4.1 The Process Driven Approach (Garton & Car 2000)

The farm manager will be the main user of the GIS as a decision support tool for the conversion and is the prime source of information relating to the required output from the system. Three areas of activity that involved the farm manager included:

- the selection of appropriate fields for conversion;

- the production of conversion plans for the accrediting body;

- the continued monitoring of the conversion process.

The process-driven approach was adopted to define the requirements of the GIS. It focused on the decision process followed by the farm manager and identified the information required to support a particular decision.

4.2.1 Selection of Fields for Conversion

In changing to organic farming methods the farm manager must make decisions as to:

- what land to convert (which fields, possibly in terms of existing crops);
- where to convert (location of fields in relation to buildings, non organic fields);
- what enterprises to convert (dairy, beef, sheep, crops);
- when to convert (spring, summer, autumn, winter);
- how to feed the organic stock (grow or purchase a proportion of organic feed).

Although it is accepted that during the conversion period it is likely that output will decrease without any compensation from premium prices (MAFF 1999), the decisions made must have a sound economic basis. The farm manager must assess different combinations of enterprises and land usage for the optimum financial return.

The main financial planning tool used by the farm manager calculated gross margins for each enterprise on the farm. (Chadwick (1998) defines the gross margin of an enterprise as its output less its variable costs). This analysis is easily performed using a spreadsheet package. However, as the variable costs vary in proportion to the scale of the enterprise, relating to the number of hectares or stocking rate (livestock per hectare), it is clear that there is a spatial dimension to the calculation (MAFF 1999). An example of a projected gross margin summary for an agricultural enterprise is shown in Table 4.1.

Table 4.1 Projected Organic Gross Margin Summary (Powell 1999, p.16)

Enterprise	Number of units	Gross Margin £/unit	Total (£)
Beef Sucklers*	36	230	8280
24 month beef*	32	360	11520
Breeding ewes*	360	60	21600
Cereals	90	350	31500
			including forage costs
Total Farm gross Margin (280 acres)		260	72800
Fixed costs/acre		175	49000
Net profit/acre		85	23800

The GIS would be required to assist in the preparation of such summaries either by reporting from the GIS itself or exporting data into a modelling package, such as a spreadsheet, for further manipulation. The final output required from the GIS at this stage would be a map (Figure 4.2) indicating which fields to convert for optimum financial return.
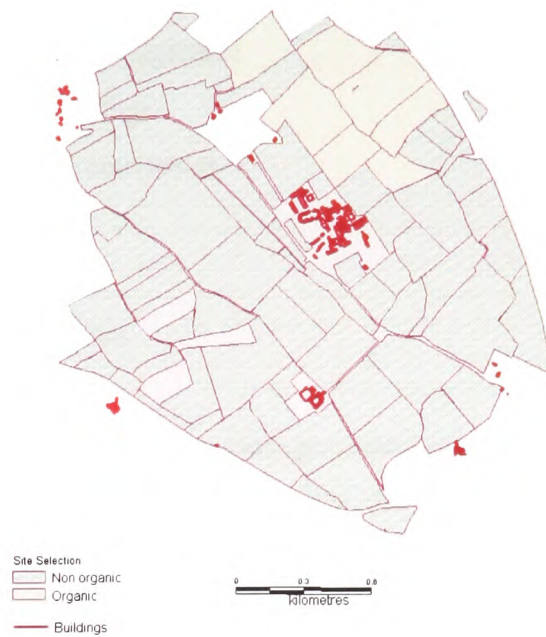
Figure 4.2 Selected fields for conversion

The farm manager must also ensure that organic and non-organic livestock are kept separate, and that the land for conversion is not contaminated through contact with non-organic material. This may have an impact on housing and manure storage and lead the farm manager to consider whether changes are required in stocking patterns. The GIS would assist in this assessment by displaying the position of existing buildings on the basic map of the farm and providing buffering tools to build zones around buildings and watercourses, for example.

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4.2.2 Production of Conversion Plans

In submitting an application form to the certifying body (Soil Association 1999), the farm manager must provide an accurate map of the farm together with conversion plans detailing (Minter 1999 p.6):

- soil management
- soil analysis
- proposed crop rotations
- supply of plant nutrients
- weed and pest control
- grazing and grassland management
- environmental conservation
- practices for livestock conversion
- feeding regimes
- disease control
- field records and histories.

In devising management plans, the farm manager must build on the basic inventory data to decide which fields should be used for forage or fodder crops and how the crops should rotate in subsequent years. The GIS would assist in the production of maps for soil management and crop rotations and act as a central mechanism for accessing field records. The Soil Association will accept field records and field history data in tabular format, ordered chronologically (Minter 1999). The availability of data required by the Soil Association is discussed in section 4.3.

4.2.3 Monitoring the Conversion Process

Once conversion is underway, the farm manager must monitor the land, with the chemical composition of the soil identified as a key indicator. The GIS would assist the farm manager by storing changes to soil data, allowing a comparison of soil characteristics at stages during the conversion. With this information, the farm manager would assess whether the conversion was proceeding well or if remedial action must be taken.

By considering the tasks of selecting suitable fields for conversion, the production of conversion plans and monitoring the conversion process, key requirements relating to output from the GIS were defined:

Requirement 1: To provide a base map of field boundaries on the farm for exploring the conversion of fields in relation to existing buildings, road access and drainage courses.

Requirement 2: To link to a package, such as a spreadsheet, to explore the financial impact of land-use options.

Requirement 3: To provide access to historical field records required by the certifying body.

Requirement 4: To assist in map production showing cropping rotations and soil management.

4.3 Datasets

As part of the submission for a grant application for organic accreditation, the farm manager must provide an up to date map of the farm with associated field records for the current year and also the previous five years (MAFF 1999). Most commercial organisations maintain such field records in agricultural database packages. In this study Optimix, (Farmplan Computer Systems, 1996), was used between 1996 and 1999 on a standalone PC to hold records relating to soil analyses, applied nutrients, fertilisers, crop varieties and yields per field. Agridata, a database package that stored records relating to cattle, sheep and land parcels, replaced Optimix in 1999 for recording local farm data.

These and other datasets used by the farm manager and maintained in the farm office are summarised in Table 4.2. These datasets formed the basis for common tasks such as the production of maps of current and past land usage and would prove most useful in supporting the farm manager in arriving at a well-reasoned decision for future land-use options.

Table 4.2 Existing datasets used by the farm manager

Dataset	Format	Computer Platform
Optimix: historical field records	dBase (.dbf, .cdx)	Standalone PC, single licence
Agridata: current records relating to stock and land parcels	Paradox (.dbf, .cxx)	Standalone PC, single licence
Annotated farm maps	Paper	
Ordnance Survey tiles	MapInfo tables	NT network
Field boundaries	MapInfo tables	NT network
Soil map	Paper	
IACS* details: historical and current	Paper	
Pollution map	Paper	
Accounts	Excel spreadsheet	Standalone PC

*Integrated Administration and Control System

The most important datasets for the farm manager were field boundaries defined on heavily annotated paper maps, and cropping details for the past 4-5 years stored in the Optimix database. Integrating these data led to:

Requirement 5: To link the spatial data represented on the farm map to the attribute data in the agricultural databases.

In this case study, Optimix and Agridata were not fully compatible with other software, raising data interoperability issues that are addressed in chapter 5, section 5.4.

4.3.1 External Data

Decisions made by the farm manager may be affected by external factors such as planning regulations, environmental constraints and grant eligibility for specific developments. The government has introduced schemes including the Countryside Stewardship Scheme, the Farm Woodland Premium Scheme and the Organic Farming

Scheme to encourage diversification amongst the farming community (DEFRA 2003). Rural recovery is particularly important following the Foot and Mouth outbreak. Information from external organisations such as DEFRA and the Environment Agency (EA) would be particularly valuable for land-use allocation. The GIS would assist the farm manager in locating external data by providing access to data catalogues on the Internet:

Requirement 6: To provide access to data catalogues on the Internet to locate relevant datasets.

The information describing a dataset is known as *metadata*. A full discussion of the importance of metadata and developing standards is provided in chapter 5, section 5.2.

4.4   Functionality

As a decision support tool, the main requirement of the GIS is to assist the farm manager in applying his/her expert knowledge to the available data. This section explores the functionality required of the GIS to support the farm manager in making informed decisions.

The fundamental functions that any GIS must perform include data capture; data manipulation; data storage and archiving; data maintenance, including updating and auditing; data analysis, spatial and statistical; data output, including display, plotting and printing (CCTA (Central Computer and Telecommunication Agency) 1994). An initial assumption that the farm manager would be a novice GIS user demanded the availability of development tools to automate repetitive tasks, the production of standard maps and reports for example.

As the farm manager's skills developed other GIS functions would be useful in exploring land-use options. These include:

- digitising new features: e.g. wildlife ponds, hedgerows;
- buffering: e.g. creating zones around watercourses and farm tracks to ensure land under conversion is not polluted from contact with non-organic treatments;

- overlay: e.g. adding data layers showing location of Sites of Special Scientific Interest (SSSI), Environmentally Sensitive Areas (ESA) and Rights of Way (ROW) that may add constraints for land-use options;

- analysis (Structured Query Language - SQL): e.g. to assist in planning crop rotations the farm manager may select land parcels meeting a specified criteria (crop="barley");

- thematic mapping: e.g. generating thematic maps of crops, soil types and, if available, clover content and water pollution risks;

- data aggregation/disaggregation: e.g. the effect of combining and splitting land parcels may be explored, with adjustments to the associated data;

- import and export functions: e.g. data may be exported to be manipulated in a financial modelling package or spreadsheet; the results may be imported to be displayed in the GIS.

- multi-criteria analysis: factors such as financial suitability, location of drainage systems, slopes, access to buildings etc. affect the selection of fields for conversion. Some may be considered more important than others and the farm manager may wish to specify weighting factors for multi-criteria analysis (Eastman et al.1993).

This section has described the basic functionality required from the GIS if it is to be a useful decision support tool for the farm manager. Examples have been provided of how more advanced functions may be used by the farm manager, though multi-criteria analysis was not considered in the implementation of the GIS in this case study. The strength of the GIS would be to allow the farm manager to explore land use options through a visual medium. These requirements are summarised as:

Requirement 7: To allow the farm manager access to a full range of GIS functionality.

4.5   Customisation

The user interface of the GIS must be designed so that the farm manager, as a novice user initially, would have little difficulty in locating data and producing the required documentation for the certifying body. This will require the modification of the generic user-interface provided by the selected GIS package, with the introduction of

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customised options for the farm manager. The GIS package must offer development tools to assist in the customisation of the interface.

Requirement 8: The GIS software must include a development language to assist in the automation of repetitive tasks.

4.6 Summary

This chapter has studied the main activities undertaken by the farm manager considering the conversion from traditional to organic farming practices: site selection; production of conversion plans; and monitoring the conversion. The process-driven approach was followed to derive the specification for the GIS at the centre of a SDSS. The factors influencing the farm manager's decisions for site selection, the documentation required by the certifying body, and the indicators used to monitor the conversion process defined the output, data sources and the functionality that must be available from the GIS. In these activities the farm manager required facilities to:

- explore the location of features such as buildings, roads and watercourses visually;
- link to a spreadsheet package to assess the financial implications;
- access existing agricultural databases containing current and historical field records;
- locate information from external organisations relating to grant aid schemes, for example.

The investigation of the datasets used by the farm manager raised data issues for the development of the prototype. The location of data from external organisations involves an assessment of their relevance and usefulness. The integration of data from other software packages requires compatibility between systems. These issues are explored fully in chapter 5 with a discussion of metadata and interoperability for decision support systems.

The farm manager identified repetitive tasks such as the preparation of standard maps and reports for the certifying body. The facility to customise the user-interface to automate these common procedures required a development language within the GIS. These factors led to eight key requirements in the specification for the GIS as a decision

support tool for the farm manager (Table 4.3). The specification formed the basis for the implementation and evaluation of the prototype GIS described in Chapter 6.

Table 4.3 Specification for a Farm GIS as a decision support tool

	Requirements
1	To provide a base map of field boundaries on the farm for exploring the conversion of fields in relation to existing buildings, road access and drainage courses.
2	To link to a package, such as a spreadsheet, to explore the financial impact of land-use options.
3	To provide access to historical field records required by the certifying body.
4	To assist in map production showing cropping rotations and soil management.
5	To link the spatial data represented on the farm map to the attribute data in the agricultural databases.
6	To provide access to data catalogues on the Internet to locate relevant datasets.
7	To allow the farm manager access to a full range of GIS functionality.
8	The GIS software must include a development language to assist in the automation of repetitive tasks.

5.1   Introduction

The starting point for this research was the premise that a SDSS would assist the farm manager in planning the conversion of farm enterprises to organic practices, and that the GIS would play a central role in integrating user queries, data and models, and generating output (Figure 3.6). The key requirements of the GIS, defined in full in chapter 4, indicated that the farm manager needed:

1. a base map of the farm for exploring alternative land-use options;
2. a facility to export data into a financial modelling package such as a spreadsheet;
3. the ability to import current and historical data from agricultural databases;
4. the production of maps and tabular data for the certifying body;
5. a link between the farm map and the data in the agricultural databases;
6. access to data catalogues on the Internet;
7. access to full GIS functionality;
8. a user-friendly interface that would assist in the automation of repetitive tasks.

These requirements raised data integration issues: the identification, location and acquisition of existing and missing datasets that would be relevant to the farm manager; and the integration of data from bespoke agricultural databases used to maintain field records. The value of metadata in describing datasets in terms of their content, availability and as an indicator of data quality was recognised. Interoperability problems, such as the compatibility of data formats, occurring when users must access more than one dataset from disparate sources were identified.

This chapter introduces the concept of levels of metadata and establishes the theoretical basis for adopting metadata standards in the development of the prototype GIS, the central component of the SDSS. Recommendations are made for metadata management, in line with the principles and good practice detailed by the Intra-governmental Group on Geographic Information (IGGI) (IGGI 2001). An overview of current research in defining metadata standards is provided together with examples of data locator services using these standards.

Interoperability between systems and the call for "Open GIS" are introduced. Interoperability strategies and the formulation of policy documents by the UK government defining an interoperability framework and metadata standard (ukgovtalk 2000) are described. The impact on the design of the prototype GIS, ensuring access to metadata records and the integration of data from external datasets is summarised.

5.2 Metadata

Data lie at the heart of a farm SDSS with the GIS acting as a powerful tool in integrating user requests, accessing data and models and generating output (Figure 3.6). However the content, location and methods of accessing appropriate datasets are not evident. To locate and access a relevant dataset a user needs (Longley et al. 2001):

- facilities for search and discovery;
- information to be able to "assess the fitness" of a dataset;
- instructions for handling the dataset effectively;
- information describing the contents of the dataset.

This *data about data* is known as metadata. This section explores the reasons for developing and maintaining metadata records and summarises the current development of metadata standards.

5.2.1 The Chorley Report

In 1985 the government established a Committee, led by Lord Chorley, with the following remit:

> "To advise the Secretary of State for the Environment within two years on the future handling of geographic information in the United Kingdom, taking account of modern developments in information technology and of market need"
>
> (Department of the Environment 1987)

The report explored, amongst other issues, the availability of data and the benefits of SDSS in linking data sets together. To achieve this linkage the report recognised two

essential factors: locational references, and data documentation and exchange standards. The report stated it was very difficult to link data sets because:

> "1.   the data are not explicitly spatially referenced, the data relate to a variety of different areas which do not match or nest into each other and the boundaries of these areas are frequently changed for administrative reasons.
> 2.   data sets are poorly or inconsistently documented; and
> 3.   different users' computer systems – including hardware, software, and data structures – and communications equipment are incompatible. "

The need for the documentation of data for future use was strongly emphasised if datasets were to be accessible by an audience wider than the organisation producing the data. Metadata provides such documentation for a dataset by detailing, for example:

- *what* the dataset contains;

- *who* owns the dataset and *who* is allowed to access or update the data;

- *where* the geographic objects covered by the dataset are located in space;

- *how* the data was collected and stored and *how* it can be accessed;

- *when* the data was collected.

This summary information implies three levels of metadata: discovery metadata, exploration metadata and exploitation metadata (NGDF (National Geospatial Data Framework) 2000). Each of these will be considered together with their relevance to the development of the prototype GIS.

5.2.2 Discovery Metadata

Discovery metadata provides the user with sufficient information to discern the content, format and scope of a dataset. The information broadly covers the "what, who, where, how and when" categories, allowing the user to decide if the dataset is potentially useful. Although the prototype GIS would be designed for the farm manager, staff and students on campus would benefit from access to the GIS. As these additional users would not be aware of datasets held by the farm manager, a facility to search and discover both local and external datasets was identified as a key requirement of the prototype (requirement 6).

The National Geospatial Data Framework (NGDF) developed and introduced a Data Locator service, askGIraffe, encouraging the public and private sectors to contribute data sets for spatial searching (FitzGibbon 2000). In 2002, responsibility for the service was transferred to the Association for Geographic Information (AGI) (AGI 2002) and renamed GIgateway (Figure 5.1). A link from the GIS to collections of metadata would allow the farm manager to search for datasets of policy areas such as SSSIs and ESAs which may affect decisions about land allocation. Information about Newton Rigg's datasets could also be made available to other users of the service.
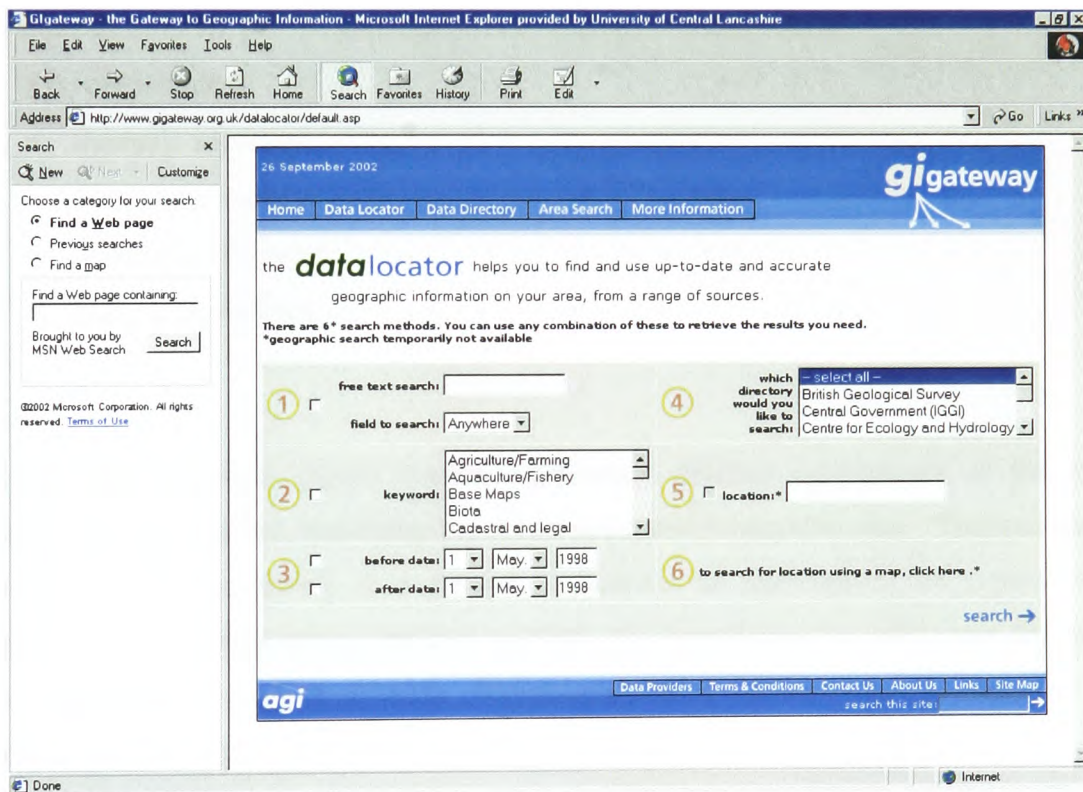
Figure 5.1 GIgateway (www.GIgateway.org.uk accessed 24 September 2002)

In April 2002, MAGIC (Multi-Agency Geographic Information for the Countryside), an initiative led by DEFRA (Department for the Environment, Food and Rural Affairs) working with the Countryside Agency, English Nature, English Heritage, Forestry Commission and the Department of Transport, Local Government and Regions was launched. The aim of the MAGIC project is to "bring together definitive rural and countryside information from the partner organisations – concentrating on rural designation and rural land-based schemes for England" (Swanton 2002a). The public

can access the MAGIC web site (www.magic.gov.uk) and a direct link from the GIS to datasets such as Woodland Grant Schemes (WGS) offered by MAGIC would be invaluable for the farm manager, staff and students.

