MODULE 3

MODULE 3: Interpretation and Visualisation of Data - An Introduction to Spatial Information Systems

Building capacity to implement natural resources information management systems.

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Guide for managers

Context

One of the prerequisites for natural resources management (NRM) involves the establishment and maintenance of a good database of information in digital format. Access to reliable and up-to-date information reduces the uncertainty in planning and management by helping identify and analyse situations and issues. Strategies to overcome them may then be prepared and implemented, with the impacts monitored as part of an overall system. The value of the information and the effectiveness of the decision-making/planning processes are very closely related to the quality and completeness of the information and the manner in which it is made available. In this respect data access, management, integration, analysis, standards, and communication are key components.

Under current arrangements, funding for NRM projects is increasingly being channelled from government agencies to regional groups, such as catchment management authorities and resource information centres.

In many situations regional groups are faced with the need to purchase spatial (or geographic) information system software. A spatial information system (SIS) is a computer system for capture (input), storage (management), analysis and display of spatial data, i.e. data that can be referenced according to location. Although an SIS is often thought of as a single piece of software, in reality, to be effective it should be considered as part of an information management system including procedures, operating personnel, data and hardware. In this context, an SIS is a computer system which facilitates the phases of data entry, management, manipulation and analysis and presentation.

Module 3: Interpretation and visualisation of data – an introduction to spatial information systems provides background material to assist regional groups obtain an understanding of spatial information systems and the visualisation of spatial data.

Actions

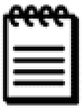
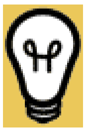
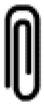
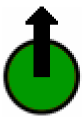
Managers should be aware of the basic operations of SIS applications and how they can support the management of natural resources. In addition, managers should be aware that a complete range of software is now available, starting with free-viewing applications (with limited functionality), through to high-end professional systems and web-based applications. As such, it is now possible for the whole community to have access to spatial data on desktop computers. An understanding of the basic functions of SIS will enable managers to more fully appreciate the benefits that can be realised from a fully integrated information solution incorporating SIS and spatial visualisation tools. In this sense, the whole community is now in a position to capitalise and leverage the benefits obtained from access to natural resource data, and the enrichment those geospatial data can bring to their profession. Numerous services are available to support this process, e.g. the Australian Natural Resources Atlas, the Australian Natural Resources Data Library, and various state-based clearing houses or data portals that enable access to spatial datasets.

Acknowledgements

This module draws heavily on material produced by the United States Geological Survey (USGS) especially as it relates to the text and graphics included at Sections 3.2 and 3.3. The source of this material is duly acknowledged.

Guide to symbols

The following symbols are used throughout the Toolkit as a guide to users, and draw attention to important issues and information.

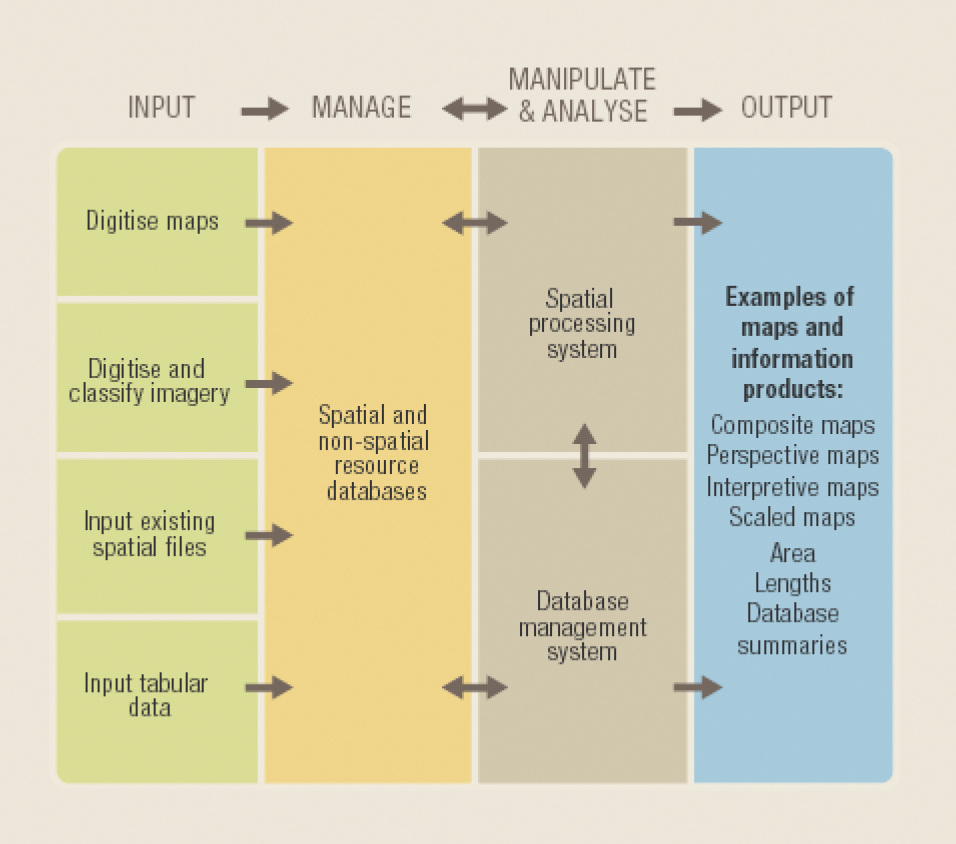
	Information which readers should take particular note of
	Best practice information
	Tips for readers—based on experience and aimed at saving time and resources
	Caution—readers are advised that particular care should be taken or that the subject issue may be complex
	Additional information
	Capability raising—used to show a signpost to a higher capability level
Bold Text	Used to highlight a particular issue
Boxed Text	Highlighting of issues specifically related to ANZLIC or the Audit

