# Spatial Data Integration

**With special reference**
**to peri-urban and high potential agricultural areas**
**in developing countries**

**FINAL TECHNICAL REPORT**
**NRSP PROJECT R5149**


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## Introduction

The steady improvement of remote sensing and GIS technologies which has been reported in the academic, professional and popular literature over recent years appears to have considerable potential for the analysis of peri-urban and high potential agricultural areas in developing countries.

This report includes a review of the formal and informal literature available in the UK and a survey of individuals and institutions in the UK who have published, or are reputed to have expertise in the techniques relevant to this study. Appendix 1 presents the supporting letter that was used for the survey, Appendix 2 lists the persons and the organisations that were contacted, Appendix 3 comprises the questionnaire and Appendix 4 summarises the responses.

The results of both the literature review and the survey suggest that while existing methodologies do show potential for the future, there are still considerable problems with the levels of resolution of the existing satellite imagery and the methods of analysis that are available for urban and peri-urban areas. Also, most studies have concentrated on developed countries where a large amount of relatively up-to-date large-scale mapping is available to act as a ground control for the imagery. Such, geometrically accurate mapping is essential for developing a reliable geographical information system (GIS).

GIS is defined and discussed in the next section. However it should be noted throughout this report that while the term is often used as an all embracing generic name for automated cartography, desktop mapping, image analysis, spatial analysis and databases with a spatial component, it also has a very specific meaning and few systems qualify as a GIS if the stricter definition is applied. There are many simpler spatial data handling technologies that may be more appropriate for use in the peri-urban areas of developing countries than a full GIS.

This report is written mainly from the viewpoint of how spatial data can be integrated using geographical information systems and it covers work in the UK.  It should be read in conjunction with a parallel report produced by Mr Keith Williams and Professor Paul Mather of the Department of geography, Nottingham University. The Nottingham report concentrates on the remote sensing side of data collection and integration

## The relationship between GIS and Remote Sensing

The term geographic(al) information system (GIS) is used loosely to describe a wide range of spatial data handling technologies. This causes difficulties in applied projects because workers with skills in agriculture, development or planning are often confused by what can be expected from a GIS.

### Simple mapping

These technologies include simple mapping programs. These are essentially display tools used for the production of maps on screen or paper. While accepting external data such programs are not designed either to store or to retrieve that data. The external data simply makes up part of the specification of the final map. Mapping can be carried out using drawing programs or computer aided design (CAD) software. If a map is designed for one time only use errors, distortions, omissions and inaccuracies, while unfortunate, do not have knock on effects and errors are not propagated. Maps, even computer based maps, are not usually used as a means of accessing an underlying database. They are also not meant to be tools for the collection, collation and analysis of multiple data sets. Frequently only the mapping capabilities of GIS packages are used in particular applications. When that is the case the demands of consistency and accuracy, which are needed for more sophisticated GIS applications, can be relaxed. However, once these requirements have been relaxed the resulting map will impose severe limitations on further work.

### GIS

There are a number of commonly used definitions of GIS. Two are particularly helpful and complementary.

The most common definition of GIS is that it is:

“ A computerised information system that can store, retrieve, analyse and display spatial data “

At first glance this might be a definition of any computerised information system. Obviously a system that could not store, retrieve or display information would be useless for any practical purposes. However the definition of GIS emphasises *spatial data* and *analysis.* Geographic information has particular characteristics not shared by other types of information that are routinely handled on computers. Firstly geographic data has a minimum of two dimensions (latitude and longitude or easting and northing). Data relating to the physical, as opposed to the cultural, environment has the third dimension of altitude. This is often handled in a different way within a GIS from the other two dimensions, largely because the information is either irrelevant or unavailable and because it is treated in a different way on two dimensional paper maps which make up an important part of the source material for most GISs. The fourth dimension, which is, at present poorly handled by GIS but is particularly important when studying development, is time. Few GIS systems have any consistent way of handling time and it is usually necessary to replicate GIS based maps for each ‘time slice’ that is of interest.

In addition to its multi-dimensional nature, spatial information represents some external fact concerning the disposition of natural or cultural features on the earth’s surface. This is different from the data that a designer might enter into a CAD system for example. In that case the designer’s idea is represented in the computer, and in turn may be realised as a physical object. In this case the data in the machine dictates the nature of the outcome in the real world. By contrast, in a GIS, facts are collected about the real world, and these can be externally validated by re-capturing or checking the data in some other way. Because the process of capturing data about the environment is error prone the issues of error and its propagation are important in GIS environments.

The other key term in the definition of GIS is *analysis*. It is the analytical capabilities of a GIS that differentiate it from mapping or other computer software environments. In particular this analysis is spatial analysis. This has been described as part of a process that takes information that is *implicit* in a map and makes it *explicit.* For example there may be a number of definitions of what constitutes a peri-urban environment. However none of these definitions would be explicitly depicted as a zone, or set of zones on a general-purpose map. Part of the implicit information that the map provides however might be the roads leading to the urban area in question. If the peri-urban zone were to be defined as a zone within a certain travel time from the urban centre, a GIS could be used to generate an ‘isochrone map ‘, a map which depicts travel times by a given mode of transport, as contour lines. The length and the direction of the roads was explicitly depicted on the map. However the generation of travel time zones involved an analytical process whose result were the time contours that make up the isochrone layer on the GIS map. Another common example of spatial analysis is the ability to specify spatial buffers around areas, lines or points in a GIS. For example certain crops may require frequent attention and must therefore be grown within a certain distance of a farmhouse. A buffer that represents the maximum normal travel distance for the farmer can be used to select the fields which would meet the distance criterion for the growth of this particular crop.

GIS systems have a small number of very powerful and versatile analytical tools. However there is a price to be paid for using these tools. In a GIS map data needs to be carefully structured into ‘objects’ which can sensibly be judged to ‘behave’ in particular ways and whose attributes can be stored in the database attached to the map. It is the combination of structured data, an attribute database and the availability of analytical procedures which allow users to analyse the relationships between different types of object on the map and can create new geographical objects, that makes GIS so powerful.

Well-structured data in a conventional GIS comprises three types of geometric primitive: points, lines and areas. These are used to represent all geographical features – a level of abstraction that can cause difficulties.

## The cartographic representation of urban areas

The representation of urban areas on maps is highly scale dependent. On a small-scale map, say, 1:1,000,000 or smaller, urban areas are likely to be represented symbolically as a circle or some other shape , possibly sized to give some impression of the total population of the settlement. As the map scale becomes larger, say, 1:100,000 urban areas begin to acquire shape and to be depicted as a filled polygon representing the built up area. By the time the scale reaches 1:10,000 – 1:50,000 blocks of buildings bounded by streets start to be depicted. At large scales 1:1,250 – 1: 5,000 filled street blocks disappear to be replaced with the outlines of land parcels and the footprints of individual buildings.

In a GIS context this substantial variation in the way an urban area is shown on different scales of map is known as 'multiple representation'. Such multiple representations can be handled in a GIS by making the representation on the screen, scale dependent. For example as one zooms into a map the representation of a street will change from a stylised, and colour coded, line of constant width to an area of land that makes up the street and its pavements.

The cartographic representation of an urban area is also interpreted on a map, additional information may be printed or data may be attached to the spatial objects in the GIS that gives their attributes. Also, non-physical information, such as administrative or statistical boundaries may be included on urban maps. Such information is helpful when attempting to integrate maps and remotely sensed images, as data on population, number of houses or occupational density may be available on the map or in the GIS. A Substantial amount of work has been done (e.g. Mesev, V. 1995) on these relationships.