5.2.3 Exploration Metadata

Once a dataset has been discovered, a user must assess its suitability to satisfy the user's requirements. This "fitness for purpose" is referred to as data quality. The AGI has produced a set of guidelines for describing geographic information content and quality (Parker et al. 1996, part B) and identifies five aspects of data quality:

- completeness;
- thematic accuracy;
- temporal accuracy;
- positional accuracy;
- logical consistency.

Exploration metadata should contain sufficiently detailed descriptions of the five aspects of data quality, specifying the scope and quality measures used. This metadata enables a user to decide if a dataset is relevant or appropriate for a particular application. As an example, the farm manager may have located a policy area defining the boundaries of designated SSSIs. The accuracy of the dataset would be important to ensure that the farm manager did not physically destroy a valuable scientific site.

5.2.4 Exploitation Metadata

The third level of metadata relates to the process of obtaining and using a dataset. This may contain information relating to the source of the data and restrictions on use (Parker et al. 1996, part C). For example, the Data Protection Act may limit the use of a dataset. Technical details such as the format of the data and the supply medium will guide the user in selecting datasets that are compatible with the user's current system.

The three levels of metadata are important for users of the GIS: discovery metadata allows users to explore and locate relevant datasets that may enhance the decision-making process; exploration metadata assists users in assessing the usefulness of the dataset; and exploitation metadata informs users of the mechanisms for obtaining the data and restrictions on their use.

5.2.5 Metadata Standards

In order to share data effectively, it is essential that data providers and data users choose common metadata elements to describe a dataset. Studies are currently underway to establish international standards relating to the composition of metadata (Salgé 1999). Examples of international standards are:

- Draft ISO Standard 15046-15 Geographic Information – metadata;
- CEN / TC 287 Draft European Standard prEN 28877009;
- United States Federal Geographic Data Committee (FGDC) standard, the Content Standards for Digital Geospatial Metadata (CSDGM);
- Dublin Core – Online Computer Library Centre.

The basis for most standards is the CSDGM. As a content standard it does not prescribe how items in a metadata archive should be formatted or structured (Guptill 1999). The main features include ((Longley et al. 2001):

- identification information;
- data quality information;
- spatial data organisation information;
- spatial reference information;
- entity and attribute information;
- distribution information;
- metadata reference information;
- citation information;
- time period information;
- contact information.

The compilation of metadata may prove costly and there is a move towards "light metadata" that provides a concise description of a dataset that is easier and cheaper to create. The Dublin Core Metadata Element Set (Dublin Core) is one such standard and comprises fifteen attributes describing metadata:

- Title
- Author/ creator
- Subject or keywords
- Description
- Publisher
- Other contributors
- Date
- Resource type
- Format
- Resource Identifier
- Data lineage/ quality
- Source
- Relation
- Coverage
- Rights management

(Longley et al. 2001)

The Dublin Core forms the basis of UK government developments and the NGDF Discovery Metadata guidelines have been adopted by the MAGIC project as a standard (Swanton 2000b). When developing askGIraffe, NGDF devised a structure that incorporated the Dublin Core and developed tools (an Access database) for the collection of discovery metadata (NGDF 2000). Using the Access database, data suppliers could submit metadata that would then be available through the data locator service. A new international metadata standard, ISO19115, requiring a complicated mapping from the NGDF guidelines to the current ISO field definitions, is currently under review (Jerome 2002).

5.2.6 Accessing Metadata

Access to metadata is varied, ranging from a simple catalogue of datasets to data locator services such as GIgateway (formally askGIraffe). There are essentially two classifications of metadata access: metadata that is machine-readable and metadata designed for more human interaction (ukgovtalk 2002). Examples of the first category include GIS and database applications. Software such as MapInfo and Idrisi read metadata directly so that the application can correctly interpret the data held in files (MapInfo Corporation 1998a, Eastman 2002). Database packages utilise a data dictionary or data catalogue to record metadata as well as the structure of database objects such as tables and relationships (Hoffer et al. 2002). The metadata within the database will also inform users of reports, queries and other facilities as well as which department or contact has overall responsibility for a dataset. The second category of metadata access, of which GIgateway and askGIraffe are examples, presents the user with basic information such as the creator, title and other data required to locate the data source.

In addition to data locator services, web pages are a very common means of supplying metadata. Many organisations have made the content of an information system available on the web, embedding Dublin Core metadata within the meta elements of HTML (Hypertext Markup Language) documents for example (Dublin Core Metadata Initiative (DCMI 2001). Other tools that have been accepted as standards are XML (eXtendable Markup Language) and RDF (Resource Description Framework). However, not all search engines (e.g. Yahoo and AltaVista) will index meta elements and the user may have to locate and configure an alternative search engine (DCMI 2001).

5.2.7 Current Metadata Developments

Since The Chorley Report (Department of the Environment 1987) the importance of metadata has been recognized internationally. The World Wide Web has opened up the possibility of the sharing of datasets between users in many countries and in many disciplines. The European Territorial Management Information Infrastructure (ETeMII)

is working on convergence for discovery metadata, based on a range of standards including Dublin Core, ISO TC 211, CEN TC 287, OGC and Madame (ETeMII 2001). This work seeks to develop user-friendly interfaces that replace data dictionaries to explain the contents of a database. One proposed solution is to build metadata catalogues of acceptable field values, using a thesaurus to find the preferred term. The thesaurus can be used either in building the catalogue or at the search stage.

The UK government has established e-GIF (e-Government Interoperability Framework), "a set of policies and standards designed to enable information to flow seamlessly across the public sector and provide citizens and businesses with better access to public services." (ukgovtalk 2002). As part of e-GIF, the policy relating to metadata, the e-Government Metadata Framework (e-GMF), states that public sector organisations must conform to the e-Government Metadata Standard (e-GMS) within their information systems. The e-GMS is currently based on the Dublin Core but work is underway to develop a more advanced specification for metadata more appropriate for the needs of the government (ukgovtalk 2002). This development reinforces the use of Dublin Core as an important standard.

5.2.8 Metadata Management

Metadata are a valuable tool for locating information sources within organisations. To ensure that the quality of the metadata does not degrade with time, IGGI has published a document detailing the principles of good metadata management (IGGI 2001). In this IGGI strongly recommends that all UK geographically referenced metadata is made available through askGIraffe and that metadata is compiled using the Dublin Core standard. IGGI has produced a Geographic Information Charter Standard Statement (GICSS) that organisations can sign, agreeing to conform to standards in the delivery of Geographic Information (IGGI 2000). The purpose of the standard is to promote effective management of data held by government. By agreeing to this standard, organisations are expected to establish metadata policies that will ensure that metadata records are reviewed and validated annually (IGGI 2001). Though targeted at government organisations, there are examples of good practice for any data holders, such as the nomination of a metadata steward whose responsibility is to ensure that

metadata is collected and maintained through adherence to strict policies and procedures.

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5.2.9 Metadata Issues for the Design of the Prototype

The farm manager required a search facility to locate relevant datasets either on campus or in external organisations such as DEFRA or EA. Metadata catalogues for external datasets could be accessed via the web. Though it was feasible to build an internal metadata catalogue for local datasets adhering to the Dublin Core standard adopted by UK government organisations (ukgovtalk 2002), it would be more consistent to record the information with a data locator service such as GIgateway. This would ensure that both local and external datasets could be discovered through the same service. To meet this requirement the prototype would offer a facility to access metadata through the GIgateway data locator on the web from the GIS.

The creation and maintenance of metadata records are important issues for both single-user and multi-user systems. In a multi-user environment serious organisational considerations may arise: who would ensure that the metadata records were kept up to date?; who would sanction the sharing of datasets with external users?; were there legal constraints and copyright issues to address? Such decisions would fall to management. IGGI indicates a metadata policy must be established to ensure that metadata records are reliable (IGGI 2001). The maintenance of the metadata records describing datasets used within the GIS would have to be assured if the prototype were to remain a useful tool for the farm manager and future users. Table 5.1 summarises the responsibilities of data providers.

Table 5.1 Maintenance Responsibilities

Activity	Responsibility	Related Activities
Update of network datasets	Dataset owner	Updating metadata catalogue
Update of standalone datasets	Dataset owner	Updating metadata catalogue Transfer to designated access area
Usage of network datasets	Network Administrator	Access rights
Back up of network data	Network Administrator	
Back up of standalone data	Dataset owner	

The importance of metadata as the mechanism for sharing data between organisations has been explored in this section and the value of incorporating access to metadata through the prototype GIS has been assessed. Recommendations for metadata management from the UK government have been presented and the implications for the organisation raised.

5.3   Interoperability

Within a single organisation most users access corporate datasets and software applications that meet the organisation's business needs. Such integrated systems are based on a limited set of data models and are implemented through common technology (Sondheim et al. 1999). As computing environments have developed, users have become more sophisticated in their use of IT, increasing the demand for open systems, where it is possible to move easily between systems supplied by different vendors. This is particularly important for users of spatial information where data has been collected, digitised, and stored in many different formats (Vckovski 1998).

Through the 1970s and early 1980s, most GIS users shared data by transferring them between systems either by using a translator or a neutral format understandable to both source and target systems. Under either mechanism, the entire data set was converted and transferred at file level, leading to inefficient datasets containing redundant data (Bishr 1998). With the development of networks and distributed database systems, GIS

users are demanding interoperable or open GIS whereby data can be shared and manipulated by each user's application.

Sondheim et al. (1999) state that the two significant challenges that must be met to ensure basic interoperability are:
"

1   *the autonomous systems must be able to exchange data and to handle queries and other processing requests;*

2   *they must be able to make use of a common understanding of the data and requests.*"

The drive for interoperability has concentrated on defining standards for network communications to meet the first requirement and standards for application programming interfaces and the transport of objects across networks to meet the second. The Open GIS Consortium (OGC) is developing an interface definition, the OpenGIS Specification, to assist software developers in creating applications that will allow users to access and process data from a number of sources (Voisard & Schweppe 1998). The OpenGIS Specification is composed of the Open Geodata Model (OGC 2002a), a collection of data types and methods organised into a class library, and the OGIS Services Architecture that facilitates the analysis and evaluation of individual geographic objects by users (Sondheim et al. 1999).

The farm manager would require access to datasets from a number of sources when using the prototype GIS: digital datasets stored on the campus network; data stored in agricultural databases on standalone systems. The use of data locator services such as GIgateway may also locate relevant datasets available from external data providers. Specialised environmental management systems and spreadsheets used for financial modelling were potential applications to be linked through the GIS. Interoperability was thus an important consideration in the development of the prototype.

5.3.1   Interoperability Strategies

A simple approach to data interoperability is the provision of a catalogue of datasets, each of which is described by its associated metadata. The Alexandria Digital Library (alexandria.ucsb.edu) is one example of such a geolibrary, providing access to maps and

images through a web-based search facility (Longley et al. 2001). More sophisticated approaches have been identified by Devogele et al. (1998) and include database integration, standardisation and software system developments.

5.3.2 Database Integration

GIS users will inevitably own datasets that describe the same geographical space. Within a local authority, for example, planning departments, engineering sections, pollution monitoring officers will collect data for their own specific purposes. The methods of collection will vary from department to department with different meanings attached to the data. The planning department may treat a road as a linear feature but the Highways Authority may consider the road to be made up of individual polygons. The decision to integrate such disparate datasets introduces problems of semantics (what do the data mean?), correlation between data structures and the choice of data conversion techniques (Devogele et al.1998). Two possible methods, direct translation and mapping to internal data models, may be used for database integration.

5.3.2.1 Direct translation

Integration of data sets by direct translation requires a data reader, a correlation table that defines the correspondence between input and output data types and values, and a writer (Sondheim et al. 1999). This method leads to ad-hoc solutions that are most successful when applied to a single dataset, ensuring that the loss of information during the conversion process is minimal (Figure 5.2). A simple example is the translation of distance between two systems where the input value is measured in miles and the output value is required in kilometres. The correlation table would indicate a single processing step using the appropriate conversion factor.
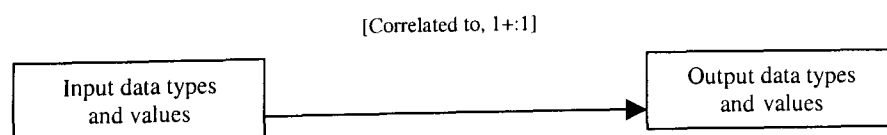
Figure 5.2 Simple translation through correlation. (*Source*: Sondheim et al. 1999)

5.3.2.2 Mapping to internal model

An alternative method to database integration maps input data types and values to types and values maintained in a single internal data model that describes the transfer characteristics. Once the data are in the transfer format, they may be redefined through a series of transformation steps. The advantage of this method is it becomes possible to consider different input and output models and to infer matches impossible with direct correlation (Sondheim et al. 1999). This type of processing is known as smart or semantic translation (Figure 5.3).
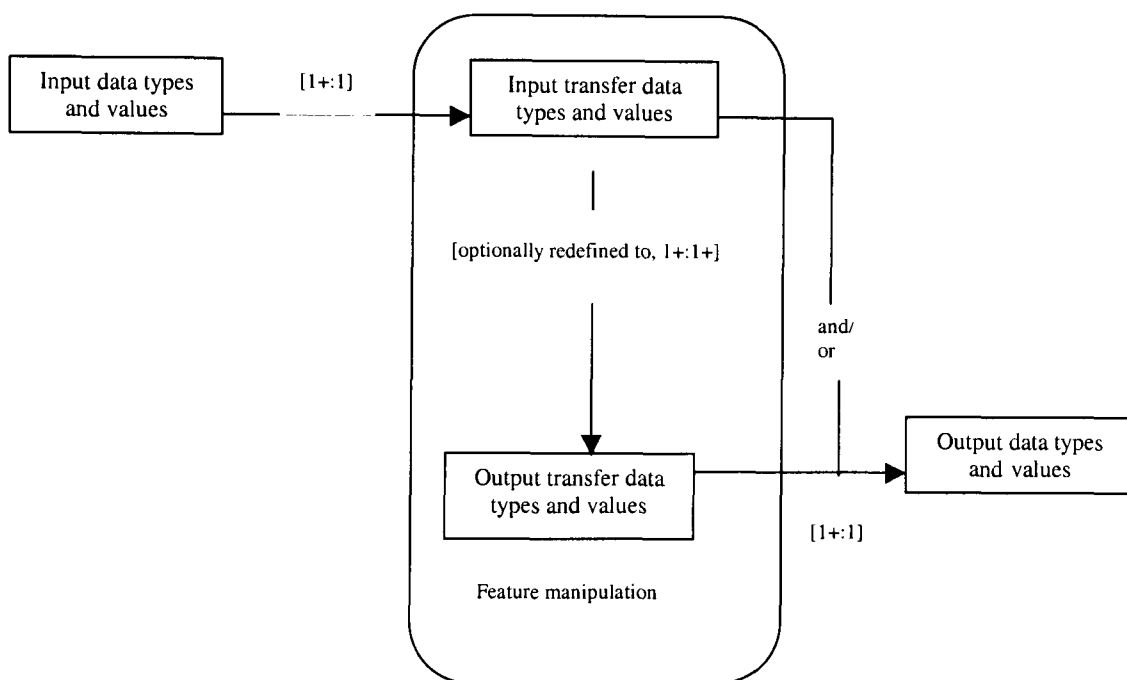
Figure 5.3 Semantic translation through feature manipulation and correlation

(*Source*: Sondheim et al. 1999)

As an example, consider the transfer of data relating to roads between a planning department, which represents roads as linear features and maintains attribute data as labels and columns in ASCII tables, and a highways department, which identifies sections of roads as polygons and maintains attributes in dbf files. A series of processing steps are necessary to combine the attributes from the planning system into a common format for output in dbf format and stages must be defined to transform the linear road feature into a series of polygons for the highways department.

5.3.3 Standardisation

A further approach to interoperability involves the development of standards for data exchange. Although the use of a common format such as DXF may allow the transfer of data between systems, the conversion may result in information loss as a description of data types and the handling of metadata are not defined within the translation. Standards for loss-less information exchange for spatial databases include the Spatial Data Transfer Standard (SDTS) from the US government and the Spatial Archive and Interchange Format (SAIF) from Canada (Salgé 1999). In the UK, the Ordnance Survey are currently replacing the National (or Neutral) Transfer Format (NTF) with the Digital National Framework (DNF) where topographic identifiers (TOIDs) act as digital hooks with the potential to link datasets together (Prendergast 2001).

Internationally a technical committee of the Comité Européen de Normalisation (CEN) is currently studying geographical information to develop a transfer method based on a logical data model and physical encoding. Another committee (ISO/TC 211) is extending the approach by CEN to include operators and services for logical model to logical model transformations (Sondheim et al. 1999).

Standards are clearly fundamental to the sharing of data across international boundaries. However, they do not address the interoperability problems of converting existing data into the selected standard format or integrating data from different sources. The third approach to interoperability, independent of data structures, must now be considered.

5.3.4 Software System Developments

The final alternative to support interoperability is the development of systems where data are accessed through software interfaces or gateways. An application-programming interface (API) allows a user's application to provide or accept data from another application without a detailed knowledge of the internal structure of the data. Microsoft offers Open Database Connectivity (ODBC) as one such interface. This connectivity allows data in the user's database to be updated and saved through commands in the second application (Lorents & Morgan 1998). A difficulty with the provision of APIs from software manufacturers is that they have not been created to any

standard specification, making the integration of data problematic (Sondheim et al. 1999).