3.1 Introduction

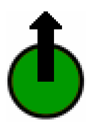
3.1.1 What is a spatial information management system?

A spatial information system (SIS) is a computer system for capture (input), storage (management), analysis and display of geographic data, i.e. data that can be referenced according to location (Figure 3–1).

Figure 3–1 Theoretical schematic for a spatial information system.



The use of a thematic layer approach makes it possible to organise the complexity of the real world into a simple representation to help facilitate an understanding of natural relationships.



Key staff and/or departmental sections demonstrate an understanding of spatial information systems, and their application to key NRM processes.

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Although an SIS is often thought of as a single piece of software, in reality, to be effective it should be considered as part of an information management system including procedures, operating personnel, data and hardware. In this context, an SIS is a computer system which facilitates the phases of data entry, management, manipulation and analysis, and presentation.

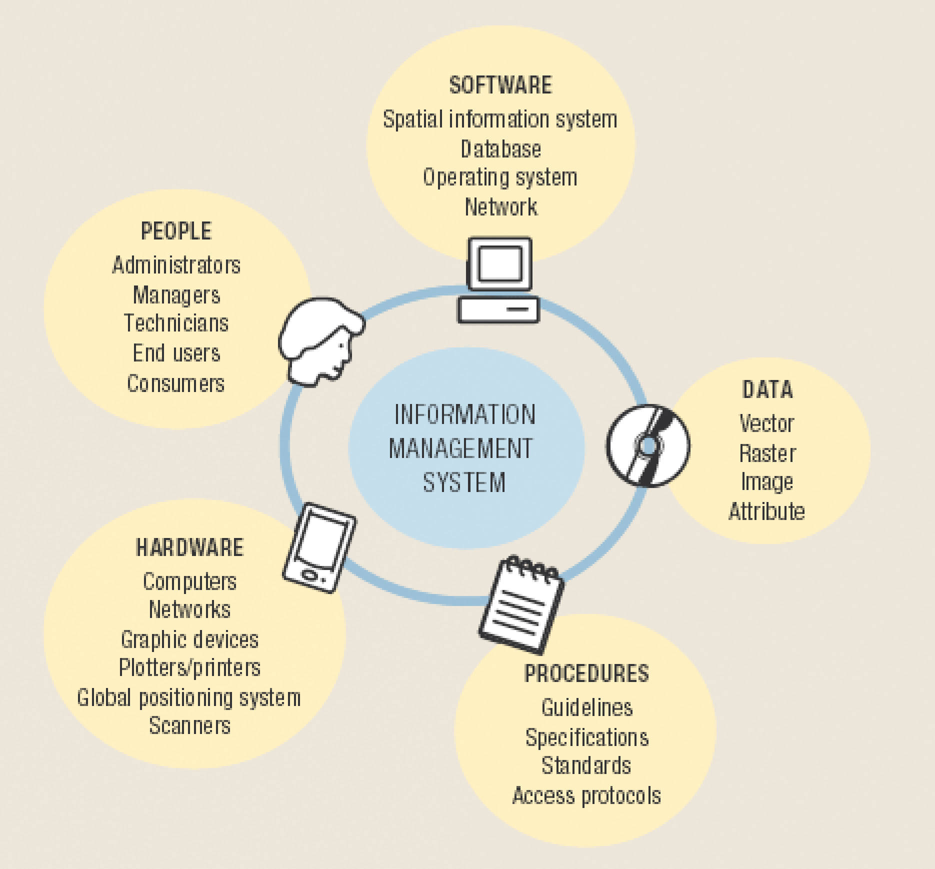


Figure 3–2 Framework for an integrated information management solution.

One of the major strengths of an SIS is its ability to link numerous databases of information within a system, making it possible to visualise and view data in a spatial context. **In this sense many datasets contained in simple external spreadsheets or large regulatory databases, which were previously only used within a discrete domain of an organisation, can be integrated into an SIS to generate an additional level of information and analysis that was not previously possible.** Once within an SIS it is also possible to produce mapped outputs which are often very useful to assist managers in the decision-making process by being able to visualise relationships.