Despite the rich variety of urban representations in many developed countries and the UK in particular, it has proved very difficult to identify urban features which appear on large-scale maps in SPOT or Landsat imagery. Small scale patterns of urbanisation are easily discerned, however the level of detail required to identify features and activities on the urban fringe simply does not exist in satellite imagery. Murray, K. (1997) has demonstrated that, if maps are to be derived from space imagery, the resolution available from SPOT with 10m pixels is unsuitable for scales any larger than 1:100,000 mapping. The high resolution satellite platforms that should have been operational by the late 1990s are intended to provide 3m pixels. Murray concludes that these may be useful for determining land-use but are inadequate for cultural features such buildings or roads. Even 1m images, also due soon, while adequate to reveal individual houses and street patterns, do not provide sufficiently detailed information to identify changes in the size or shape of a house. 1m marks the limit to minimum pixel size that is expected in the near future.

To move to larger scales a shift from space imagery to aerial photography is required. Digital air photos (photographs captured directly to a digital camera with no intermediate film or print stages) typically have pixel sizes of about 25 cm, and in precision applications may have pixels as small as 10 cm. Such aerial photography, which has been post-processed to geo-reference it to real world co-ordinates, i.e. perfect alignment with a map of a suitable scale, is known as digital orthophotography. Such products with a simple interpretative text layer are beginning to replace conventional mapping in some cities, particularly in the US.

### The analysis of urban and peri-urban areas in developed counties

The best-mapped cities in the developed world have a reliable large-scale mapping template to which ortho-rectified digital air photography can be attached for completeness or to bring old mapping up to date. In such areas new sources of large-scale imagery may be exploitable to track urban change. However, despite there being a large amount of evidence in the literature that such analysis ifs feasible it is very seldom done.

### Developing countries

Developing countries seldom have either the large scale mapping, or the digital imagery required to carry out the analysis of peri-urban areas. Mapping at scales larger than 1:50,000 is relatively rare. In rapidly urbanising areas maps are seldom up-to-date. There are often severe restrictions both on map use and on aerial photography on security grounds. In these circumstances the use of a methodology that involves the integration of Remote Sensing and GIS would also involve a mapping operation and new aerial photography. Except for the best funded projects, such an effort is unlikely to be affordable as part of a development project.

## Potential Methodological improvements

If existing sources of data for GIS are inadequate, is there a prospect that better, cheaper and more timely data will become available for use in peri-urban environments in developing countries?

### Higher resolutions from space

Respondents to the survey and Mather and Williams, in their parallel report, have made reference to the fact that commercial high-resolution satellite imagery is likely to become available in the early years of the coming century. Launch programmes have suffered a number of set-backs in the last couple of years, but it can be anticipated that satellite data in the 3m – 1m pixel range will become available in the near future. Microsoft's Terraserver WWW site (www.terraserver.com) is already showing the way, with recently de-classified Soviet panchromatic imagery what a commercial image service might look like. The Soviet data is dating rapidly, however, the frequency of over-pass of the new satellites will be such that timely data should become available for most parts of the Earth's surface.

The infringement of national sovereignty, that will be involved in such public satellite surveillance, will raise important matters of principle in many developing countries, which may seek to use international law to suppress access to such data However, even if available, without good quality well structured base maps, to which the imagery can be related, the new high resolution sources alone will not solve the problem of peri-urban analysis in developing countries.

### Aircraft borne sensors

A lower cost route, already tried in some NRI project areas, is to custom fly areas of interest with light aircraft and digital cameras. An even less costly method of collecting airborne imagery is to use modern digital video cameras (which can work in panchromatic or infra-red mode) and then to capture scenes directly from video-film. Such scenes can be ortho-rectified for referencing to a base map. The quality of product possible when using this approach is not as good as that possible with a good quality still digital camera and even less good than is available from aerial photography onto conventional film. However the prospect of obtaining areal coverage at little more than the cost of flying will be tempting for many development agencies

### Better mapping

The key to peri-urban analysis, however, will not lie in the nature of the sensor or the choice been aerial photography or satellite imagery. It will lie in the quality of the base map, and the attribute information that can be collected for areas identified on that map

### Ortho-photographic approaches

Traditional air photo interpretation can provide much of the information required to map peri-urban areas. However this is a highly skilled and costly exercise, particularly where oblique or uncorrected air photos are used. The new techniques of digitally rectified images have much to commend them and, over the last two years software for producing rectified images has come down significantly in price and has become easier to use.

However there is a ‘catch 22’ in the production of ortho-photos. Ortho-photographic images with some annotation are becoming excellent replacements for maps, but they cannot be created without a set of known ground reference points to register the image. These would normally, in a developed country, come from mapping but with no map it is not possible to acquire registration points so easily.

### Ground based road and track digitising

The features that stand out most strongly on an aerial photo are roads and tracks, particularly where these have been stripped of vegetation. So in order to provide the necessary tie-points for registering an ortho-photo it is necessary to map road and track locations. This can be done relatively easily by using vehicle-borne GPS (Global Positioning System) receivers, differentially corrected by reference to a fixed receiver at a known location.

One the road network has been surveyed, it will provide a firm foundation for geo-referencing imagery, however it will not provide the necessary set of basic spatial units for assessing land-use and land-use change.

### Land parcel mapping

In a peri-urban environment, if it is intended to plot change over time, it is vital that a set of recognisable land parcels should be mapped and their attributes should be recorded in the database that is integral to the GIS being used. Land parcels can be most easily identified from the aerial photography once it has been geo-referenced against the road/track network. These units are the vital precursor to the semi-automated analysis of land-use change that then becomes feasible.

## Conclusions

### Existing methods show promise but are not yet suitable for general deployment

The bibliography and the abstracted articles attached to this report make it clear that over the last decade there has been a considerable amount of research into the integration of GIS and remotely sensed date. However the survey and closer reading of the literature also make it clear that, while showing a considerable degree of promise, neither the data sources nor the integration methods are yet suitable for widespread low-cost deployment to monitor and support development projects.

The main reason for this is that the data collection, data cleaning and data structuring operations that these methods demand are non-trivial and require heavy investment of time and money, as well as needing skilled personnel. The technical and administrative infrastructure required to maintain such an effort is unlikely to be found in a development project area, unless the project is very well established and long-term funding is assured. This is seldom the case where development teams visit infrequently, and for short field periods. Rapid Development Assessment methods may be much more suitable in such circumstances and these would not justify the work required to produce a GIS based information system for an area.

### Digital aerial photography and field sketching may be appropriate for some studies

If the only objective is to carry out a Rapid Development Assessment then the traditional field sketching and aerial photo interpretation methods are likely to be quite adequate. Digital aerial photography reduces costs and speeds up the availability of images.

### GIS only justified where there will be long term involvement

GIS is only likely to be justified in a long term project where there is a commitment to *measuring,* rather than simply estimating, environmental change over a number of years. Where that is the objective a reliable and repeatedly identifiable set of basic spatial units must be defined and base maps produced with clearly identifiable geo-referencing points to allow aerial imagery to be rectified and matched to the maps at each pass.

### Multiple users of the system required

For such systems to be justified and maintained it is important that they should be integrated into the local economy and the local administrative environment. The technical issues in integrating remote sensing and GIS are now ell understood and relatively easy to use software is available. The cost of the computing power required to run such software and maintain the large data sets involved has fallen to a level where it is counter-productive to economise. Even in the poorest environments the hardware and software necessary for an integration project will be one of the smallest cost elements. The core issues are institutional and cost-benefit related. In that way the use of GIS technology for integrating peri-urban environmental data in developing countries is constrained by very similar challenges to those face in the more developed world.