Current work on the development of the OpenGIS Specification defines a common interface to integrate geospatial data and geoprocessing (OGC 2002b). Interfaces that comply with this specification allow access both to new and legacy systems (Figure 5.4). Requests made by an application flow to the common interface which returns the required information as encapsulated objects, complying with a distributed computing platform (DCP) specification. Examples of DCPs include the Common Object Request Broker Architecture (CORBA) from the Object Management Group; Object Linking and Embedding (OLE), Common Object Model (COM), Distributed Common Object Model (DCOM) and ActiveX from Microsoft; and Java and Java Beans from Sunsoft (Sondheim et al. 1999).
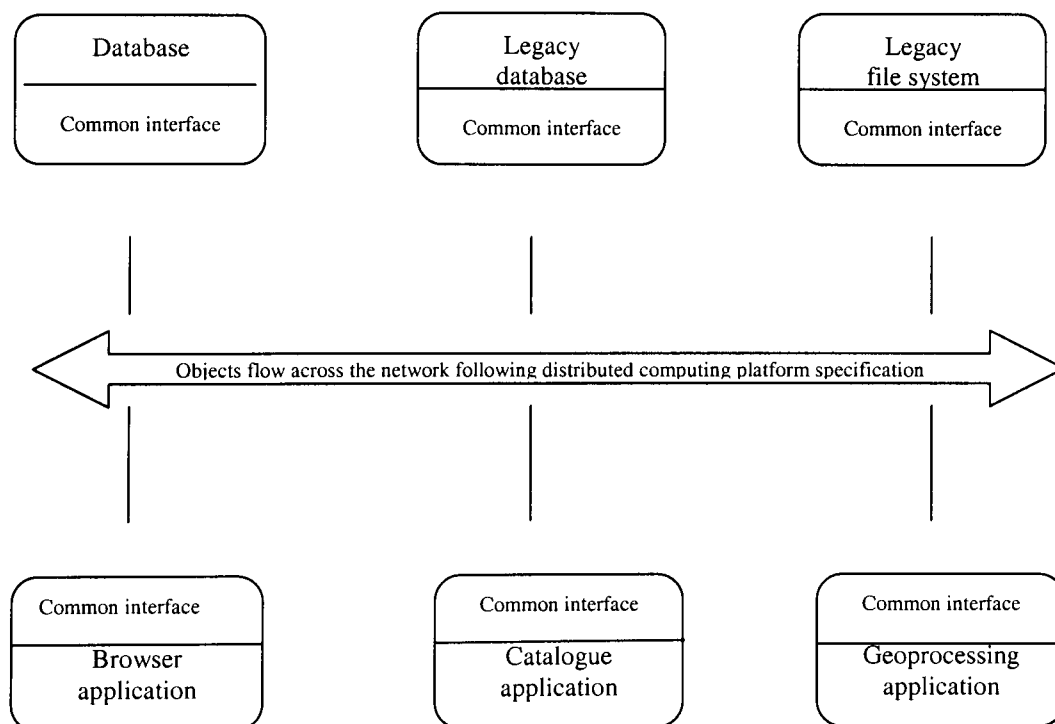
Figure 5.4 Interoperability through a common interface (*Source*: Sondheim et al. 1999)

An example of the use of a common interface lies within the Land Allocation Decision Support System (LADSS) currently under development at the Macaulay Land Use Research Institute (Matthews et al. 1999). Here the GIS and the knowledge-based

system (KBS) at the centre of LADSS are maintained as two separate systems overlain by a common user interface with visualisation, customisation and explanation functionality. This approach, proposed by Fedra (1996), recognises that certain functions within each system do not have to be integrated, thus simplifying the programming requirements.

5.4 Interoperability Issues for the Development of the Prototype

For the farm manager, the prime function of the prototype GIS would be to provide historical and current information relating to land usage on the farm (requirements 3 and 5). Table 4.2 listed local datasets that would prove most useful in supporting the farm manager in arriving at a well-reasoned decision for future land-use options. The formats were diverse, including analogue hard copy; database formats such as dBase and Paradox; MapInfo and ArcView GIS datasets. Some paper maps, such as the pollution map, were simply indicative, with no locational accuracy. The integration of these datasets and those identified through a data locator service defined an important area to explore in the development of the prototype with implications for the design of user-friendly interfaces (requirement 8).

5.4.1 Database Applications

In this case study the main database applications used by the farm manager were Optimix and Agridata, as described in section 4.3. These applications were studied to identify the data integration issues the prototype would have to address. File directories on the standalone PC indicated that the Optimix database created dBase files (.dbf and .cdx). However, these files did not import into packages such as Excel, MapInfo or ArcView with complete success. Figure 5.5 shows that the contents of some data fields were not converted correctly and were unreadable.

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Figure 5.5 Optimix data fields

Agridata records were stored in Paradox database format (.dbf, .cxx). As with Optimix, the files were not successfully imported by other packages. Figure 5.6 shows the result of importing one file within the database into Excel.

Figure 5.6 Agridata Field Data

A further consideration for the prototype was that field boundaries recorded on the farm manager's paper maps had changed over time. How would historical records link to the correct field map for that period (requirement 5)?

5.4.2   GIS and Database Integration

In small farming enterprises, the GIS and agricultural databases would generally be used by one user, the farm manager, and be available on a standalone PC in the farm office. MapInfo offers Open Database Connectivity (ODBC), linking to databases such

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as Access and Oracle. Some pre-processing is necessary to add spatial co-ordinates to a data table to make it "mappable", that is, to allow the table to be displayed in a Map window (MapInfo 1998a). ArcView 3.2, the version available for this development, provides a database connection feature, which creates a table containing records from the database. Though direct editing is not permitted, the data can be added to a map by joining it to the attribute table of a theme through a common field (ESRI 1996). Commercially ArcView 3.3 and ArcView 8 have replaced ArcView 3.2. ArcView 8 allows the user to create and edit simple geometric features in a personal database such as Access (ESRI 2003).

Although MapInfo and ArcView both support external data in formats such as dBase (.dbf) and delimited ASCII text files, data in Optimix and Agridata were not imported successfully (Figures 5.5 and 5.6). During the implementation of the prototype it would be necessary to develop a process to convert the data from the database packages into a format readable by the GIS software. Optimix offered a reporting facility that exported data in Comma Separated Variable (CSV) format. As the data was historical, it was possible to create new datasets in the GIS based on the Optimix records, a conversion that was undertaken only once. Agridata did not offer a data export option and posed the greater problem. The development of a programming solution, invoked from within the GIS, would be one possible option. MapInfo and ArcView have their own associated programming languages, MapBasic and Avenue, though later versions of the software allow direct data manipulation through languages such as Visual Basic (MapInfo 1998b, Maguire 1999). Avenue is no longer used with ArcView 8 which allows developers to customise applications using the built-in Visual Basic for Applications (VBA) as well as other languages such as Visual Basic, Visual C++ or Delphi (ESRI 2003).

The connection to existing data sources from the GIS presented major challenges in the design of the prototype. Mechanisms such as ODBC, joining tables through a common field, the generation of reports using comma separated variables, writing conversion routines in a programming language such as Visual Basic were identified as possible solutions. Chapter 6 describes the development of the GIS and the solutions proposed in this case study.

5.5 Summary

This chapter has presented data as the major component of a SDSS to support the farm manager in the decision-making process. Metadata will increase awareness amongst users of datasets available both locally and externally and allow an assessment of their quality and accuracy to be made. The importance of metadata and metadata standards has been discussed, with the Dublin Core emerging as a standard adopted by UK government departments. Services such as askGIraffe, GIgateway and MAGIC have developed utilising the Dublin Core standard for the structure of metadata records. In following the Dublin Core standard, the prototype would be in line with current developments in this area. The database tool provided by NGDF would be used to set up and search metadata records for local datasets.

The proposed system must allow easy access to data and permit the transfer of data and commands between applications through the design of interfaces acting as bridges (Djokic 1993). A careful consideration of the approaches to the interoperability of systems has shown that a number of methods may be considered: database integration, standardisation and the development of software interfaces. The methods employed in the development of the prototype would be constrained by the datasets themselves, the computing infrastructure and the resources available for customising the interface between systems. The GIS software packages, MapInfo and ArcView, installed on the campus would be evaluated for ease of customisation of the user interface and the transfer of data between different software packages. Users would benefit from Internet access to sites such as askGIraffe, GIgateway and MAGIC and would be able to explore scenarios by exporting data to a modelling package such as Excel. Data management procedures must be developed to ensure the data integrity of common datasets shared by users (Jones and Taylor 2003). Users would be confident that they were working with the most up to date data available. With sound management of the selected computer platform, data owners would know their datasets were protected from accidental changes. It may prove difficult to identify someone within the organisation to take on the role of "data steward" but guidelines for data management would be produced as part of the scope of the prototype.

The opportunity to make informed decisions or to explore the impact of certain policies will be lost if data are hidden in a complex labyrinth or the system is too cumbersome to use. The main objective of the prototype would be to allow users to explore data without the necessity of learning a GIS package. By following metadata standards within the prototype, users would be able to assess the scope and limitations of available datasets. By identifying methods of interoperability users would benefit from access to datasets derived from a range of sources. Though only users can make decisions, the GIS within the prototype would act as a powerful tool in delivering data.

6.1   Introduction

This chapter introduces the systems life cycle and prototyping as methodologies for system development. The limitations of the traditional systems life cycle approach for a GIS are discussed and the final selection of prototyping as the preferred methodology for the design of the GIS is justified. The user plays a key role in the development of a prototype, ensuring that problems are identified and resolved early in the design of the system. Though a specific implementation is discussed, the tasks, datasets and requirements are considered typical for a farm manager considering new farming enterprises.

The farm manager, as a representative user of the GIS as a decision support tool, was consulted throughout the implementation. The main activities of the farm manager planning the conversion to organic farming were considered in chapter 4, leading to eight specific requirements for the prototype GIS. The importance of GIS interface design in meeting these and data integration issues is recognised and general principles for the design of user interfaces are introduced.

ArcView, offering development tools for the customisation of the user interface was chosen to implement the prototype. How each requirement was realised in the prototype is described together with an indication of some of the difficulties encountered. The criteria for the evaluation of the prototype GIS are defined: the match to the requirements in the original specification; the usability of the system; and an assessment of the level of accuracy of datasets. The system was evaluated against these criteria and areas for future development are proposed.

6.2   Approaches to System Design

6.2.1   The Systems Life Cycle

The traditional approach to the development of an information system involves a number of stages known as the systems life cycle (SLC) (Grimshaw 2000). The

commonest representation of the SLC is the waterfall method (Figure 6.1) where each stage flows sequentially into the next. The method was originally proposed to enable a software project to be planned and managed following engineering standards (Boehm 1976). The basic assumption is that a problem can be well defined and an optimal solution reached step by step.
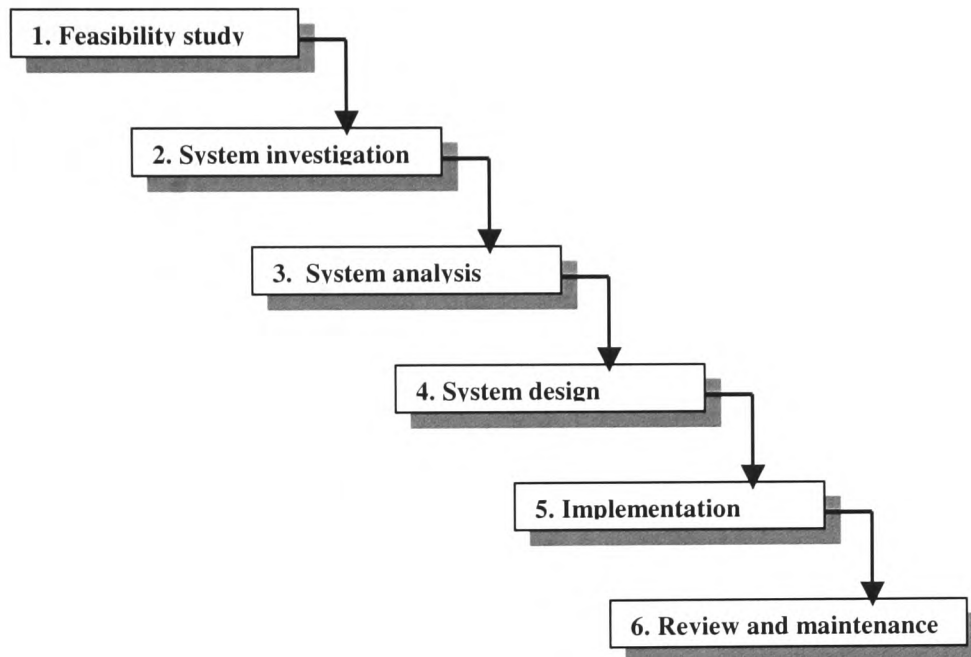
Figure 6.1 Traditional waterfall model of systems development

(*Source*: Grimshaw 2000)

The main criticism of the traditional life cycle is its inflexibility. Maguire (1999) questions the use of the SLC in GIS developments, criticising the length of time going through the life cycle. User requirements and technology may change over the development of the system. In areas where a GIS is introduced for the first time, users may not fully appreciate what the system will do until it is implemented. Attempts may be made in the maintenance stage to adapt or "patch" the delivered system to meet the users' changing needs, resulting in increased development costs (Hoffer et al. 1996)

6.2.2 Prototyping

The second most common methodology used by the GIS designer is prototyping. Hoffer et al. (1996) define prototyping as:

> "An iterative process of systems development in which requirements are converted to a working system that is continually revised through close work between an analyst and users".

The approach involves continual dialogue with users, ensuring that the new system meets the users' evolving needs (Heywood et al. 2002). Figure 6.2 presents prototyping in the form of a spiral in which decisions are made early in the development and refined through several iterations (Maguire 1999).
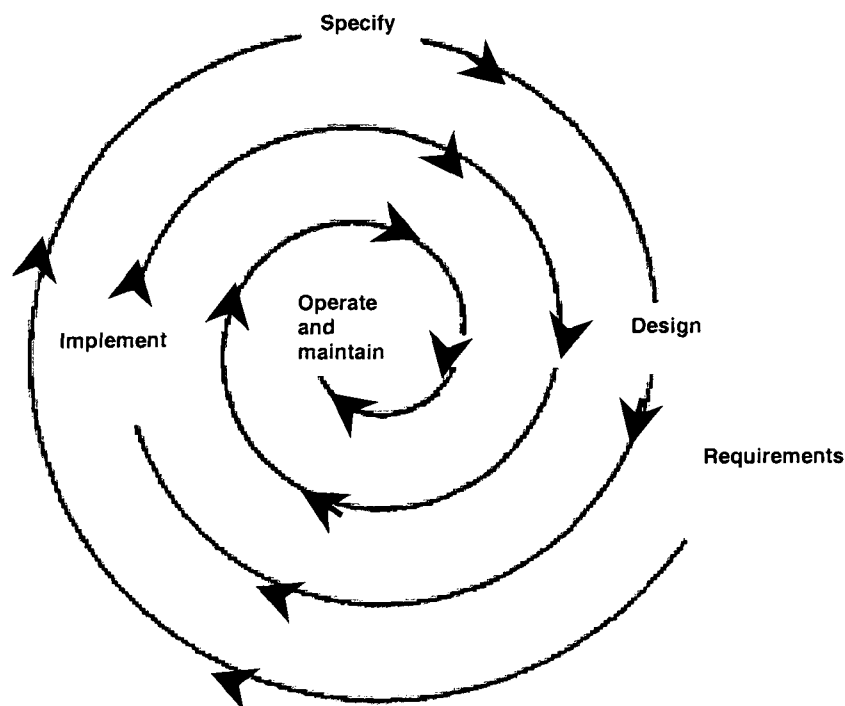
Figure 6.2 The prototyping approach to software development
(Source: Maguire 1999)

The main feature of a prototype is that a working version of the required system is constructed at an early stage. The prototype acts as a focus for discussion between the developer and user, and problems are tackled as they occur. Evaluation of the prototype by users provides feedback relating to the functional specification and the usability of the system. This feedback is used to improve the design of the prototype, which is taken back to users for further evaluation. Evaluation by users is thus crucial to the success of the prototype in defining and meeting user requirements.

6.2.3 Selection of the Prototyping Approach

The involvement of users from the beginning of a system development clearly offers advantages over the traditional SLC method: requirements are regularly checked and the system may be modified as objectives change. For a GIS development, where problems are not always well defined, the prototyping approach offers greater flexibility than the SLC. However, the iterative nature of prototyping, continually allowing enhancements and refinements to the developing system, may be difficult to stop and requires careful management (Heywood et al. 2002).

In this implementation prototyping techniques were chosen as the preferred methodology for developing the GIS at the centre of the decision support system. The reasons were:

- the system was a new development and the farm manager would not have a well-defined specification in mind;

- the development had to be flexible enough to incorporate new ideas throughout the construction of the prototype.

6.3 System Design Issues

The architecture for a SDSS proposed by Densham (1991) and presented in Figure 3.2 illustrated that a GIS at the core of an SDSS would have to connect to other systems: a model base management system; database management system; display and report generators. In addition, the GIS also interacted with the decision-maker by presenting and allowing the evaluation of alternative scenarios. The farm manager maintained field records in agricultural databases and used a spreadsheet as a financial modelling

package. As a decision support tool, the GIS would need to access these datasets and software applications, raising interoperability issues between systems. The design of the GIS required the development of a GIS interface that would assist in the integration of data from disparate sources.

The importance of the user interface was raised in The Chorley Report (Department of the Environment 1987), in which poor interfaces were recognised as severely impeding the development of spatial data handling in the UK. As a novice user the farm manager would not possess GIS expertise but would have an intimate knowledge of the farm and the requirements of the certifying body. The design of the GIS interface would be crucial in providing an effective tool for the farm manager. Elements of good GIS interface design have been defined by Cassettari (1993) and Armstrong et al. (1991) and include:

- the recognition of users and their level of expertise;
- an understanding of the tasks performed by users;
- the different levels of support and help facilities required;
- the provision of alternative interface types;
- clear screen layout of icons and tools;
- open communication between users and system through the use of metaphors and messages.

These design elements are derived from studies in Human-Computer Interaction (HCI), a rich and complex field that investigates the factors involved in the effective use of computer systems. Preece et al. (1994) summarise "the role of HCI in system design is to enhance the quality of the interaction between humans and computer systems".

This overview of system design issues emphasises the key role of the GIS interface as a link between systems and the user. In addition to the eight specific requirements defined by the farm manager, interoperability between systems and usability of the prototype would underlie all major design decisions.

6.4   Implementation

A prime requirement of the prototype GIS was that it offered the farm manager customised menus for printouts of standard maps but full functionality for exploring land-use allocation. The development tools in MapInfo and ArcView were investigated but, for ease of use, the features offered by ArcView were preferred. ArcView 3.2 was available for the development, with Avenue as the programming language for customising the GIS interface. ESRI has released ArcGIS and ArcView8 with advanced features for metadata creation and management and Visual Basic for Applications (VBA) for customisation (ESRI 2003). These facilities would undoubtedly assist future developments.

Regular meetings with the farm manager were held to demonstrate the features of the prototype and to clarify the requirements proposed in the original specification (Table 4.3). Sections 6.4.1 - 6.4.8 describe the implementation of each requirement in the prototype.

6.4.1   Requirement 1

To provide a base map of field boundaries on the farm for exploring the conversion of fields in relation to existing buildings, road access and drainage courses.

The completion of this requirement was fundamental to the use of the GIS as a decision support tool. Ordnance Survey Land-Line tiles covering the farm were identified and acquired. The digital field boundaries were compared with those on heavily annotated paper maps used by the farm manager and found, in some cases, to differ. If field boundaries are changed, the farm manager must record the changes on a Field Data Printout sheet provided by MAFF (Appendix A). The paper maps and the Field Data Printout sheets were used to digitise the field boundaries for 2001. MapInfo was selected to digitise the field boundaries, chiefly because of familiarity with the process in that software package. The final MapInfo table was converted into an ArcView shape file (Figure 6.3). This map allowed the farm manager to explore the location of buildings, roads and watercourses on the farm visually. The fields selected for conversion must not be polluted by contact with non-organic material.

