and indicates the impact that such interventions can have. For example, various agencies have their sights set on a fertile zone of Maputaland called the Makatini Flats which encompasses the floodplain of the Pongola River. Two development agencies, one in crop production, the other in nature conservation, have nominally reserved a large proportion of these Flats for their expansion programmes.

Within the GIS these proposals can be matched with other factors in the system (notably, population distribution and density) and the implication of the proposals evaluated. By asking the "What if?" questions, the system has indicated that these proposals could result in local population relocations of considerable proportions. Examination of the resources of the rest of Maputaland suggest that these people would be unlikely to find suitable alternate resources to support their traditional life-styles. The GIS is thus able to show the inherent flaws in these development proposals.

The GIS staff have noted wariness on the part of agencies and those involved in Maputaland development to consider the technology as relevant to their 'approaches' to problem resolution. Vested interest in the 'rightness of one's current approach' is a powerful motivating force and when it is tied to having to absorb the merits and pitfalls of a new technology, then adoption of that technology a part of the way people tackle problems will take time.

Scarcity of data on key variables has proved to be another problem of the Third World context in which the GIS operates. This lack of information, rather than the technology itself, is a major limiting factor to the more rapid acceptance of GIS within the development and conservation arena.

Three general principles emerge from the Maputaland GIS:
1. GIS provides the technical capability to answer "What if?" questions.
2. GIS potentially offers a means for promoting holistic planning and conflict resolution.
3. The serious lack of data in Third World situations hampers strategic planning.

The lack of vital data (the demographic data, although good by African standards, is still very inadequate) is an issue which faces development initiatives in most Third World countries. It is essential that this issue is addressed in setting up GIS. This means that one will have to:

(i) cost in the expense of data collection above and beyond data capture,
(ii) learn to use surrogate variables,
(iii) develop modelling tools which will enable one to use auxiliary variables to extend and map expensive or patchy spatial data sets.

Resource Management in the Alpine Zone of Lesotho
Lesotho, with an area of over 30 000 km2 and a population of 1.3 million, is an independent landlocked country. Nine tenths of the country consists of highlands with peaks such as Thabona Nylenyana rising in excess of 3550 m.

The ambitious Lesotho Highlands Water Project (L.H.W.P.), a complex of dams and tunnels to store and transfer water as well as generate electricity, has been welcomed with great optimism because of its ability to generate employment and provide a much-needed injection to the Mountain Kingdom's economy. The L.H.W.P. is situated downstream of the alpine zone in eastern Lesotho and, because of its proximity to the industrial complex of the Witwatersrand area, will have an assured market for its water into the Twenty-First century.

The GIS was set up by the Institute as part of a project to provide policy guidelines for the Lesotho Government for managing part of the eastern highland or alpine region of Lesotho. Management for this region was seen as vital because of its fragile nature, the pressure on it from pastoral activities, the concomitant threat of soil erosion, and its role as a water resource area for the L.H.W.P.

The GIS was to provide a single geographic data base in which the programme co-ordinators draw together the results from numerous sub-projects concerned with the human use, hydrology and vegetation of the project area.

The GIS also had to be designed in such a way that it could be readily transposed into Lesotho and function as a long-term system for updating, maintaining and analysing data within the system by Lesotho. Training of Lesotho personnel was undertaken from the project's inception and added a further dimension to work undertaken.

To date, the initial system has been set in place and the incorporation of geo-referenced material from sub-projects successfully assimilated. However, in reviewing the draft policy statement to the Lesotho Government (Government of the Kingdom of Lesotho 1989), it is evident that GIS has not been fully institutionalised within the proposed strategic decision support system (DSS).

Given the pioneering nature of the overall study, the co-ordinators, understandably, failed to identify the comprehensive role GIS should have played in the DSS. A major problem, as many other case studies have revealed, is that the GIS remained technology-driven rather than user-driven.

A further principle emerges from the Lesotho work: GIS must be an integral part of the DSS from the outset of a
study. In this case, GIS still functioned as an 'add-on' co-ordinator of data. Figure 1 illustrates the GIS as an 'add-on' in which the data are problem specific.

\[
\begin{align*}
\text{DATA 1} & \quad \text{PROBLEM 1} & \quad \text{DATA 2} & \quad \text{PROBLEM 2} \\
\downarrow & & \downarrow & \downarrow \\
\text{GIS AS AN ADD-ON} & & \text{DSS} & \\
\end{align*}
\]

Figure 1. GIS as an Add-on. (After Piper, S. 1990.)

A preferable concept is shown in Figure 2, in which GIS is an integral part of the DSS, and problem-independent data are used by many problems and integrated into the DSS.

\[
\begin{align*}
\text{DATA 1} & \quad \text{DATA 2} \\
\downarrow & \quad \downarrow \\
\text{GIS} & \\
\downarrow & \quad \downarrow \\
\text{PROBLEM A} & \quad \text{PROBLEM B} \\
\end{align*}
\]

DSS

Figure 2. GIS as integral to the DSS. (Ibid.)

Fortunately, the merits of the Lesotho system, with its ability to model alternative scenarios with the existing data, has continued to receive support from key organisations within Lesotho, particularly the Range Management Division of the Department of Agriculture. A training programme is in force and there is every opportunity that the DSS for range management will continue with GIS as the driving technology. Furthermore, the long term possibility to link the alpine work with that of the L.H.W.P. remains a possibility. The possibility to develop a regional computer networking system for management is an envisaged goal.

Assessment and Conclusion

GIS technology is in its infancy in southern Africa. There is little doubt that as the scarcity of natural resources become more apparent and demand rises, managers of those resources will need to improve their access to and manipulation of environmental data.

Furthermore, from a development perspective, the urgent need to improve or maintain living standards will require current information and the ability to consider the likely impacts of alternative development strategies.

The studies reported on in this paper continue to reflect, in part, the anecdotal rather than analytical and the particular rather than the general approach (Wellar, 1989) to furthering knowledge of GIS. However, knowledge will always be furthered by intuition, common sense and everyday experience as well as through the establishment of principled research.

There is, however, no doubt that the attainment of a robust and rich GIS knowledge base will only emerge if more philosophical rigour accompanies particular GIS developments. As such, the notions of conceptual modelling depicted by Williamson and Hunter (1989) have considerable merit.

The area of institutional commitment to GIS remains a serious problem as these case studies show. An important initiative at the Institute, the creation of a Rural Areas Water Plan (RAWP) for a major proportion of the Natal region, will address forcibly to modelling procedures identified by Williamson and Hunter (1989).

The grave shortage of technical, managerial and subject-specific skills will continue to haunt the successful implementation of GIS in southern Africa. A possible solution exists, in the case of projects undertaken by the Institute, of providing both conceptual and technical backup to local GIS development initiatives. To this end, the work in the programme has been divided as follows:

(i) project conceptualization, problem definition and system design,
(ii) training,
(iii) data capture.

Such liaison suggests a route of distributed production and processing which will make the best use of limited personnel skills.

Dangermond (1988) has suggested three goals for a GIS:

(i) to increase productivity,
(ii) to better manage data and avoid duplication of effort, and
(iii) to facilitate effective planning.

While the first generation of projects discussed in this paper have had limited success in achieving these goals, they have provided insights into important problem areas. Greater philosophical rigour and a stronger adherence to establishing the principles governing successful GIS implementation will mark the next generation of Institute-related GIS work.

Acknowledgements

The authors wish to thank Steven Piper, Department of Surveying and Mapping, University of Natal, for his criticism of the manuscript and to Norma Tucker for typing the draft and final MS.

References


The Use of GIS in the Resolution of Land Use Conflicts in Tasmania

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Abstract
The acceptance of the recent nomination of twenty percent of the State of Tasmania, Australia for inclusion in the World Heritage List, brings to a culmination many years of debate over land-use.

This paper describes the use of a Geographic Information System by the Forestry Commission, Tasmania to examine resource and environmental values to formulate land-use decisions. These decisions are largely reflected in the selected World Heritage boundaries.
Introduction
Tasmania is the smallest state of the Commonwealth of Australia, with an area of 6.8 million ha, and a population of approximately 450 000 people. Nearly 50% of the State is covered with forest of which three quarters is publicly owned. Forests are mostly native eucalypt. They include the tallest hardwood trees in the world. Ten per cent of the State is covered by cool temperate rainforest. There are small areas of exotic softwood plantations of mainly radiata pine.

Forest industries in Tasmania are worth $1 billion to the economy and directly employ 5.5% of the workforce. Tasmania is the largest contributor by volume to national forest production from 9% of the nation’s forest area.

A significant part (20%) of Tasmania is inscribed on the World Heritage List. The Tasmanian Wilderness World Heritage Area of 1 374 000 ha. was accepted in 1989 due to its outstanding cultural and natural values. Most of the World Heritage Area is or will be declared a National Park resulting in a total area of reserved land managed by the State’s park service of 2 200 000 ha (32% of Tasmania). Figure 1 shows Crown land tenure in Tasmania.

The listing of the World Heritage Area brings to a culmination many years of debate over land-use in the western part of the State. Much of the land was previously State forest or other public lands on which the considerable forest and mineral resources of the area were available for utilisation.

This paper describes the background to environmental debate on land use in the region and how a geographic information system was used to evaluate the impact of different options for wood production and land preservation on that part known as the Southern Forests.

The Southern Forests
The Southern Forests region of Tasmania is an elongated strip of land about 20 km wide and 85 km long in the central and southern part of the state lying between the infertile Precambrian quartzite mountains of the west and the drier settled agricultural areas of the east. The area of land to the west of the Southern Forests planning area is part of the Southwest National Park. Figure 2 shows the location of the Southern Forests planning area.

It is characterised by a rugged topography, high rainfall (1000-3000mm) and diversity of vegetation. The tallest stands of hardwood in the world grow here, notably Eucalyptus regnans which has been recorded to grow to almost 100 metres.

Since European settlement of Tasmania in 1803, the Southern Forests have been a major focus for the island’s development, through the exploitation of the forest resources.

The Southern Forests continue to be an important source of timber supplying many sawmills, a newsprint mill, a pulp mill and two export woodchip plants.

The Southern Forests also contain many significant natural and cultural resources some of which are not compatible with wood production uses. In particular, the preservation of remaining areas of oldgrowth tall eucalypt forests and the maintenance of existing wilderness quality and quantity are highly valued aims of the conservation movement (Harwood and Kirkpatrick 1980, Ziegler 1983). Southwest Tasmania’s wilderness areas are one of only three large temperate wilderness areas remaining in the Southern Hemisphere.

Land Use and Management in Tasmania
Use of Crown land in Tasmania is decided by State Parliament through Acts of Parliament. There is no land-use authority to examine competing claims for land use.

State forests are Crown lands managed by the Forestry Commission, Tasmania under the Forestry Act 1920. Primarily, the Commission is charged with management for a sustainable supply of wood to industry, but practices multiple-use management for the conservation of flora, fauna, recreational, scenic and other environmental values.

The Commission is responsible for the planning for management of all land under its control. It does this formally
through a Working Plan which specifies the area and volumes of timber to be harvested over a period of time, and for some areas through a Forest Management Plan which specifies which parts of a Planning area are to be used for various purposes and how they are to be managed. The later plan is required to follow a public and interdepartmental comment process.

Land Use Planning and Conflict in the Southern Forests
Most of the Southern Forests were dedicated as State forests in the 1920's. Significant parts of the area to the west of the Southern Forests were declared National Parks in the 1960's and 1970's. These parks were part of the 1982 World Heritage Nomination in Tasmania.

Although the parks protected many important values and features, there were significant areas of high conservation and recreational value excluded, as they were within State forest. Of particular note were areas of high wilderness value and significant unlogged stands of tall eucalypt oldgrowth forest. Representation of these forest types in the existing State Reserve System was low (Forestry Commission 1987, Kirkpatrick et al 1988).

Listing of these forests on the Register of the National Estate by the Australian Heritage Commission and the listing of the adjacent National Parks on the World Heritage List in 1982 plus a growing focus by the conservation movement on protection of remaining wilderness areas and National Estate forests led to the need for a detailed evaluation of the areas resources and plans for future management.

The Forestry Commission’s Geographic Information System
The Forestry Commission began investigating the acquisition of a computerised GIS in 1982 in response to a need for more powerful techniques to store, update and analyze the ever increasing natural resource data it was gathering.

The Commission purchased the ARCINFO software from Environmental Systems Research Institute in late 1984 and currently runs the software on two PRIME 4050 minicomputers, each with 16 megabytes of CPU. Disk storage is currently 2.7 gigabytes. There are eight graphics terminals (Tektronix 4200 series), six digitizing tables and three plotters. In addition there are ten microcomputers with Tektronix emulation and more than 30 text only terminals all connected through an Ethernet network (Fenn and Weston 1989).