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## Selected Bibliography and Abstracts

Abts, Els & Vereecken, Harry (1991) ‘The use of GIS and image processing combined with a mathematical model for estimating the regional ground water recharge,’ *Proceedings, 2nd. European Conference on Geographical Information Systems, Vol. I*, page 9, Brussels.

*“Established geographical data base for the river Uzer catchment containing 6 layers of information incorporated in GIS. Land use data derived from multi-temporal satellite image. After conversion, overlay of climate, soil and land use grid was performed”.*

Badji, M., & Mallants, D., (1991) ‘Integrating GIS and process models: a new perspective for decision support systems(DSS) in irrigation water management,’ Proceedings, 2nd. European Conference on Geographical Information Systems, Vol.. I, page 48, Brussels.

*“Explores the potential use of GIS and process models as a basis for DSS in irrigation water management. GIS’s ability to overlay and interchange different sets of information over time and space is highlighted. Irrigation water management is a locational/allocation procedure and therefore a spatially related process Models can be used widely in addressing water management issues. Integration will provide a more powerful tool for supporting this decision-making.”*

Barr, S. & Barnsley, M., (1995) ‘A Region-Based Spatial Analysis and Modelling System for Urban Land Use Mapping’ Proceedings 21st Annual Conference, Remote Sensing Society, University of Southampton, Sept. 1995, page 1179.

*“This paper discusses the development and application of a region-based Spatial Analysis and Modelling System (SAMS) designed to obtain high-level thematic information from digital images acquired by high spatial resolution satellite sensors”.*

Brown, R., Slater, J. & Askew, D., (1995)’ Monitoring Environmentally Sensitive Areas using satellite imagery, within GIS,’ Proceedings 21st Annual Conference, Remote Sensing Society, University of Southampton, Sept. 1995, page 486.

*“This paper describes a project assessing the suitability, accuracy and cost effectiveness of satellite imagery for monitoring Environmentally Sensitive Areas. A land cover map updating system has been developed which allows baseline land cover maps produced from air photography, to be updated using satellite imagery within a proprietary GIS/image processing system. Initial results from detecting arable/grassland change in the Broads, and discriminating grassland types of different conservation interest in the Pennine Dales, are discussed. The importance of integrating satellite imagery with maps and other data within a GIS framework is stressed”.*

Burrill, A., & Terres, J, M. ‘Agricultural information systems for Europe’. GIS Europe, vol. 3 (4) 1994, pages 22- 25.

*“Billions of ECUs are spent annually on agricultural planning and subsidy payments to farmers for specific crops and set-aside land. This article reviews ways in which remote sensing and GIS are being exploited for greater planning efficiency by the European Commission and as a means of exercising operational control within the 12 member states”.*

Cadoux-Hudson, J. ‘Imagery in GIS’. The 1994 European GIS Yearbook, Pages 143 - 146.

*“Developments in air photos have brought considerable advances in capturing and interpreting the material - though this brings other problems in its wake, such as how to store and retrieve the vast*

*quantity of data gathered. But air photos have much to offer the GIS user, and in an increasing number of application areas".*

Caracciolo, V. 'Progetto Teleter. Monitoring of Southern Italy Urban Areas Through GIS and Remote Sensing: The Volturno Piana Case', Proceedings, 1st. European Conference on Geographical Information Systems, Vol. I, pages 173 - 177, Brussels.

"This paper describes the methodology and results of the research that Formez has carried out within the 'Training programme on GIS and Remote Sensing applied to earth resources and environmental monitoring".

Cleynenbreugel, J. van, Fierens, F., Suetens, P. & Oosterlink, A., (1991) 'A strategy to incorporate GIS knowledge during road extraction from satellite imagery,' Proceedings, 2nd. European Conference on Geographical Information Systems, Vol. I, page 197, Brussels.

*"We present a strategy for (semi-) automatic road delineation on high resolution satellite images that is meant to integrate different GIS-related knowledge sources for this problem. A general description of the strategy is given. An actual implementation in an object-oriented image understanding environment is briefly mentioned. The feasibility of the strategy is shown for three practical case studies using SPOT and LANDSAT TM data".*

Cope-Bowley, T. & Poulter, M., (1995) 'Remote Sensing for Urban Planning,' Proceedings, 21st. Annual Conference, Remote Sensing Society, University of Southampton, Sept. 1995, page 301.

*"In urban regions of rapid growth and change, typified by Durban, South Africa, strategic planners require regular information on what is happening on the ground. Through the analysis of SPOT panchromatic and multispectral images, over four years, a variety of change has been identified and the relevance to planners and developers confirmed. In this paper we concentrate on the recognition and characterisation of the burgeoning informal settlement areas [shacklands] from space. The use of radar ERS!/SAR data in its provision of structural information is explored as is the potential combination of SPOT optical data with the radar towards producing a unique signature for informal settlement".*

Curran, P. 'Earth observation comes of age'. GIS Europe, Vol. 2 (4) 1993, pages 27 - 31.

*"Earth observation, the use of image data from sensors on aircraft and satellites for the understanding and management of our environment, is accounting for an ever-greater proportion of the European expenditure on space activities. The British National Space Centre (BNSC) now allocates around half of their space funds to Earth observations alone".*

Downey, I. D., Heywood, D. I., Petch, J. R., 'Digital Remote Sensing Information in Urban Environmental GIS', Proceedings, 1st. European Conference on Geographical Information Systems, Vol. I, pages 282 - 287, Brussels.

*"The GIS/Remote Sensing Unit at the University of Salford has been assessing the utility of different remotely sensed data for incorporation into a range of GIS for urban environmental inventory, analysis and planning. When used with care, remotely sensed data can provide an input to GIS which is generally useful and often irreplaceable".*

Doytsher, Y. & Shmutter, B. 'Digital urban Mapping'. The Cartographic Journal, Vol.24, December 1987, pages 125 - 130.

*"Mapping is gradually passing from the domain of graphics to the domain of numbers. Whereas in the traditional mapping process the aerial photography has been transformed directly into a line map, the*

*new approach to mapping yields primarily a digital representation of the area, the plotted map becoming but one of the possible output forms".*

Dunn, R., Harrison, A. R. & Turton, P. J. 'Rural-to-urban land-use change: approaches to monitoring and planning using GIS'. Mapping Awareness, May 1991, pages 26 - 29.

*"Two important capabilities of Geographical Information Systems technology are data integration and the provision of dynamic user interfaces for map composition and database querying. In this article we utilise these two features of GIS in the specific context of monitoring and planning rural-to-urban land use change. Examples are presented from a wider study of the potential of GIS to assist policy makers with environmental remits. It is argued that in a period of increasing pressures on land, GIS has an important decision support role to play improving the information base available to policy makers".*

Ferreira, Joseph Jr. & Wiggins, Lyna, L., (1993) 'Computing technology for land-use and regional planning: the case of the National Capital Planning Commission,' Proceedings , 3rd. International Conference on Computers in Urban Planning and Urban Management, Vol. I, page 285, Georgia Institute of Technology, Atlanta.