Interoperability issues were raised in this requirement as Land-Line tiles in NTF format were downloaded from *Digimap*, unzipped and translated into MapInfo Interchange Format (MIF). In this implementation NTF2MIF, a program freely available from *Digimap* was used (*Digimap* 2001). For a commercial enterprise an NTF translator would have to be purchased. The translation process, initiated and managed by the user, provides an example of loose coupling between systems.
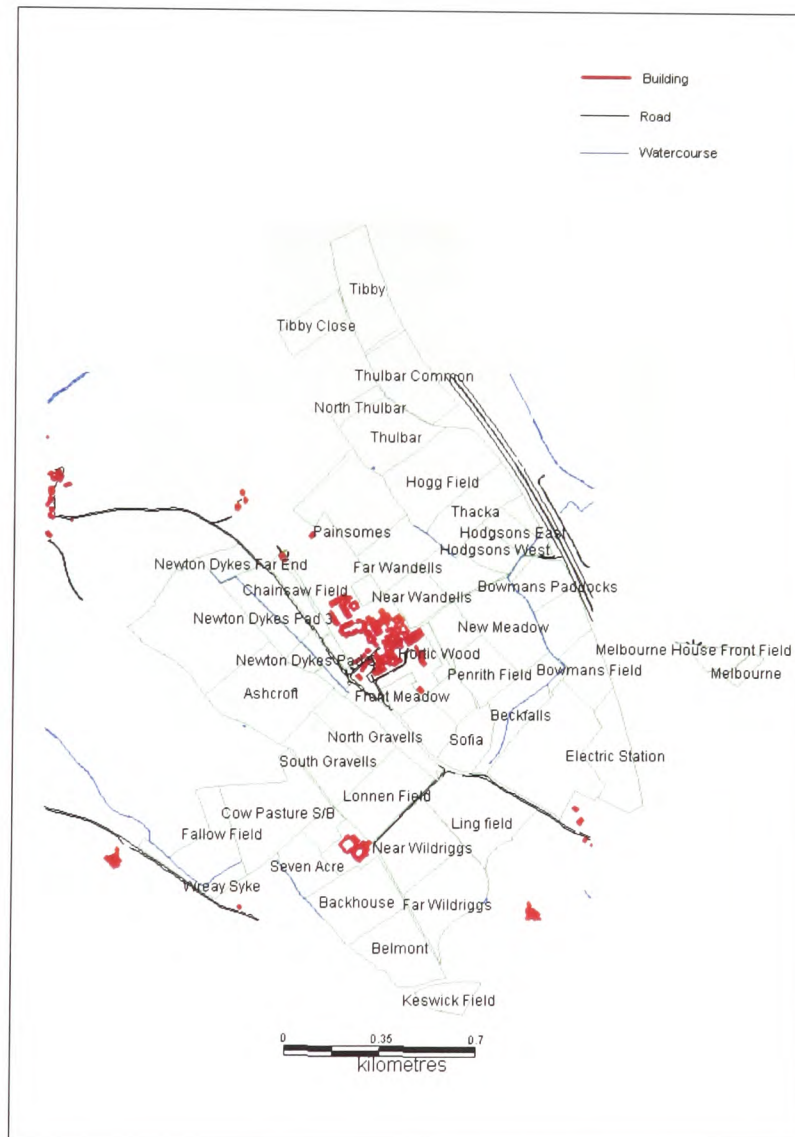
Figure 6.3 Field Boundaries

6.4.2 Requirement 2

To link to a package, such as a spreadsheet, to explore the financial impact of land-use options.

The farm manager required access to current crop data in Excel for financial modelling and gross margin analysis (Table 4.1). A menu option *Send Data* was provided to export the current crop data (crops2001.dbf) to Excel (Figure 6.4).

Figure 6.4 Export of current crop data to Excel

Within a full SDSS, the farm manager would want changes made in Excel to be fed back into the GIS for map output. This was beyond the scope of this implementation and would be a major challenge in designing the interface between the users and the individual components of the SDSS. With some training, the farm manager would manage the data transfer and generate new thematic maps based on the decisions made in Excel. This solution provides a further example of loose coupling to modelling software in which the user manages the transfer of data between systems (section 3.3).

6.4.3   Requirement 3

To provide access to historical field records required by the certifying body.

The submission of an application by the farm manager to the certifying body required detailed field histories for the past five years. These records were stored in the agricultural databases Optimix and Agridata. Though ArcView offered ODBC, interoperability problems arose, as several fields in Optimix (dBase format) and Agridata (Paradox format) were not interpreted correctly. As the farm manager indicated that access to historical data in Optimix would be useful, data was exported in comma separated variable (CSV) format and a single conversion undertaken to display field records in Excel format (Figure 6.5).
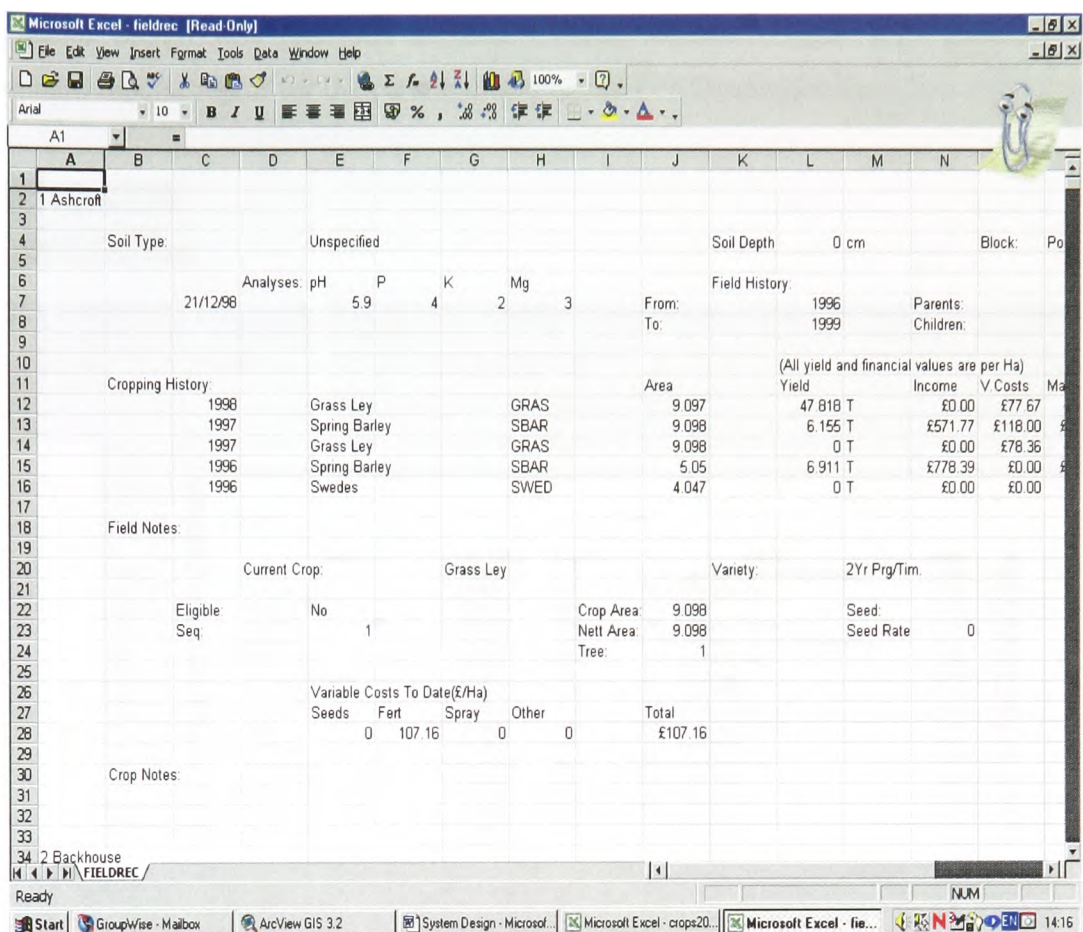
Figure 6.5 Data exported from Optimix into Excel

Agridata did not have an export facility and a programming solution to translate data fields automatically may be explored as part of future work.

A menu option, *Get Data*, provided the link to historical data by activating a script that opened Excel and displayed field records exported from Optimix (Figure 6.6). The user could then explore the data within Excel.
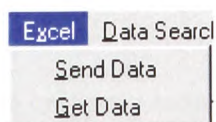
Figure 6.6 Excel menu options

A menu option was provided to open *Crystal Reports* (Figure 6.7), generating a standard tabular report for the current cropping records (Appendix B).
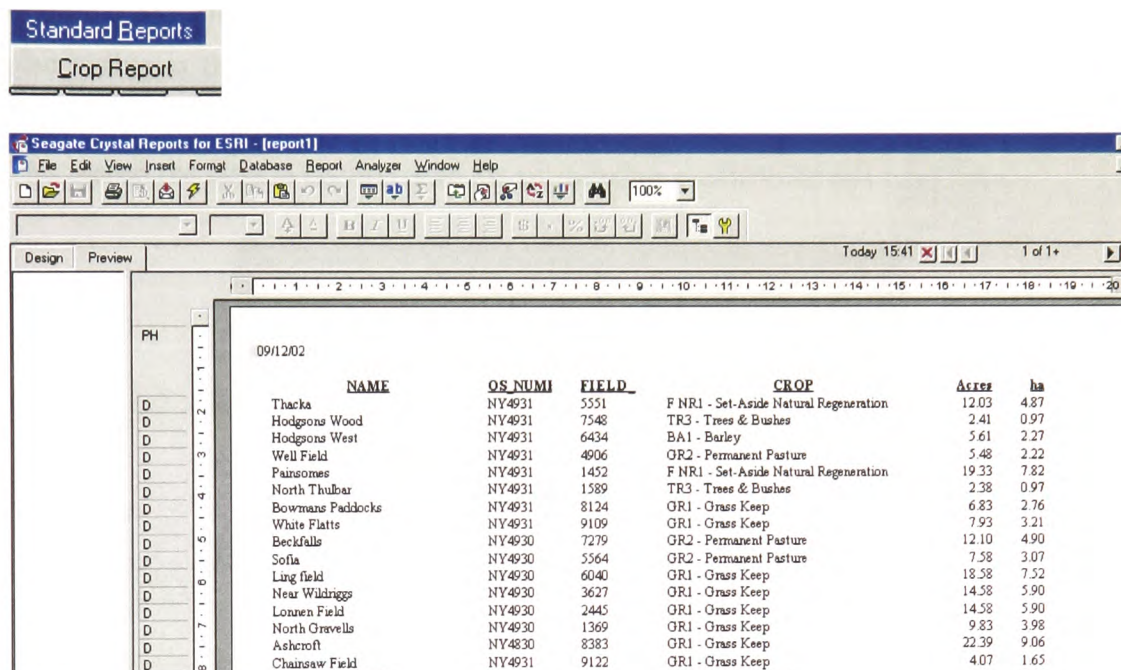
Figure 6.7 Access to standard reports

The farm manager could use this facility to produce other reports but, in practice, the reporting tools in the agricultural databases would be used to generate the historical records for the certifying body.

Users other than the farm manager would not be aware of the datasets containing historic field records. Metadata describing local datasets would be necessary to direct users to relevant information and is covered in section 6.3.6, requirement 6.

6.4.4 Requirement 4

To assist in map production showing cropping rotations and soil management.

The farm manager identified standard maps required from the GIS that would help in the selection of fields for conversion: field boundaries, crops, soils and pollution risks. A Crops 2001 theme, based on the field boundaries for 2001, was created from paper

records. New themes were digitised from analogue maps recording soil texture and subgroups. Drainage data was not available but an interpretative map of pollution risks based on the location of watercourses was digitised and added to the project's themes (Figure 6.8). These datasets were automatically loaded in the project with the cropping plan visible as the default setting. Other datasets included an aerial photograph of the farm, contour lines and a backdrop of Ordnance Survey tiles for the immediate vicinity. This placed the farm in context with the surrounding countryside and road links.
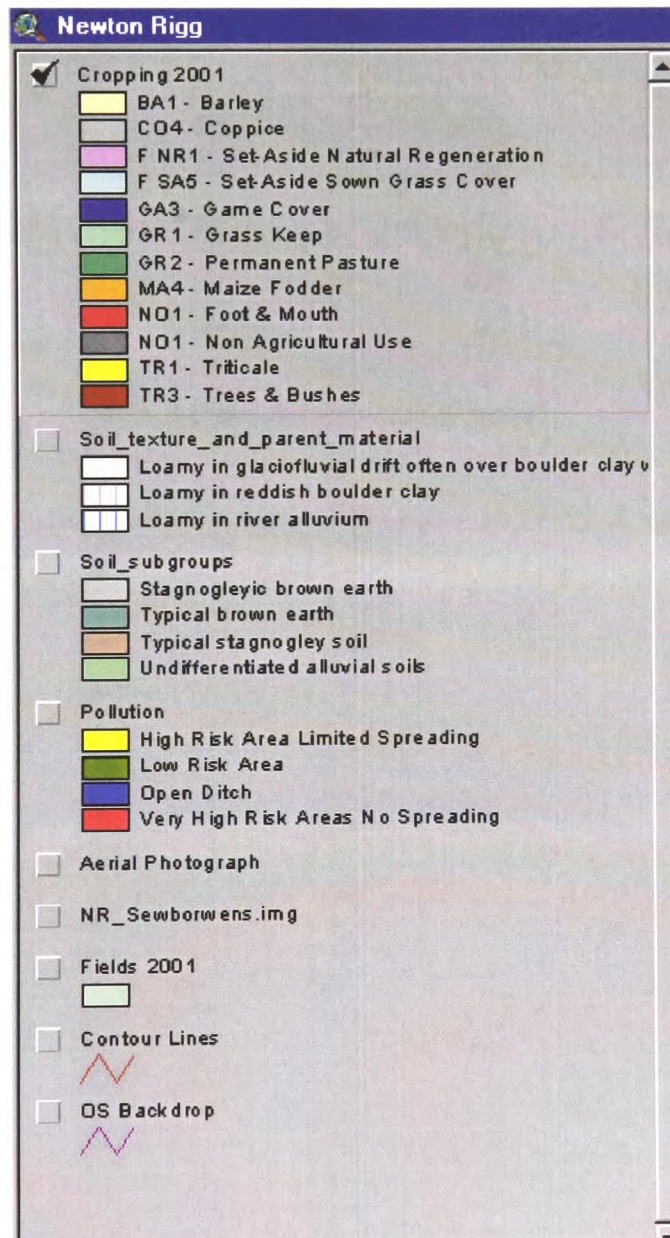
Figure 6.8 Project Themes

Maps were generated and saved using the layout facility in ArcView. The layouts were locked so that the farm manager obtained the correct printout, irrespective of the zoom level set for viewing. The scale for each map was *1:20000*. A future improvement would allow the farm manager to select a scale of *1:2500* or *1:10000*.

Maps were chosen from the *Print Maps* menu (Figure 6.9). Each option ran an Avenue script that activated the correct theme and deactivated those that were not required.
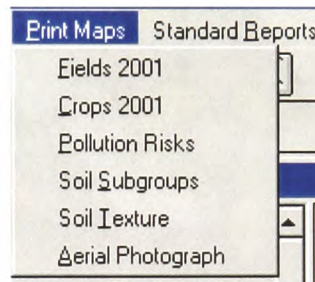
Figure 6.9 Print Maps menu

Examples of standard maps are provided in Figures 6.10 - 6.12. A complete set of printed maps is included in Appendix B.

Cropping Plan 2001
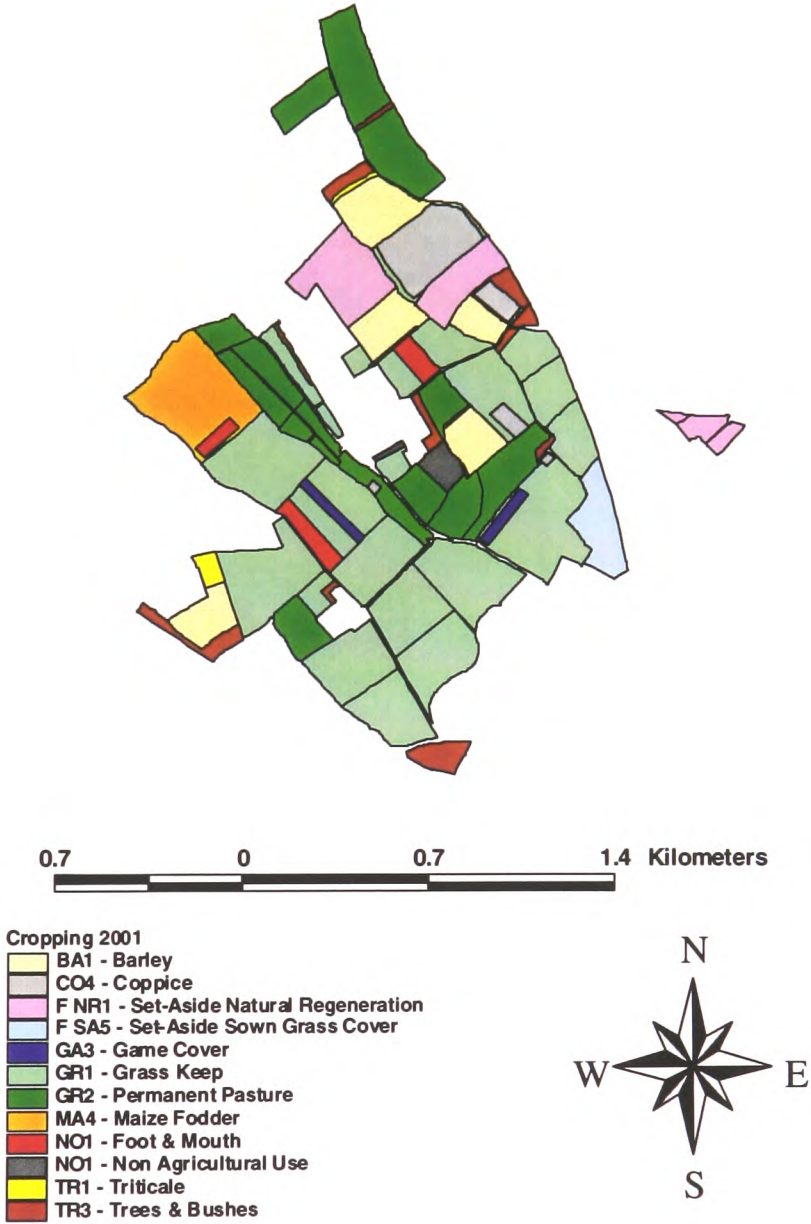
0.7   0   0.7   1.4 Kilometers

Cropping 2001
- BA1 - Barley
- CO4 - Coppice
- F NR1 - Set-Aside Natural Regeneration
- F SA5 - Set-Aside Sown Grass Cover
- GA3 - Game Cover
- GR1 - Grass Keep
- GR2 - Permanent Pasture
- MA4 - Maize Fodder
- NO1 - Foot & Mouth
- NO1 - Non Agricultural Use
- TR1 - Triticale
- TR3 - Trees & Bushes

Figure 6.10 Cropping Map

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Pollution Assessment
John Berry (Farm Manager 1984-2000)