GIS use in Planning for the Southern Forests
The first major project for which the Commission's GIS was used was the production of a new Forest Management Plan for the Southern Forests. This area provided a complex array of overlapping resource and environmental values.

The planning method involved
1. Selection of land uses to be evaluated
   Evaluation of non-wood use was limited to those that were seen to be incompatible to some degree with wood production. This greatly reduced the cost of data collection and simplified analysis and presentation.

Four uses evaluated were:
• wilderness
• landscape
• flora conservation
• recreation

2. Selection of the Land Unit for Evaluation
The basic logging unit (coupe) was chosen as the land unit for comparison of wood and environmental values. This enabled the outcome of the planning process to be directly related to operational boundaries in the field.

Definition of future coupe boundaries enabled the ready identification of areas not practicable to be harvested at an early stage, thereby further simplifying the evaluation.

Areas already developed for wood production were also identified at this stage and removed from further consideration.

In this way the total planning area of 165 000 ha was reduced to an area of 32 000 ha which has undeveloped potential wood production value.

3. Resource Evaluation
Each of the 342 provisional coupes within the conflict area was allocated a wood value and a non-wood value on a ranking of 1-4.

Wood values resulted from
• estimated recoverable volume
• estimated site potential
• roading cost
• topography and harvesting difficulty

Volume and site potential were derived from digital forest-type maps which record species, height and stand density classes interpreted from aerial photographs.

Non-wood values were derived from previously prepared manual maps resulting from detailed studies of:
• wilderness - derived from estimates of remoteness and naturalness of the coupe and the impact of harvesting the coupe on adjacent areas of high remoteness and/or naturalness.
• landscape - derived from evaluation of whether the coupe could be seen from remote viewpoints within the recognised adjacent wilderness area, and whether the view is part of a natural or non-modified viewshed (Chetwynd 1989).
• flora conservation - derived from information on occurrence of rare species, whether the coupe forms part of a flora conservation proposal or whether harvesting would pose a risk to nearby fire sensitive communities (Williams 1987).
There was much public concern over the extension of new roads into the Farmhouse Creek and East Picton areas, approved under previous management plans (Forestry Commission 1983, 1995).

A major Environmental Impact Study on the export woodchip forest industry was conducted in 1985 (TWE Study Group 1985) which lead to a Memorandum of Understanding (MOU) between the State and Federal Governments over logging in various National Estate areas.

The MOU allowed the planned logging to go ahead, subject to protection of National Estate values. However, conservationists staged a series of protests in the forests which received national media coverage. They continued to press for fundamental changes in forest land use (Rolley 1989). Responding to this pressure, the Federal Government, facing an election in which the green vote was crucial, set up a new legislative initiative, The Lemonthyme and Southern Forest Inquiry Act 1987. The Act halted all forest operations in a defined area for 12 months while an inquiry was held into whether the area had World Heritage values and whether there were feasible alternatives to harvesting these forests. The Inquiry Area included most of the Southern Forests planning area.

The Inquiry handed down its decision in May 1988 recommending that only 10% of the inquiry area had World Heritage values (DASET 1988). This was unacceptable to the conservation movement and politically unacceptable to the Federal Government, who in November 1988 negotiated an agreement with the State Government to nominate 71% of the Inquiry area for World Heritage in return for financial compensation.

In most part the boundaries of the additional World Heritage Area in the Southern Forests followed the limit to logging line determined by the Forestry Commission's planners. In other parts of the Inquiry area, where similar planning work had not been carried out, substantial areas of planned wood production forest were included and some difficult management boundaries resulted.

Throughout this political process which took several months of negotiation and involved Federal Cabinet in many days of heated debate, the value of the Commission's investment in the GIS was apparent.

Federal and State politicians and bureaucrats asked frequent and often complex questions over the area, timber resource, wilderness and tall forest values of particular pieces of ground, in an attempt to resolve the debate with minimal impact on the resource available to forest industry and hence jobs. The GIS enabled relatively rapid and accurate responses to be made.

The result was a boundary that was for the most part manageable and preserved significant environmental values. Resource loss overall was about 9% of the State's sustainable yield of sawlogs. Within the Southern Forest net resource loss was lower.

4. Analysis of Options

A series of GIS generated maps were presented to managers indicating different boundaries separating wood production areas from non-wood production areas, and the potential impact on available wood resource and loss of environmental values.

5. Decision

Senior management used the options to derive a 'limit to logging' line for the Southern Forests. A draft Forest Management Plan was then prepared for public comment. Proposed management zones are shown in Figure 2. Details of the planning process are described in Ingles and Wood (1987).

Lemonthyme and Southern Forests Inquiry

Whilst the planning process described above was going on, timber harvesting in the Southern Forests was continuing.

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The World Heritage Nomination
The recent nomination of the Tasmanian Wilderness World Heritage (1989) area was even larger than the November 1988 proposal. This was due to a change in Government in Tasmania from the pro-development conservative Liberal Government to a Labor-Green Independents alliance who came to power in June 1989 with an Accord which included additional World Heritage Area nominations. Again, areas added in the Southern Forests were consistent with the Commission's planning options. (See Figure 2)

Most of the defined non-wood zone in the draft Forest Management Plan has become part of the World Heritage Area, leaving the Forestry Commission to manage the State Forest wood production zones.

Conclusion
The Forestry Commission's purchase of a GIS has enabled forest and land-use planning to be conducted at a level of sophistication not previously possible. Complex sets of data have been able to be efficiently used to present clear information to managers.

The Commission's use of GIS reports and maps during a public and legalistic inquiry into land-use considerably enhanced the public and professional image of the Commission.

Data capture is being extended statewide to enable similar planning exercises to be conducted.

As a consequence of the Commission's lead, other agencies and private companies are seeking GIS advice, assistance and data from the Commission.

The use of the GIS by the Commission was recognised by the awarding of the 1988 Australian Government Technology and Productivity Gold Award.

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The Global Forest Inventory: Measurements using Satellite Imagery and Geographic Information Systems in Amazonian Forests

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Extended Abstract
Forests are secondary only to the oceans as an earthly force influencing climate and the human habitat. The area of forests globally has declined almost continuously with the expansion of the human population. The destruction continues with the present surge in human numbers. The effects are measured in the accelerated accumulation of carbon dioxide and methane in the atmosphere, the rapid loss of species from once-rich terrestrial habitats, in the accelerated impoverishment of large areas cleared of forests but incapable of supporting sustained agriculture, and in changes in the abundance and quality of water in streams. These transitions are currently common in the tropics, but are also occurring in the middle and higher latitudes of both hemispheres as human influences continue to spread.

Contemporary data defining the dimensions of forests, especially their distribution and area, changes in area, their stature, productivity, and carbon content are now clearly fundamental to appraisals of both the causes and effects of the warming of the earth, to efforts at protecting the diversity of life, and to regional and, now global, efforts at stabilizing climate.

We have explored techniques for using satellite imagery with geographic information systems for appraising changes in the area of forests in both temperate and tropical zones. The higher resolution satellite data such as TM and SPOT can be used with high fidelity to recognize and distinguish forest and non-forest, usually without visiting the site on the ground. The low resolution data such as those from NOAA AVHRR LAC offer much uncertainty in this classification. Where this classification has been established with accuracy, estimates of deforestation are commonly exaggerated.

The compromise between economy and accuracy argues for a combination of the higher and lower resolution imagery in a sampling system. Such as system is being applied in the Amazon Basin.

The importance of such data in the evolution of international management of the biosphere is difficult to exaggerate. One of the most constructive steps that the US might take at the moment would be to make imagery from these satellites available cheaply around the world and to encourage use of the imagery not only in appraising the current status of forests but also the patterns of land use. Such data are now potentially available globally and are fundamental to the challenge of managing the global commons of air, water and land.
Global Perspectives

Session E5
Global Perspectives - 2

The Ecological Consequences of Land Use Change

GIS for Sustainable Development in the Nordic Countries - Case Studies from Norway

The Lands System - A Land Analysis and Decision Support System
The Ecological Consequences of Land Use Change

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Abstract
One of the functions of the Institute of Terrestrial Ecology (ITE) as a research institute within the Natural Environment Research Council (NERC) is to define the effects of changes in land use on ecology and the environment within the United Kingdom (UK). An essential part of ITE's role is to assess the implications of past, present and future national and international policies on the terrestrial environment. Information about the consequences of land use change is required by many organizations including all types of land user, government agencies and parliamentary committees. As the results of ITE's studies are sometimes required to be applied at a national level, there is an obvious need for a system which can manipulate and present ecological and environmental information in a geographical format. The solution currently being employed is the use of a stratification of 1 km squares which allows surveyed information to be collected in detail and analysed at national and regional levels.
Introduction
Much of the information which is required to assess the consequences of policy change on the environment is impossible to census completely at a national level. So, in 1975, ITE established a classification of land in Great Britain (GB) as a basis for stratified sampling for a national survey of vegetation and land use. The system has been used in many subsequent national and regional studies, including ecological surveys of GB in 1978 and 1984; it is proposed to carry out a re-survey in 1990. There are several benefits in the application of a stratification to surveys, especially if the features of interest are correlated to the variables upon which the classification is based.

The aim of this document is to review the ITE approach describing the classification, its application and analysis using Geographical Information Systems (GIS). The paper is divided into 3 sections,
1. the ITE Merlewood Land Classification,
2. field survey,
3. manipulation and analysis involving GIS

1. The ITE Merlewood Land Classification
The decisions taken during the creation of the land classification were made during the mid-1970s prior to the major expansion in the use of multivariate classification techniques, and at a time when computers were less powerful than now. It is therefore useful to provide the historical summary of the context in which decisions were made so that their consequences can be fully understood.

The requirement in 1975 was to provide information on the distribution and total area of main vegetation types and land uses. Complete census of most UK environmental parameters was not possible then and is still not practical today. ITE recognized the need for a system which could provide a description of the land types in GB as a sampling framework for field surveys. The system needed to reconcile the requirements for detailed ecological assessment, within the limits of resources for survey. The system had to be flexible, handle a range of ecological parameters, produce statistics at national and regional levels and, above all, be objective.

It became clear that a sampling strategy would have to be devised. The approach adopted was analogous to that used in the production of opinion polls, in which the population is divided into predetermined social strata from which samples are drawn. The strata, in the present situation, were defined by environmental characteristics and were subsequently sampled for a variety of ecological purposes. The techniques had been developed and tested in regional studies in the Lake District (Bunce et al., 1975) and then more widely in Cumbria (Bunce et al., 1978).

The system of classification and survey was based on the grid defined by the Ordnance Survey with each sample unit being 1 km square. The intention was to provide a convenient base suitable for field survey which was readily referenced by map and consistent over the whole country. There are, therefore, two types of application: first, to provide assistance in deciding where sampling information should be obtained (section ii describes the field survey); and second, to convey information about the probable characteristics of an area which has not been subject to field sampling.

The principle behind the land classification is that the major significant ecological variables are associated with environmental variables (e.g., altitude) which can be recorded from existing cartographic sources. A regular sampling grid of 15 km x 15 km was placed over maps of GB and information recorded for each 1 km square which occurred at the intersections of the grid. This produced a systematic sample of 1228 1 km squares. Environmental parameters of 4 types were recorded for each 1 km square.

1. Climate
2. Topography
3. Human geography
4. Geology and drift

The approach was to include as many variables as possible in an attempt to remove bias due to selection, with limitation of availability from existing maps. A total of 47 environmental variables (e.g., altitude) were recorded; these were divided into 188 attributes by division into 4 equal categories. A further 93 attributes (e.g., geological formations) were also recorded giving a total of 281 attributes overall. The analysis was carried out using Indicator Species Analysis (ISA) (Hill et al., 1975), from which Twinspan has subsequently been developed.

The classification was stopped after 5 levels of division, which produced 32 groups, termed land classes. ISA works first by ordering the records (in this case the 1 km square) according to the attributes present and absent and then dividing them into two groups. Each group is then successively ordered and divided further, the classification method being as polythetic, hierarchical and divisive. The technique identifies the attributes upon which the divisions are based (indicator attributes). The indicator attributes can then be used as a key to identify the land class of any further 1 km square (Barr et al., 1989) with 76 attributes being identified from the initial 281 as indicators of land class. These indicator attributes were then recorded for the 4 x 1 km squares offset by 3 x 1 km squares on the diagonals from the corners of each of the original 1228 x 1 km squares. This provided a further sample of 4800, allowing for those falling in the sea, on an almost even grid of squares. The land class of these squares was then identified using the key. When combined with the initial 1228 1 km squares, a total of 6028 1 km squares been identified by land class, a sample of approximately 1.45 (the deficit being those that fell entirely in the sea) of the 1 km squares in GB (Figure 1).

Every 1 km square in GB (approximately 233 000) has been identified to land class using the discriminant analysis on a reduced number of variables. This has produced approximately 45% agreement with the original classification, which is being repeated (using Twinspan) on as near to the original dataset as possible.