2 ▸▸ 3

From a senior level down the organisation or NRM group demonstrates its understanding of spatial information systems and their relevance to core business activities. Such commitment may be illustrated by the use of spatial information products in the support of decision-making processes and the formalised support of tools, technologies and resource allocation.

3.1.2 Spatial data and geoinformation

Many practitioners often use the terms *data* and *information* interchangeably, without the risk of being confusing. There are occasions however, where it is important to distinguish them. In general:

Data are statistics, facts, concepts or instructions organised in a formalised manner suitable for communication or processing by humans or computer.

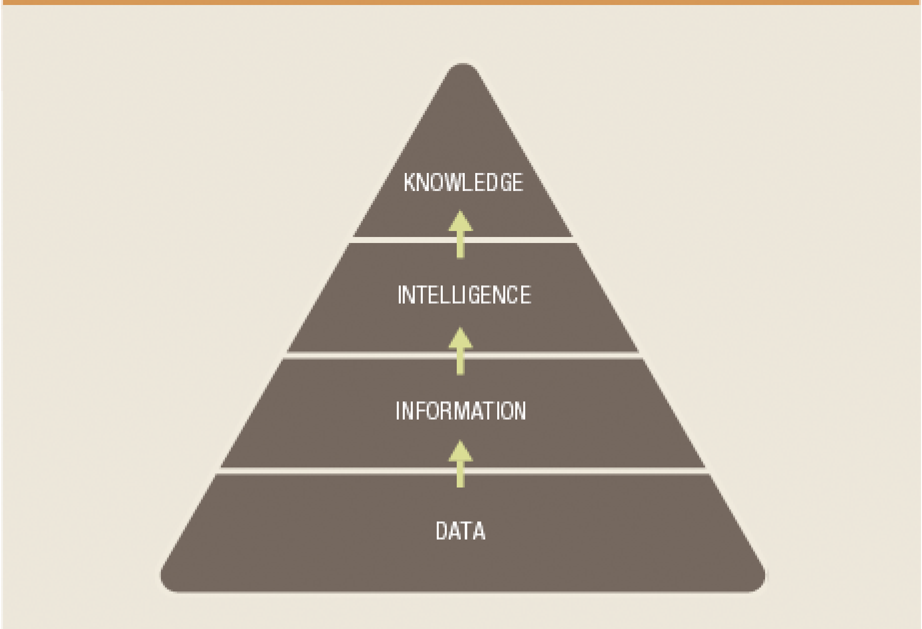
Spatial data are data that have positional values related to them. In some situations the term geospatial data is used as a further refinement—this refers to spatial data that have been georeferenced. (Note: Strictly speaking spatial data that are not georeferenced can have positional data that are not related to the earth's surface. For example, in an industrial engineering design, the parts of an engine may be defined relative to each other as opposed to their location relative to the earth's surface).

Information is data that have been value-added, processed and interpreted.

Geoinformation is a specific type of information which involves the interpretation of spatial data. It has been argued that it is the transformation of data to decision making which brings a level of understanding and knowledge, and the ability to make informed interventions to improve the management of natural resources.

A schema for this concept is illustrated at Figure 3–3.

Figure 3–3 Schematic illustration of the progression of data into knowledge.



The goal of information systems is to convert data into information. Data are considered to be the 'input' to a process where information is created. For example, daily rainfall recorded over long periods can be used to produce a monthly mean average for a particular location.

An SIS is used in NRM to provide the elements of measurement, mapping, monitoring, and modelling which facilitates improved management decisions.

3.2 How does an SIS work?

3.2.1 Relating information from different sources

The power of an SIS lies in its ability to relate different layers of information through the same location, and to derive conclusions about the relationship. It has been estimated that 80% of data have some form of graphical component, and can therefore be referenced to geographical locations such as points, lines or areas. For example, when rainfall data are collected it is important to know where the collection station is located. This is done by using a location system, such as longitude and latitude. Comparison of rainfall information with other thematic data, such as the location of wetlands within a catchment landscape, may reveal that some wetlands receive little direct rainfall and in fact receive most of the their water from streams or underground sources. This may indicate that these wetlands could be severely impacted if the underground water table level dropped due to excess pumping for irrigation, or if streams feeding the wetlands are diverted for irrigation projects further up in the catchment area. Such information can assist in determining the most appropriate decisions on how to manage the resources wisely.

SIS technology is widely used in the management of natural resources to reveal new information that ultimately leads to more informed decision making. Strategies for their improved management can then be developed with the results monitored as part of an overall system.

Many datasets produced by Australian, state, territory and local governments, private companies, universities, international and non-profit organisations available in spreadsheet or database format, can be directly entered into an SIS—either as a new data layer or linked to existing data layers. An example of such layers is given in Figures 3–4 to 3–10.

