ENVIRONMENT DESIGN GUIDE

GIS AND REMOTE SENSING FOR TRANSPORT, LAND USE, SITE PLANNING AND LANDSCAPE PLANNING

Hemayet Hossain and Elizabeth Morse-McNabb

SUMMARY OF

ACTIONS TOWARDS SUSTAINABLE OUTCOMES

Environmental Issues/Principal Impacts

Outlines key environmental considerations of issue:

- GIS will be able to provide decision support to improve and protect both the natural and built environments to ensure long-term sustainability of the human habitat.
- Remote sensing is an objective source of data that can be provided over long time periods and spatial scales.

Basic Strategies

In many design situations, boundaries and constraints limit the application of cutting EDGe actions. In these circumstances, designers should at least consider the following:

- GIS requires the informed development and use of a database map digitising system, geographic analysis system, image processing system, statistical analysis system and decision support system.
- Remote sensing requires a clear understanding of the application of each sensor based on its spectral, spatial and temporal resolution. Image processing software and a trained expert is required to undertake the analysis.

Cutting EDGe Strategies

- One of the most popular applications of GIS is suitability modelling, where selected factors are analysed to determine suitable sites for locating certain types of development, either urban, industrial or agricultural.
- Remote sensing has the ability to provide new data sets that contain information in a manner not possible through traditional means. This often provides cost savings and improves the information source.

Synergies and References

- Civil engineers and landscape architects should take advantage of GIS and RS techniques while undertaking development designs.
- *BDP Environment Design Guide* note GEN 37, Sustainable Land Resource Assessment, Victor Sposito, February 2001.
- *BDP Environment Design Guide* note DES 50, Sustainability and Urban Containment, Victor Sposito, November 2002.
- The Australian Centre for Remote Sensing (ACRES) website: www.ga.gov.au/acres/.

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As an introduction to both Geographic Information Systems (GIS) and Remote Sensing, this article describes GIS and explains its components and applications The basic components of remote sensing such as the electromagnetic spectrum, spectral, spatial and temporal resolution are also described. An example of the use of GIS and remote sensing is presented in section two, where a new data set was developed using both disciplines.

1.0 GEOGRAPHIC INFORMATION SYSTEMS (GIS)

1.1 What is a GIS?

A *Geographic Information System* (GIS) is a computerised database integrating the attribute data and its geographic location map. GIS links locational (spatial) and database (tabular) information to visualise where things are and understand why things are where they are. The system shows trends, patterns and relationships amongst phenomena in reference to their geographic location. This gives the user insight into a place. The purpose of a GIS is to provide a spatial framework for planning and management of our resources in a sustainable manner.

One of the earliest GIS can be credited to a transportation study done by the City of Chicago in the late 1950s (Boyce, et al 1970). However, the work that has established GIS as a tool of planning was done by Ian McHarg (1969). The map overlay system McHarg introduced in his *Design With Nature* is one of the most powerful and popular techniques of GIS.

During the last three decades the scope of GIS has increased significantly. This has been supported by phenomenal advancement in computer hardware and software. Almost all professional fields that have reference to locations (most do) have moved to GIS to enable integration of spatial and attribute data and to enhance analytical capability to address planning and management of natural and human-made resources.

1.2 What GIS can do?

GIS can capture relevant phenomena from various sources and translate them into map layers. It can assist in the analysis of these map layers and formulate new composite maps depicting the relationships amongst those phenomena. These become useful information and provide new understanding to assist decision-making in terms of planning and management of natural and human-made resources.

More specifically a GIS can help to do the following:

Mapping spatial distribution – GIS can help find the locations of a phenomenon or an object of interest by querying the maps and associated attribute database. It can also help understand why they are where they are and whether there is a pattern of distribution for a particular phenomenon. One may also be interested to find out places where particular phenomena occur most or least or want to study the density of the distribution.

Finding what's inside – Often one would like to know whether an area contains a phenomena or an object of interest. For example, an engineer may want to know whether there is any historical site within the municipal jurisdiction requiring attention.

Mapping nearness – Similarly, one may want to find out phenomena that are adjacent or nearby. For example a potential tenant may want to know whether a house is next to a double-storey building or whether there is a school nearby. You may also want to find out markets that are within say a 5 kilometre radius from your neighbourhood.