0.8   0   0.8   1.6 **Kilometers**

Pollution
- High Risk Area Limited Spreading
- Low Risk Area
- Open Ditch
- Very High Risk Areas No Spreading
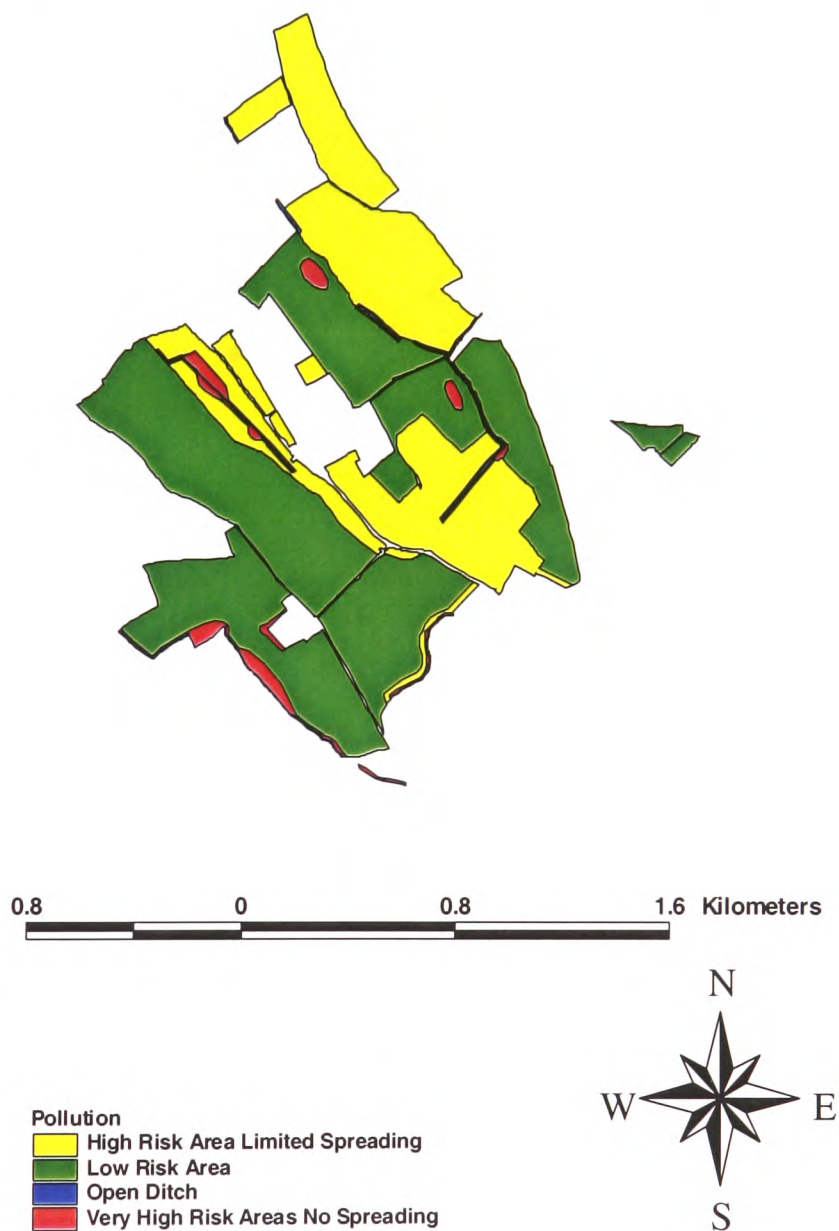
Figure 6.11 Pollution Risk Assessment

Soil Subgroups

0.8   0   0.8   1.6 Kilometers

Soil_subgroups
Stagnogleyic brown earth
Typical brown earth
Typical stagnogley soil
Undifferentiated alluvial soils

N
W   E
S
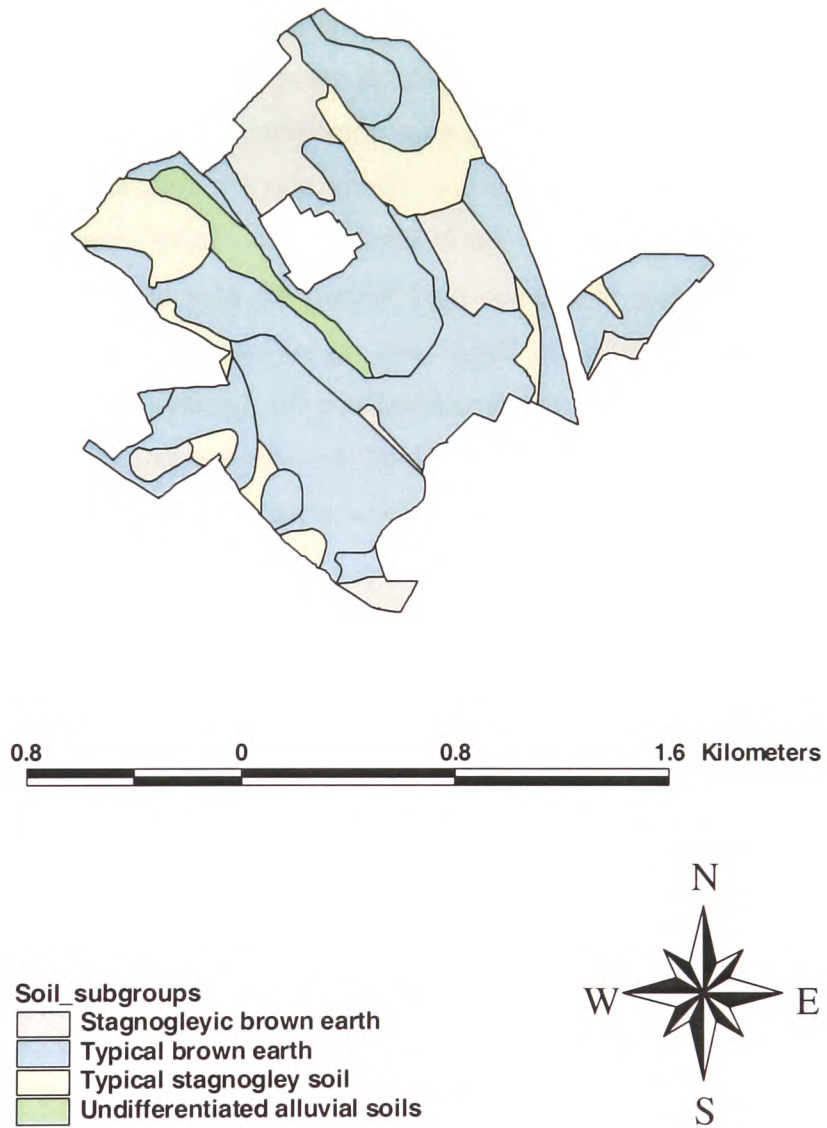
Figure 6.12 Soil Subgroups

6.4.5 Requirement 5

To link the spatial data represented on the farm map to the attribute data in the agricultural databases.

This requirement posed the greatest challenges for interoperability between systems and was not met. Although the farm map and the databases referred to the same land parcels, inconsistent identifiers meant that there was no common field in the two datasets that could be used to *join* the database tables with the attribute tables in the GIS. The problems of database integration were considered in section 5.3.2. An ad-hoc solution proposed there for a single translation, with minimal loss of information is recommended to make Optimix data available in the GIS: the Optimix data, exported to Excel, should be updated with the current field names and identifiers to allow *joins* within ArcView. Agridata is no longer maintained but a historical dataset could be established after direct editing of problematic fields. Remaining interoperability problems include the interpretation of fields that were not imported correctly into ArcView and the link to land parcels where the field boundaries have changed over time.

6.4.6 Requirement 6

To provide access to data catalogues on the Internet to locate relevant datasets.

The farm manager required a facility to check policy areas (SSSIs, ESAs, for example) as background to grant applications. A customised menu was created to allow access to metadata for local and external datasets. The data locator services GIgateway and MAGIC were accessed directly from the menu to provide metadata for external datasets (Figure 6.13). The farm manager would manage the acquisition of relevant datasets, either by contacting the data provider or by downloading data directly from the Internet. Metadata records would provide the essential information for data handling.
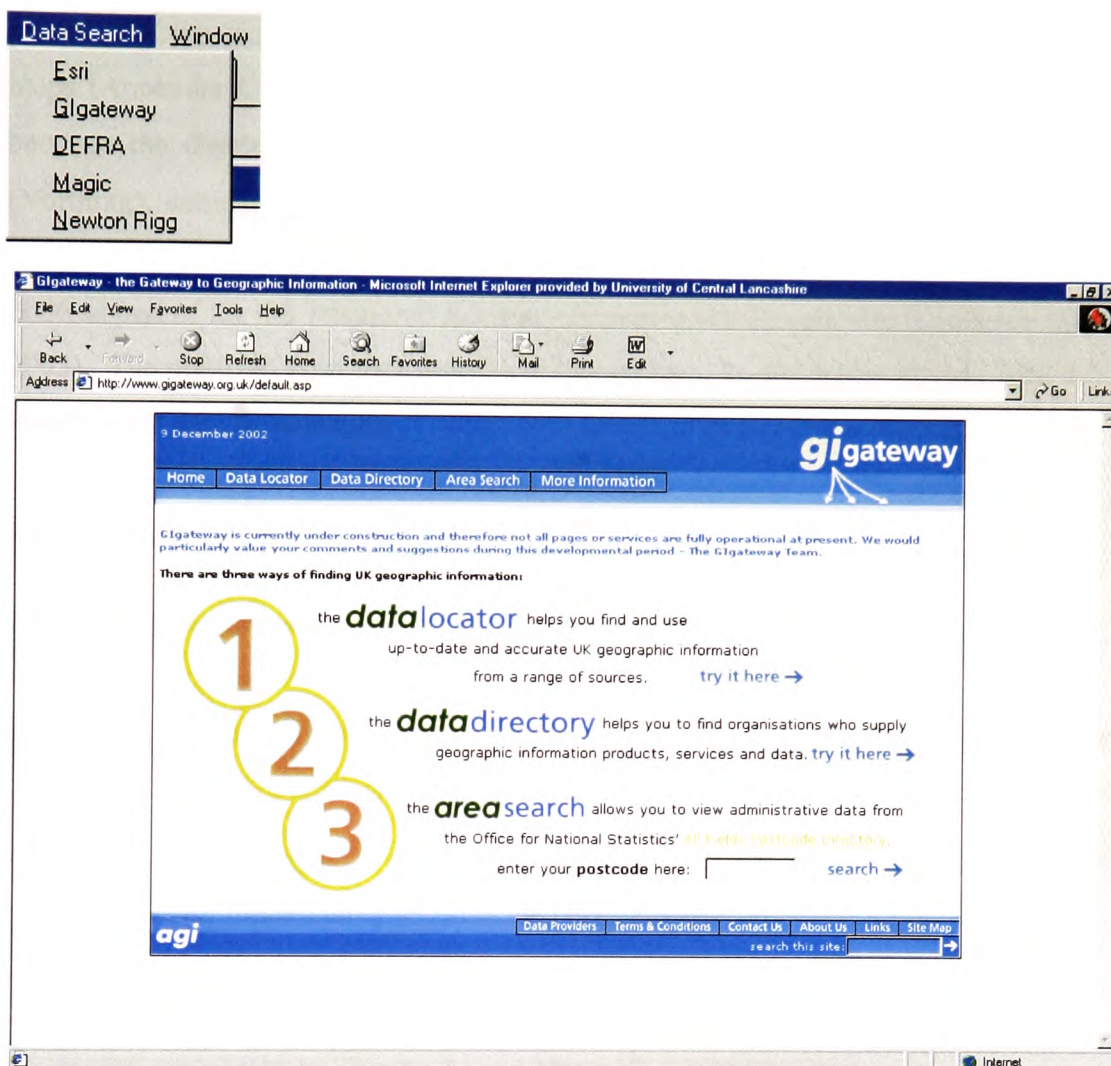
Figure 6.13 Access to Metadata provided by GIgateway (December 2002)

Metadata records for local datasets were stored in the NGDF database tool implemented in Microsoft Access (NGDF 2000). The successful use of this tool however required some expertise in the use of Access. An alternative proposal is to submit metadata for local datasets to GIgateway and use the data locator service to provide a consistent interface for all searches. This may have disadvantages in that the farm manager would be committed to maintaining the metadata information and responding to requests from outside enquirers.

As the Dublin Core requires a statement about data quality, an assessment of the accuracy of field boundaries was made by comparing the location of 100 digitised points with the locations of the equivalent 100 points on the Ordnance Survey (OS) maps (Appendix C). The calculated root mean squared error (RMSE) for differences between the digitised and OS grid references were ± 2.34m (Easting) and ± 2.35m (Northing), comparing favourably with the quoted RMSE of < ± 2.8m for Land-Line tiles (Ordnance Survey 2002). The underlying OS dataset is due for revision in 2005-2006 as part of the OS Positional Accuracy Improvement Programme (Ordnance Survey 2003). The digitised farm data must be reviewed then, as discrepancies may arise when layered over the OS base map.

6.4.7 Requirement 7

To allow the farm manager access to a full range of GIS functionality.

The toolbars in ArcView were tailored to allow the farm manager to select the preferred mode of operation, novice or advanced user. The project defaulted to the customised menu bar that gave access to standard maps and reports. When clicked, the button provided the full functionality of ArcView (Figure 6.14).
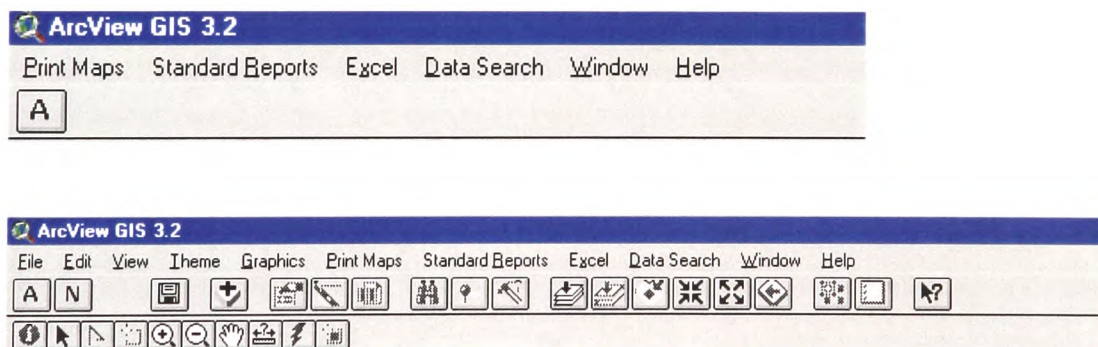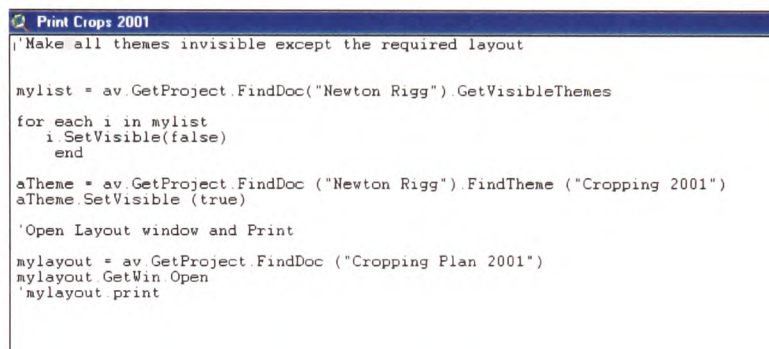
Figure 6.14 Customised and Standard Menus (December 2002)

6.4.8 Requirement 8

The GIS software must include a development language to assist in the automation of repetitive tasks.

ArcView 3.2 included its own object-oriented programming language, Avenue. Avenue was used to create scripts that were activated from menu options or buttons on the toolbars. Figure 6.15 is an example of code used to print out standard maps.

```
Print Crops 2001
'Make all themes invisible except the required layout

mylist = av.GetProject.FindDoc("Newton Rigg").GetVisibleThemes
for each i in mylist
    i.SetVisible(false)
    end
aTheme = av.GetProject.FindDoc ("Newton Rigg").FindTheme ("Cropping 2001")
aTheme.SetVisible (true)
'Open Layout window and Print
mylayout = av.GetProject.FindDoc ("Cropping Plan 2001")
mylayout.GetWin.Open
'mylayout.print
```

Figure 6.15 Sample of Avenue programming

ArcView provided a menu editor that was intuitive to use. Figure 6.16 illustrates the ease with which existing menus could be customised, increasing the speed of development.
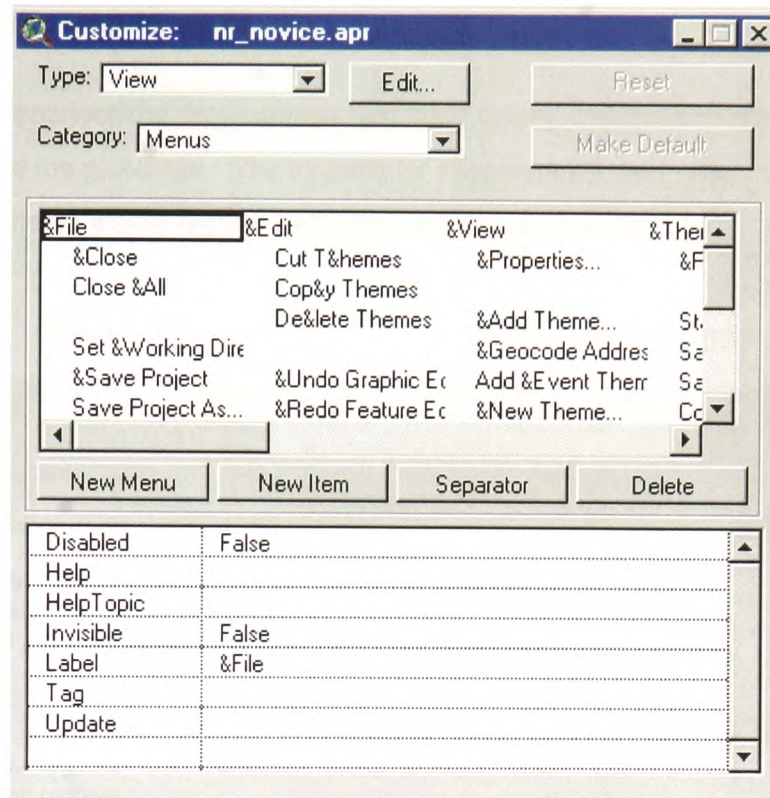
Figure 6.16 ArcView facilities for customising menus

6.5   Evaluation of the Prototype

As a component of a SDSS, the quality of a decision reached through using the GIS would be difficult to quantify. However a measure of the success of a computer system is if people can use it effectively (Worboys 1995). Heywood et al. (2002) consider the crucial test of whether a GIS application is successful is if users are using the application for its original purpose. The prototype was designed as a decision support tool for the farm manager considering the conversion to organic farming, which demanded an exploration of alternative land-uses. The criteria selected therefore to assess the GIS were:

1   does the GIS meet the requirements specified by the farm manager?

2   is the GIS easy to use?

3   are the data provided by the GIS accurate enough for possible grant applications?

The prototype would be measured against these criteria, considered in sections 6.5.1 – 6.5.3.

6.5.1 Match to Requirements

Table 6.1 summarises the requirements specified during systems analysis and the level of provision in the prototype. The majority of requirements were met. Those that were partially completed would require additional development work.

Table 6.1 Requirements and Provision by the Prototype

Requirement	Status
1 To provide a base map of field boundaries on the farm for exploring the conversion of fields in relation to existing buildings, road access and drainage courses.	Completed: current boundaries for 2001 provided; buildings; roads and watercourses
2 To link to a package, such as a spreadsheet, to explore the financial impact of land-use options.	Completed: current cropping data can be exported into Excel for manipulation
3 To provide access to historical field records required by the certifying body.	Partially completed: the farm manager can import historic data in Excel format into the GIS. Access to Crystal Reports allows production of standard reports. The translation of data from agricultural databases has not been automated.
4 To assist in map production showing cropping rotations and soil management.	Completed: customised menu options; datasets for crops (2001), soil and pollution provided; Additional datasets provided include aerial photographs, OS backdrop, contours
5 To link the spatial data represented on the farm map to the attribute data in the agricultural databases.	Not completed: inconsistent data between databases does not allow joins with spatial data.
6 To provide access to data catalogues on the Internet to locate relevant datasets.	Completed: Direct access to Metadata records on GIgateway, MAGIC and Newton Rigg provided.
7 To allow the farm manager access to a full range of GIS functionality.	Completed: Expert user option provided.
8 The GIS software must include a development language to assist in the automation of repetitive tasks.	Completed: Standard tools available in ArcView Completed: customised menu option for standard maps and reports

6.5.2 Usability

The GIS interface was designed following HCI elements described in section 6.3 and developed with the farm manager. Although a novice GIS user, the farm manager was familiar with the standard Windows interface using windows, icons, menus and pointing devices (WIMP-style interface). This interface was maintained in the final application and customised menus were created to automate common tasks such as the production of standard maps, the import and export of data in Excel format, and access to catalogues for data exploration. A feature of the final design was the facility to choose the level of expertise at which to operate. An assumption was made that the user would not have GIS expertise and that the facilities available through the menu structure would suffice. However, as expertise developed, the farm manager may require the full functionality of the GIS.