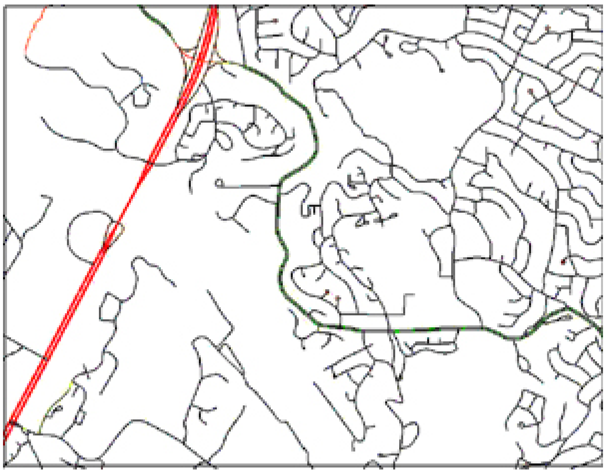


Figure 3–4 Digital line(vector) data for roads

Figure 3–5 Rivers

Figure 3–6 Contour lines

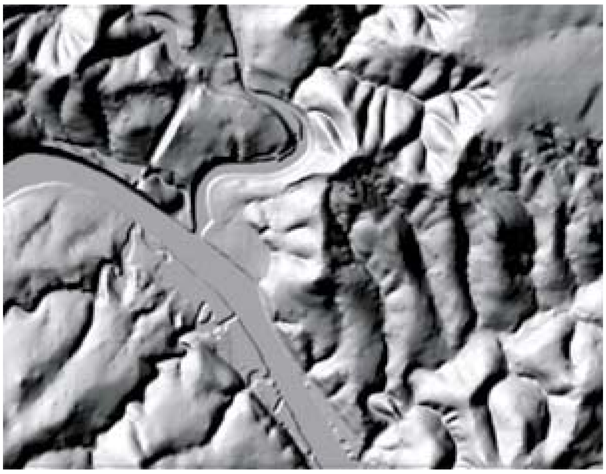


Figure 3–7 Digital elevation model DEM, (raster data)

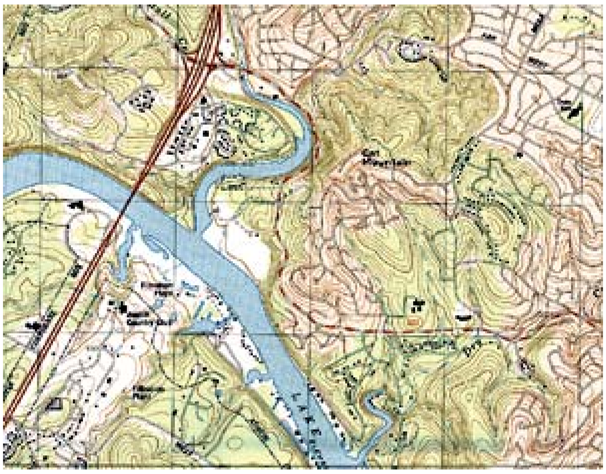


Figure 3–8 Scanned, rectified topographic map called a digital raster graphic (DRG)

Figure 3–9 Digital orthophoto

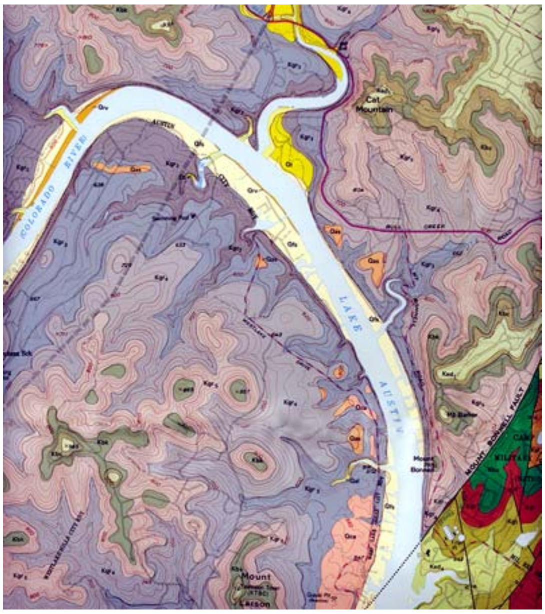


Figure 3–10 Geology map

In addition, an SIS can also import or convert digital data from other sources into a form which can be displayed and used for analysis. Thus, a digital Landsat ETM 7 satellite image may be in the supplier's native data format, e.g. the Australian Centre for Remote Sensing (ACRES) format[1]. This can be imported into the SIS where it can be analysed using specialised remote sensing procedures to produce a digital land use/land cover layer (Figures 3–11 and 3–12).