The land classes show well-defined geographical distributions which can be interpreted in terms of combinations of
II. Field Survey

The classification has been used as the basis for 2 major national surveys. In 1978, 8 km x 1 km squares were drawn at random from each of the 32 land classes from the 1228 squares (i.e., a total of 256 squares) of the initial analysis carried out in 1977 (the additional squares were not available until 1979). Each 1 km square was visited and the land use of each parcel and dominant vegetation was recorded. The vegetation was sampled in more detail by sampling with 200 m² quadrats and linear quadrats. Information on soil was recorded and sampled at the quadrat sites and livestock types and woodland types recorded. A summary of the land use and land cover information from the 1978 survey is given by Bunce & Heal (1984).

In 1984, the same 256 x 1 km squares were revisited, but the sample size was increased by drawing a further 4 x 1 km squares from each class (i.e., 384 x 1 km squares in total, Figure 2). The aims of the second survey were (1) to detect change from 1978 (2) to improve the characterization of the strata, (3) to collect more detailed information about land use and cover in each square. The quadrat and soil information (items i-iii in the list above) were not repeated. The information was recorded by marking the actual areas, or lengths of linear features on each of 5 maps, namely:
Some of the major changes recorded between the 1978 and 1984 surveys were presented in Barr et al. (1986). Further analyses are in progress.

The field data recorded for each land class is combined together with the cartographic environmental information to provide detailed descriptions of the land classes (Bunce et al., 1981 and Benefield et al., 1982). The 6028 1 km squares classified by land class enabled the estimation of the total number of squares in each land class in the whole of GB. The procedure involves an error term for each class of up to 0.7% of the total number of 1 km squares in GB (233 775). These errors will be removed when the complete coverage of GB is available (Section 3.1). The land class sample mean for a given land cover type is multiplied by the estimated number of squares in order to obtain estimates of land cover types of that land class found in GB. A national total can be produced by summing the areas for each land class. The formulae for error estimation are provided by Cochran, (1968) equations 5.1, 5.10 and 5.11.

It is also possible to predict the amount and distribution for regions within GB, by using the area of each land class within the region, rather than the national totals. Such a procedure is analogous to use of regression relationships to predict other members of a population.

The variables used to create the land classification were those readily available in cartographic form and define the main physical features of GB. Soil type was not included because, firstly, the information was neither even in quality nor available in sufficient detail in 1975 and, secondly, one of the initial objectives was to obtain independent soil data included in the field surveyed information.

Since the production of the classification, more generalized soil information has become available, in particular the soil maps at a scale of 1:250 000. Resources have not been available for the incorporation of the complete digitized soil map into the land class definitions, but it is hoped that such soil map data will shortly be incorporated in order to improve the definition of the characteristics of the land classes.

The figures published by MAFF and DAFS provide a convenient test of the sampling system and the estimates agree reasonably with them, particularly for crops with large areas. For example, the DAFS/MAFF figure for wheat (1978) was 1.16 x 106 ha, whereas the land classification figure was 1.11 x 106 ha, and for barley were 2.31 x 105 ha and 2.19 x 106 ha respectively. A complete table is given by Bunce et al., (1981). Other published data show similar patterns of comparability with estimates from the land classification. The area of increase urban land was estimated by Best (1976) at 148 km squares/year, whereas a trial study using the classification suggested that it continued at an average rate of 148 km squares/year between 1971 and 1981. A third example results from the MAFF study of improvable land carried out in 1980 in the north of England. Measurements were made of the area of Agricultural Land Classification (ALC) grades 4 and 5 for the entire region during the study and were subsequently repeated using a sample number of squares drawn from the land classification procedure. From the ALC map the proportions of land graded 4 and 5 were 31.0% and 15.6% respectively, and from the land classification 26.1% and 15.7%.

Various types of correlation analyses can be carried out to test the overall links between the environmental classification and the various sets of survey data. For example, the mean value of the first reciprocal averaging ordination axis of the initial environmental data used by ISA to produce the first division in the land classification was calculated for each land class. Principal component analysis was used to extract component values from the matrix provided by the mean values of the areas of the land use in the sample squares from each of the 32 land classes. Similarly, component values were extracted from the mean proportions of each soil group in each of the 32 classes. The correlation coefficients from the mean axis scores from the land classification were 0.823 with the first component of the land use data and 0.923 with the first component of the soils data (P<0.001, 30 of in both cases). The procedure followed is comparable with that described by Fourt et al., (1971) and demonstrates the high correlations present between the analysis of map data and subsequent field survey.

III. The Application of GIS Techniques

The data is all identified by 1 km square grid references, but the analysis and presentation are effectively at two resolutions; first, where the 1 km square is the complete domain and second, where GB is described as a raster image composed of 1 km square pixels. Surveyed information has all been digitized and is manipulated in vector form. Initially, the requirement was to produce estimates of areas and lengths of features, which could then be presented as land class means and applied to the national distribution to produce totals for GB. The analysis has been performed on a variety of systems, but now would be done in ARC/INFO or Laser-scan.

We are concerned about the error terms within the process, which we are not currently estimating; these include the accuracy of the original Ordnance Survey map, the accuracy of the field recorder, the accuracy of the digitizing and the accuracy of the different systems upon which the work has been carried out. There is a common belief that census data, expressed without error terms, is totally accurate; it may be that the deviations are negligible but they must be recognized and assessed.

The surveyed squares have also been examined in desk top studies to identify potential changes; for example, the land available for forestry was identified under different economic scenarios by comparing the profitability and suitability of every parcel to different forestry and agricultural
managements. The potential for different agriculture is also being modeled using a linear program built around the land classes of Harvey et al. (1966).

More recently we have been investigating the differences in pattern recorded in different land classes. This has involved a number of measurements, ranging from descriptions of populations of parcels (eg, size and perimeter), through measures of relationship of different parcels to position in space. The scale of pattern is being investigated using a two term local quadrat variance method (Hill 1973).

One of the strengths of the ARC/INFO system is that it allows predictions made for individual 1 km squares to be overlaid and predictions of the gross interaction to be made, rather than producing population estimates which will only allow net differences to be assessed. Ecologically, the gross management of the environment may be far more important than the population totals.

The other style of data for manipulation is a large raster dataset describing the whole of GB. The data are held as a complete raster in an ORACLE database, although for some variables (such as land class) a quadtree or run length system would be more efficient. Maps are produced using a Graftix system written by NERC Computer Services, which is GKS-based; analyses are produced using a variety of packages including SAS. The information held includes that on which the classification is based and Ordnance Survey data describing towns, villages, woodlands, roads etc. The information has been combined in a study to identify the potential for wind energy, which identifies unsuitable squares from data such as the human geography and designated constraints (eg National Parks) and overlays the information with the predictions of the mean number of turbines which could be built in each land class. The mean number of turbines was identified by visually assessing the 384 1 km squares, although a software solution would now be possible (Figure 3).

In summary, the classification was produced initially as a structure to direct field surveys. It was designed to be an ecological and environmental classification; accepting that there will be many features for which it is not the optimal solution. One of the main problems the system avoids is the expense of the production of absolute census data and it has the advantage of allowing the sampling error to be assessed. The system has been extended to be used as a modeling framework, allowing both expert opinion and calculated predictions to be applied to Great Britain.

References


GIS for Sustainable Development in the Nordic Countries - Case Studies from Norway

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Abstract
There is a strong tradition of mapping for land use planning in the Nordic countries, but use of GIS for sustainable development must be said to be in the starting phase. This application is expected to undergo dramatic development in the 1990's.

Five case studies from Norway are presented. Case A describes development of a GIS with natural resource data for use by agriculturalists, foresters and other professionals over the entire country. Case B discusses cooperation between 8 townships to develop a GIS with environmental data for use in land and developmental analyses in the area. Case C gives examples of use of the GIS in environmental planning in a township and a county. Case D discusses research and development work to combine raster and vector data in mapping and management of vegetation and other land resources. Case E considers image analysis of digitized colour infrared aerial photos to document tree damage in parks and productive forest.

The oral presentation is illustrated with colour slides.
Introduction

There is a long and strong tradition of mapping for land use planning and use of natural resources in the Nordic countries (Denmark, Finland, Iceland, Norway and Sweden). At the end of the 1960's, digital map production methods were introduced and gained increasing importance throughout Scandinavia in the 1970's and 80's. The last few years have witnessed an accelerating growth in the use of geographic information systems (GIS) in physical planning, mapping of natural resources, planning in forestry, and work with other environmental data. It is probable that all of the approximately 1500 townships in Scandinavia will in the course of the 1990's introduce GIS as a tool for increased effectiveness, improved analysis and presentation, and increased public participation in physical planning.

Seen in this perspective, Scandinavia is in the initial phases of using of GIS technology. Even though large national systems are being planned and established, routine use of GIS connected with efforts for a more sustainable development is still very limited, and the activity may often be characterized as developmental work. The first Nordic conference on the use of GIS, held in Norway in November 1989, however, showed that many users are now about to take the step from developmental projects to operative use of GIS. This also applies to applications of direct relevance for sustainable development.

The case studies presented here are chosen somewhat arbitrarily, but should give participants at GIS'90 some insight into the "state of the art" in Norway. The examples are reasonably representative for the rest of Scandinavia as well. The oral presentation is accompanied by colour illustrations slides. For technical reasons, none of these are reproduced in this paper.

Figure 1 shows the geographic location of the case studies presented.

Case A
Geographic Information System for Natural Resource Data at the Norwegian Institute of Land Inventory (NIJOS). Users: Foresters, Agriculturalists and other Professionals Over the Entire Country.

NIJOS is a publicly-funded institute operating over the entire country. The Institute's main endeavor over the last 20 years has been the mapping of the natural resource bases for production for agriculture and forestry in Norway. These data are presented on "Economic map of Norway" at original scale 1:5 000. Approximately 200 000 sq. km. are mapped. This corresponds to the presumed productive area under the forest limit, plus some of the area over forest limit. The remaining 124 000 sq. km. of mainland Norway are primarily mountain plateaus and glaciers.

A digital soils register for Norway was begun as early as 1975. This register was not linked to maps, and could only give users standard data printouts sorting the land area information by administrative units, owner and user boundaries of properties, altitude, etc.

NIJOS has now undertaken the development, operation, and maintenance of a GIS for soil, forest and vegetation resources. The strategy is that NIJOS, by building up a GIS for these natural resource data, will encourage multiple use of the data, with distribution primarily by network. In addition to a series of standard graphical and numeric products, NIJOS will also be able to "tailor-make," on order, using a flexible report generator, various user-adapted products. One can consider here, for example, thematic maps that can contribute to better planning aimed at reducing pollution from agriculture. After the "algal catastrophe" in the North Sea in the summer of 1988, this problem has received increasing attention in Scandinavia. As examples, we will look at some of the products this can lead to.

The basis map is the Economic Map. This is supplemented with more detailed data on soil types. A soil type is defined by physical, chemical and climatic criteria, and represents a relatively homogeneous area with respect to the most important environmental factors for plant cultivation, and therefore, also a certain yield potential. At least one soil profile within each type distinguished is described in detail. The soil type map is therefore a very detailed map, presented in the original scale 1:5 000.

For farmers and planners in general, the original material will be difficult to access or unavailable. The data base contains, however, a multitude of possibilities for producing simplified, "management-oriented" thematic maps of, for example, drainage requirements, irrigation requirements, suitability for various cultivars, fertilizer requirements for various cultivars, erosion susceptibility, likelihood of phosphorus runoff, etc... Figure 2 shows some examples of such products.

Corresponding models will be developed for various kinds of forest use, and existing models for production of derived thematic maps from maps of natural vegetation based on ecology/plant sociology will be adapted to the possibilities offered by GIS. This has the potential to eventually become a very important data base for practical use in planning for a sustainable development.

Case B

Nidar group is an inter-township association in the Arendal area. Six townships cooperate through it to resolve social issues where there is agreement that the boundaries of each township give a too-restrictive geographical framework for resolution of the problem. The Environmental Data Project is one such cooperative task. Participants include, in addition to the Nidar group, the Geodatansenter in Arendal, the County Mapping Authority in Aust-Agder, VIAK a/s, and the County Environmental Protection Office of Aust-Agder. As in Case C, the project is part of a comprehensive national program to strengthen environmental protection work at the township level.

Nidar group has decided to prepare a land and development analysis to clarify and prioritize land uses for the near
future. This is necessary because of increasing land pressure and resulting conflicts regarding land use.

The base map and contents of the plan are established in a GIS at the Geodatasenter. Nidar group uses digital base maps with water contours, road net, and administrative boundaries. Environmental data are extracted from plan documents in the six townships and adapted for coordinated analysis and presentation. Necessary supplemental environmental data are entered in the property database for use in the analysis work.

On the basis of digital map information and associated property databases, various thematic maps, graphics and statistics are produced for use during the planning process and for public information and participation.