Mapping change – Change detection, that is comparing conditions at different times, is useful to understand trends. This helps one to see how things move over a period of time and can assist in future planning and management. This can also assist to study the impact of a certain policy that has been implemented or the impact of some environmental change. For example, engineers can analyse the effect of climate change on agriculture or infrastructure such as bridges or dams.

1.3 GIS data base

A GIS database includes maps showing geographic locations of phenomena and is always linked to their attribute table. These phenomena could be represented as either a point feature (showing an electric post for example), or a linear feature (such as a road) or an area feature (such as a lake).

On a map, these features are usually represented graphically by points, lines and area surfaces. A GIS can store graphical information in two data formats: raster and vector. Vector format defines the graphical representation by x,y coordinates whereas raster format defines it using grid systems. Vector format is preferred where high locational accuracy is required and raster grids are preferred for modelling purposes. Of course, a GIS can easily convert data between these two structures when required. The following diagram shows raster and vector representations of the same features (Cropland 1, Lake 2, Residential 3) in an area.

1	1	1	1	1	1	1	3	3	3
1	1	1	1	1	1	1	3	3	3
1	1	1	1	1	1	3	3	3	3
1	1	1	2	2	2	2	3	3	3
1	1	1	2	2	2	2	3	3	3
1	1	1	2	2	2	2	3	3	3
1	1	1	1	2	2	2	3	3	3
1	1	1	1	1	1	3	3	3	3
1	1	1	1	1	1	1	3	3	3
1	1	1	1	1	1	1	1	3	3

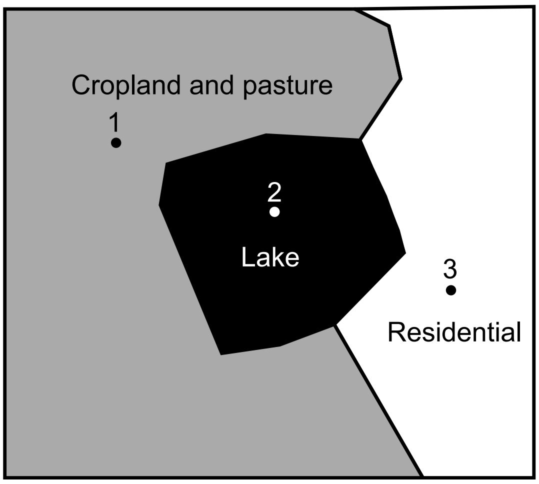

Figure 1. Raster and vector representations of the same features (from www.usgs.gov)

1.4 Components of a GIS

A GIS usually consists of computer hardware, software, data and trained people. GIS requires a powerful computer with necessary peripherals and capable software to do complex quantitative and graphic manipulations. However, because of the exponential development in hardware and software during the last three decades, one can establish a reasonably effective GIS using a high-end PC. There are many GIS software programs available with varying capabilities to suit different needs.

A modern GIS should include the following components:

Database – An integrated spatial and attribute database is core to a GIS and is the most expensive and time consuming part of the comprehensive system. This is a collection of digital maps describing the spatial shape and position of geographic features and associated attribute tables describing the characteristics of these features.

Map Digitising System – This allows digitising of maps either using a digitising tablet (A4 to A0 size) or a scanner. However, the need for this component has reduced significantly over the last two decades since many maps are already available in digital form.

Geographic Analysis System – This provides analytical tools to manipulate data. Relationships amongst phenomena can be studied based on their spatial location. Spatial overlay of maps is a powerful and unique capability of GIS that helps study relationships amongst phenomena that may not even follow the same boundaries. This has helped widen the scope of inquiry in a way that was not possible before. For example, we may now relate slope, soil and utility service areas (all having dissimilar boundaries) to locate suitable residential development.

Image Processing System – An image processing system is an important component of a GIS since remotely sensed images, including aerial photographs, are important data sources on many occasions. For example, satellite images are analysed in conjunction with other field-surveyed data sets to produce a land use map.

Statistical Analysis System – A GIS analysis also involves statistical manipulation of data and therefore is an important component of a comprehensive GIS. This helps to study the attributes of phenomena to understand the data behaviour and make inferences.

Decision Support System – This is the most useful outcome of a GIS in developing analytical and modelling tools to support decision-making in an organisation. This requires development of tools by incorporating and integrating analytical and modelling (internal or external) modules with a user-friendly interface for easier operation. These are developed by organisations to support specific planning and management tasks.