*"Developers and users of Geographic Information Systems (GIS) must make crucial decisions about the content, scale, and accuracy of the layers in their spatial databases. Issues to be considered include: What content should be standardized; what scales are appropriate (and practical) for typical planning applications; and what accuracy results from a typical McHargian overlay of GIS layers having varying scales and accuracy? Recently, such questions of GIS content and 'fitness for use' have received increased attention from Goodchild and others. In this paper, we focus on these questions in a regional planning context. We illustrate our discussion with examples drawn from our work for the National Capital Planning Commission, and other work involving typical Regional Planning Agencies. The increased availability of digital spatial data from governmental and private sources is beginning to drive the choice of both content and scale. The advent of TIGER line files and digital 'quad' sheets have prompted many state and regional authorities to standardize on 1:24000 and 1:100000 scales. More recently, the improved cost effectiveness of satellite imagery, global positioning systems, and digital orthophotos have enabled systematic consideration of accuracy issues and have facilitated the cross-referencing of spatial data layers arising (at different scale) from a variety of sources. The examples illustrate the potential benefits, and gaps, implied by these trends".*

Fierens, F., van Cleynenbreugel, J., Suetens, P., & Oosterlink, A., 'A Software Tool for Symbolic Reasoning on Raster Based Image Data,' Proceedings, 2nd. European Conference on Geographical Information Systems, Vol. I, page 333, Brussels.

*"For the (semi-)automatic interpretation of satellite images, information that resides in a GIS database can serve as a valuable knowledge source. ID order to apply knowledge based techniques, this knowledge must be represented in an explicit symbolic form. This is more or less the case in a vector based GIS. The original satellite images however, as well as data in a raster based GIS, contain information in an implicit, signal-like format. A large representation gap exists between the 2-D signal-like data on images and (raster based) maps, and the symbolic representations that automatic reasoning and especially artificial intelligence techniques use. In this paper, we propose a software tool, originally developed for knowledge based image analysis, that contains features to bridge this gap. We will give some examples of its use in the development of GIS database modules that extract and access information from image-like data. The tool is based on the object oriented philosophy, thus allowing an easy interfacing with an object oriented GIS. More general database research issues such as structuring and indexing of the data will not be considered here".*

Foody, G M (1995) 'Land cover classification by an artificial neural network with ancillary information,' in Information Journal Of Geographical Information Systems 9 (5): 527-542

*“Remote sensing is an important source of land cover data required by many GIS users. Land cover data are typically derived from remotely-sensed data through the application of a conventional statistical classification. Such classification techniques are not, however, always appropriate, particularly as they may be untenable assumptions about the data and their output is hard, comprising only the code of the most likely class of membership. Whilst some deviation from the assumptions may be tolerated and a fuzzy output may be derived, making more information on class membership properties available, alternative classification procedures are sometimes required. Artificial neural networks are an attractive alternative to the statistical classifiers and here one is used to derive a fuzzy classification output from a remotely-sensed data set that may be post-processed with ancillary data available in a GIS to increase the accuracy with which land cover may be mapped. With the aid ancillary information on soil type and prior knowledge of class occurrence the accuracy of an artificial neural network classification was increased by 29.93 to 77.37 per cent. An artificial neural network can therefore be used generate a fuzzy classification output that may be used with other data sets in a GIS, which may not have been available to the producer of the classification, to increase the accuracy with which land cover may be classified”.*

Fouda, Y.E., El-Kadi, H. & El-Raey, M., (1993) ‘A Geographic Information System for environmental auditing of the Sixth of October City, Egypt,’ Proceedings, 3rd. International Conference on Computers in Urban Planning and Urban Management,
Vol. II, page 121, Georgia Institute of Technology, Atlanta.

*"This paper presents a study carried out over the SIXTH OF OCTOBER city in Egypt, as an application of geographic information systems in environmental auditing. Due to the nature of the dense and spreading industrial activities at the city, performing environmental studies on such case was needed. The study discusses and clarifies the extent of impacts caused by new industrial activities on the natural environment, and investigates impacts caused by the human interference. It also audits natural environmental parameters surrounding and affecting the city, such as sand-loaded wind, and moving sand dunes. An air modelling technique based on the Gaussian plume model was developed and used to derive the plume spreading profile of the gaseous industrial pollutants. Data was processed and analyzed using a geographic information system, which developed information on the hot spots suffering from various impacts. /t was also possible to forecast the future situation due to the expansion of the industrial activity. This technique could be used to audit and monitor the pollution indices of other gaseous pollutants in similar situations. It can also be used through a decision support system for the environmental impact assessment of new urban conglomerations having wide spreading industrial activities".*

Gorte, Ben (1991) ‘ Data integration in future versions of ‘ILWIS’ software,’ Proceedings, 2nd. European Conference on Geographical Information Systems, Vol. I, page 351, Brussels.

*“Since the beginning of 1986, an interdisciplinary team at ITC has been working on the development of a Geographic Information System software, which to date is known as the ILWIS system. From the beginning the aim has been to develop tools for Geographic-data storage and manipulation, together with methods for information extraction. Because of its multidisciplinary nature, the emphasis has been on the support of a variety of different data types (raster, vector and non-spatial) on the combination of data of these different types, and on the goal of making the tools as "general purpose" as possible. Indeed, the system has proven to be suitable for a large number of applications in different fields of earth science. As a consequence, however, the system has become quite complicated to operate in certain circumstances. Loosely speaking it turned out that the capability to perform complex tasks also complicates performing "routine"*
*tasks. Currently, design considerations are being made with the purpose of removing this drawback while preserving the flexibility. The solutions are found in a more consistent Data Base Management System approach for Geographic-data, including well known DBMS concepts such as Data Dictionary and User Views. Instead of allowing the "combination" of data of different types, the system should allow the "integration" of these data, by managing them in a uniform manner using (at least from the point of view the user) a single Geographic-Data Base Management System”.*

Haemers, P. B. M., 'Integration of GIS and Remote sensing Data: Accuracy Assessment', Proceedings, 1st. European Conference on Geographical Information Systems, Vol. I, pages 428 - 436, Brussels.

*"Integration of remote sensing and GIS data has been made possible by modern GIS and remote sensing systems. Remote sensing data can be used now to add information into a GIS to update GIS information".*

Hartman, J.L.,(1991) 'Visualization techniques for GIS,' Proceedings, 2nd. European Conference on Geographical Information Systems, Vol. I, page 406, Brussels.

*"Visualisation techniques in traditional GIS-systems are based on traditional cartographic methods and inherently vector oriented. Many more techniques, most of which raster-based, are available from other fields related to computer graphics, such as CAD/CAM and remote sensing- This paper will discuss the practical possibilities of techniques like false-color, shading/texturing, rendering, halftoning and image enhancement for GIS-applications and indicate ways in which these can be integrated into existing systems- The evolving standard for raster-graphics, X-Windows, is a very important factor in this process of integration and will be discussed as such".*

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Hinton, J. 'The best of both worlds: developing GIS for vector and raster data analysis'. GIS Europe, Vol. 3 (9) 1994, pages 32 - 34.

*"In the UK, an integrated GIS is being used to help maximise results from a forest-mapping project. Researchers based at the UK Natural Environment Research Council (NERC)'s Remote Sensing Applications Development Unit (RSADU) are using the new system to analyse raster and vector datasets. NERC is combining its digital vector maps with raster-based remote-sensing data to identify tree species".*

Hoey, M., & Whelan, D., (1991) 'A PC based GIS that integrates image data, map data and attribute data,' Proceedings, 2nd. European Conference on Geographical Information Systems, Vol. I, page 469, Brussels.