All data compiled in the Environmental Data Project are immediately available for viewing on a terminal or as plotter printouts through menus in the information system. Using ARCINFO, portions of the data contents can be sorted and presented by desired parameters.

Nidar group's conclusions after completion of the pilot stage of the project are:

1. GIS methodology is regarded as clearly superior to the former, more traditional working methods using analog maps and EDB registers. Some of the reasons for this are:
   - Plan changes can be visualized immediately,
   - Maps and graphics/statistics for use during the planning process can be produced in small numbers at a very competitive price,
   - "Management-related" thematic maps can easily be derived, for example, bus routes/recreational areas, habitation/containers for glass recycling, bathing areas/bathing water quality, sewage network/placement of unconnected buildings, etc.

2. The project has also shown that more work is needed in some areas, for example:
   - Ownership rights to data,
   - Maintenance routines,
   - Classification of sensitive data (limited access),
   - Spread of unauthorized data.

Figure 3 shows examples of material from Nidar group's GIS.

**Case C**

**Use of GIS in Planning at the Township and County Level in Vestfold County.**

1) Adoption and presentation of thematic maps for township plans in Notterøy township, Vestfold. Notterøy township is part of the pilot project for development of maps and geodata relevant to environmental planning in townships. In connection with this project, the County Mapping Authority in Vestfold made map databases of areas that were protected or warrant protection, (recreational areas, etc.). The Institute for Environmental Analysis had previously made a digital-based map of wildlife regions for the entire county, and the Notterøy portion of this was used. All maps were digitized from manuscripts at a scale of 1:10 000. During the digitization, good possibilities for thematic separation and coupling to register data were incorporated. The map material is processed in ARCINFO and can be presented as plotter printouts or colour scans for printing in larger numbers. Figure 4 shows examples of thematic maps produced for use as posters with information about the work in Notterøy, and at a smaller scale, as maps appended to the land use portion of the township plan.

According to the environmental protection consultant in Notterøy township, the map material has had an important function in the planning process with regard to public information and participation. Work is now underway for the township itself to install programs to use GIS in planning.

2) Evaluation of the coastal area in Vestfold county with regard to raising fish and shellfish. The LENKA project covers the entire Norwegian coast, and aims to give a better basis for correct use of resources in this important zone. A wide range of data are mapped, including appropriate use of the areas, release of waste water and other forms of pollution, existing protected areas, etc. Digital maps with coupled property databases have been prepared. The material is used both for public information and as a basis for evaluating applications for permits to establish new fish farms. Figure 5 shows examples of cartographic presentation of some of the information.

**Case D**

**Combination of Raster and Vector Data in Mapping Vegetation and Land use in Aust-Agder and Telemark Counties.**

Satellite images from Landsat 5 Thematic Mapper and from SPOT were used in several subprojects for the purpose of mapping vegetation and land use. The work has focused on clarifying what level of detail is possible, given the Norwegian landscape conditions, and in what degree satellite data can supplement mapping based on aerial photography and/or field studies.

The projects were carried out by the Telemark Research Foundation, the Centre for GIS And Remote Sensing a/s and VlAk a/s in cooperation. Base funding was through the Royal Norwegian Council for Scientific and Industrial Research. The Forestry Association of 1950, the Norwegian Forest owners Association, and Bykle and Valle townships have contributed financially. The State Mapping Authority has provided the project with base maps.

As mentioned under Case A, detailed data on the resource base for production in agriculture and forestry exist in the Economic Maps of Norway. In addition, an even more detailed forest survey for planning and management purposes is being carried out by two forest-owner associations, both in large forest properties and by townships in areas having many smaller forest holdings. This mapping is conducted using detailed field work supported by aerial photo-interpretation.
It is improbable that satellite data with a pixel size corresponding to a minimum ground area of 30 x 30 m (TM data), 20 m x 20 m (SPOT) or 10 m x 10 m (SPOT panchromatic data) can replace large-scale aerial photography as the basis for studies at the level of detail desired. But satellite data has the advantage of simultaneous coverage of relatively large areas, and can among other things be used for mapping changes in land use and to give an overview of the main features in distribution of vegetation types and other areal categories. In addition, it provides the possibility of mapping Norway's large mountain areas, that for the most part are only covered by topographic maps at a scale of 1:50 000 or less.

All satellite data are first precision-corrected, that is, made to correspond to existing maps within defined limits of deviation. This allows coupling of the satellite image to topographic base maps or other vector-based information.

Two main types of image analysis are then used: colour-coding with HLS-transformation for visual interpretation, and the so-called cluster technique. Briefly, colour-coding with HLS entails using an algorithm describing colour as hue (H), light intensity (L) and saturation (S) to present the registered spectral signature as a colour image, instead of using the common RGB coding (red, green, blue). This gives improved possibilities for colour coding suitable for visual interpretation.

In clustering, the spectral signatures clustering around a given value are assigned to that value. Each cluster can then be presented with a given colour, preferably such that there is a logical connection between the colours and related vegetation and land area types.

1) The Hovden area was used as a test region for visual interpretation of colour-coded satellite images, partly because we had available a detailed map of vegetation by plant sociological criteria covering an approximately 30 sq. km. area. Boundaries and type codes from this mapping were digitized and processed using ARCLINFO, and a property database with supplementary information about each polygon (each separated areal unit) on the map. We can enter additional information into the property database using dBASE. The digital map and property database provide the basis for producing a number of derived maps, for example, simplified map overviews of main vegetation features, nutrient relations, water source, duration of snow cover, etc., or corresponding statistics, diagrams, etc.

These thematic maps have been used to document areas warranting protection in a nature reserve and parts of a protected landscape region in Hovden. The Environmental Protection Office in Aust-Agder commissioned the mapping.

Information from satellite images can be processed using the image analysis program ERDAS, which is compatible with ARCLINFO, and thereafter combined (using ARCLINFO) with detailed vegetation maps, maps derived from these, etc. We expect that such combinations of raster and vector data will open possibilities for analysis, for example, of variations in the spectral signature of the satellite image and details in the vegetation cover. It also gives new possibilities for presentation of raster - and vector-based data.

Figure 6 shows a photographic combination of vector and raster data. A detailed plant-sociological vegetation map was combined with a precision-corrected, colour-coded section of a SPOT scene. Spectral signatures from land surfaces having certain physiognomic features in common are closely related. An interpreter doing a visual interpretation of a colour-coded satellite image will, therefore, perceive these as belonging to the same area type. This research shows what the various units that can be visually separated may include, and we can evaluate whether the degree of separation attained is satisfactory for a given application or mapping task.

2) Further research with precision-corrected satellite data has been carried out using the cluster technique. The test area here is a valley in Valle township, at an elevation of 250-1300 m o.s.l.. Figure 7 shows a combination of Economic Map 1:20 000 in scale and satellite data. Even though this technique can't compete with the precision that detailed field work and aerial photography gives, it is in our opinion, a useful tool for small-scale mapping and the calculation of areas of the various categories. This method will be particularly appropriate in areas lacking detailed land resource maps.

Case E
Image Analysis of Digitized Colour-Infrared Aerial Photos for Analysis of Tree Damage.

The trials were carried out in a test area in Porgrunn town in Telemark, near Norsk Hydro's industrial area. The Porgrunn Park Authority has contributed its time to the project. Norsk Hydro Research Center has contributed financially.

Aerial photos on colour-infrared film at an original scale of 1:7 500 and 1:50 000 were digitized using a colour scanner and analyzed by the same methods as the satellite images. The scanner resolution and original scales used gave pixel sizes corresponding to ground quadrats measuring 40 cm x 40 cm and 2.5 m x 2.5 m, respectively.

Good results have been achieved in identifying the state of vitality in trees using digitized aerial photos with 40 cm x 40 cm pixel size (Figure 6). At a pixel size of 2.5 m x 2.5 m, it is not possible to identify smaller trees, but the main features with respect to vitality can still be observed. A practical limit for reliable identification of individual trees is considered to be a pixel size of about 1 m x 1 m for Norway. Until such time as imaging spectrometry becomes a fully operative technique, we would consider the method described to be a relevant remote analysis method for practical mapping of vitality in parks or in permanent control plots in productive forests. Since aerial photos can often be used for several purposes in the study area, the cost of this kind of remote analysis can be affordable.
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The LANDS System -
A Land Analysis and Decision Support System

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Abstract
This paper presents a GIS-based Land ANalysis and Decision Support (LANDS) system. The LANDS system integrates GIS applications with relational data base management (RDBM), mathematical programming, and expert systems applications. The paper describes the programs and procedures used to construct a mathematical program to match crop systems to land types. The resulting land use plan maximizes net farm income for the region. The LANDS system uses the GIS module to define land management units (LMUs). These areas are homogeneous in biophysical, land use, and economic characteristics. The LANDS system uses the RDBM module to create a mathematical programming model to allocate LMUs to crop systems. The GIS displays the results of the land allocation model.
1 Introduction

This paper describes a regional Land ANalysis and Decision Support (LANDS) system developed in cooperation with the Malaysia Department of Agriculture. The system uses a land allocation model to identify patterns of land use which return the highest regional net farm income. It does so within the controls of policy and limited resources such as land and labour. Land use options include growing crops on different rotations. They also include different methods of growing the crops. The system assigns limited resources to user specified land use options. The land analysis and decision support system displays the proposed distribution graphically, as maps, and in report tables.

1.1 The LANDS Shell

The LANDS system uses a set of custom and commercial programs called the LANDS shell. The LANDS shell provides geographic data analysis and manages the biophysical, economic, resource, and production data. It also produces crop budgets, generates the computer code to run the optimization model, and reports model results. Land evaluation specialists use the shell to build and run the land analysis and decision support models.

1.2 Land Analysis and Decision Support Definition

Land evaluation is a widely used term. Some uses restrict the meaning to the interpretation of biophysical properties for forest or agriculture capability or crop suitability. In some cases, evaluation procedures use simple economic analysis (e.g., benefit-cost analysis) to rate feasibility. The procedures described in this paper integrate economic with biophysical analysis to assign crop systems to land. They optimize the use of available resources. The LANDS system assists with or supports land use decisions. It does not make land use decisions. The term land analysis and decision support emphasizes this role. The following procedures define the LANDS system.

1. Define the management goals.
2. Define the options for meeting these goals.
3. Define the resources available to meet the goals.
4. Define a land allocation model to meet the management goals.
5. Execute the allocation model.

2 The LANDS Shell

The LANDS shell consists of several commercial and custom designed computer programs. A custom program provides a menu system to access the various components of the shell. Other programs perform budget analysis, build models and process and transfer data between applications. They also produce reports and provide input for the production of maps. Another set of programs convert geographic data from an unsupported geographic information system to the LANDS system GIS. The commercial programs manage data (Oracle1), perform geographic analysis (TerraSoft2), and solve optimization problems (LINDO3). Figure 1 displays the structure of the shell.

1Oracle Corporation, Oracle RDBMS. 20 Davis Drive, Belmont, CA 94002-9606
2LINDO Systems Inc., LINDO, Linear Discrete Optimizer. P.O. Box 148231, Chicago, Illinois 60614

Figure 1. The LANDS Shell

2.1 Geographic Information System

The geographic information system (GIS) stores, edits, analyses, and retrieves geographical data as maps. In addition to providing digital storage and retrieval of map data, the GIS provides the following functions.

1) calculation and storage of data on areas, locations, and topology of classes of land.
2) overlay of map themes to produce composite themes.
3) evaluation of data attached to polygons and development of interpretations from these data.
4) plotting of interpretations as maps.

2.2 Data Base Management System Module

The data base management system (DBMS) inputs, stores, edits, updates, and retrieves data. The data base is designed to store data in only one place. All models or programs which use the data automatically reflect any changes made to the data. The DBMS applications retrieve and analyze data. These applications provide data to the expert system, produce crop budgets, and build the land allocation model. They also link land allocation model results to the GIS for display.

2.2.1 Budget Application

The budget application is a set of custom programs written and run from within the DBMS. It calculates input costs, production revenues, and annual net farm income for each land use option. Other applications use these values.

2.2.2 Mathematical Programming System (MPS) Application

The MPS application is a set of custom programs built and executed from within the DBMS. It processes information supplied by the DBMS and builds the land allocation model. The application retrieves the data which define the land use options, resources, and limitations to production. It also calculates and formats the input data for the land allocation model.

3Digital Resource Systems Ltd., TerraSoft: Geographic Information System., 402-495 Dunsuir St., Nanaimo, B.C. Canada, V9R 2V2
2.2.3 Report Application
The report application presents the results of the land allocation model. Reports include summaries of crop areas and production, resource requirements, and annual net farm income. Changing input to the land allocation model provides a method of sensitivity analysis.