1.5 How to do a GIS project

The following are usual steps in a GIS project and would be carried out by a trained GIS user.

- Identify the problem and note how it is solved now. Set objectives and formulate a GIS approach to resolve the problem.
- Build the necessary database from existing or newly collected data and convert them to formats appropriate for required analysis.
- Develop analytical/modelling tools to carry out required analysis of data. This may be a selection of geographic tools already available in a GIS or may be a complex integration with external models.
- Perform the analysis using methods developed. Depending on the complexity of analysis, size of the data (a factor of data type, resolution and study area) and the capability of the hardware it may take from minutes to days to process the data.
- Finally, present the results in suitable maps, tables and graphics (on screen and printed hard copies) to the project team.

1.6 Why use GIS?

Make better decisions – Better decisions are made based on better knowledge and understanding of the systems, whether natural or human-made, we are trying to improve upon. Equipped with unique geographic analytical ability and inter-active visualisation, GIS provides information in a manner that has expanded the scope of knowledge and understanding of decision-makers, and provides them with a tool to make much better decisions. User-friendly GIS driven visual information over the Internet is a new-dimension of public access and participation.

GIS provides a decision support system that has never been possible to develop or use in the past.

Improve organisational integration – GIS provides an opportunity to integrate information over an organisation. It enforces logical integration and reduces duplication. Since this offers an integrated database the accuracy and consistency of data improves across the departments. An integrated information system also influences better organisational integration.

1.7 Applications of GIS

As is proclaimed by Jack Dangermond, President, Environmental Systems Research Institute (ESRI, world leaders in GIS software products), the application of GIS "is only limited by the imagination of those who use it." Over the last three decades the scope of GIS applications has increased enormously.

Some of the common applications of GIS across organisations today are the following.

Information retrieval – A user can query into the database to find features of interest based on certain criteria and display them in a map. He/she can also point to a feature in a map and see its attributes in a table. Similarly, one can locate a feature in a table and can then see its representation in a map. This is possible because the locational map and the attribute table are always linked.

Topological modelling – The most important ability of a GIS is the topological modelling based on the spatial relationships of mapped phenomena. This enables GIS to answer what is next to what (adjacency), what is enclosed by what (containment), and how close is something to something (proximity).

Network analysis – A GIS can represent resource flow through networks such as road networks, water networks, gas networks, electricity networks, sewerage networks, etc. Subsequently network analysis can help understand flow through networks and determine efficiency or bottlenecks in the network and assist in future planning and management of resource delivery through the network.