*"This paper describes an image processing and GIS software system for IBM MS-DOS microcomputers and compatibles, developed for the European Less Favoured and Marginal Areas Programme. The system integrates remotely sensed image data with map and attribute data. It is relatively inexpensive and maximises the use of the basic IBM and compatible graphics hardware without resorting to additional image processing hardware".*

Ireland, Peter (1995) 'GIS: taking root in a hostile climate,' GIS Europe, vol. 4 (6), pages 24-27.

*"A major difficulty for farmers in southern Europe is the lack of water for irrigation. Prolonged drought, evaporation and unprecedented demand means that new ways must be found to keep crops flourishing. Fortunately, the UK's Insitiute of Arable Crops Research has been working with European partners to exploit GIS in a search for answers".*

de Jong, Steven M. & Riezebos, Hans Th., (1991) 'Use of a GIS-database as 'a priori' knowledge in multispectral land cover classification,' Proceedings, 2nd. European Conference on Geographical Information Systems, Vol. I, page 503, Brussels.

*"Land use and land cover in Kakamega district (Kenya) is mapped using multispectral Thematic Mapper data. First results of a maximum likelihood classification were rather poor. Several crops and types of land cover were spectrally confused. Land use in the study area is characterized by a specific spatial pattern. This pattern is caused by a rather steep gradient in precipitation from south to north. This gradient causes a change in the physical land suitability to grow certain crops. This spatial pattern of land use and land cover is described in general terms by the Agro-Ecological Zones of the*

*FAO. The division into Agro-Ecological Zones is based on the temperature and water requirements of the main crops. A map of the Agro-Ecological Zones was digitized and is used as "a priori" knowledge in a second maximum likelihood classification of the TM-image. In the maximum likelihood procedure the probability values of the crops were adapted depending on their location in a specific Agro-Ecological Zone. The accuracy of the multi-spectral classification improved considerably using the zonation as additional knowledge. Overall classification accuracy increased from approximately 45% to 65%".*

de Jong, S. M., 'Integration of Remotely Sensed and GIS Data to Determine SPOT Classification Accuracy,' Proceedings, 1st. European Conference on Geographical Information Systems, Vol. I, pages 517 -525 , Brusse

*"Land use and land cover of an area in the southern Netherlands is mapped in two ways: firstly by a conventional field survey using general land use classes and secondly by classifying a multispectral SPOT-image".*

Jehangir, S. & Millington, A. (1995)' Development of a GIS model for the assessment of hydrological impacts of land cover changes in the Siran Basin,' Pakistan, Proceedings 21st. Annual Conference, Remote Sensing Society, University of Southampton, Sept. 1995 page 256.

*"This paper describes the development of a deterministic model capable of simulating the hydrological impacts of land cover changes in the Siran catchment northern Pakistan. Spatially distributed parameters for this model are extracted from a regional GIS developed specifically for the project. Land cover mapping and change detection have been carried out through the digital processing of two Landsat MSS and TM images. Particular attention has been paid to the problem of relative relief and shadowing. Methods to overcome shadowing affects in image processing in rugged mountain terrain have been developed. Land cover was mapped and checked against an independent set of field data".*

Jones, B., Hollis, J., King, D., Daroussin, J., (1995) 'Back to the land: towards sustainable land use in Europe,' GIS Europe, vol. 4 (6), 1995, pages 28-30.

*"Scientists in the European Union have been working together to build an information base that will support agricultural land-use decisions into the next century".*

Van Der Laan, F. 'Policing Europe's Common Agricultural Policy: GIS and remote sensing take up the challenge'. GIS Europe, Vol. 3 (4) 1994, pages 32 - 35.

*"GIS and remote sensing show promise of helping to monitor the European Union's largest drain on finances - the Common Agricultural Policy - but there are many challenges yet to be faced".*

Lakerveld, M., Harts, J. & Ottens, H.F.L., (1991) 'The use of GIS for a municipal planning information system: integration of administrative databases and CAD data in A GIS environment,' Proceedings, 2nd. European Conference on Geographical Information Systems, Vol. I, page 591, Brussels.

*"In this paper we will examine how of Geographical Information Systems (GIS) are used in the overall planning process in local government. For three different types of municipal department, we describe the data and information systems used to manage (daily) operations. Most large GIS software packages can integrate a variety of data and are dedicated for all sorts of applications. Two strategies to introduce GIS in municipal planning are discussed here. To find out how they work in practice, we carried out a pilot study. On that basis, this paper explores the possibilities of integrating municipal administrative databases and CAD maps in a GIS environment".*

Leykauf, J. & Villwock, G. 'Urban-Ecological GIS for the Urban Region of Hall (Eastern Germany),' Proceedings, 2nd. European Conference on Geographical Information Systems, Vol. I, page 646, Brussels.

*"Creation of a GIS containing selected environmental characteristics of the urban area of Halle enables the analysis of urban-ecological conditions. Besides the inventory of the present situation and its valuation, the GIS is suitable for development of spatial oriented planning variants. The inventory of ecological structures is founded on parameters available by interpretation of aerial photographs and maps. These parameters reflect as indicators main aspects of environmental conditions within delimited spatial units. Division of the urban area into "Urban-ecological landscape units" (ULU) provides the reference units for this GIS. The choice of main attributes for characterization of ULU's considers their significance as regards environmental conditions and the given possibilities of their townwide collection. Linking of attribute and geometrical data within GIS allows application of various valuation methods and computer-assisted presentation of maps".*

Leysen, M. M., & Goossens, R. E. 'Forest map updating in a GIS using a high spatial resolution satellite data', Proceedings, 2nd. European Conference on Geographical Information Systems, Vol. I, page 653, Brussels.

*"The production of the forest map of Flanders was based upon CIR orthophotomap (1:5000) interpretation. The matching forest database contains all graphic and attribute information. For the 10 yearly updating, a more cost effective alternative was desirable. The adopted method should maintain the high level of spatial and informational detail and allow for automation. Since the exact geometric base is already available, satellite images offer an adequate tool for updating".*

Milnes, M., (1995) 'Sugar beet prediction and management project: results of the pre-operational trial,' Proceedings, 21st. Annual Conference, Remote Sensing Society, University of Southampton, Sept. 1995, page 478.
*"The sugar beet prediction and management project is a three year project during which a system is being developed and exploited to produce yield estimates of the sugar beet crop in the UK using a range of satellite data including SPOT HRV, Landsat TM and ERS SAR data. The project is divided into three parts each of one year duration, namely; a pilot programme, a pre-operational trial, and an operational test. This paper reports on the results of the pre-operational trial, which covered the 1994 growing season. The objective for 1994 was to refine the satellite image processing and sugar beet growth models, and to operate the yield prediction system in a semi-operational environment, using data for the current year (1994) as it became available. This has demonstrated that the methodology developed by the Logical consortium is proven to meet the requirements of British Sugar on the data from the pre-operational year. Much of the information provided is new to British Sugar, and provides more detail and accuracy of forecasts (measured against actual factory outputs) than has hitherto been available".*

Nelson, Arthur C., (1993) 'Estimating small area non-residential land use requirements,' Proceedings, 3rd. International Conference on Computers in Urban Planning and Urban Management, Vol. II, page 171, Georgia Institute of Technology, Atlanta.