Figure 3–11 Landsat 7 satellite image from which land cover information can be derived

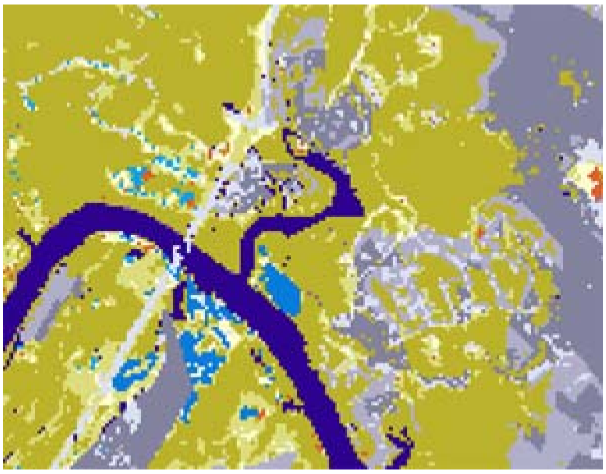


Figure 3–12 Satellite image data in Figure 3–8 have been analysed to indicate classes of land use and cover

[1] *Satellite receiving stations often have their own formats in which they ship data. The Australian Centre for Remote Sensing (ACRES) has a specific format for Landsat 7 Thematic Mapper imagery known as TM Landsat-7 Fast-L7A ACRES. Imagery supplied in this format can be imported to enable it to be displayed and used for analysis.*

Similarly, census or other tabular data such as hydrological data for a stream gauging station can be integrated into an SIS and displayed as map data (Figures 3–13 and 3–14).

Figure3–13 Part of a census data file containing address and owner information

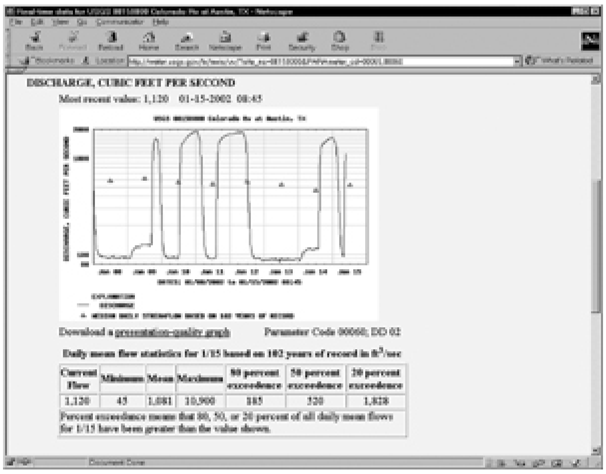


Figure 3–14 Part of a hydrologic data report indicating the discharge and amount of river flow recorded by a particular stream gauge that has a known location

3.2.2 Data capture

For data to be used within an SIS they must be in a suitable format. Various techniques can be used to convert data into a form that can be recognised within an SIS. For example, hardcopy (paper) maps can be digitised by using a digitising tablet to trace and collect the spatial features from the map. Alternatively, the map may be scanned and converted into an image, rectified and then digitised on screen using a mouse—often referred to as 'heads-up digitising' (Figure 3–15.

Figure 3–15 Scanning paper maps to produce digital data files for input into an SIS

Figure 3–16 Collecting latitude and longitude coordinates with a global positioning system (GPS) receiver

In addition, coordinates from global positioning systems (GPS) receivers (Figure 3–16) can be uploaded directly or manually entered into an SIS. GPS surveys can be very time consuming and expensive, and therefore need to be carefully designed and planned to return maximum benefit. A number of issues need to be considered prior to undertaking a GPS survey. Extensive support on GPS surveys, including a technical background to GPS, and best practice guidelines is presented in Module 10.

Data capture involves entering an object into the system and attaching the relevant attributes. Spatial relationships (e.g. whether features intersect, or are adjacent to another object) are the key to SIS-based analysis, i.e. an SIS can be used to identify spatial relationships among objects. It is this feature that separates an SIS from other computer-aided design or mapping systems. For example, a computer-aided mapping system may represent a road as a line (in which case the object carries the information, e.g. track as a thin line versus highway as a thick line) whereas in an SIS the road is a line to which the attributes are attached (e.g. track or highway). In addition, an SIS can recognise the road as a line but also as a boundary between wetland and urban development in two local government areas.

3.2.3 Data integration

Using spatial information software it is possible to integrate or link data and information that would otherwise be difficult to associate. For example, imagery from satellites, aerial photography, digital elevation and tabular data can be analysed, and new variables derived as outlined in Figure 3–17. As a result, it is possible to combine agricultural records with stream data to determine which streams will carry certain levels of nutrients due to fertiliser run-off from agriculture fields.

Agricultural records can also indicate how much herbicide was applied to a parcel of land. SIS technology can be used to predict the amount of nutrient run-off in each stream by locating the relevant fields and intersecting them with streams. Where streams converge this process can be further developed to calculate the total loads downstream where the water course enters a lake or wetland area. Further information on the compilation of such data is given in Section 3.3.4 using an example of processing development applications.