The usability of the system was evaluated with the farm manager, a forestry lecturer, a computing student and two student farm managers. None of the users were familiar with ArcView. Working individually and without assistance, the users were asked to attempt specific tasks and assess the level of difficulty in completing them (Appendix D). The results are summarised in Table 6.2. All users experienced difficulties in locating metadata records for local datasets (Task 5). Users did not understand the structure of the database and were not familiar enough with Microsoft Access to use the generic tools the application provided. Users were asked for suggestions that would make the GIS easier to use. Comments included a) confirmation that the Access database was the correct tool to locate local datasets and b) a friendly front end that would assist in searching the database. A context-sensitive help facility would also prove useful.

Table 6.2 Results of Evaluation by Users

Task	Description	Results
1	Print the cropping map	Very Easy: 5/5
2	Print the soil map	Very Easy: 5/5
3	Link to the MAGIC web site from the GIS	Very Easy: 3/5 Straightforward: 2/5
4	Send data from the GIS to Excel	Very Easy: 3/5 Straightforward: 2/5
5	Find who owns the accounting data relating to Newton Rigg Farm	Difficult: 1/5 Impossible: 4/5

The results of the evaluation provided useful feedback for the future development of the prototype.

6.5.3 Data Accuracy

As a SDSS component, the GIS prototype would produce maps to support grant applications based on area or distance calculations relating to land parcels. As the field boundaries were manually digitised and amended from changes recorded on the Field Data Printout forms, errors were inevitably introduced (Heywood et al. 2002). A comparison of calculated field areas and perimeters with those officially recorded on the IACS returns to DEFRA showed a high level of agreement (Appendix E). As a basis for submitting applications for funding, the farm manager considered the data accuracy acceptable.

The prototype performed well when measured against the criteria chosen for evaluation of the GIS: match to requirements; usability; and data accuracy. During the evaluation users contributed useful suggestions (Appendix D) for potential improvements. Future developments are summarised in section 6.6.

6.6 Future Developments

The evaluation of the GIS after implementation using ArcView confirmed that the prototype provided a good base for further development. The enhancements required included more data provision and increased on-line support. Table 6.3 summarises the main areas of activity for future work.

Table 6.3 Future Developments

Area of Development	Requirement	Potential Improvements/ Issues
Datasets	1. Generate themes for 1998, 1999 and 2000 field boundaries.	Digitising new themes from Field data printout sheets.
	2. Convert historic data into a database that could be joined to attribute data as the basis for thematic maps.	Identification of field parcels and allocation of common field Ids. Field boundaries have changed over time.
	3. Investigate GPS data to incorporate new features on the farm.	GPS training
Map Presentation	4. Explore colours for thematic maps. 5. Selection of scale.	Colour or grey-scale?
Usability	6. Help facility that is context sensitive. 7. Transfer between applications	Interoperability; incompatible file formats and inconsistent field Ids.
Data Accuracy	8. GPS check for location of digitised points.	GPS training

6.7 Summary

This chapter has described the development of the GIS using the prototyping methodology. Evaluation of the prototype by the farm manager throughout the implementation was crucial to a full understanding of the required functionality and the usability of the system. The requirements specification produced during systems analysis was useful in avoiding scope creep, ensuring the implementation focused on the original eight requirements. The design of the user interface was crucial to the effectiveness of the system and HCI principles were followed throughout the implementation. Demonstrations during the development of the GIS allowed the farm manager to comment on the interface and improve the final design.

As a component of a SDSS, the GIS must integrate data and models. Datasets and software packages used by the farm manager were identified, introducing interoperability problems during the implementation of the GIS. Incompatible file formats between systems were resolved for historical data by a single export operation in comma separated variable (CSV) format. An automatic translation of data between systems would be the preferred solution for a novice GIS user, pointing to an area of further work. Other difficulties arose through inconsistent field contents in historic datasets (Optimix and Agridata) that would not allow the combination of datasets. A more complex translation tool or an investment of time in cleaning the datasets would be required to address this issue.

The evaluation of the system, measured against set criteria, was described and an indication of further work that would increase the usability of the GIS was summarised. The new developments included the expansion of the datasets available through the GIS and improvements of the features for the farm manager: context sensitive help; simplified access to historical data records and ease of transfer of data into other packages. Though refinements to the implementation of the system were identified, the core functionality was achieved.

7 CONCLUSIONS

7.1 Summary

This research has investigated data integration issues relating to the use of GIS as the core component of a spatial decision support system for a farm manager. The implementation of a farm GIS-based SDSS focused on a farm manager considering the conversion to organic farming. The key issues addressed were:

1. the transfer of map data from paper to digital format;
2. the integration of digital data in different formats;
3. the access to metadata describing data and methods of data handling;
4. the seamless interoperability between systems;
5. the usability of the system by non-GIS users.

By concentrating on these issues, a methodology was developed to evaluate the effectiveness of GIS as a decision support tool for the farm manager. The application of the methodology determined the data and functional requirements of the GIS and involved an investigation of theoretical concepts relating to a) spatial decision support systems, b) the location of data and an assessment of data quality and c) the integration of spatial data.

A pilot study was undertaken and a prototype GIS built to apply and evaluate the theoretical concepts discussed.

7.2 Research Objectives

The overall aim of this research was to demonstrate that GIS is an effective tool as the key component of a farm spatial decision support system. This was achieved through the following stages:

1. Definition of the role for GIS as a decision support tool for the farm manager. This included the investigation of the current use of SDSS in agriculture and land use allocation (*Chapters 2 and 3*).

2. Development of the GIS functionality required for this application. Theoretical concepts relating to data integration issues were investigated, leading to a detailed specification of the data handling and analytical requirements for a farm GIS-based SDSS (*Chapters 3, 4 and 5*).

3. Application of the theoretical concepts to a pilot study area through the development of a prototype GIS (*Chapter 6*).

4. Evaluation of the effectiveness of using GIS as a decision support tool for the farm manager (*Chapters 3 to 7*).

7.3 Main Conclusions

7.3.1 The role of GIS as a decision support tool for the farm manager

Farming is an industry in decline. The UK Government is seeking to redress this through the introduction of new schemes designed to assist in the recovery of the rural economy. As a result, the farming community is faced with a complex array of funding schemes from which to choose how land may be used, to meet commercial or environmental objectives. In investigating one scheme, The Organic Farming Scheme, it was clear that, though practical advice is offered to farm managers considering conversion, no help is available to assess the financial implications (Chapter 2.3).

Current research in agricultural and environmental SDSS views GIS as a key component, enhanced by links to more powerful statistical and modelling packages. At sub-field level, GIS is the central hub in Precision farming (Chapter 3.4.1), integrating the collection of data and the use of modelling software to direct the application of seed and nutrients using an onboard computer in the tractor cab. At the whole farm level, the farm manager maintains data in standard enterprise databases and farm management records. GIS, with its ability to display and analyse spatial data, can act as a decision support tool for the farm manager by integrating data from these datasets (Chapter 3.4), providing links to financial modelling packages and producing output in an appropriate format. It is these requirements that are developed in proposing GIS as powerful tool within a SDSS.

7.3.2 Analysis of data integration issues for a spatial decision support system

Spatial decision support systems offer the decision-maker a flexible environment in which to explore alternative models before making an informed decision. SDSS assist the decision-maker dealing with spatial problems by incorporating 1) a model management system, 2) a database management system, 3) display and report generators and 4) a user interface. As the decision-making process tends to be iterative, with the results of an iteration feeding into the next, a final component of a SDSS is 5) evaluation of solutions by the user. The restricted modelling facilities and the absence of embedded expert knowledge limit the success of GIS as a platform for a DSS. However the strength of a GIS as a medium to explore and visualise ideas can be exploited by the decision-maker (Chapter 3.3). GIS functions to integrate, analyse and display spatial data can, when coupled with other modelling software, form the core of a SDSS. Development languages within commercial GIS allow the design of customised user interfaces to support the iterative decision-making process (Chapter 3.5).

The main decisions by the farm manager considering the conversion from traditional to organic farming related to site selection and the identification of suitable enterprises. The certification body also required conversion plans and monitoring of the conversion. The analysis of these tasks defined the output (Chapter 4.2), the key data sources (Chapter 4.3) and the functionality (Chapter 4.4) of the GIS. As a decision support tool, GIS are required to locate and incorporate data from disparate sources and, for historic data, in inconsistent spatial units. The GIS must provide access to modelling software packages, co-ordinating the transfer of data between systems (Chapter 4.2.1).

Metadata standards were investigated in order to provide a mechanism for the identification and assessment of datasets from the GIS (Chapter 5.2.5). Through the different levels of metadata, datasets may be identified, judged for their relevance, quality and accuracy, and acquired by the user. National metadata standards, defined and adopted in e-Government policy documents (Chapter 5.2.7), were followed for local datasets, with a recommendation to submit metadata records to Internet data locator services (Chapter 5.2.9).

To achieve interoperability between information systems techniques for database integration, standardisation and the development of software interfaces were studied. The issues that emerged related to the structure of the data, the computing infrastructure and the resources available for customising the interface between systems (Chapter 5.3). As a decision support tool, a GIS must be transparent to the user. The main challenge for the developer is the design of a user interface that assists in the exploration of decisions by providing seamless access to data and models (Chapter 5.4.4). A prototype GIS was developed to investigate solutions proposed for these issues.

7.3.3 Development of a prototype GIS

A pilot study was undertaken to investigate the requirements and implementation issues in the development of a GIS as a spatial decision support tool. Prototyping techniques (Chapter 6.2.2), in which the user is consulted throughout the system design, were employed, ensuring that the required functionality was understood and met. The design of the user interface was crucial to the effectiveness of the system. ArcView was selected to implement the GIS for the facilities it offered for the customisation of the user interface.

As a decision support tool, the GIS needed to integrate data and models and allow a visual exploration of ideas. Datasets and modelling tools used by the farm manager were reviewed, defining the integration problems to be resolved in the implementation of the GIS (Chapter 6.3). The conversion of paper maps and records into digital format involved validation and an assessment of the data quality. Incompatible file formats in legacy systems required the successful translation of data. An investigation of the underlying structures of historic data led to a single ad-hoc translation of data into CSV format so that data could be imported into other systems for modelling (Chapter 5.4). A structure for metadata records, based on international standards, was developed to describe the local datasets and implemented through the NGDF database tool. Access to external metadata was through data locator services on the Internet (Chapter 6.4).

The GIS was applied as a tool in the decision-making process for the conversion to organic farming. Data were retrieved and displayed using customised menus in the GIS. Data were exported into a spreadsheet package for financial modelling. Standard

maps of cropping rotations, pollution risks and soil components were printed for consultation and a facility for report generation was provided. Information relating to funding schemes and policy areas was located through metadata records and accessed directly from the GIS. The GIS acted as a platform co-ordinating data from multiple systems (Chapter 6.4).

7.3.4. Effectiveness of GIS as a decision support tool

The effectiveness of GIS as a decision support tool was assessed by an evaluation of the prototype (Chapter 6.5). The prototype was designed for the farm manager considering the conversion to organic farming, which demanded an exploration of alternative land uses. By integrating local and external data and providing links to other modelling software, the GIS provided a single environment to assist in:

1. the selection of sites for organic conversion;

2. the production of conversion plans;

3. the monitoring of the conversion process.

The development of transparent data handling routines within the GIS could lead to the analysis of key data for informed decision making.

7.4 Future Work

In adopting GIS as an additional tool for decision support, complementing existing information systems and modelling packages, users will demand mechanisms for the seamless integration of data. Ideally software vendors would adopt standards for loss-less information exchange for spatial databases, including SDTS from the US government and DNF from Ordnance Survey in the UK. In practice, GIS software products such as MapInfo and ArcView offer import, export and translation functions, which assist in the transfer of data between systems. However, as a decision support tool used by non-GIS experts, an automatic translation of data between systems would be the preferred solution (Chapter 5.3.2). This identifies an area of work in this particular implementation.

Within the DNF format, Ordnance Survey uses TOIDs, a unique reference which identifies spatial features (Chapter 5.3.3). If present, the TOID would successfully link data from spatial databases. This would eliminate the difficulty encountered where inconsistent spatial identifiers in the available data would not allow the combination of datasets. A more complex translation tool or an investment of time in cleaning the datasets to ensure consistent identifiers would otherwise be required to address this issue.

The desire for open GIS systems, integrating geospatial data and geoprocessing, has led to the development of the OpenGIS specification (Chapter 5.3.4), which establishes standards for common interfaces between systems. In the future, interfaces complying with this specification will allow access to new and legacy systems. Currently application-programming interfaces such as ODBC offer a mechanism to access data from other applications. The development of object-oriented databases will introduce further interoperability issues, though standards such as CORBA currently facilitate the transfer of objects through an object request broker (Chapter 5.3.4).

The increasing demand for spatial data requires the provision of metadata so that an assessment of data quality and suitability may be made. The adoption of international metadata standards will play an important role in identifying and delivering data, particularly as the Internet offers access to global searches. Locally, the maintenance of metadata records will require management procedures so that up to date information is available. A method of accessing metadata should be a core function of the GIS (Chapter 5.2.9).

The construction of user-friendly interfaces will increase the speed of uptake of GIS as a decision support tool. It must be recognised that many decision-makers will have limited IT skills and will not be able to work with an unfriendly system. Programming and macro development languages will assist in customising generic GIS interfaces for specific applications and ease the data integration between systems. Embedding objects such as maps and spreadsheets in environments that conform to Microsoft's OLE/COM or ActiveX software specification (Chapter 5.3.4) may also enhance the user's interaction with an application.

The evaluation of the prototype GIS identified future developments that users felt would enhance the system (Table 6.3 and Appendix D). An expansion of the datasets accessible to users through the GIS requires:

- further digitising to create field boundaries for 1998, 1999, 2000;
- cleaning of historic data to allow access through the map interface;
- GPS training to create themes of new features on the farm and assess the accuracy of digitised datasets;
- improved access to metadata records.

The usability of the GIS may be improved through the development of routines to assist in the automatic transfer of data between applications, the provision of context sensitive help and further customisation of the user interface to offer additional functions (Chapter 6.6). Users may wish to amend standard thematic maps and alter map scales to create maps for their own requirements, for example. These areas of further work will increase the use of the GIS by assisting in the exploration of data without demanding GIS skills of users.

7.5   Concluding remarks

GIS has been presented as the core component of a spatial decision support system for land use allocation. The architecture proposed for the SDSS identified the GIS interface as the link between the decision-maker and database, modelling, and display and reporting modules. A GIS interface was designed to ease the acquisition and manipulation of spatial data by the decision-maker and to provide a visual medium to explore the impact of individual solutions. The development of the GIS raised data integration issues that must be resolved if GIS is to have value as a decision support tool. The opportunity to make informed decisions will be lost if data are hidden or the system is too complex to use. GIS must embrace the developing standards and mechanisms for data exchange between systems to meet this challenge.

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Field Data Printout 2001

Integrated Administration and Control System

Sample Sheet and Maps

MAFF Integrated Administration and Control System

Field Data Printout 2001

Form IACS 11 (1/2001)

This sheet number: 2

Before you start to complete this Field Data Printout please read the IACS 2001 Booklet. If you complete this Field Data Printout incorrectly you may lose some or all of the payments you are claiming. YOU MUST CHECK THE PRINTED INFORMATION IN SECTION I, II, III & V TO MAKE SURE IT IS CORRECT.

Please use BLOCK LETTERS and BLACK INK throughout. Any alterations to entries you have made must be initialled by you. You may use this sheet to record newly acquired land, or land rented on a short-term basis, including your grass keep. FOLD ON DOTTED LINE.

Holding number of this sheet: 3/0007
Main holding number (if different): 08/.. J007

Yield region(s): England

PR 3978

Line No.	FOR FARMER'S OWN USE	A Ordnance Survey (OS) Map sheet reference	B National Grid (NG) field number	C Total Ordnance Survey (OS) field size (ha)	D Part field suffix	D Part-field size (i.e. area which you own, rent or use if less than area declared in Column C) (ha)	E1 Elig-ible for AAPS? (Y/N)	E2 Eligible for libre for libre flax or hemp but not AAPS? (Y/N)	F LFA & Moor-land Status	G SAPS LFA used for sheep prod-uction? (Y/N)	H Forage area (to 2 decimal places) (ha)	J Forage cover or crop grown	L Area (to 2 decimal places) (ha)	M Crop (please give additional details as indicated in J7 of the IACS booklet)	N Area (to 2 decimal places) (ha)	O Type of Set-Aside	P Green cover type	Q Crop grown, (including variety) and for those grown under contract, forecast yield (tonnes/ha)	R Frequency of harvest and growing period for perennial crops	S ERDP code	T Main use in 2001
1	CALF CLOSE / NR	NY4931	1919	1.20		0.77	N	N	N	Y	0.77 / 0.74	GR1	XXXXXXX XXXXXXX	XXXXXXXXXX XXXXXXXXXX	XXXXXXXXX XXXXXXXXX	XXX XXX	XXXX XXXX	XXXXXXXXXXXXXX XXXXXXXXXXXXXX	XXXXXX XXXXXX		
2	ELECTRIC / FIELD	NY4930 See Street 2	8688 Line 4,5,6,7	11.52		11.50	N	N	N		11.50	GR2	XXXXXXX XXXXXXX	XXXXXXXXXX XXXXXXXXXX	XXXXXXXXX XXXXXXXXX	XXX XXX	XXXX XXXX	XXXXXXXXXXXXXX XXXXXXXXXXXXXX	XXXXXX XXXXXX		
3	Cowpasture / SB	NY4830	8439	8.99		8.92	N	N	N	Y	8.92	GR1	XXXXXXX XXXXXXX	XXXXXXXXXX XXXXXXXXXX	XXXXXXXXX XXXXXXXXX	XXX XXX	XXXX XXXX	XXXXXXXXXXXXXX XXXXXXXXXXXXXX	XXXXXX XXXXXX		
4	ELECTRIC / STATION	NY5030	0960	5.43		5.26	Y	Y	N	N			5.26 BA1		5.26	F	SA5				
5	FALLOW / FIELD	NY4930 See Street 2	6326 Line 8,9,10	4.85		4.55	Y	Y	N		4.55	GR1	XXXXXXX XXXXXXX	XXXXXXXXXX XXXXXXXXXX	XXXXXXXXX XXXXXXXXX	XXX XXX	XXXX XXXX	XXXXXXXXXXXXXX XXXXXXXXXXXXXX	XXXXXX XXXXXX		
6	CAR / MEADOWS	NY4930	4810	6.14		6.14	N	N	N	Y	6.14	GR1	XXXXXXX XXXXXXX	XXXXXXXXXX XXXXXXXXXX	XXXXXXXXX XXXXXXXXX	XXX XXX	XXXX XXXX	XXXXXXXXXXXXXX XXXXXXXXXXXXXX	XXXXXX XXXXXX		
7	Howsons / WEST	NY4931	6434	2.30		2.29	Y	N	N	N			2.29 M4 / 2.29 BA1								
8	LING HEAD	NY4930	6040	7.60		7.60	Y	N	N	Y	7.60	GR1	XXXXXXX XXXXXXX	XXXXXXXXXX XXXXXXXXXX	XXXXXXXXX XXXXXXXXX	XXX XXX	XXXX XXXX	XXXXXXXXXXXXXX XXXXXXXXXXXXXX	XXXXXX XXXXXX		
9	LONLAN / FIELD	NY4930	2445	5.90		5.90	N	N	N	Y	5.90	GR1	XXXXXXX XXXXXXX	XXXXXXXXXX XXXXXXXXXX	XXXXXXXXX XXXXXXXXX	XXX XXX	XXXX XXXX	XXXXXXXXXXXXXX XXXXXXXXXXXXXX	XXXXXX XXXXXX		
10	FRONT / FIELD NTH	NY5030	3786	5.06	Q	4.88						LAND GIVEN UP NOT YET FENCED.			5.26					

II LIVESTOCK SCHEMES
Forage area. Complete this section ONLY for land (other than common land) which you are claiming towards your FORAGE area

III ARABLE AREA PAYMENTS SCHEME
Complete this section only for land which you are claiming under the Arable Area Payments Scheme

Total forage (this sheet): 29 30 LAND GIVEN UP

Total Set-aside on AAPS eligible land (this sheet): 2.29
Total cereal (this sheet)
Total oilseeds (this sheet)
Total protein (this sheet)
Total linseed, fibre flax and hemp on AAPS eligible land to support AAPS Ineligible (this sheet) ·
Total fibre flax and hemp on AAPS Ineligible land (this sheet) ·
Total maize (this sheet)
Total sweetcorn (this sheet)

Total Set-aside on AAPS Ineligible land (this sheet): 5 26

· see annex 4 of IACS booklet

Make sure you have entered any necessary changes

Signature: Carpenter

Date: 2/5/01

Telephone No. for enquiries: 0768 863791

IV ENGLAND RURAL DEVELOPMENT PROGRAMME SCHEMES

V OTHER LAND Complete this for all other fields

Electric Field
NY 4930 8862
Green Sheet 2, Line 4, 5, 6, 7
Holding No 08/143/0007

Carpenter 2/5/01

a. grass 10.36 ha

c. ———— game
cover
1.00 ha.

b.