2.3 Mathematical Programming Module
The mathematical programming module performs part of the economic analysis required by the LANDS System. It maximizes or minimizes an objective function subject to defined limits or constraints. The mathematical programming module solves the land allocation model to maximize regional net farm income.

2.4 Expert System Module
The expert system module (AgriExpert) is a custom program designed to match two sets of resources. It uses an 'inference engine' which compares the properties of two sets of resources. One application is the determination of soil suitability for crops. The inference engine compares the range of properties of each soil with the requirements of each crop. If the range of soil properties required by the crop encompasses the range of properties in the soil, the soil is suited to the crop. If the range of soil properties required by the crop does not overlap the range found in the soils, the soil is not suited to the crop. If the ranges partially overlap, the program identifies the conditions where the soil and crop match.

2.5 Climate Analysis Module
These custom programs analyze daily records of rainfall and potential evapotranspiration, based on a regression and crop use factors. It calculates the chance that each ten day period will be too wet or too dry. The program then produces a distribution of soil water condition, by 10 day period, for each climate station analyzed.

3 LANDS System Procedures
3.1 Management goals.
The land allocation model of the LANDS System uses mathematical programming to assign areas to each land use option. This requires a goal which can be stated in mathematical terms as an objective function. Our current model maximizes net farm income.

3.2 Land Use Options
A land use option is a set of conversion, improvement, and crop system operations practiced on a type of land. Some land use options may not require improvements. Defining land use options requires defining Land Management Units (LMUs) and conversion, improvement and crop system operations.

3.2.1 Land Management Units
A land management unit (LMU) is a class of land which is relatively homogeneous in its biophysical, land use, and economic properties. Definition of LMUs requires the combina-

3.2.1.1 Crop Management Units
The crop management unit (CMU) is the biophysical component of the LMU. The CMU incorporates the climate, soil, and terrain properties which define biophysical crop suitability. Regional climate and microclimate dictate the range of crops and maximum production potentials of an area. Climate is not normally subject to management, although microclimatic limitations can be modified. Soil and terrain conditions impose further limits to crop suitability. Some of these limitations are manageable, others are not. Crop management units are defined in 4 stages.

Stage 1 defines the biophysical crop requirements. Matching improvement and crop system operations to land requires information on the biophysical requirements of the crops under consideration. These requirements are the basis for setting up land classes which can support the same range of crop systems. The crop specialist is responsible for providing class limits which define suitable soil, terrain, and climate conditions for each crop.

Stage 2 defines agroclimatic areas. Climate defines the range of crops which will grow in the area. Custom programs within the LANDS will analyze climate station data to determine climatic conditions related to crop growth. Climate classes determined at each station provide the data to produce agroclimatic maps. These maps are drawn manually and digitized for use in the geographic information system.

Stage 3 overlays the climate areas defined in stage 2 with the soil and terrain maps for the study area. The resultant polygons carry the biophysical attributes used to determine crop suitability.

Stage 4 defines land units which have the same kind and degree of limitations to crop production. Soil and terrain conditions restrict suitable cropping systems. They also dictate the land improvement operations required to produce specific crops or crop mixes. The land area must be classified to form units having the same suitable improvement and crop production systems and the same expected crop responses.

3.2.1.2 Land Use Classes
Existing land use and cover determine the operations and costs of establishing a proposed land use. The existing land use maps provide area summaries of existing land use. Generalized land use classes are based on the type of cover as it relates to clearing and land preparation costs. Example classes are tree and shrub cover (e.g., secondary jungle or coconut-coffee plantations) and shrub cover (e.g., tea or coffee plantations or abandoned land). Perennial crops keep their original land use class because the land allocation model uses the area and age of existing perennial crops.

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3.2.1.3 Economic Zones
In general, unit costs of production decrease with increasing intensity of agricultural land use and transportation efficiency. They increase with distance to market or supplies. The Department of Agriculture's Agriculture Information System uses administrative districts to record commodity and resource price data. The project uses these units as a first approximation of economic zones. Subdivisions of these units, based on intensity of use and transport distances, will define economic zones in the future.

Overlaying maps of CMUs, land use classes, and economic zones delineates polygons carrying attributes of each theme. Each unique combination of CMU, land use class, and economic zone defines a Land Management Unit.

3.2.2 Operations and Commodities
The LANDS system requires data on all operations for the land use options in the planning area. The required data are the type of operation and the quantity and type of commodities associated with the operation. Commodities are resources and crop products. Operations include land conversion, land improvement, and crop system activities.

The following kinds of operations may be required by a land use option. These operations occur within a given year of the crop's rotation.

a. Land Conversion Operations: Existing land use influences the establishment of a crop system. Conversion operations are the operations necessary to convert existing land use to the proposed crop system.
b. Land Improvement Operations: Soil and terrain conditions may prevent the growth of climatically suitable crops. Land improvement operations are the operations necessary to remove these limitations. Some land use options may not require land improvement.
c. Crop System Operations: A crop system is a unique set of operations, along with the resources required to produce a crop or mix of crops. Crop systems include mono cropping, double cropping, intercropping, and crop rotations.

3.2.3 Defining Land Use Options
The combination of conversion, improvement, and crop system operations with a land class defines a land use option. The MPS application of the LANDS system defines the land use options. It links land improvement and crop system operations to the CMU component of the LMU, using a table of crop systems suited to each CMU. The expert system module can construct the table from data in the data base. The MPS application also links conversion operations to the land use component of the LMU.

3.2.3.1 Yields
The LANDS system requires estimated yields for each land use option. The crop system carries an estimated yield. The combination of crop management unit and crop system has a yield factor attached to it. During any yield calculation, the yield factor attached to the CMU modifies the yield attached to the crop system.

3.2.4 Available Resources
Certain resources may limit the area assigned to a land use option. Limited resources may also limit the total area of land which can be used. The LANDS system therefore requires data on the kind and quantity of any resources which may limit land use options. Land is a resource along with capital, labour, equipment, chemicals, etc. Land resources are discussed separately because of the method used to determine available land.

3.2.4.1 Land resources
All land uses or biophysical conditions which prevent agriculture as an option reduce the area of land available. The GIS overlays land reserves, zoned non-agriculture, etc., on crop management units. It then extracts for analysis only that land which is available for agriculture. The system reports the area of each LMU which is available for agriculture.

3.2.4.2 Other resources
Data for other potentially limiting resources come from questionnaires, surveys, and government sources. Most of this information comes from the Malaysia Department of Agriculture's Agriculture Information System. The DBMS manages this data.

3.3 Crop Budgets
The budget application calculates annual cash flows for land use options. Crop budgets require data on prices and quantities of commodities for each year of a crop rotation.

3.4 Land Allocation Model
The land allocation model identifies patterns of land use which return the highest regional net farm income. It does so within the limitations of policy and available resources. The MPS application produces the code necessary to solve the land allocation problem. All the necessary data come from the data base. The application calculates all needed coefficients. The coefficients include discounted net farm income, resource requirements, and yields. The following sections describe the major components of the model.

3.4.1 Time Frame
The model distributes resources and activities across periods. The current model uses a 5 year planning period. Each year is a period. The number of periods is adjustable. The MPS application needs to know the number of periods to construct the land allocation model.

3.4.2 Activities
1) Opening stock defines the area of land already in perennial crops. Land in perennial crops is not available for conversion to alternative crops until the end of the crop rotation. The model requires the definition of age classes for perennial crops. The age classes define resource requirements and the times at which land conversion to alternative crops can occur.

2) Planting activities are unique combinations of conversion, improvement, and crop system operations, on given land classes (land use options), for a given period. The land
allocation model requires data about which crop systems are possible on which land classes. Crop management units define the possible combinations.

3.4.3 Constraints
1) Land constraints impose limits on the area of land assigned to planting activities. The area of land, assigned from a given class, cannot exceed the total area of land in that class. The model requires data on the total area of land in each class.

2) Opening stock constraints make sure that land under perennial crops remains under that crop until the end of the crop rotation. The model requires data on the area of land in perennial crops and the age of the existing crop.

3) Resource constraints make sure that resource use does not exceed resource availability. The model requires the total of each potentially limiting resource.

4) Policy constraints make sure that the land allocation solution meets government production quotas or targets. Policy requirements may impose resource allocations that reduce the net farm income.

3.4.4 Activity Interactions
Activities are dependent on each other because they may compete for the same resources. Also, the choice of certain activities may explicitly require or exclude the choice of other activities. Coefficients entered into the rows of the land allocation matrix define the nature of these interactions.

1) The objective function defines the possible activities and their relative contributions towards the objective. This requires the specification of each activity’s coefficient. The coefficient for each planting activity is the present value of net farm income corrected to compare crops of different rotation ages.

2) Constraints define the limitations to production. Coefficients, in the appropriate rows, define these interactions.

3.5 Reports and Maps
The LANDS system can produce an annual cash flow and discounted net present value for each planting activity. It can also produce maps and tabular reports of the proposed land use for each year of the planning period. An important capability of the LANDS system is its ability to perform sensitivity analysis. The land allocation model output provides information on the costs of forcing a planting activity into or out of the plan. This output can also show the sensitivity of the land use recommendations to changes in the net farm income of a given activity. In addition, the LANDS system provides a valuable "what if" tool to assess the effect of price, yield, or policy changes.

4 Conclusions
The LANDS system provides an effective tool to assist with regional land use planning. Output from the system is useful to guide land use decisions. It is useful for assessing the impact of policy or guiding land use changes to meet production goals. The system uses generalized land data and should not be used for site specific crop allocations. An important application of the system is the performance sensitivity analysis and "what if" planning. The primary limitation of the system is the number of activities which the land allocation model can evaluate. The current limitation is approximately 15,000 activities. This is not enough to evaluate individual map delineations for a large map. The next stage of the project is developing a farm level application that will provide site specific land use plans. We will enhance the capability the system to deal with different types of objective functions, constraints, and activities.

5 Acknowledgements
The LANDS system is part of CIDA Project 600/12419. The following people were integral members of the project team: Ahmad Fauzi Fuasa, Chiow Hye Yang, Darus Ahmad, Faridah Hj Ahmad, Glen Langford, Mohamad Sabtu, and Mansor Abd Rahaman.
Data Issues and Remote Sensing

Session F1
Data Issues in Remote Sensing

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Sustainable Development in GIS as a component in Statewide Decision Support Systems
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Remotely Sensed Data: Sensors, Coverage, Data Availability and Access, Cost
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Abstract
Over the past two decades, digital remotely-sensed data has evolved from a largely experimental data source to an integral input into the resource management decision-making process. Information provided by remotely-sensed data now permits timely, accurate and consistent decision making in a cost-effective manner for many operational resource management organizations around the world.

This paper will discuss airborne- and satellite-based digital remote sensing technology and its role as a data source for integrated resource management information systems.
Background
Canada, and in particular Western Canada, bases much of its economic well-being on the export of natural resources. In fact, Canada’s largest export industry revolves around the forest sector. The management of Canada’s natural resource base is now becoming increasingly complex owing to such issues as integrated land use, environmental concerns and sustainable development. In addition, the public is now demanding a much more active role in the management of these resources.

All of these issues point to the need to provide those charged with managing a resource base with a fully integrated, pro-active decision support capability. The concept of the Integrated Resource Information Management System (IRIMS) is one that has evolved chiefly as a result of this need.

The IRIMS represents an integrated systems solution to operational resource management requirements. It comprises a hierarchical structure consisting of people, information, tools, procedures and communications. This hierarchical structure addresses the requirements for decision makers at all levels within the operational organizations that are involved in resource management, from the definition of policy and associated strategy to the execution of the resulting procedure.

This paper explores the remotely-sensed data sources that are, or will be, available on an operational basis for resource management applications in the foreseeable future and will highlight two applications implementations.

Survey of Remotely Sensed Data
Traditionally, the remotely-sensed data used in resource management has been based on cameras which record the energy variations on photographic film. However, photographs are an inherently inflexible media, which require time consuming, subjective operator-intensive analysis, interpretation and correction.

Although digital remote sensing data has been available since the launch of the first Landsat satellite in 1972, the cost-efficient application of this data to the increasing requirements for efficient resource management has been hampered by several factors. Paramount amongst these were the unreliability of the digital data source, and the difficulty in extracting accurate information from this digital data.

In the last few years, technology has advanced to a point whereby the remotely-sensed data can be thought of as quantitative measurements, and objective analysis is now being operationally performed by many resource management organizations. Passive and active digital imagery and digitized photographs provide a variety of sources for the data, which permits objective resource planning and management. Objective quantitative analysis of these measurement sets provides for an accurate and unbiased information source.

There are several characteristics of these measurements that ensure that this remotely-sensed data can be used to support consistent decision-making:
- the digital nature of the data,
- the multispectral component,
- the accuracy of the data,
- the timeliness of the data availability, and
- a secure data source.