*"Governments managing the development of small areas need to estimate non-residential land use requirements associated with the private sector over five to twenty year planning horizons, but they fail to do so adequately. One problem is the lack of good information about land use parameters. Another problem is with the level of data that are available. This paper presents a method for estimating small area non-residential land use requirements principally using secondary data or locally derived data together with planning decisions. Issues reviewed include: land use ratios for workers in different land use categories; adjustments to account for gross floor area and gross land area; adjustments to account for normal vacancy rates; and adjustments to account for market flexibility consistent with locally adopted planning criteria such as preventing or containing urban*

*sprawl. The paper offers a methodology that, while developed for application throughout North American, can be tailored to any country by simply inserting local parameters".*

Ohshima, K., Hagishima, S., Vindenes, H., Yudino, A., & Tokitsu, B., (1993) 'Development of an expert system to support land use planning in developing counrties,'
Proceedings, 3rd. International Conference on Computers in Urban Planning and Urban Management, Vol. II, page 227, Georgia Institute of Technology, Atlanta.

*"The purpose of this paper is to describe the development of an expert system that can support land use planning in developing countries. Knowledge of experts and various existing geographical information from Yogyakarta Province in Indonesia are transformed to mesh data. These data are clarified by means of the "Hayashi Quantification Theory 1" and transformed to a computer system which makes a planning map. The system draws eight different land use zones. These zones are set up through a four stage process. The first stage sets up four different preservation zones by using data on natural factors and actual land use. The second stage sets up activity centers by means of transportation network data, and the third stage sets up four different urbanized zones following a method in which meshes are ranked according to distance from activity centers. The fourth stage amends the land use so far proposed for each mesh by considering the proposed land use of surrounding meshes".*

Rado, B. Q., Sperry, S. L. & Smith, C. C. 'Raster - Vector Integration: Case Study Examples of Urban, Wetlands and Regional Studies', Proceedings, 2nd. European Conference on Geographical Information Systems, Vol. I, page 914, Brussels.
*"The need for fast and efficient GIS data base updating has brought raster technology to the vector world. The Live Link, developed through a joint agreement between ERDAS and ESRI enables ERDAS and ARC/INFO users to take advantage of both raster and vector technologies interchangeeably, in one processing session, on one computer. ERDAS - enhanced satellite data can be used as a backdrop for vector maps, facilitating fast updates and accurate change detection. Three projects illustrate the effectiveness of using both raster and vector data for a superior GIS".*

Sadler, G. J., Barnsley, M. J. & S. L. Barr. 'Information Extraction from remotely-sensed images for urban land analysis', Proceedings, 2nd. European Conference on Geographical Information Systems, Vol. II, page 955, Brussels.
*"Recent improvements in satellite sensor technology, together with the more widespread availability of Geographic Information Systems (GIS), allow the full potential of remote sensing for land-cover mapping to be realised through the integration of remotely-sensed imagery with other types of spatially-referenced data".*

Sadler, G. J., Barnsley, M. J. 'Use of population density data to improve classification accuracies in remotely-sensed images of urban areas', Proceedings, 1st. European Conference on Geographical Information Systems, Vol. II, pages 968 - 977.
*"In the U.K., population data are routinely recorded for relatively small spatial units, known as Enumeration Districts (EDs). Data such as these, from the 1981 national Census, are used as an ancillary data plane to improve the classification of land cover types in a digital, remotely-sensed image of London".*

Short, N.M; Dickens, L (1995) 'Automatic generation of products for terabyte-size geographical information systems using planning and scheduling,' Information Journal Of Geographical Information Systems 9(1):47-65.
*"The growth of the remote sensing field has caused an explosion in the size and complexity of Earth satellite image databases. The explosion of data is already challenging current satellite-based GIS databases. New technologies for information management will be required in the future to maintain these large geographically-orientated systems crated by projects such as NASA's Earth Observing System (EOS). This paper presents a technology adapted from the planning/scheduling field in*

*Artificial Intelligence (AI) that promises to automate and facilitate the process of creating and storing satellite images and their associated data products".*

Verstraete, M.M., Pinty B., & Curran, P., (1995) 'MERIS potential for land applications,' Proceedings, 21st. Annual Conference, Remote Sensing Society, University of Southampton, Sept. 1995.
*"The MERIS instrument, to be flown on the Envisat platform, contributes to the effort made by space agencies to generate Earth observation data that are optimised to the needs of the users. This paper briefly reviews the relevance of finer radiometric and spectral resolution, programmability, and the availability of an on-board calibration system for terrestrial applications. Scientific challenges related to scale issues, the definition of appropriate algorithms for the optimal exploitation of these data, the opportunity for synergistic studies and the comparison of MERIS data with those collected by the AVHRR and other precursor instruments is reviewed. The need for an intensive and sustained research and development programme to define and validate a panoply of high-level products optimized for terrestrial applications is stressed".*

Wagner, Mary Jo (1995) 'The view from up here: emerging techniques for satellite image mapping,' GIS Europe, vol. 4 (7), 1995, pages 44 - 47.
*"Over the past decade, the technology for producing high-quality images maps from satellite data - both optical and radar - has moved on apace. Users can now obtain pre-processed custom maps of the world's most inaccessible and problematic areas for traditional cartography".*

Waters, P. A. 'Integrating remote sensing and GIS - why it remotely makes sense'. Mapping Awareness, Vol. 5, (1) 1991, pages 48 - 50.
*"The past five years have seen a meteoric rise in the significance of Geographic Information Systems (GIS) in a wide variety of sectors from oil exploration to retail location, and environmental monitoring to distribution and transportation studies. Information from earth observation satellites and airborne scanners has increasingly played a valuable role in providing the interpreter with geographical, geological, environmental or cartographical information in support of field or ground-based research".*

Weber, C. & Hirsch, J., 'Estimation of Variables with Remote Sensing Information in a Geographical Information System'. Proceedings, 1st. European Conference on Geographical Information Systems, Vol. II, pages 1140 - 1153.
*"Urban analysis needs more and more descriptive data, to be efficient. Unfortunately they are often not usable jointly. The GIS approach gives the possibility to combine them. But, to use all the data in an optimal way, we have to estimate the values of a variable for an areal unit different from that for which it has been measured".*

Webster, Christopher J., (1993) 'Testing the predictive power or urban texture measures in the estimation of population from satellite data,' Proceedings, 3rd. International Conference on Computers in Urban Planning and Urban Management, Vol. II, page 295, Georgia Institute of Technology, Atlanta.

*"One of the accuracy constraints when attempting to monitor population change from space is the relatively poor performance of per-pixel classification methods in discriminating between different urban ground-covers. There is, however, much potentially useful information in an urban scene that cannot adequately be exploited by such methods. Pattern and contextual information are both of primary importance in human visual interpretation and if appropriately measured should, it may be conjectured, improve the accuracy of computer interpretations. Advances in spatial pattern recognition algorithms together with the data integration power of GIS open new possibilities for exploring this conjecture. The paper presents results from a series of experiments which test the power of various texture statistics measured from high spatial resolution satellite data in predicting fine variations in urban population density stored in a co-registered GIS database. the statistics tested measure morphological regularity in a city and are computed in the grey-scale joint-probability domain and in Fourier space".*

Wilkinson, G. G. & Burill, A. 'Integration of GIS-derived spatial data with satellite imagery for improved land cover mapping using an expert system', Proceedings, 2nd. European Conference on Geographical Information Systems, Vol. II, page 1241, Brussels.