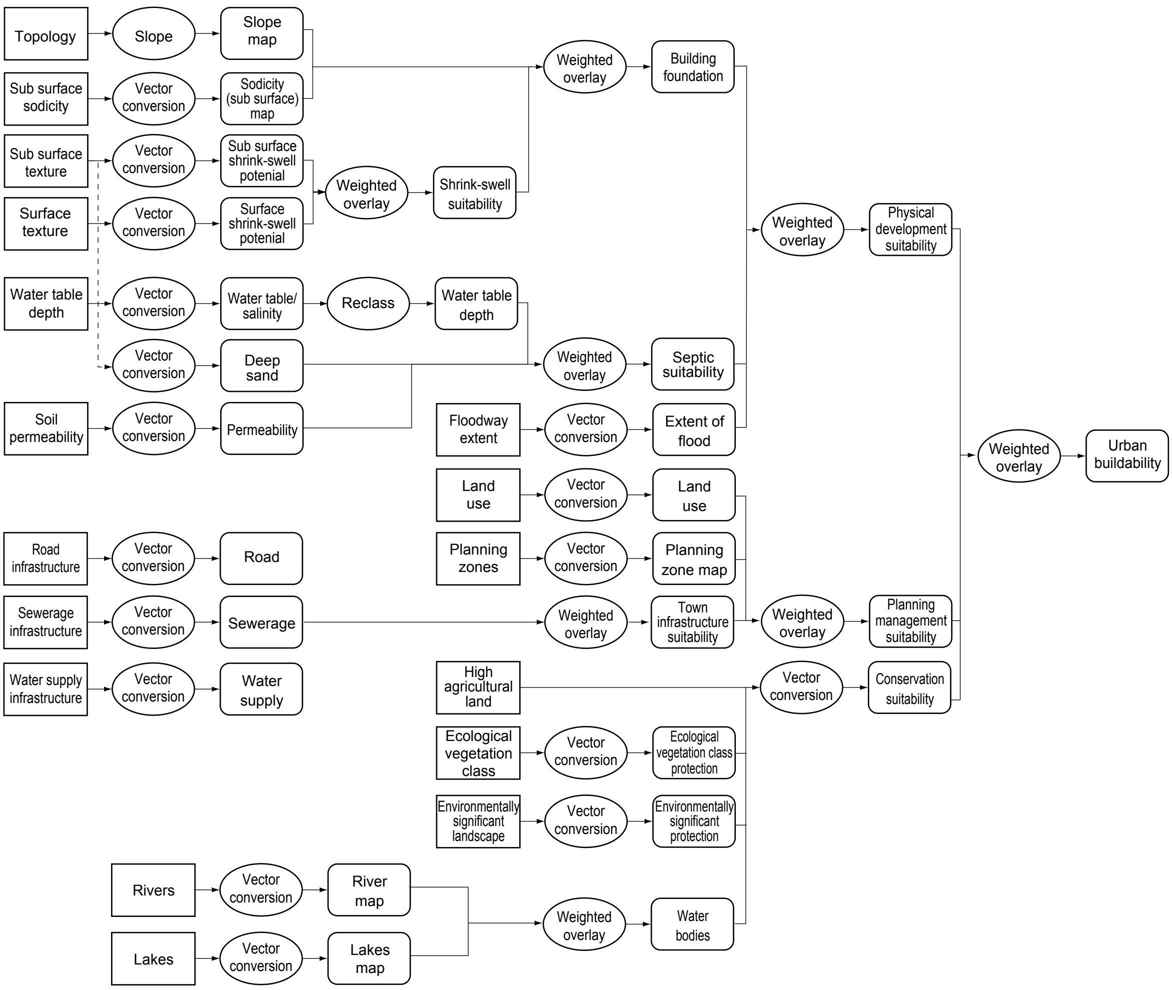

Figure 2. Urban buildability model

Site selection – One of the most popular applications of GIS has been in the suitability modelling where selected factors are analysed to determine suitable sites for locating certain types of development. For example, the Urban Buildability Model (Sposito 2002), Figure 2, considers physical, environmental and infrastructure factors to identify land suitable for urban development.

Emergency response planning – A recent application of GIS has been in the development of an emergency response system. For example, a system can be developed to tackle fire management tasks after a forest fire breaks out. GIS is also being used to quickly provide services in medical emergencies. These systems utilise the geographic analysis functions to identify target sites where emergency services need to be provided quickly.

3D visualisation – Increasingly, three dimensional modelling is being used in a GIS to represent phenomena in a more realistic perspective. In many urban municipalities it is now a requirement to submit a 3D perspective to see the impact of the proposed development.

Internet GIS – In recent times many organisations have started developing internet web sites to deliver information and services. A logical extension has been the development of GIS-engined visual information over the internet. This has enhanced public access to information and participation to a new dimension.

1.8 GIS in transport

As previously mentioned, one of the early applications of GIS was in the field of transport engineering. GIS is now being used to make better decisions in regard to transport network planning and management around the world and includes road, rail, water, and air transport. It is estimated that more than 80 percent of the information used in transport management has a spatial component.

More specifically, GIS helps in the study of travel demand, traffic flow, asset management, road and infrastructure management, inter-modal transport management, safety analysis and providing information to the public through the Internet.

GIS is also being used to find the best way to deliver goods and services, track fleet vehicles, manage road design and construction.

1.9 GIS in land use planning

One of the major uses of GIS has been in land use planning and zoning. Most local governments, whether urban or rural, now use GIS to formulate land use plans.

This involves the use of GIS to study the current social, economic, demographic, physical and environmental conditions and forecasts of possible future scenarios utilising GIS analysis and modelling tools. Optimal land use plans are then selected to meet desirable objectives. GIS also assists the implementation of the land use plans and zoning.