A Digital Data Source
The quantization of reflected energy into digital measurements permits computer processing. This is much quicker than photographic interpretation, and is less dependent on the analytical skills of the interpreter. It is therefore a less biased data source. Moreover, the increasing power and sophistication of digital processing means that information can be accessed by users who are not required to be computer experts, but instead be applications experts.

A Multispectral Data Source
The ability to identify and measure different features on the earth’s surface based on variations in intensity of recorded energy is greatly enhanced when using sensors that operate over a wide range of the electromagnetic spectrum. Multispectral imagery is multiple simultaneously-recorded images, inherently registered to the same coordinate system, each covering a separate range of spectral wavelengths.
The sensors on existing and planned satellite and airborne systems are sensitive over far greater ranges of the spectrum than aerial photography. In particular, the short wave infrared bands of the Landsat Thematic Mapper have proven to be indispensable to many resource managers actively using remotely-sensed data. Table 1 illustrates the wavelengths in which the Landsat satellite records and describes the features which they have been designed to identify.

An Accurate Information Source
Techniques for geometrically correcting the satellite data have been refined to easily address recognised mapping standards. As well, advanced digital processing systems make this a quick and highly automated process.

Indeed, the geometric correction of imagery to standard map projections, or Geocoding, as it is termed, has proven to be highly accurate. Therefore, this data provides an ideal source for geographic information systems. Satellite imagery also provides wide area coverage and is therefore extremely cost-effective on a per unit/area basis.

Having a cost effective, accurate digital data source means it is possible to combine and compare images from different dates and sensors and to obtain derived information.

Timeliness
Satellite sensors are an ideal data source for resource management because they provide regular and repeated coverage. For instance, Landsat permits complete coverage of the earth every 16 days, while SPOT permits 26-day repeat radar coverage. However, because SPOT can alter the viewing angle of its sensors, there is the potential to revisit any area every 3 or 4 days at Canadian latitudes.

Where higher resolution or more frequent coverage is required, airborne sensors can supplement the spaceborne data. The other key benefit is the digital nature of the data. Such data can rapidly be processed into information and formatted for the particular user, (i.e., maps, reports, statistics, GIS data).

Availability - A Secure Data Source
In the last few years, the availability of this data has become far more secure, with the U.S. Landsat and French SPOT programs creating an operational demand for their products. Recently the Japanese, Indians and Russians have all entered the civilian remote sensing marketplace.

The 1990's will see something of an explosion in the launching of remote sensing satellites. Table 2 illustrates the key characteristics of the satellites to be launched over the next five years. For the next few years, it is the optical sensors such as the Landsat TM and SPOT HRV that will continue to play the most important role, guaranteeing that these programs will run well into the next decade.

Landsat-5 was originally launched in March 1984, and was planned to have a five-year lifetime. The satellite is working perfectly and is expected to fulfil its operational expectations for several more years.

SPOT-1 is also performing beyond its design expectations, and the 10-meter data has proven particularly useful in applications requiring a more accurate data source, such as

<p>| Table 1 LANDSAT 5 TM Bands And Their Applications (Lillesand and Kiefer) |</p>
<table>
<thead>
<tr>
<th>Band No.</th>
<th>Band Width (μm)</th>
<th>Approximate Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.45 to 0.52</td>
<td>Visible blue/green: Provides maximum penetration of water, which is useful for bathymetric mapping in shallow water. Also useful for distinguishing soil from vegetation and deciduous from coniferous plants.</td>
</tr>
<tr>
<td>2</td>
<td>0.52 to 0.60</td>
<td>Visible green: Corresponds to the green reflectance peak of vegetation, and so is useful for assessing plant vigour.</td>
</tr>
<tr>
<td>3</td>
<td>0.63 to 0.69</td>
<td>Visible red: Radiation in this band indicates the level of chlorophyll absorption in plants, and so is important for discriminating vegetation types.</td>
</tr>
<tr>
<td>4</td>
<td>0.76 to 0.90</td>
<td>Infrared reflected by the earth's surface: Useful for determining biomass content and for mapping shorelines.</td>
</tr>
<tr>
<td>5</td>
<td>1.55 to 1.75</td>
<td>Reflected infrared: Indicates moisture content of soil and vegetation, penetrates through thin clouds, and provides good contrast between vegetation types.</td>
</tr>
<tr>
<td>6</td>
<td>10.40 to 12.50</td>
<td>Radiated or &quot;thermal&quot; infrared: Provides night time images useful for thermal mapping and for estimating soil moisture.</td>
</tr>
<tr>
<td>7</td>
<td>2.08 to 2.35</td>
<td>Reflected infrared: Corresponds to band of radiation absorbed by hydroxyl ions in minerals. Useful for mapping hydrothermally altered rocks associated with mineral deposits, particularly when compared with Band 5.</td>
</tr>
</tbody>
</table>
forest clear cut mapping. The stereo capability of this satellite has meant that topographic maps and digital elevation models can be derived entirely from the digital information.

The Landsat-6 satellite is currently being constructed for a July 1991 launch. Not only will this satellite have the successful TM sensor, but it will also provide Enhanced TM data with a 15-meter panchromatic resolution. This will supplement the availability of the SPOT 10-meter panchromatic data, which has proven to be extremely useful, especially when used in combination with the spectral information from the TM.

SPOT-2 is ready for an early 1990 launch and SPOT-3 is being built for a 1992 launch. All of these sensors will be the same, ensuring the continuity of the data source. SPOT-4 is being developed for launch in 1994. This will be an improved sensor, carrying the useful SWIR band for vegetation discrimination. 10 meter images will also be more easily attained with this new sensor as one of the multispectral bands is planned to have 10 meter resolution.

Of particular interest will be the increasing availability of radar data. Since radar sensors provide all-weather and day/night operation, they are able to provide data on demand, a key requirement in resource management. The first of the radar sensors will be launched on ESA's ERS-1 satellite in late 1990. This will be followed by the Japanese ERS-1 in 1992 and Canada's own Radarsat, currently scheduled for a 1994 launch.

As we have demonstrated, one of the key factors in developing an IRIMS is that the data source should be digital, as the ease with which information can be extracted from this data is really the key issue. Satellite sensors provide just one source of data and an important role will also be played by airborne sensors, such as MEIS or airborne SAR. These sensors are particularly important when there is a need for additional large scale information.

For instance, the MEIS scanner provides spatial resolutions of 1 meter and above, and more importantly provides a spectral resolution of 8 selectable bands in a range from 400-1000 nm. This data has proven to be particularly useful to the Canadian Forestry Service who are able to identify the effects of insect infestation and other diseases in individual trees, a major forest management problem.

**Applications**

With the acceptance of remotely-sensed data as a viable data source for operational applications, more and more organizations are investing in the acquisition and development of customized systems to meet their specific operational requirements. These organizations are turning to this technology not simply to exploit technology for evaluative purposes (although this is often a first step), but because it makes sound business sense on a cost/benefit basis.

<table>
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<tr>
<td>Characteristic of Some of the Future Satellite Sensors</td>
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<tr>
<td>Sat</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>SPOT-2</td>
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</tbody>
</table>

* 5 Day Revisit Off-Nadir  ** 2HRV Sensors Operating Side-by-Side

| Landsat | Mid 1991 | 4 | 705 | 16 | 185 | ETM | PANCHROMATIC | 15 | Cartography |
| | | | | | | VISIBLE | 30 | Thematic |
| | | | | | | NEAR IR | 30 | Mapping |
| | | | | | | SWIR | 30 | |
| | | | | | | THERMAL | 120 | |

| ERS-1 | Oct 1990 | 3 | 777 | 3 | 100 | SAR | C-Band | 30 | Earth Obs |
| | | | | | | | | | |
| JERS-1 | 1992 | 2 | 568 | 44 | 75 | SAR | L-Band | 18 | Earth/Ocean Observation |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| RADARSAT | 1994 | 5 | 1000 | 1* | 130 | SAR | C-Band | 28 | Ice/Vegetation Monitoring |

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In Canada several organizations have taken a leadership role in incorporating remote sensing technology into their day-to-day operations. Two examples of such organizations are the British Columbia Ministry of Forests and the Ice Centre, Environment Canada. These organizations utilize large volumes of remotely-sensed data on a daily basis as part of their management and forecasting activities.

In the area of forest management remote sensing technology has proven to provide tangible benefits for such activities as:
- inventory mapping and update,
- forest sampling and plot analysis,
- regrowth monitoring,
- insect and disease assessment,
- forest change monitoring.

Substantial research in these areas has taken place, and the ability to use remotely-sensed data sources to address these activities is well defined and documented (Ahern and Leckie). This is not to imply that further research in this area is not required. It simply demonstrates that research performed to date justifies the use of remote sensing technology in an operational forest management environment. The issue that is now facing many organizations is that of implementing systems that maximize the return on investment in terms of tangible benefits to that organization.

The Inventory Branch of the British Columbia Ministry of Forests maintains a program to update approximately 6600 1:20 000 scale forest inventory maps on a 2-year cycle, based on satellite imagery (Hegyi). In this case, the primary data source is the Landsat Thematic Mapper. These updates account for such forest changes as harvesting, fire and damage by insects and disease.

One other field in which the benefits of remotely-sensed data are well established is sea-ice mapping. In Canada the monitoring and forecasting of sea-ice movement is critical to the safe operation of shipping lanes and oil drilling platforms in eastern and arctic Canada. With the upcoming launches of several radar satellites (ERS-1, JERS-1, Radarsat) and the current availability of airborne SAR, operational forecasting of ice from digital imagery has proven operationally viable.

Perhaps the world’s most advanced sea-ice forecasting implementation can be found within the Ice Centre, Environment Canada, a branch of the Canadian Atmospheric Environment Service. Recognizing the benefits of exploiting digital remotely-sensed imaging technology, and digital processing in general, the Ice Centre has undertaken a major expansion program involving the development and implementation of an integrated systems infrastructure.

In the spring of 1989, the Ice Centre took delivery of the Ice Data Integration and Analysis System (IDIAS), which was designed and built by MacDonald Dettwiler. IDIAS, the heart of the system, is a highly automated system that uses real-time digital data from a number of airborne and spaceborne imaging sensors to produce digital and analogue ice forecast products for eastern and arctic Canada on a daily basis. IDIAS can accept input image data volumes in excess of 500 MBytes per day from such sources as the Landsat TM, SPOT, NOAA AVHRR, Airborne SAR and SLAR. As well, IDIAS will accept data from ERS-1 and Radarsat once those sensors enter operation.

These two examples demonstrate organizations that have evaluated the benefits to be gained by utilizing remotely-sensed data and have successfully exploited the appropriate data and systems technology to address their unique operational applications. Other organizations, particularly in the forest resource management field, have recognized the benefits to be had from remotely-sensed data, and are acquiring the systems infrastructure required to successfully reap the benefits.

Summary

During the 1990s, Canada will witness a proliferation of integrated resource management systems designed specifically to address the requirements across the decision-making levels of operational organizations. For the full potential of these operational systems to be realized, a viable source of data must be available.

Fortunately, remotely-sensed imagery addresses many of those needs. The combination of spaceborne and aerial sources provides consistent, accurate and timely data in a cost-effective manner that is useful for numerous resource management applications. With the ever increasing number of remotely-sensed data sources, operational organizations can now implement systems to exploit this technology with minimal risk. In fact, it is becoming increasingly clear that now is the time for operational resource management organizations to implement systems to address their exacting requirements.

References


Sustainable Development in GIS as a Component in Statewide Decision Support Systems

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USA

Abstract
Earth Observations, their descriptive attributes and graphic annotations (maps), have historically been the three prime sources of data required for resource management decision making. During the past two decades of the seventies and eighties, Computer Aided Design (CAD) technology, emerging from the engineering disciplines, was embraced by the resources management community. Concurrently, high-resolution satellite imagery became available in digital form. Concomitant extension of database management into digital graphic applications, provided the integration methodology, the availability of low-cost computing, and the analytical capabilities for many users to take advantage of developing Geographic Information Systems technology. This included resource managers at the State level, where the basic mandate to meet agencies requirements, county demands and regulations at all levels, needed an economically viable means to monitor and update the information. Under these circumstances, a sustained GIS capability is not a choice but a prerequisite if the States are to meet their requirements and maintain control of their future growth.
Introduction
With respect to the management or general stewardship of the Nation's natural resources, this paper might be titled: "Sustainable Development in GIS as a Component in Decision Support Systems." In this regard, the states of the Union hold no unique requirements. Yet, the states do hold a unique responsibility in serving their constituencies in managing the state's resources. To successfully carry out their mandates, states must rely on their several agencies, county and local governments. All need current information provided on a timely basis. Traditionally, information required in resource management were derived from three primary data sources: Earth observations, their descriptions (statistics and attributes), and delineations (maps providing geographic referencing and depicting boundaries and cultural features). Unfortunately, by the time all these data came together in final format, the information was obsolete, and updating, if accomplished at all, was tedious and expensive. Such information in support of the decision making process, was marginal and not sustainable from a practical standpoint.