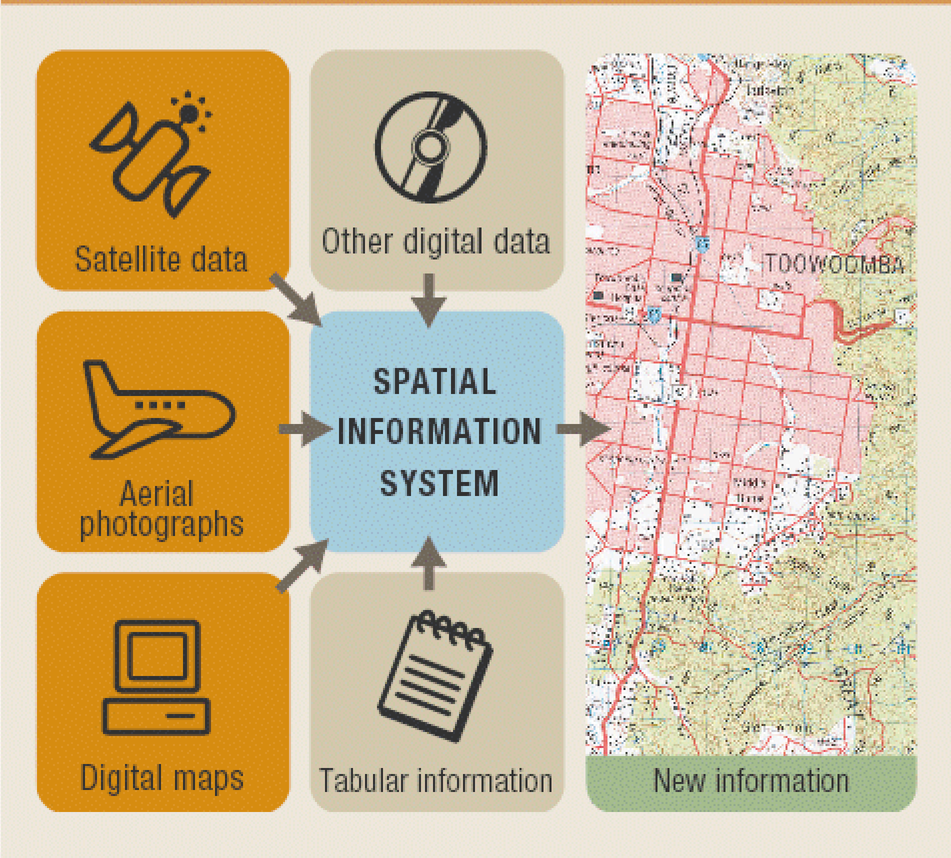


Figure 3–17 Data integration is the linking of information in different forms through a spatial system.

3.2.4 Projection and registration

In many cases NRM regional groups encounter situations where a property ownership map may be at a different scale and projection from a soils map. **Map information in an SIS must be manipulated so it registers or 'fits' with the information gathered for other layers.** Therefore, before such datasets can be analysed to determine patterns or relationships within the SIS, they may have to undergo certain manipulations, such as projection conversions to ensure that all datasets being analysed have the same datum and projection.

Projections are an essential component when making maps and undertaking spatial analysis. In simple terms, a projection is a mathematical model which transforms the locations of features on the earth's three-dimensional, curved surface, to locations on a two-dimensional surface such as a computer screen or map. It should be noted that different projections are used for different purposes—some preserve shape, others preserve the accuracy of area, distance or direction. The examples presented in Figures 3–18 and 3–19 illustrate how datasets in different projections can be transformed into a common projection.

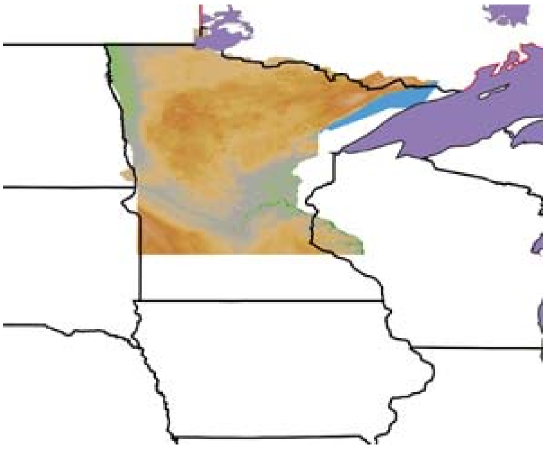


Figure 3–18 A digital elevation model exists in a different scale and projection from the lines on representing administration boundaries

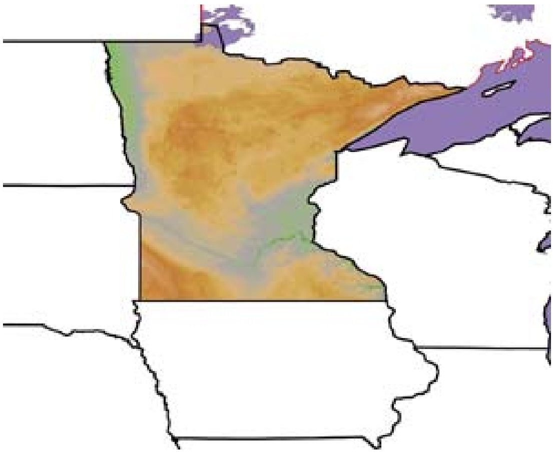


Figure 3–19 The elevation dataset has been reprojected to match the projection and scale of the administration boundaries

In addition, there are often corrections that need to be carried out when inputting data into an SIS due to surveying errors or poor copies being made of original diagrams. These issues are faced daily by SIS specialists within regional NRM groups, who often have established procedures and processes to handle such situations.