*"The classification of remotely-sensed satellite imagery for thematic mapping applications can be improved by the use of ancillary geographic information derived from maps. Two methodologies have been developed for using such information in the automatic processing of imagery: namely an expert system method and a neural network method. Both approaches require accurate co-registered datasets derived from a GIS".*

Woodfine, A.C., Flasse, S., Sear, C.B. & Wheelan, D., (1995)' Integrating local satellite data reception with GIS for effective operational information systems delivery in developing countries,' Proceedings 21st. Annual Conference, Remote Sensing Society, University of Southampton, Sept. 1995 page 249.

*"The Natural Resources Institute (NRI) Local Applications of Remote Sensing Techniques (LARST) initiative has demonstrated that remotely sensed data from polar orbiting and geostationary satellite can have operational impact (Williams and Rosenberg, 1993). Working with colleagues in the UK and with clients in the developing world, LARST systems now have the potential to make remotely sensed data central to the decision making process for environmental resource management, disaster preparedness and early warning. These systems are now being developed to make local access to low resolution satellite data even easier by developing "Windows"- based software for data capture, pre-processing and application product generation. This paper outlines on-going work which aims to integrate the satellite data streams with other data sources in a GIS environment and to provide tailored operational products. This will be a powerful tool for local managers and researchers".*

Young, R. N. 'Digital Imaging System Link Airphoto Interpretation to GIS', GIS Europe, vol. 1 (3), 1992, pages 34 - 37.

*"The use of aerial photography in the United Kingdom has increased in recent years because of the introduction of high resolution colour films and cheaper processing. Previously, developments in GIS were not suited to storing large numbers of high-resolution images. Recent improvements in the storage media and PC platforms opened the prospect of aerial photographs becoming a more widely available source of spatial data for many GIS users".*

## Appendix 1 Introductory Letter

22/4/96

Dear

The Manchester Regional Research Laboratory and the Department of Geography at Nottingham University are conducting an ODA-NRI (Overseas Development Administration - Natural Resources Institute) funded survey of methodologies for the integration of data on *peri-urban* and *high potential agricultural areas* in developing countries.

Manchester’s brief is to discover what remote sensing and GIS techniques are currently used, or being developed, by UK institutions for their projects. We are also interested in identifying similar techniques used in developed countries, which may be transferable to developing countries. Finally we would be interested in your views on the needs for further research.

We would like to speak to you if:

- your institution has used remote sensing or geographical information systems for projects on peri-urban or high potential agricultural systems in developing countries.
- your institution has equivalent experience for projects in *developed* countries: this may include potentially transferable methods of image calibration; image registration; pattern recognition; change detection; integration of data formats; dealing with error propagation and scale issues.
- your institution has views on research needs in this area.

The results of the project will be published in a report aimed at resource managers in developing countries. It will include: a list of institutions with relevant experience; an analysis of existing methodologies, which are potentially transferable to developing countries; and case studies of work carried out by UK institutions illustrating best practice. All participants in the survey will be acknowledged and will receive a copy of the report. It is hoped that the report will increase the awareness of participants’ work in developing countries, encourage networking with colleagues in developing counties and identify topics for future research funding.

I will telephone in the next few days to see if you would be prepared to participate. Involvement could be on several levels; a taped telephone interview (of about 15 - 25 minutes at a time convenient to you), completion of a questionnaire (enclosed) or by sending us any relevant publications and reports. Meanwhile, if you do want your institution to be involved, it would be very helpful if you would identify the most appropriate person to deal with my enquiries and copy this letter to him or her. We would also be grateful if you could tell us of any other institutions or individuals that we should contact.

We are very aware of the pressures on your time but hope that you will feel there is mutual benefit in participating.

Thank you for your time and co-operation.

Yours sincerely,

Lilian Wardle
Research Administrator.

# Appendix 3 Questionnaire

## RRL Manchester, Department of Geography, University *of* Manchester

**ODA-NRI Questionnaire**

Thank you for agreeing to participate in this survey, the main objectives of which were set out in our recent correspondence. The questionnaire is in 5 sections:

1. General information
2. Project information
3. Remote Sensing details
4. Geographic Information Systems details
5. Other relevant details

Please answer the questions in 1 and 2, and then any relevant questions in the remaining sections. Please continue on a separate sheet if necessary.

***Section 1* General Information**

1) Has your organisation used remote sensing (RS) or geographic information systems (GIS) for projects in *developing* countries (DCs)? Yes ☐ No ☐
   If **Yes**, please go to **Question 2.**
   If **No**, please go to **Question 6.**

2) To what extent have you used RS for project planning?

3) To what extent have you used RS for project implementation?

4) To what extent have you used GIS in project planning?

5) To what extent have you used GIS in project implementation?

6) Has your organisation used RS or GIS for research on peri-urban/urban or high potential agricultural areas? Yes ☐ No ☐
   If Yes, where were these projects in:
   Developing countries ☐
   Developed countries ☐
   Both ☐

***Section 2*** **Project Information**

Title of Project

______________________________________________

Location of Project

______________________________________________

Start and end dates

______________________________________________

Principal Investigator

______________________________________________

Funding body

______________________________________________

Project aims & objectives:

***Section 3*** **Remote Sensing**

1) Which RS data sets were used?

| Sensor | Image date(s) | Format (hard copy/digital) |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |

2) Were there any problem(s) in obtaining RS data for the project? Yes ☐ No ☐
If Yes, what was/were the problem(s)?

3) Were other RS data sets considered but not used? Yes ☐ No ☐
If Yes, please specify the image type and reason why it was not used:

4) Comments on the suitability of the image resolution for peri-urban/urban areas (if appropriate).
e.g. any special factors affecting detectability, i.e. size or contrast of scene elements

5) Were any of the following used? Please specify method if known:

| | | Method |
|---|---|---|
| Image registration | Yes ☐ No ☐ | |

| | | |
|---|---|---|
| Radiometric corrections (e.g. calibration to radiance, inter-sensor calibration, atmospheric correction) | Yes ☐ No ☐ | |
| Geometric correction (e.g. first order correction, nearest neighbour resampling) | Yes ☐ No ☐ | |

6) Were any of any of the following techniques used?

| | Peri-urban/urban areas | High potential agricultural areas |
|---|---|---|
| Visual interpretation of hard copy | Yes ☐ No ☐ | Yes ☐ No ☐ |
| Multispectral classifiers (please state type) | Yes ☐ No ☐<br>Type: | Yes ☐ No ☐<br>Type: |
| Neural nets (supervised or unsupervised) | Yes ☐ No ☐<br>S ☐ U ☐ | Yes ☐ No ☐<br>S ☐ U ☐ |
| Spectral mixture modelling | Yes ☐ No ☐ | Yes ☐ No ☐ |
| Textural measures | Yes ☐ No ☐ | Yes ☐ No ☐ |
| Other (please specify) | | |

For the techniques ticked Yes, please comment on their suitability for analysing peri-urban/urban or high potential agricultural areas in DCs.

### *Section 4* Geographic Information Systems

1) Which map(s) were used as the geographic base?

| | Map1 | Map2 | Map3 | Map4 | Map5 |
|---|---|---|---|---|---|
| Map source (mapping agency) | | | | | |
| Map series | | | | | |
| Map scale | | | | | |
| Map projection | | | | | |
| Map date | | | | | |
| Date of updates | | | | | |

3) Which map was used as the base map?

Were the other maps registered to the base map's scale and projection? Yes ☐ No ☐
If No, why not?

What software was used for the registration?

Was the process supplemented with field measurements? Yes ☐ No ☐
If Yes, how were the field data obtained? Field survey ☐
GPS ☐
Other (please specify):

2) How have the map data been digitised?
Manually? Yes ☐ No ☐
If Yes, which features were digitised?