It is often said, "knowledge is power." According to Webster, knowledge is the orderly synthesis of information. Clearly, those who have "prior knowledge" (information) have a decided advantage in decision making over those who do not. Prior knowledge is defined here as the presentation and integration of information in a time frame and context not at all available by traditional means; that is, before rather than after the fact. Geographic Information Systems (GIS) having earth observations as their centerpiece, yield and maintain exactly these types of data, and when integrated with other geographically relevant information, provide a complete and fully current source of knowledge germane to the decision making process. Earth observations represent the "prior knowledge" component that provides the system dynamics required for sustainability and lifts GIS above a mere static phenomenon. Integrated data providing relational information represents the knowledge base need for intelligent statewide decision making.

Background
With the launch of the Earth Resources Technology Satellite (ERTS I) in July 1972, technology was demonstrated having the potential to dramatically change the way the world and its resources were perceived. By the time ERTS II, (now called Landsat II) was launched in 1975, the feeling was almost euphoric at the "better than expected" data being collected by the Multi Spectral Scanner (MSS). With the excitement, expectations grew beyond those ever intended for the system. While perhaps satisfactory on a project basis for government supported scientific research and development, the system was never designed to meet the rigorous criteria of the commercial marketplace.

The failure of Landsat to meet all its early expectations went beyond the lack of philosophical perspective and market commitment required for success. Technical considerations, beyond Federal government control, also played a significant role in the slow user acceptance of the data. Supporting technologies in geographic referencing, overlay and annotation were not in place, data base management methodologies for spatial applications were not developed, nor was the low-cost computing to accomplish all this available.

During the decade of the seventies, Computer Aided Design (CAD) technology emerged out of the engineering arena and found almost immediate acceptance in the resource management community. Concomitant extension of data base management methodology into digital graphic applications, provided the capability for the relational integration of graphic, attribute and statistical data into digital GIS configurations. The advent and subsequent explosion of microcomputer technology has put substantial GIS capability into the hands of virtually all serious users.

On February 21, 1986, the French launched the SPOT satellite into near-polar sun-synchronous orbit. Significantly, the SPOT program, represented in the United States by SPOT Image Corporation (SICORP), of Reston, Virginia, presented the first "made for commercial" venture in civilian satellite data delivery systems to the United States remote sensing user community. SPOT's contribution to the menu of available digital image products has been substantial, but not so much as a result of new additions of exotic technology. It has been rather, the innovative rearrangement of existing capabilities, and in packaging them to meet real and perceived market needs.

The Opportunity
From a statewide applications standpoint, the unique technical advancements represented by the SPOT satellite were significant. The linear array or "push broom" design of the two identical High Resolution Visible (HRV) instruments provide (1) broad band panchromatic data with a ground resolution of ten meters, and/or (2) multispectral data in three bands with a ground resolution of 20 meters. The nominal SPOT scene covers a 60 x 60 km area. When both HRV's are working in a twin vertical mode, there is a 3 km sidetap yielding a double swath width of 117 km. The panchromatic mapping opportunities provided by these resolutions are significant.

Each HRV instrument is equipped with a strip selection mirror that allows viewing up to 27 degrees off nadir. Such oblique viewing provides a nominal scene with variable size, from 60 km vertical (nadir) to 81 km at the full off-nadir angle of 27 degrees. This capability provides a 950 km viewing corridor for each pass of the satellite. Within this corridor, two independent nominal scenes can be collected in P, XS or both simultaneously. The off-nadir viewing capability presents opportunities to image the same ground location from several different orbits and at several different angles. This capability provides for rapid revisits, by minimizing cloud effects, and stereo viewing, both in the P and XS mode. The topographic mapping opportunities provided by these capabilities are significant.

The opportunities presented go beyond the technological developments made over the past decade and a half. Less emphasized, but no less significant has been the substantial
body of practical applications developed over this same period of time. Many of these were accomplished by state universities under federally funded programs variously called Applications Systems Verification and Test (ASVT), Applications Pilot Test (APT) and more generically, Technology Transfer. States, through their universities, were actively involved, and a wide range of projects were undertaken and applications were developed. In support of this activity, considerable, if not elaborate, facilities were installed.

With few exceptions, these projects and applications never matured enough to move to implementation, although most were well thought out and had merit. In virtually all the government projects and applications, image data not only were held up as the centerpiece of spatial information systems, but were considered as the only significant source of information in the system. Other data, if and when used, were brought in as ancillary additions. As funding was withdrawn from the various government programs, the pure image-based information approach could not be justified at the state or local level. Facilities languished, but generally were not dismantled, as resources were reallocated to activities generating more revenue.

Earth observations represent the spatial context within which geographical information are cast, and from this point of view, imagery can honestly be considered the centerpiece for GIS, but imagery cannot stand alone. As the "prior knowledge" (before the fact) component of GIS, synoptic earth observations over large areas represent a place to start in lieu of little or no existing information. With the advent of higher resolutions (10 meter), broad area characteristics of the image remained, but the image contents have been lifted beyond the synoptic to the detailed representations of the landscape. This permits data base establishment, maintenance and update at very workable scales and at very attractive unit area costs.

In the world of 'high tech', nothing remains static very long. Dramatic changes in technology and agenda cast new light on the role of GIS, and provided great opportunities in the statewide decision making process. The data are in place, and products and services are being provided and are driven by the public and private marketplace. The supporting technologies not available during the remote sensing 'heydays' of the seventies, have been developed and implemented, and low-cost analytical capabilities are available for virtually all who wish GIS solutions. It is time to reassess the utility of image based geographic information systems in statewide schemes for information management.

Discussion

Issues of global change have attracted widespread attention and are currently receiving major emphasis. So long as the world population continues to grow and environmental, economic and social factors continue to thwart efforts to increase food production, this issue will remain a cause for concern. If the technically advanced countries of the World in general, and the United States, in particular, do not take the lead in resolving these issues, then we will stand in default while the rest of the world sets the agenda.

If the United States is to assume the lead in world information management technology, it must also set the example. Given that the whole is the sum of its parts, the ability of the United States to manage its natural resources is predicated on the ability of the individual states to manage their resources. State programs are carried out by the various state agencies, county and local governments. In addition, the state has the responsibility to meet and implement Federal and other regulatory guidelines. Environmental monitoring, urban and regional planning issues and the management of the state's forest and natural area resources, are compelling reasons for active GIS applications and development.

Geographic Information Systems utilizing earth observations from satellites are especially well suited to environmental monitoring and mapping. Single scenes provide current large area views (3600 square km per SPOT scene, for example) and yet have ground resolutions capable of producing accurate mapping scales to 1:24 000 and larger. This allows for the identification and mapping of small but critical land use/land cover features. Traditional techniques for measuring and mapping change are time consuming, labor intensive and costly.

Water runoff presents a serious environmental problem in many areas. Runoff, as it effects marine vegetation and fresh water supplies, remain areas of debate and enforcement. Studies conducted in the Delaware Bay area near Lewes, Delaware, demonstrated a strong correlation between calculated vegetative index (VI) and biomass as measured from satellite derived imagery. The study was replicated in time over a three-year period using both Landsat and Spot data. The high resolution of SPOT was very useful in mapping small estuaries and creeks entering the marsh. The results indicated wide variation in VI, as predicted by the biomass measurements, occurring spatially and temporally. (Klemas, et.al., 1987). Since vegetative index is also correlated with the marsh's productivity, such data are essential on a recurring basis to monitor and map overall productivity levels within the marsh.

Groundwater and non-point source pollution are major issues faced by the five water management districts of Florida. In a project loosely titled 'Land Use Mapping', the Northwest Florida Water Management District contracted Landmark Technologies of Jacksonville, Florida, to map and assess the major landforms and cover types in the coastal panhandle of Florida, near Panama City. Landmark elected to use data from the SPOT satellite to first update the USGS base maps. The most recent maps were from the U.S. Army in 1944. The high resolution, and inherent capability of multispectral data to differentiate land and water interfaces, provided an excellent means to update and map wetlands within the area of interest. Once the data capability became obvious through several field visits, the general nature of the project shifted to be more specifically one of wetland inventory. Deer Point Lake, just west of Panama City, is a major source of fresh water in the region. Large sod farms in the area tend to encroach on the natural drainage system, and dangerous levels of agricultural
pollutants are finding their way into the Lake. The magnitude of this problem was not realized before this project.

Being in the recently uplifted lower coastal plain, the Florida Panhandle is covered with residual depressions, variously called ponds and bays. These physiographic structures are heavily vegetated with a variety of tree and brush species, and range in size from fractions to hundreds of hectares.

The larger and deeper ones tend to remain the same except for encroachment along the margins. The smaller features are being heavily impacted by cultural conversion carried on by the two major pulp and paper companies in the area, in order to increase their productive acreage. The Water Management District is interested in monitoring the rate of this land conversion, its pattern and possible impact on the future water supply for the region. It will take a sustained information system (GIS) to help the District monitor the management of the area, and to provide the basis for intelligent regulation, if such is required.

Direct pollution from toxic dumping is a continuing concern for environmental management. The identification and mapping of illegal sludge pits and oil spills, which are a significant hazard to wildlife in petroleum production areas, is difficult because of their wide spread and rather random locations. In a study conducted by the College of Agricultural Sciences, Texas Tech University, a 1951 square km (750 sq. miles) area near Denver City, Texas was selected to evaluate the ability of SPOT data to detect and map such features (Fish, 1988).

It is estimated that several hundred or even thousands of these illegal oil deposits currently exists in scattered locations across the oil production areas in west Texas. The pits are diked earthen structures designed to catch overflows or spills of oil and oil/water mixes from tank batteries or pump sites. They vary in size from as small as 12 square meters to 12 hectares or more. These pits are so pervasive that it is estimated upwards to 220,000 birds are killed annually as a result of contact with these deposits.

Locating pits and spills through traditional means is not feasible, given the currently available resources. The use of digital SPOT imagery allowed very large areas of land to be surveyed quickly and cost effectively. Enhancement of the spectral bands helped investigators discriminate the targeted sludge pits from similar appearing features such as open water bodies, wet soils, asphalt and sewage lagoons. The algorithms and methodology developed during this project are directly transferable into ongoing operational information systems.

Perhaps no area has been impacted more by GIS than the urban and regional planning disciplines. This is true for both the broad land cover classifications and the basic updating and maintenance of the existing line maps. This capability has effected the regional and county planning departments and the engineering firms they use to accomplish their mapping tasks. Proposed highway corridors represent a special mapping problem faced by the planners. Demo graphic patterns, wetlands and many other cultural consid-erations must be weighed in designing the routes for these corridors. Here, it is essential that current maps be generated as a prerequisite. Landmark Technologies of Jacksonville, Florida, was involved with the local engineering firm of Prosser, Hallock & Kristoff, Inc., in mapping alternative road corridors around the city of Jacksonville, as a preliminary to designing an outer beltway around the city.

The area, a 45 km x 6 km (28 miles x 6 miles) swath north west of Jacksonville, was quickly and accurately classified. Especially important to the Department of Transportation were the fertile transition zones between wetlands and the mesophytic uplands. Because of the combination of soil characteristics and vegetative association, SPOT data delineated these areas with precision. Three corridor alternatives, each 1.2 km (4000 feet) wide, were digitally overlaid on the classified image. Once the preliminary assessments were made the engineers could efficiently plan the aerial photographic mission for the selected route, only 122 m (400 ft.) wide. This project was completed at roughly one sixth of the cost normally incurred for such a task.

The matter of the nation’s forests, their management and regulation is becoming of increasing concern. Whether it is public or private timber, there is pressure to fulfill wide ranging agendas, not necessarily compatible with the objective of ownership. The forest is a dynamic entity, and to establish its extent, structure and condition is tedious and costly. In addition, once the job is complete, it is obsolete, so the ability to monitor and update in a timely fashion is absolutely necessary if the information required for decision making is to be current and pertinent.

Satellite image based GIS’s have utility in forestry applications as they did in other environmental issues. In fact, one of the strong points for wide area generalized coverage provided by SPOT data, is the wide variety of interests represented on one scene.

Using the same data set as previously described in the road corridor selection process near Jacksonville, Florida, a subset of some 14,000 ha (35,000 acres) was analyzed by Landmark Technologies to demonstrate the capability and cost advantages of the approach in forestry applications. The data were formatted and geometrically corrected. Ancillary data from USGS 7.5 minute quadrangle maps were used to capture the public land survey data of township, range and section, and other cultural features. These data were then integrated with SPOT data, clustered and classified. Aerial photography, flown a year previously at a scale of 1:15,840, was typical of photography used for forest planning purposes. The cover typing and digitizing of these photographs were accomplished, and the cost was used for comparison.