Module 9: Map production guidelines discusses the use of different projections depending on the particular need.

3.3 Data structures

An SIS stores two types of data—vector and raster.

Vector data are captured as points, lines (a series of point coordinates that are connected), or areas (polygon shapes that are bounded by lines) (Figure 3–20). Property boundaries and roads are typically stored in vector format with a corresponding attribute file. Property parcels contain details of owner name, valuation and land use zone, while the road file may contain details such as type (e.g. highway or track).

Raster data files consist of rows of uniform cells coded according to data values (Figure 3–21). For example, a satellite image (which uses a raster structure) can be interpreted using remote sensing tools to produce a land use/land cover map also in raster format. (Figure 3–12). Raster files are generally larger in size than vector files and are sometimes less visually appealing than vector data files. However, raster data systems are very good at evaluating environmental models such as soil erosion, land slide vulnerability, forest management suitability or fire hazard management. They are also valuable for providing backdrops of aerial photography for land use planning and a range of other NRM decision-making processes.

Figure 3–20 Example of the structure of a vector data file.

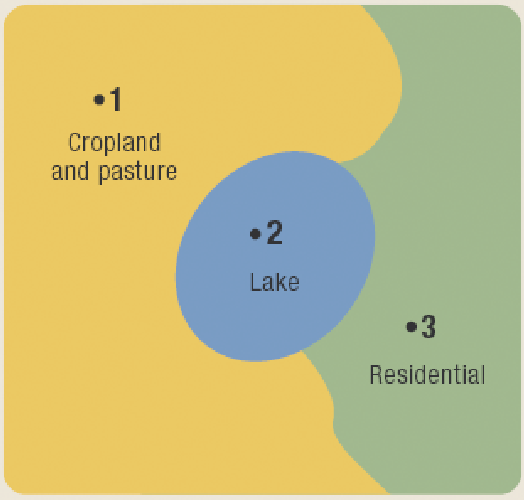
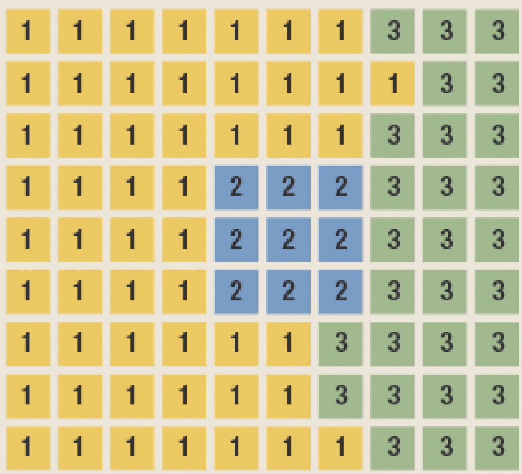


Figure 3–21 Example of the structure of a raster file.



Data restructuring can be carried out using SIS to convert data between different formats, e.g. from raster to vector or vice versa. As a result, an SIS can be used to convert a raster land use/land cover map (interpreted from a satellite image to a vector structure) by generating lines around all the cells with the same classification, whilst determining the spatial relationships of the cell, such as adjacency or inclusion (Figures 3–22 and 3–23).

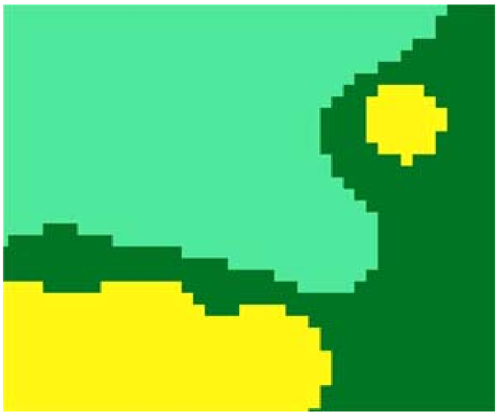


Figure 3–22 Magnified view of the same SIS data file, shown in raster format—previous Figure 3–12