More common applications include:

- general plan mapping and analysis
- zone mapping
- demographic analysis and mapping
- economic development
- land suitability modelling
- permit issuance
- sub-division review/lot mapping
- property assessment and tax mapping
- land acquisition and disposition
- building and property inventory
- crime analysis
- facility siting and analysis
- cadastral mapping
- providing information to the public through the Internet.

1.10 GIS in landscape planning and site development

Traditionally, landscape architects and engineers have been using CAD software for landscape planning and site development tasks. However, in recent times, the application of GIS is seen as a complementary tool since it adds useful analytical capabilities for landscape and site analysis. Responding to the demand, GIS software now provides options to import existing CAD data into GIS.

The pioneering work by McHarg (1969) has established the GIS approach for landscape planning with an emphasis on sustainable natural resource management. GIS is being used by landscape architects for monitoring landscape change, significant landscape analysis, watershed management, historic preservation, environmental risk analysis and management, land resource analysis, land capability modelling and landscape mapping.

GIS is also being used in site design for subdivision layouts, resort designs, park master planning, trails planning, visual analysis and green way designs, etc. GIS provides more opportunities in site suitability analysis than the traditional site design approach. Hanna and Culpepper (1998) give a good introduction on the application of GIS and site design.

1.11 Conclusions

Professionals in many disciplines have benefited from GIS and its scope is increasing. Since GIS can integrate data from many diverse sources with a variety of attributes that can be analysed and viewed in both 2D and 3D, its application and outputs have become much more acceptable to decision makers. GIS has combined techniques from cartography, surveying, remote sensing, global positioning systems, photogrammetry, and geography and has evolved to become a discipline in its own right.

With the advancement in computer hardware and software, GIS will be able to provide decision support to improve and protect both the natural and built environments to ensure long-term sustainability of the human habitat.

2.0 REMOTE SENSING

2.1 Introduction to remote sensing

Remote sensing is the science, technology and art of obtaining information about objects or phenomena from a distance. It provides a synoptic (large area, all-at-once) view from a bird's-eye perspective. Imagery can be obtained rapidly and repeatedly over large areas by aerial and satellite based sensors.

Remote sensing is an objective source of data that can be provided over large time periods and spatial (i.e. geographic) scales. As the data is collected from a range of regions in the electromagnetic spectrum (Figure 3), it is possible to obtain specific information on the characteristics of the Earth's surface and atmosphere. Sensors are either active or passive. Passive sensors require reflected radiation from the Earth's surface. As the majority of passive sensors record in the visible spectrum, they also rely on the illumination of the Sun, therefore they cannot image at night and the images are interrupted by cloud. Active sensors are most commonly radar-based sensors. These instruments emit a source of electromagnetic energy at a specific wavelength and then measure the returned signal. Therefore, they are not influenced by cloud cover or the solar cycle.

The spectral resolution of a sensor describes the area of the electromagnetic spectrum that is measured and recorded. A commonly used remote sensing satellite for environmental assessment, LANDSAT ETM+, currently measures electromagnetic reflectance from 8 bands of the spectrum, three bands in the visible spectrum (blue, green and red), one near infrared band, two middle infrared bands, one thermal infrared and one panchromatic band covering the green, visible red and near infrared range. A recently launched satellite that has freely available data is MODIS, it measures in 36 bands of the electromagnetic spectrum, from 405nm to 14.4µm (where 1m = 10^6µm = 10^9nm) in the electromagnetic spectrum. There are sensors that measure hundreds of bands and these are called hyper-spectral sensors. The width of the bands is very small in these cases to accommodate the large number and therefore the measured reflectivity in each band is very specific. For example the Hyperion sensor onboard the EO-1 spacecraft has 220 bands ranging from 0.4–2.5µm in the electromagnetic spectrum and each band has a spectral resolution (band width) of only 10nm. For further information on these and other satellite sensors visit www.ga.gov.au/acres/prod_ser/sensor.htm.

Apart from the considerations of spectral band number and width it is important to understand the constraints of spatial and temporal resolution. The spatial resolution of satellite imagery describes the size of each individual area measured by the instrument that combines to make the whole image. This is commonly called the pixel resolution. As an example the spatial resolution of LANDSAT ETM+ is 30 metres, therefore each 30x30m area on the surface is assigned a measure of reflectance in each of the 8 bands.