Coppice 0.14 ha.
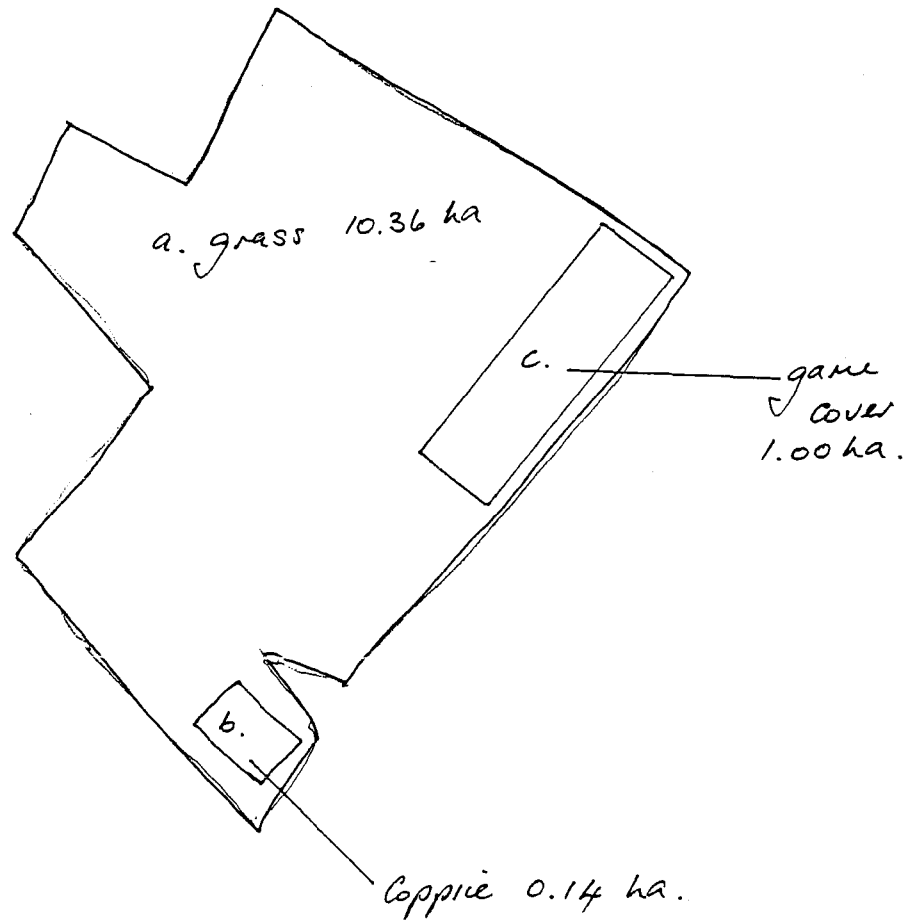
Fallow Field
NY 4830 6326
Green Sheet 2   Line 8, 9, 10
Holding No.   OF/143/0007

Cov Winter 2/5/01

b. 1.00 ha
Triticale

a.   3.55   Spring Barley
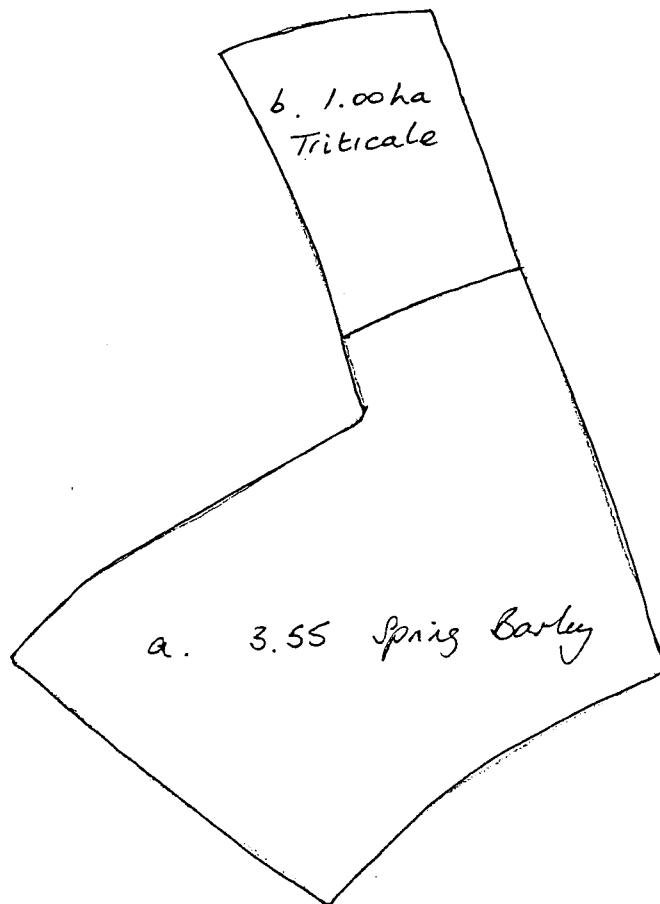
Prototype Output

Standard Report

Cropping Report 2001

Standard Maps

Field Boundaries 2001

Cropping Plan 2001

Pollution Assessment (John Berry)

Pollution Risks

Soil Subgroups

Soil Texture and Parent Material

Newton Rigg and surrounding area

Newton Rigg Aerial Photograph

CROPPING REPORT 2001

NAME	OS NUMBER	FIELD NO	CROP	Acres	ha
Thacka	NY4931	5551	F NRI - Set-Aside Natural Regeneration	12.03	4.87
Hodgsons Wood	NY4931	7548	TR3 - Trees & Bushes	2.41	0.97
Hodgsons West	NY4931	6434	BA1 - Barley	5.61	2.27
Well Field	NY4931	4906	GR2 - Permanent Pasture	5.48	2.22
Painsomes	NY4931	1452	F NRI - Set-Aside Natural Regeneration	19.33	7.82
North Thulbar	NY4931	1589	TR3 - Trees & Bushes	2.38	0.97
Bowmans Paddocks	NY4931	8124	GR1 - Grass Keep	6.83	2.76
White Flatts	NY4931	9109	GR1 - Grass Keep	7.93	3.21
Beckfalls	NY4930	7279	GR2 - Permanent Pasture	12.10	4.90
Sofia	NY4930	5564	GR2 - Permanent Pasture	7.58	3.07
Ling field	NY4930	6040	GR1 - Grass Keep	18.58	7.52
Near Wildriggs	NY4930	3627	GR1 - Grass Keep	14.58	5.90
Lonnen Field	NY4930	2445	GR1 - Grass Keep	14.58	5.90
North Gravells	NY4930	1369	GR1 - Grass Keep	9.83	3.98
Ashcroft	NY4830	8383	GR1 - Grass Keep	22.39	9.06
Chainsaw Field	NY4931	9122	GR1 - Grass Keep	4.07	1.65
Newton Dykes Pad 2	NY4831	8416	GR2 - Permanent Pasture	6.54	2.65
Newton Dykes Pad 3	NY4831	7911	GR2 - Permanent Pasture	6.01	2.43
Newton Dykes Far End	NY4831	6730	GR2 - Permanent Pasture	4.23	1.71
Cow Pasture S/B	NY4830	8439	GR1 - Grass Keep	21.79	8.82
Seven Acre	NY4830	9620	GR2 - Permanent Pasture	7.23	2.92
Broadmires	NY4931	5028	GR1 - Grass Keep	7.38	2.99
Newton Dykes Pad 5	NY4830	9595	GR2 - Permanent Pasture	1.87	0.76
Newton Dykes Pad 4	NY4930	0587	GR2 - Permanent Pasture	0.95	0.38
Newton Dykes Pad 1	NY4930	0393	GR2 - Permanent Pasture	2.63	1.06
Sheepshed Field	NY4931	0304	GR1 - Grass Keep	1.20	0.49
Todd Close	NY4930	3971	GR2 - Permanent Pasture	6.06	2.45
Todd Close Arboretum	NY4930	4881	NO1 - Non Agricultural Use	4.56	1.85
Backhouse	NY4930	1607	GR1 - Grass Keep	15.47	6.26
Belmont	NY4929	3188	GR1 - Grass Keep	13.37	5.41
Far Wildriggs	NY4930	4810	GR1 - Grass Keep	15.07	6.10
Bowmans Field	NY4930	9989	GR1 - Grass Keep	8.18	3.31
Keswick Field	NY4929	4872	TR3 - Trees & Bushes	4.71	1.91
Electric Station	NY5030	0960	F SA5 - Set-Aside Sown Grass Cover	12.96	5.24

NAME	OS NUMBER	FIELD NO	CROP	Acres	ha
Wreay Syke	NY4830	5613	TR3 - Trees & Bushes	4.24	1.72
Tibby	NY4932	1534	GR2 - Permanent Pasture	15.79	6.39
Tibby Close	NY4832	9718	GR2 - Permanent Pasture	6.75	2.73
Thulbar Common	NY4932	3102	GR2 - Permanent Pasture	14.13	5.72
Thurlbar Wood	NY4932	2413	TR3 - Trees & Bushes	0.67	0.27
Hortic Wood	NY4930	4496	TR3 - Trees & Bushes	1.89	0.77
Chainsaw Wood	NY4831	9424	TR3 - Trees & Bushes	0.91	0.37
Beckfalls Conservation Area	NY4930	8787	TR3 - Trees & Bushes	0.78	0.32
Melbourne House Front Field	NY5030	3786	F NR1 - Set-Aside Natural Regeneration	0.70	0.28
Melbourne House Field	NY5030	4797	F NR1 - Set-Aside Natural Regeneration	3.31	1.34
Bowmans Wood	NY4931	7634	TR3 - Trees & Bushes	1.87	0.76
Track Through Bowman	NY4931	7634	TR3 - Trees & Bushes	0.07	0.03
Melbourne	NY5030	5592	F NR1 - Set-Aside Natural Regeneration	1.86	0.75
Calf Close S/B a	NY4930	0333	GR1 - Grass Keep	2.99	1.21
Calf Close S/B b	NY4930	0333	TR3 - Trees & Bushes	0.60	0.24
Hogg Field a	NY4931	4465	GR1 - Grass Keep	2.31	0.94
Hogg Field b	NY4931	4465	CO4 - Coppice	19.03	7.70
Hodgsons East b	NY4931	7142	GR1 - Grass Keep	0.75	0.30
Hodgsons East a	NY4931	7142	CO4 - Coppice	3.19	1.29
Front Meadow a	NY4930	3183	GR1 - Grass Keep	2.58	1.04
Front Meadow b	NY4930	3183	NO1 - Non Agricultural Use	0.67	0.27
Long Meadow a	NY4930	2671	GR2 - Permanent Pasture	6.53	2.64
Long Meadow b	NY4930	2671	CO4 - Coppice	0.37	0.15
Far Wandells a	NY4931	2934	BA1 - Barley	10.18	4.12
Far Wandells b	NY4931	2934	TR1 - Triticale	0.42	0.17
Thulbar a	NY4931	2577	BA1 - Barley	13.68	5.53
Thulbar b	NY4931	2577	TR1 - Triticale	0.84	0.34
South Gravells b	NY4930	0358	GA3 - Game Cover	2.64	1.07
South Gravells a	NY4930	0358	GR1 - Grass Keep	5.53	2.24
South Gravells c	NY4930	0358	NO1 - Foot & Mouth	4.85	1.96
Penrith Field a	NY4930	6091	BA1 - Barley	8.41	3.40
Penrith Field b	NY4930	6091	TR1 - Triticale	0.32	0.13
Fallow Field a	NY4830	6326	BA1 - Barley	8.67	3.51

NAME	OS NUMBER	FIELD NO	CROP	Acres	ha
Fallow Field b	NY4830	6326	TR1 - Triticale	2.49	1.01
Electric Field b	NY4930	8862	CO4 - Coppice	0.35	0.14
Electric Field a	NY4930	8862	GR1 - Grass Keep	25.88	10.47
Electric Field c	NY4930	8862	GA3 - Game Cover	2.48	1.00
New Meadow a	NY4931	6809	GR1 - Grass Keep	13.52	5.47
New Meadow b	NY4931	6809	CO4 - Coppice	2.22	0.90
Near Wandells a	NY4931	3617	GR1 - Grass Keep	3.71	1.50
Near Wandells b	NY4931	3617	NO1 - Foot & Mouth	3.54	1.43
Thirty Acre a	NY4831	5705	MA4 - Maize Fodder	29.66	12.00
Thirty Acre b	NY4831	5705	NO1 - Foot & Mouth	2.05	0.83
Calf Close N/R a	NY4931	1919	GR1 - Grass Keep	1.83	0.74
Calf Close N/R b	NY4931	1919	NO1 - Foot & Mouth	0.03	0.01

Field Boundaries 2001

Tibby
Tibby Close
Thulbar Wood
Thulbar Common
North Thulbar
Thulbar a
Hogg Field a
Hogg Field b
Painsomes
Thack
Hodgsons Wood
Hodgsons West
Far Wandells a
Bowmans Wood
Newton Dykes Far End
Calf Close N/R
Broadmiree
Near Wandells
Newton Dykes Pad 2
Bowmans Paddocks
Thirty Acre
Newton Dykes Pad 3
New Meadow a
Sheepshed Field
Well Field
White Flatts
Newton Dykes Pad 1
Hortic Wood
New Meadow b
Ashcroft
Penrith Field a
Bowmans Field
Melbourne
Todd Close Arboretum
Beckfalls
Todd Close
North Gravells
Solia
Electric Station
South Gravells a
Electric Field a
Lonnen Field
Fallow Field b
Cow Pasture S/R
Ling field
Fallow Field a
Near Wildriggs
Seven Acre
Wreay Syke
Backhouse
Far Wildriggs
Belmont
Keswick Field

| 0.8 | 0 | 0.8 | 1.6 | Kilometers |

N
W   E
S

Cropping Plan 2001

0.7   0   0.7   1.4 **Kilometers**

Cropping 2001
- BA1 - Barley
- CO4 - Coppice
- F NR1 - Set-Aside Natural Regeneration
- F SA5 - Set-Aside Sown Grass Cover
- GA3 - Game Cover
- GR1 - Grass Keep
- GR2 - Permanent Pasture
- MA4 - Maize Fodder
- NO1 - Foot & Mouth
- NO1 - Non Agricultural Use
- TR1 - Triticale
- TR3 - Trees & Bushes

N
W   E
S

Pollution Assessment
John Berry (Farm Manager 1984-2000)

0.8   0   0.8   1.6   Kilometers

Pollution
- High Risk Area Limited Spreading
- Low Risk Area
- Open Ditch
- Very High Risk Areas No Spreading

N
W   E
S

Pollution Risks
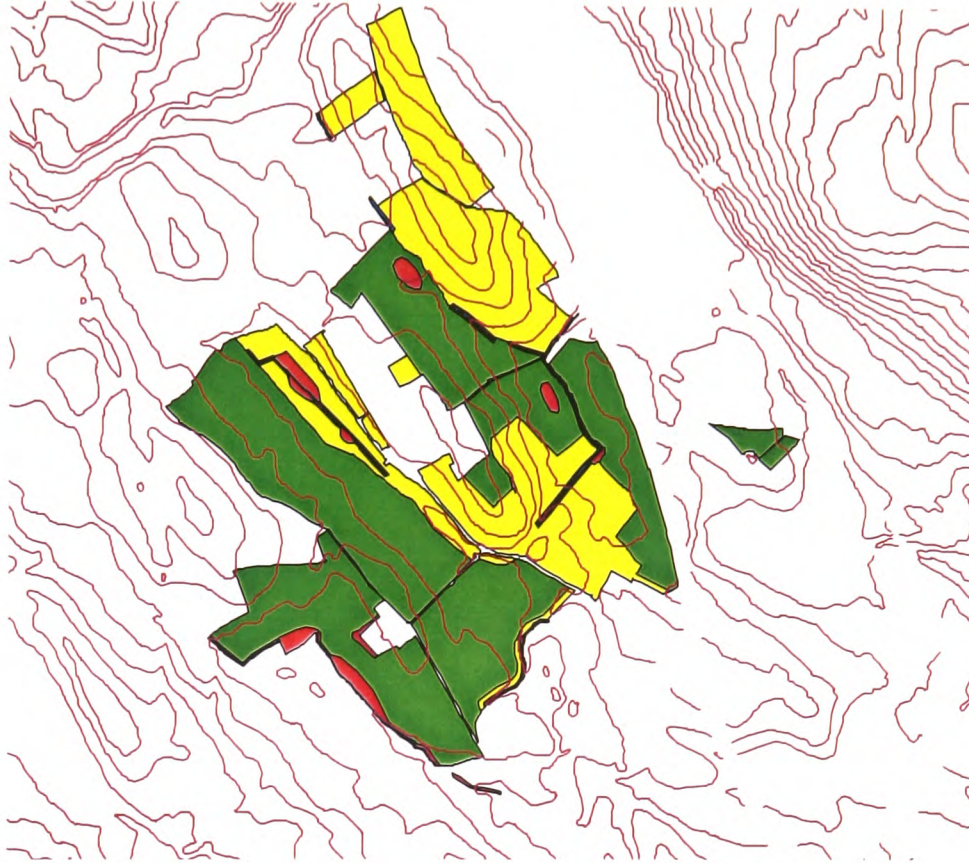
0.9   0   0.9   1.8   Kilometers

N
W   E
S

Contour Lines
Pollution
High Risk Area Limited Spreading
Low Risk Area
Open Ditch
Very High Risk Areas No Spreading