It was demonstrated that the SPOT data were at least as accurate as the photo-interpreted results. More impressive were the cost estimates which were 2 to 1 in favor of SPOT data. Initial inventory is costly and requires the greatest amount of field activity to establish a sound basic database.
The utilization of SPOT and selected site specific aerial photography as ancillary data should reduce, if not eliminate, the need to ever repeat an inventory from scratch.

To compound the state's resource management and monitoring needs, regulation demands at the county and local levels are increasing. When more than one county is involved, or where the general good of the state is involved, the states, too, are being pressured to enact statewide regulations. The degree of involvement depends on the state and its willingness to allow local autonomy. While the turf battles are just beginning as to who has the regulatory responsibilities, the reality of regulation is here, and pressures to increase the controls on how public and private lands are administered are being felt. Whether it be tree preservation, road degradation or smoke management, the effectiveness and fairness of implementation rests on the state's ability to define and monitor its own resources. To do this, a sustainable GIS capability is not an option, but a necessity.

References


Remotely Sensed Data: Sensors, Coverage, Data Availability and Access, Cost

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Abstract
This paper reviews the various sensors which currently generate remotely sensed data, the coverage available, availability of and access to the data, distribution media-analog or digital, and ordering mechanisms. Private sector involvement in data distribution is described and the Canadian radar satellite is discussed.
Introduction
The Canada Centre for Remote Sensing (CCRS), established as a branch of the federal Department of Energy, Mines and Resources on April 1, 1971, is the central agency in the nationwide remote sensing program. A major activity of the program is the collection and distribution of remotely sensed data. This activity includes the operation of two satellite receiving stations, one at Prince Albert, Saskatchewan, and a second at Gatineau, Quebec, for the reception and archiving of remote sensing satellite data. The ground stations receive data from the American Landsat series, the National Oceanic and Atmospheric Administration (NOAA) meteorological satellites, the French SPOT-1 satellite, and more recently, the Japanese MOS-1 satellite. CCRS is preparing for the reception, processing and distribution of data from the Synthetic Aperture Radar aboard the European Space Agency satellite ERS-1 scheduled for launch in 1990 and for RADARSAT, to be launched in 1994.

This paper will discuss the various sensors generating remote sensing data, the coverage available, access to the data, and describe the products produced by CCRS from this data. It will describe private sector involvement in the data distribution, and discuss RADARSAT, Canada’s first Earth Observation Satellite.

Landsat Sensors
The first of the Landsat series of satellites was launched by the United States in 1972. Each one has carried electro-optical sensors: the Multispectral Scanner, which has been in use since 1972, and the Thematic Mapper, which began transmitting images in 1982.

Multispectral Scanner (MSS)
Images produced by the multispectral scanner cover an area of 185 km by 185 km or approximately 34,000 km². The sensor’s ground resolution is 80 metres and its radiometric resolution is 64 gray levels. It produces images in four spectral bands: one in the green portion of the spectrum, another in the red, and two in the near or reflected infrared.

Thematic Mapper (TM)
The Thematic Mapper is an improved sensor which features more spectral bands, seven versus four, along with better spatial resolution and improved radiometric resolution. The sensor covers an area of 185 km x 185 km with spatial resolution of 30 metres and its radiometric resolution is 256 gray levels.

The TM spectral bands are normally used in combinations. However, a description of each of the TM bands is given in Table 2 for the reader’s general information.

Table 2: Single-band descriptions of TM sensor

<table>
<thead>
<tr>
<th>Spectral Bands</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 0.45 - 0.52 micrometre (blue)</td>
<td>Not recommended for use alone because of low contrast and sensitivity to haze.</td>
</tr>
<tr>
<td>2 0.52 - 0.60 micrometre (green)</td>
<td>Not recommended for use alone because of low contrast and sensitivity to haze.</td>
</tr>
<tr>
<td>3 0.63 - 0.69 micrometre (red)</td>
<td>Best for showing roads and other non-vegetated features. Not particularly useful for identifying waterbodies. Minimal conifer-deciduous contrast.</td>
</tr>
<tr>
<td>4 0.76 - 0.90 micrometre (near-infrared)</td>
<td>Best for conifer-deciduous contrast and burned areas. Also useful for delineation of waterbodies.</td>
</tr>
<tr>
<td>5 1.55 - 1.75 micrometres (shortwave infrared)</td>
<td>Best single band overall. Excellent haze penetration. Waterbodies and variations in forest composition are visible.</td>
</tr>
<tr>
<td>6 10.5 - 11.5 micrometres (thermal infrared)</td>
<td>This spectral region responds to the thermal (heat) radiation emitted by the target. This band presents some difficulties for multispectral analysis or band combinations because of lower resolution (120 m). The band offers some potential in geothermal and hydrogeological applications.</td>
</tr>
<tr>
<td>7 2.08 - 2.35 micrometres (shortwave infrared)</td>
<td>This is another reflective IR band but has even greater haze penetration ability than band 5. Image quality, however, is generally poorer since it has a lower signal-to-noise ratio.</td>
</tr>
</tbody>
</table>
SPOT-1 Sensors
Launched by France in 1986, the SPOT (Systeme pour l’observation de la Terre) spacecraft carries two nominally identical High Resolution Visible (HRV) imagers and is designed to operate in either of two modes, a panchromatic (PLA) mode or a multispectral (MLA) mode. In addition, the SPOT HRVs are pointable across the track allowing access to areas other than those directly below its path.

MLA (Multilinear Array)
Images recorded in the MLA mode have a swath width of 60 km for nadir viewing and 80 km for extreme off-nadir. The ground resolution is 20 metres and the radiometric resolution is 256 gray levels. The MLA produces images in three bands similar to Landsat’s MSS green, red, and near-infrared bands.

PLA (Panchromatic)
Alternatively, the sensors can provide black and white images with a high 10 metre resolution and a radiometric resolution of 64 gray levels.

Table 3: SPOT-1 Sensors

<table>
<thead>
<tr>
<th>PLA</th>
<th>MLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swath Width</td>
<td>60 or 117 km</td>
</tr>
<tr>
<td>Spatial Resolution</td>
<td>10 m</td>
</tr>
<tr>
<td>Spectral Bands</td>
<td>0.51 - 0.73 micrometer</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiometric Resolution</td>
<td>64 gray levels</td>
</tr>
</tbody>
</table>

MSR
The MSR continuously scans the earth’s surface conically for a swath of 317 km as the satellite travels. During this process the MSR receives weak radio waves in the two frequency bands of 23.8 and 31.4 GHz. Its resolution is 32 km in the 23.8 GHz band and 23 km in the 31.4 GHz band. The MSR will survey snow, ice, and water vapour by monitoring micro-wave radiation from the earth’s surface.

Table 4: MOS-1 Sensors

Multispectral Electronic Self-Scanning Radiometer (2) (MESSR)

| Swath Width | 100 km |
| Spatial Resolution | 50 m |
| Spectral Bands | 1 0.51 - 0.59 micrometer (green) |
| | 2 0.61 - 0.69 micrometer (red) |
| | 3 0.73 - 0.80 micrometer (near infrared) |
| | 4 0.80 - 1.10 micrometer (near infrared) |

Visible and Thermal Infrared Radiometer (VTIR)

<table>
<thead>
<tr>
<th>Visible</th>
<th>Thermal Infrared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swath Width</td>
<td>1500 km</td>
</tr>
<tr>
<td>Spatial Resolution</td>
<td>900 m</td>
</tr>
<tr>
<td>Spectral Bands</td>
<td>0.5 - 0.7 micrometer</td>
</tr>
<tr>
<td></td>
<td>2 26.0 - 7.0 micrometer</td>
</tr>
<tr>
<td></td>
<td>3 10.5 - 11.5 micrometer</td>
</tr>
<tr>
<td></td>
<td>4 11.5 - 12.5 micrometer</td>
</tr>
</tbody>
</table>

Microwave Scanning Radiometer (MSR)

| Swath Width | 317 km |
| Spatial Resolution | 32 km |
| Frequency Bands | 23.8 GHz |
| | 31.4 GHz |

NOAA-AVHRR Sensors
The Advanced Very High Resolution Radiometer on board the National Oceanic and Atmospheric Administration meteorological satellites records data in 5 spectral bands with a spatial resolution of 1.1 km. It has an almost circular orbit approximately 840 km above the earth and crosses the equator on its ascending pass in the afternoon and on its descending pass in the middle of the night.
Table 5: NOAA-AVHRR

<table>
<thead>
<tr>
<th>Swath Width</th>
<th>2500 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial Resolution</td>
<td>1.1 km</td>
</tr>
<tr>
<td>Spectral Bands</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.58 - 0.68 micrometer (red)</td>
</tr>
<tr>
<td></td>
<td>0.725 - 1.10 micrometer (near infrared)</td>
</tr>
<tr>
<td></td>
<td>3.55 - 3.93 micrometer (infrared)</td>
</tr>
<tr>
<td></td>
<td>10.5 - 11.3 micrometer (thermal infrared)</td>
</tr>
<tr>
<td></td>
<td>11.5 - 12.5 micrometer (thermal infrared)</td>
</tr>
</tbody>
</table>

Available Coverage

Data is received of all passes within the coverage capability of the two CCRS reception stations under the CCRS Satellite Reception and Image Archive Policy.

Landsat 5 and SPOT 1 are routinely recorded from 15 March to 31 October. Landsat 4 MSS reception is on demand only from 15 April to 15 September. NOAA-AVHRR reception on demand from 15 April to 15 September and MOS-1 will also be tracked on demand.

To ensure that representative and useful satellite imagery of Canada exists and is accessible for retrospective studies, CCRS maintains an archive of data sets from the previous Landsat satellites as well as currently recorded data. A copy of the complete CCRS Reception and Archive Policy may be requested from the User Assistance Unit, CCRS, Ottawa.

Data Access

If you are interested in data availability for a particular area CCRS maintains several 'aids' to assist your search. First, there is QUERY, a utility computer program to interrogate the CCRS imagery data bases using your search criteria to generate a listing of available scenes. The service is free and covers Landsat 1 to 5, SPOT-1, and MOS-1.

A second source of information is the imagery of Landsat and SPOT on microfiche which permit preliminary evaluation of image quality and cloud cover. Every image acquired is reproduced on microfiche. The fiche is available for viewing at CCRS and various provincial centres or may be purchased through the Prince Albert Order Desk. CCRS also produces hard-copy catalogues listing the imagery in our Landsat and SPOT data bases. Both the catalogues and microfiche are organized by the Landsat World Reference System of path and row and by the SPOT Ground Reference System. Landsat Index Maps and the Catalogues are available from User Assistance at CCRS, Ottawa.

Products

CCRS processes remote sensing data using Mosaics, the Multi-observation Satellite Image Correction System at the Prince Albert Satellite Station facility.

MOSAICS produces a full range of products from geometrically raw to precision geocoded and offers flexible product options to suit the user's needs. Geometric corrections are calculated for sensor and platform, as well as earth geometry. Output products are available in a radiometrically raw form, or with full radiometric corrections. Products can be framed in a variety of ways. Bulk products can be framed using the standard reference systems for each satellite, WRS for Landsat, or GRS for SPOT, with products being identified by standard path and row indicators. As well, bulk products can be specified by a latitude and longitude value for the scene centre. In addition, Landsat TM quadrant products may be produced for the four standard quadrants and eight offset quadrants. Geocoded products are specified by a map sheet identifier corresponding to a 1:50 000 scale National Topographic System (NTS) map. In addition to the standard radiometric corrections, CCRS offers users the option of specifying a radiometric enhancement for film products. The enhancement can take the form of a histogram based contrast stretch, a sun angle or haze correction, a reflectance enhancement, a multiplicative enhancement or a custom enhancement defined specifically for that particular product.

All Mosaics products are available on CCT in the standard Landsat Ground Stations Operators' Working Group (LGSOWG) format. This standard family of formats allows products to be recorded at either 6250 or 1600 bpi, in either band interleaved by line (BIL) or band sequential (BSQ) format.

Any product can be requested as a film image, in either black and white (B/W) for single band images, or in colour for combinations of three bands. There is no restriction on the bands that are exposed on film. This flexibility in band selection coupled with the capability to apply a wide variety of standard and custom radiometric enhancements affords users a high degree of choice.

Table 6: MOSAICS Products and Correction Options

MOSAICS produces the following full range of products:

- Precision-corrected geocoded subsence
  - projected to a geoid at mean sea level,
  - rotated to UTM projection,
  - full radiometric and geometric correction with ground control points (GCPs).

- Systematic-corrected geocoded subsence
  - along-scan and across-scan geometric corrections,
  - no GCPs and radiometric correction,
  - rotated to UTM projection.

- Geo-referenced full-scene and quadrant (TM only)
  - full radiometric correction and along-scan geometric correction only (no GCPs).

- Raw full-scene and quadrant (TM only)
  - no radiometric or geometric corrections.

NOTE: Full radiometric correction includes both relative and absolute correction.