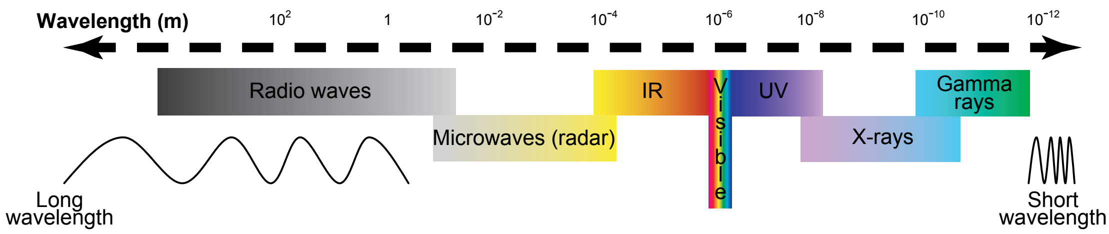

Figure 3. The electromagnetic spectrum

Satellite	Spectral	Spatial	Temporal
Landsat ETM+	8 bands, 7 single multi-spectral bands and 1 panchromatic band covering the green, visible red and near infrared range.	18m panchromatic pixel resolution, 30m multi-spectral resolution. Swath width (total image width) = 185km.	16 day repeat coverage interval.
MODIS	36 bands from visible through to far infrared/microwave.	Bands 1 and 2 have a 250m pixel resolution while bands 3–7 is 500m and bands 8–36 is 1000m. Swath width = 2330km by 10 degrees of latitude.	Daily
Hyperion	220 bands from 0.4–2.5µm with 10nm band resolution.	All bands have 30m pixel resolution. The swath width is 7.7km by 42km.	16 day repeat coverage interval.
ERS	One band in the microwave region at 56mm with a 15.55MHz bandwidth.	The pixel resolution ranges from 4m x 8m to 24m x 24m depending on the level of processing. The swath width is 100km.	35 day repeat coverage interval.

Table 1. Four examples of satellite remote sensors

Temporal resolution describes how often the same surface area will be measured. This time can vary from hours in meteorological satellites to weekly or monthly revisits in many environmental satellites. Table 1 gives four examples of satellite spectral, spatial and temporal resolution. Further general information about these sensors and data purchase information is given on the Geoscience Australia web site, www.agso.gov.au/acres/.

Interpretation of the resultant remotely sensed imagery requires extensive processing and transformation of the data before any analysis of the data can be done. This requires specific software and trained analysts to use the software. Considering the remotely sensed imagery is effectively a raster grid of values for various bands at various times, quantitative analysis can be made that endeavours to identify various land cover types, plant health and land cover extent etc. Classification of imagery is one standard procedure used in quantitative image analysis; it groups all pixels with the same spectral signature through a range of bands. This process can be achieved by the analyst defining areas of known cover type or by letting the software divide the image into a defined number of discrete classes. It is important to check the results of such classifications by field assessment or comparison to data of known accuracy.

Remote sensing is a very useful tool for the provision of data temporally and spatially through means not readily available otherwise. However, the spatial, spectral and temporal resolution of the imagery must be very carefully matched to the intended use. Without this consideration the data will always fail to provide the desired information.

2.2 Applications of relevance

Remote Sensing can be used in many planning applications. The most obvious and easily applicable are land use planning, site development and landscape planning. Transport planning can and does use many forms of remote sensing; however, these are commonly site-specific, task-specific sensors, not multi-tasked commercially available sensors that have been discussed in this note. Within land use planning, remote sensing could be used for land evaluation, zoning evaluation, land use planning and management. Site development can be aided by remote sensing as a timely and cost effective additional method of site assessment and analysis, site selection and site mapping. Remote sensing is essential to landscape planning, due to the scale of many investigations and the necessity to gain information from public and private land equally. An example of some of the considerations required before using remote sensing in these planning areas is shown in Table 2.