Soil Subgroups

0.8　　　　　0　　　　　0.8　　　　1.6　**Kilometers**

Soil_subgroups
- Stagnogleyic brown earth
- Typical brown earth
- Typical stagnogley soil
- Undifferentiated alluvial soils

N

W　　E

S

Soil Texture and Parent Material

0.8   0   0.8   1.6   Kilometers
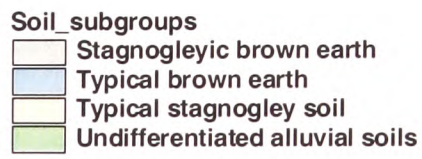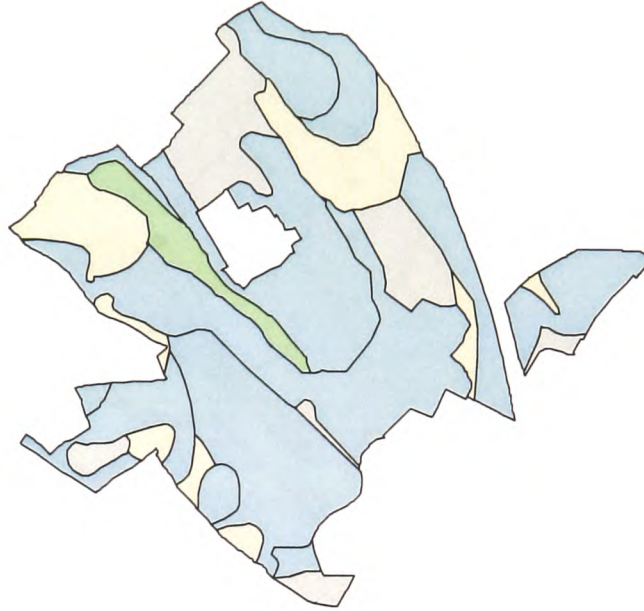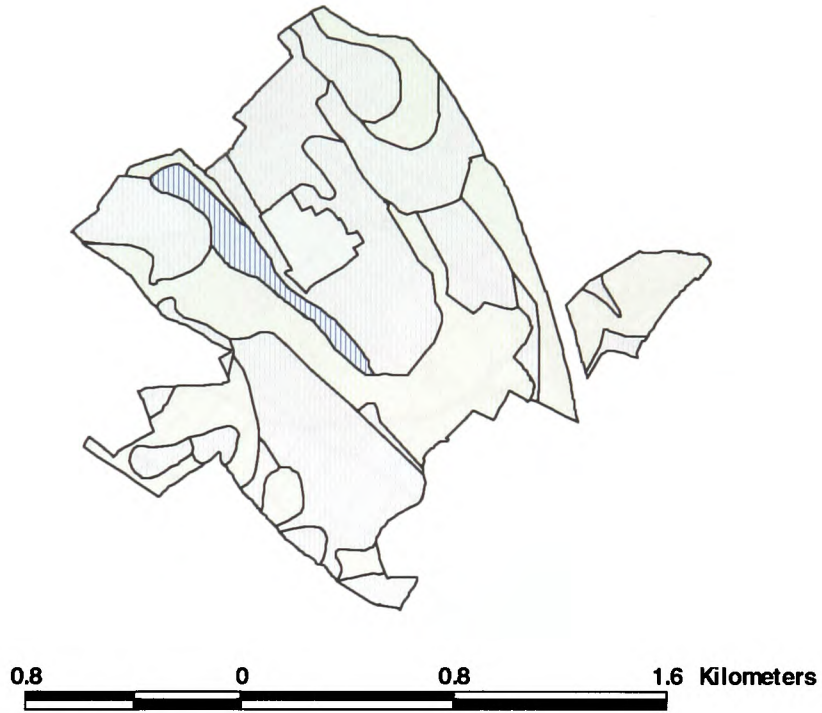
Soil_texture_and_parent_material
- Loamy in glaciofluvial drift often over boulder clay within 80cms of surface
- Loamy in reddish boulder clay
- Loamy in river alluvium
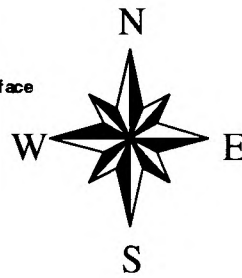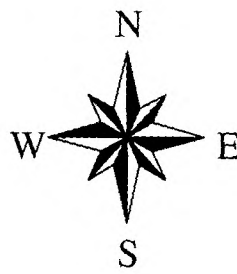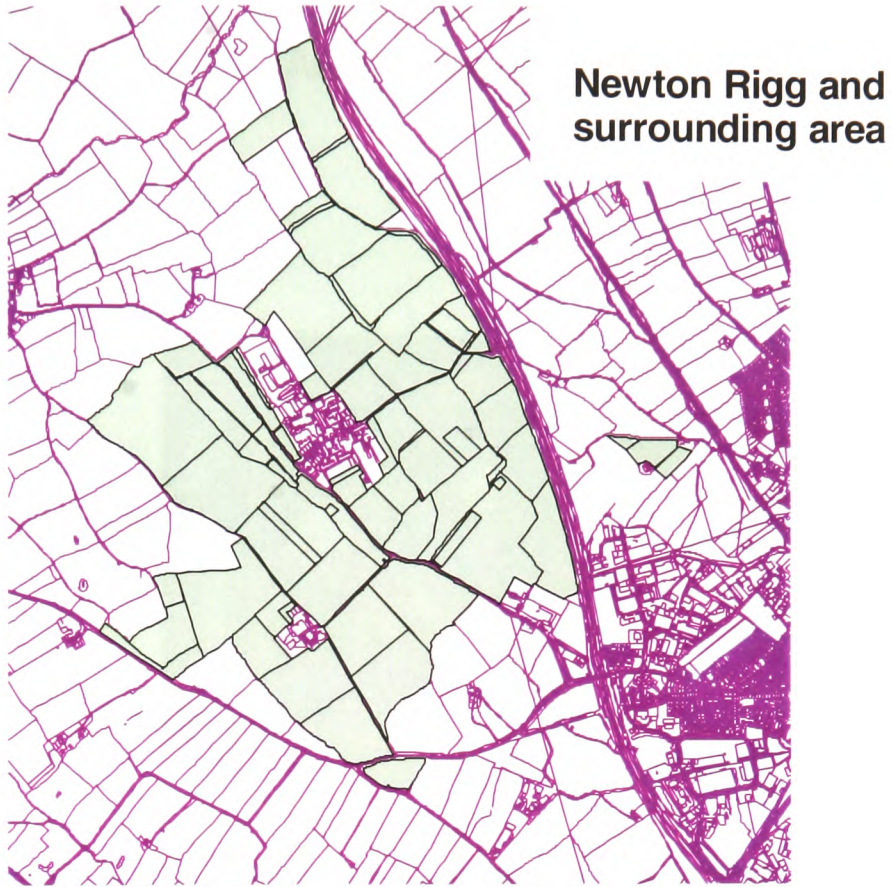
Newton Rigg and
surrounding area
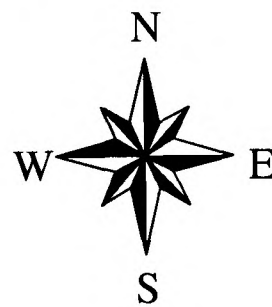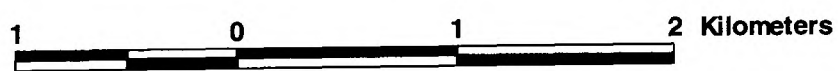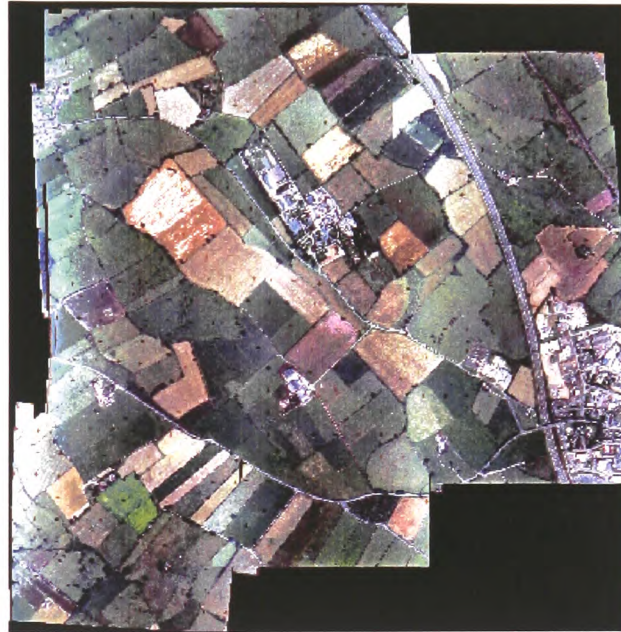
0.9   0   0.9   1.8   Kilometers

N

W   E

S

Newton Rigg
Aerial Photograph

1   0   1   2 Kilometers

N

W   E

S

Comparison of Digitised and OS Locations

Comparison of Digitised and OS Locations

0.8   0   0.8   1.6 Kilometers

N
W   E
S

- OS Locations
  Fields 2001
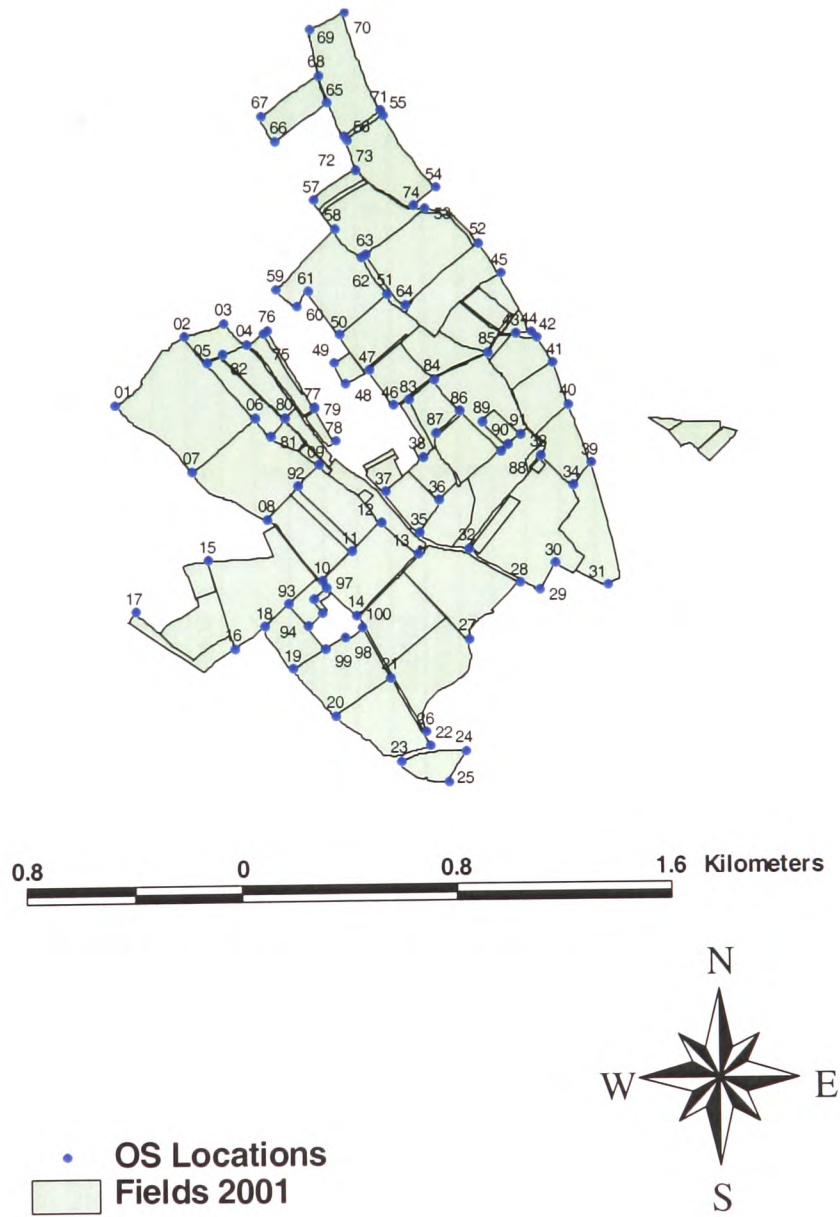
Digitised Easting	Digitised Northing	Point_id	OS Easting	OS Northing	Easting Difference	Northing Difference	East Square Error	North Square Error
348295	531068	1	348294	531069	1	-1	1	1
348551	531325	2	348550	531323	1	2	1	4
348701	531376	3	348699	531379	2	-3	4	9
348786	531296	4	348783	531295	3	1	9	1
348638	531226	5	348636	531227	2	-1	4	1
348818	531020	6	348817	531018	1	2	1	4
348580	530819	7	348583	530818	-3	1	9	1
348861	530640	8	348862	530640	-1	0	1	0
349056	530843	9	349053	530846	3	-3	9	9
349069	530407	10	349064	530407	5	0	25	0
349176	530519	11					0	0
349287	530628	12	349282	530629	5	-1	25	1
349425	530509	13	349429	530511	-4	-2	16	4
349196	530280	14	349203	530283	-7	-3	49	9
348639	530488	15	348638	530486	1	2	1	4
348738	530158	16	348741	530160	-3	-2	9	4
348367	530296	17	348365	530293	2	3	4	9
348851	530240	18	348851	530244	0	-4	0	16
348956	530080	19	348955	530077	1	3	1	9
349115	529904	20	349114	529904	1	0	1	0
349323	530047	21	349324	530049	-1	-2	1	4
349471	529788	22	349471	529788	0	0	0	0
349357	529734	23	349356	529736	1	-2	1	4
349599	529771	24	349600	529771	-1	0	1	0
349536	529653	25	349535	529655	1	-2	1	4
349454	529843	26	349454	529842	0	1	0	1
349616	530189	27	349615	530184	1	5	1	25
349808	530400	28	349805	530402	3	-2	9	4
349885	530371	29	349885	530370	0	1	0	1
349938	530473	30	349941	530472	-3	1	9	1
350134	530388	31	350133	530391	1	-3	1	9
349616	530528	32	349618	530533	-2	-5	4	25

349886	530877	33	349885	530880	1	-3	1	9
350011	530763	34	350008	530764	3	-1	9	1
349435	530589	35	349432	530587	3	2	9	4
349505	530712	36					0	0
349304	530744	37	349299	530742	5	2	25	4
349446	530872	38	349450	530872	-4	0	16	0
350076	530848	39	350077	530850	-1	-2	1	4
349994	531068	40	349996	531066	-2	2	4	4
349936	531226	41	349936	531230	0	-4	0	16
349878	531320	42	349881	531322	-3	-2	9	4
349800	531334	43	349796	531331	4	3	16	9
349854	531342	44	349859	531342	-5	0	25	0
349742	531564	45	349739	531561	3	3	9	9
349336	531066	46	349333	531062	3	4	9	16
349246	531197	47	349243	531197	3	0	9	0
349156	531148	48	349158	531146	-2	2	4	4
349115	531226	49	349114	531220	1	6	1	36
349137	531330	50	349137	531331	0	-1	0	1
349314	531487	51	349316	531485	-2	2	4	4
349661	531676	52	349661	531678	0	-2	0	4
349461	531809	53	349459	531807	2	2	4	4
349500	531886	54	349502	531885	-2	1	4	1
349304	532158	55					0	0
349166	532063	56					0	0
349038	531838	57	349037	531842	1	-4	1	16
349118	531729	58	349117	531724	1	5	1	25
348900	531502	59	348899	531499	1	3	1	9
348978	531440	60	348979	531437	-1	3	1	9
349018	531494	61	349014	531495	4	-1	16	1
349222	531625	62	349225	531626	-3	-1	9	1
349239	531635	63					0	0
349384	531443	64					0	0
349093	532204	65	349096	532201	-3	3	9	9

348897	532058	66	348896	532060	1	-2	1	4
348847	532153	67	348844	532153	3	0	9	0
349060	532308	68	349060	532307	0	1	0	1
349028	532482	69	349029	532481	-1	1	1	1
349161	532543	70	349158	532544	3	-1	9	1
349297	532177	71	349296	532179	1	-2	1	4
349156	532079	72	349155	532078	1	1	1	1
349198	531952	73	349199	531956	-1	-4	1	16
349414	531818	74	349414	531819	0	-1	0	1
348851	531337	75	348851	531335	0	2	0	4
348867	531350	76	348864	531352	3	-2	9	4
349038	531061	77	349040	531058	-2	3	4	9
349118	530933	78	349119	530931	-1	2	1	4
349043	531054	79	349046	531052	-3	2	9	4
348931	531020	80	348931	531017	0	3	0	9
348878	530949	81	348877	530952	1	-3	1	9
348694	531257	82	348692	531258	2	-1	4	1
349396	531088	83	349397	531092	-1	-4	1	16
349488	531163	84	349491	531167	-3	-4	9	16
349694	531264	85	349692	531269	2	-5	4	25
349587	531044	86	349592	531041	-5	3	25	9
349499	530963	87	349499	530964	0	-1	0	1
349737	530894	88					0	0
349672	531005	89					0	0
349767	530921	90					0	0
349813	530957	91					0	0
348975	530763	92	348975	530760	0	3	0	9
348939	530323	93	348938	530324	1	-1	1	1
349014	530240	94	349018	530242	-4	-2	16	4
349069	530289	95	349072	530289	-3	0	9	0
349033	530342	96	349035	530345	-2	-3	4	9
349084	530381	97	349081	530382	3	-1	9	1
349152	530199	98	349149	530195	3	4	9	16

349079	530158	99	349079	530156	0	2	0	4
349215	530233	100	349219	530233	-4	0	16	0
				RMSE			2.34	2.35

User Evaluation

Evaluation of a Farm GIS				

Please attempt the tasks described below. Indicate how difficult you found each task by circling the appropriate description (very easy, straightforward, difficult or impossible)

Task 1	Print the cropping map for 2001			
I found this task:	Very easy	straightforward	difficult	impossible

Task 2	Print the soil map			
I found this task:	Very easy	straightforward	difficult	impossible

Task 3	Link to the MAGIC web site from the GIS			
I found this task:	Very easy	straightforward	difficult	impossible

Task 4	Send data from the GIS to Excel			
I found this task:	Very easy	straightforward	difficult	impossible

Task 5	Find who owns the accounting data relating to Newton Rigg farm			
I found this task:	Very easy	straightforward	difficult	impossible

Task 6	Please write down any suggestions you feel will make the GIS easier to use			

Task 7	Are there any other features you would like included in the GIS?			

Thank you for participating in this evaluation

	Analysis of Results			
	(5 users)			
	Very Easy	**Straightforward**	**Difficult**	**Impossible**
Task 1	5			
Task 2	5			
Task 3	3	2		
Task 4	3	2		
Task 5			1	4
Task 6	The NGDF metadata was not easy to understand. A more direct link from the menu would be useful. No clear idea of how to search the NGDF database. Confirmation that Access DB is the correct tool for task 5. A friendly front end is required.			
Task 7	Update soil map for additional fields Include watercourses on pollution map Add contours to pollution map			

APPENDIX E

Comparison of IACS and GIS Data

Comparison of IACS and GIS Data
for a sample of digitised fields

Name	IACS recorded area (ha)	GIS calculated area (ha)
Thacka	4.90	4.87
Painsomes	7.80	7.82
Sofia	3.07	3.07
Ashcroft	9.06	9.10
Seven Acre	2.94	2.92
Electric Station	5.26	5.24
Tibby Close	2.73	2.73
Long Meadow a	2.65	2.64
Far Wandells b	0.17	0.17
Calf Close N/R	0.77	0.75

Compiled using the Integrated Administration and Control System (IACS) Field Data Printout sheets for 2001