Scanned? Yes ☐ No ☐
Combination of the two? Yes ☐ No ☐

3) Is any data being added from documentary sources? Yes ☐ No ☐
if Yes, what are the sources?
(e.g. electoral registers, census, cadastral information, tax records)

4) Is remote sensing data being integrated into the GIS? Yes ☐ No ☐
If Yes, what procedures are being used?

***Section 5*** **Other Relevant Details**

**Please return this questionnaire and any other relevant publications/reports, as soon as possible to:**
**Manchester RRL**
**Geography Department**
**Mansfield Cooper Building**
**University of Manchester**
**Oxford Road, Manchester M13 9PL**

## Appendix 4 Summary of responses (and non-responses)

The contact list (Appendix 2) that provided the sampling frame for this survey comprises 94 possible respondents. This list was compiled from an initial trawl through the Remote Sensing Society Yearbook and then by a snowball technique, where team members suggested respondents, who in turn suggested further respondents. The aim was to identify every GIS or Remote Sensing specialist in the UK who may have worked on the integration of Remote Sensing and GIS in peri-urban areas, both in the UK, developed countries or developing countries.

Every potential respondent was sent the introductory letter and questionnaire. This was followed up by a telephone call and the offer of completing the questionnaire as a recorded telephone survey.

However, despite the greatest efforts by two members of staff over a period of some four weeks, the respondents in the sampling frame yielded only 11 completed or partially completed questionnaires. A response rate of only 12%. This was extremely disappointing.

A number of reasons were given for non-response. The most common was that the respondent had not carried out, and was not planning to carry out, any relevant studies. The second most commonly cited reason for refusal was lack of time, however this may have been a convenient surrogate excuse for those who were not doing relevant work but who preferred not to admit it, or, those who considered their work to be commercially confidential. In fact a number of respondents who refused to participate in the survey were concerned that NRI, which was seen as a commercial competitor, was seeking to obtain commercially valuable information from competitors.

However the overwhelming reason for lack of response, and one which became clear in the replies of the 11 who did complete the questionnaire, was the fact that the technologies we were investigating have not been deployed. The principal reason for this was not an absence of software or integrating methodologies. These are generally well understood, except for the more exotic techniques. The primary reason for not using the technology was the poor quality, low resolution and high cost of existing data sets.

The single clearest result from the survey process was that there is a potential demand for the technologies we were investigating, but despite a large and enthusiastic, though largely speculative literature, the field is, as yet mainly theoretical.

### Summary of responses

Due to the very low response rate no firm conclusions can be drawn from these results. It should be noted that of the 11 responses all but one were peri-urban projects in the developed world.

*Data sources – Remotely Sensed Data*

The vast majority of the respondents were using SPOT and Landsat data. However, for peri-urban agricultural areas in developed countries, and particularly the UK, obtaining cloud-free scenes. There was a particular problem with finding usable scenes which were optimally timed during the growing season for the crops that were of interest. Cost was mentioned as a major constraint in a number of studies, while in others the absence of SAR imagery limited what could be done.

Barnsley, M. and Barr. S. pointed out, and referred to their 1995 paper, that peri-urban land use typically involves a mixture of built structures and natural vegetation. This complex mixture of land cover types, each of which has a markedly different spectral signature, makes conventional single pixel techniques inappropriate when using relatively low-resolution sources such as Landsat or SPOT.

They have developed a two stage classification to deal with this problem. However, even using such techniques the basic flaw in the existing sources of satellite data, its low resolution, is an unavoidable issue in peri-urban areas.

*Data sources – Mapping*

Almost all the respondents were using UK mapping sources, namely Ordnance Survey mapping at scales of 1:10,000 or l:25,000 from recent series. These were scanned or manually digitised to provide the GIS data for projects. It should be noted that mapping of this quality or at such large scales is very rarely available in developing countries, and where it is, can be subject to severe restrictions on civilian or foreign use.

*Scale Issues*

There was a consensus among respondents that “high resolution” satellite mounted sensors such as SPOT, Landsat TM and ATM, which were specifically designed to ‘examine the potential of high spatial resolution remotely sensed images ….. [ to study ] ….. urban / peri-urban land use’ are too coarse to define intra-urban land use consistently.

One respondent focused attention on the fact that scale and resolution alone are not the key issues. Unless geo-correction and registration issues are dealt with, higher resolution alone would not necessarily give better results in complex peri-urban areas.

Other respondents felt that the higher resolution sensors due to be launched in the late ‘90s which should offer satellite sensed resolutions of between 1m and 5m per pixel, will offer much more scope for peri-urban analysis.

*Data Integration*

Respondents differentiated between four different types of data integration

*a) Different sensors, different times*

This form of integration aims to evaluate change over time. Of the 11 responses 4 projects were involved in integrating data fro a range of sensors over periods up to 7 years

*b) Different sensors same time*

Two projects used data from two or more sensors that was collected at about the same time. The advantage of integrating a number of sources in this way is that a degree of synergy can be achieved so that the interpretation of the results takes advantage of the relative strengths of each sensor and the result can be greater than the sum of the parts.

*c) RS and GIS data/technology compatibility*

A number of respondents mentioned issues in using separate software for each part of the analysis. Since the questionnaires were administered both GIS and Image analysis software vendors have made great strides to allow interoperability between products. However accurate geo-referencing, the identification of points on an image that correspond to the same points on a map and, and rectification, the warping of the image to match the map, remain time consuming and labour intensive activities. High-resolution satellite imagery has been delayed because of a number of accidents leading to the destruction of launch vehicles and satellites. However digital aerial photography is filling the gap and becoming a relatively inexpensive data source. The cost of rectifying digital photography is typically higher than the cost of the original flights and photography.

*d) Raster and vector data*

In addition to the improvements in interoperability, GIS products are increasingly able to handle raster image data. Where such data is properly rectified it can be overlaid on map data for the two area and many operations can be carried out on both data sets. Similarly, image analysis packages, can now handle vector data, usually imported from a GIS, to assist in classification and other operations on images.

These changes go a long way to dealing with comments from a number of projects on the difficulties of integrating data across software platforms.

However some projects stopped short of attempting the geometrical matching of data sets and used a visual interpretation of uncorrected aerial photography to update Land-use maps.
A number of projects used digitised statistical boundaries to provide an element of ‘ground truth’ to assist in interpreting imagery. In the UK the availability of high resolution census boundaries for areas as small as 100 – 150 households has provided measures of population density. Some of the projects have made reasonable progress in relating imagery to population density by estimating the building density in census areas. However these techniques are not yet capable of providing an adequate way of estimating peri-urban population densities I developing countries.

*Future developments*

A number of returned questionnaires discussed plans for future work. These involved the development of statistical methods and the exploitation of higher resolution data from new sensors.

None of this work appears to have come to fruition in the three years since the survey was conducted.

*Conclusions*

It is not possible to draw any firm conclusions from the survey results. The low response rate and the fact that the majority of responses came from a very small number of players in this field in the UK who had most to gain from talking up the potential of GIS/Remote Sensing integration, makes the results from the survey suspect.

The high proportion of refusals reflects the fact that, at the time of the survey, the operational use of GIS/Remote Sensing integration for the analysis of conditions in peri-urban areas was rare. The reduction in the flow of literature over the last three years suggests that this situation has not changed. The arrival of higher resolution satellite imagery, more powerful personal computer based workstations, and better local mapping in developing countries may change this situation in the future.