An example of remote sensing assisting in achieving environmentally sustainable development

A recent study completed by the Strategic Resources Planning Unit, Primary Industries Research Victoria, catalogued the environmental features of Wyndham City Council in Melbourne. GIS was used extensively through this project to combine, collate and associate various features in the council area. Remote sensing was used to develop new information about rock outcrops in Wyndham. Wyndham is largely sited in the newer volcanic geological zone of Victoria that stretches from Wyndham's eastern boundary to Colac in the west of Victoria. Typically, newer volcanic zones have extensive areas of rock outcrops at or near the soil

Application	Spectral	Spatial	Temporal
Land Use	Multi-spectral imagery is essential for this use in order to differentiate land cover types. It may also be useful to gain information in the microwave regions to help differentiate land use further.	As many land use studies are done on a regional basis. Pixel resolution from 10–30m would be adequate to development land use information at a scale of 1:50,000 and 1:100,000 respectively. Cost may inhibit the use of finer resolution imagery at the regional scale.	Differentiating the seasonal growth patterns of different land cover types is a very useful way to accurately establish land use. Therefore land use mapping of the non-built environment would require 3–6 images over one year.
Site Development	Multi-spectral imagery is not always important in this case – it just produces a prettier picture. However, some building versus vegetation classification may be helpful if multi-spectral imagery were available at the right spatial scale.	This is the most crucial component for site development as the scale is commonly in the range of 10s to 100s of hectares not 1000s as in land use planning. Here pixel resolutions of <5m would be best. At this resolution, aerial photography is still competitive in price to fine resolution satellite imagery.	Current data would be most useful (< a month) in order to get a real life perspective of what's on the ground. Historical data may also be interesting; however it is unlikely to have the same spatial scale or spectral range (1–2 images).
Landscape Planning	The spectral range needed depends on the type of landscape under investigation. However, in the majority of cases a multi-spectral sensor with Red, Green and Blue in the visible spectrum and near infrared would be OK.	If analysing large areas (1000s of hectares) then 10–30m pixels are fine. Smaller pixels may introduce variance and increase processing requirements too much.	The revisit time is not as important as obtaining one or two good/ clear images during important seasonal events (1–3 images).

Table 2. Application considerations

surface. These rock outcrops are extremely good habitat for native flora and small fauna. From a development point of view, they can present many challenges for building foundations and infrastructure. Rock outcrops are often difficult to see in a landscape as grass will cover their extent and often these newer volcanic areas have many loose surface rocks and boulders making the surface very difficult to traverse.

The image used to determine the extent and type of rock outcrop in Wyndham was a satellite (no longer in use) called JERS (Japanese Earth Resource Satellite). This satellite sensor was an active radar sensor with a spectral resolution of 23cm. The spatial pixel resolution of the sensor was 12.5m with a whole image (swath) width of approximately 90km x 90km. The image was taken in April 1996. Due to the consistency of rock formations over time the temporal resolution was irrelevant for this investigation. A successful identification of rock outcrops and areas covered with surface rock was achieved in this case because the sensor had a spectral resolution that would provide information about hard and dense surfaces and the area under investigation had very little tree cover to interrupt the surface signal.

As a result of image analysis an important new data set was developed that was a major influence in highlighting areas of potentially rich native flora and fauna habitat in a peri-urban environment under increasing development pressure.

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BIOGRAPHY

Dr Hemayet Hossain (MSc [Dakha], DED [Texas]) has wide-ranging experience in Resource Management Information Systems with a particular interest in the appropriate use of GIS-based social and environmental data analysis. He has developed a broad range of information systems to manage social and environmental resources for government and private organisations involved in natural resources, land use, agriculture, housing, transport and utility services.

Hemayet received a Master of Science degree from the University of Dakha, Bangladesh, and a Doctorate of Environmental Design from Texas A&M University. He has worked extensively in Asia and held major academic appointments at the Bangladesh University of Engineering and Technology, Texas A&M University and Melbourne University. He is currently a Senior Fellow in the Faculty of Architecture, Building and Planning, University of Melbourne.

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Elizabeth Morse-McNabb BAgSc has strong interests in agricultural sustainability, remote sensing and GIS applications. Elizabeth completed a Bachelor of Agricultural Science at Melbourne University which provided an excellent grounding in plant pathology, botany, animal husbandry and crop physiology among many other fields. Remote sensing and GIS subjects were undertaken in the Department of Geomatics, at Melbourne University, as part of her undergraduate degree in order to fully understand the important relationship between agricultural management and remote sensing.

Elizabeth has recently completed a PhD thesis, which has undertaken to combine her knowledge of agricultural management systems and remote sensing and GIS skills. The aim of the project has been to develop a correlation between the backscattering coefficient, from the satellite radar sensor ERS-2, and soil moisture measurements taken in a Victorian dryland cropping environment.

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