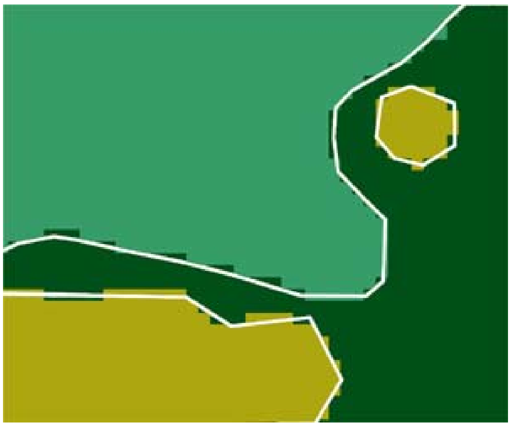


Figure 3–23 Magnified views of the same SIS data file converted into vector format

3.3.1 Data modelling and interpolation

A model is a relationship between located observed values that provides a prediction of the value for un-observed locations, i.e. in effect it can be seen as a method of describing something that cannot (or has not) been observed directly. Given that it is not feasible to collect data from every square meter of a catchment area, models can be used to create simplified representations of reality. Apart from making it easy to process, analyse and combine spatial data, spatial information technology has also made it easy to arrange and integrate spatial processes into larger systems in which thematic layers and their relationships can be modelled using spatial analysis tools.

For example, based on the input of points representing pH results from soil test locations in a paddock, an SIS can quickly generate a map with isolines (or contour lines) representing the level of pH throughout the paddock (Figures 3–24 and 3–25). Such a map can be thought of as a soil pH contour map. Many methods can be used to estimate the characteristics of surfaces from a limited number of point measurements. Two- and three-dimensional contour maps, derived from the surface modelling of soil pH sampling point measurements, can be analysed together with any other map (e.g. soil texture, depth, moisture holding capacity, etc.) in an SIS to determine relationships and investigate other variables such as yield. Much of the current work being done in 'precision agriculture' involves investigations of this nature.

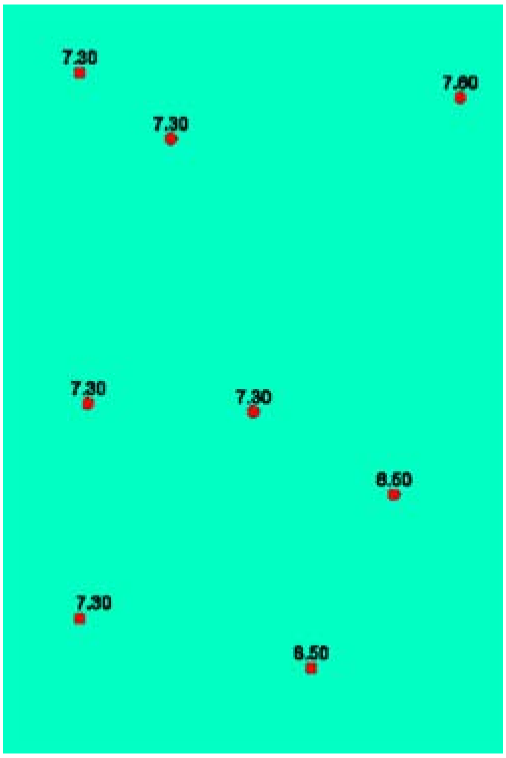


Figure 3–24 Points with soil pH values

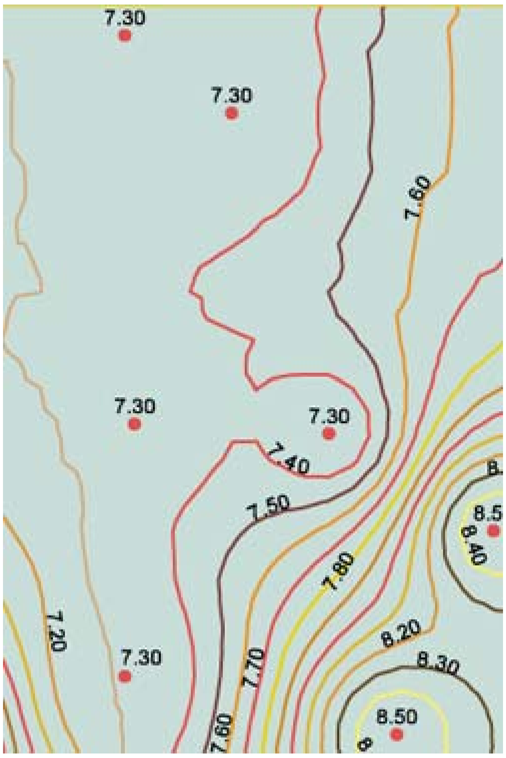


Figure 3–25 Contour map made from soil pH values shown in Figure 3–21

3.4 What is special about a spatial information system?

The way that maps and other data can be stored as layers of information (related by the same referencing system) in an SIS makes it possible to perform complex analyses.

It is the only system that uses location and arrangement of objects as a feature.

3.4.1 Information retrieval

An SIS makes it possible for the user to 'point' to a location, object or area on the screen and retrieve information that is stored as attribute data in some form of database (Figure 3–26).

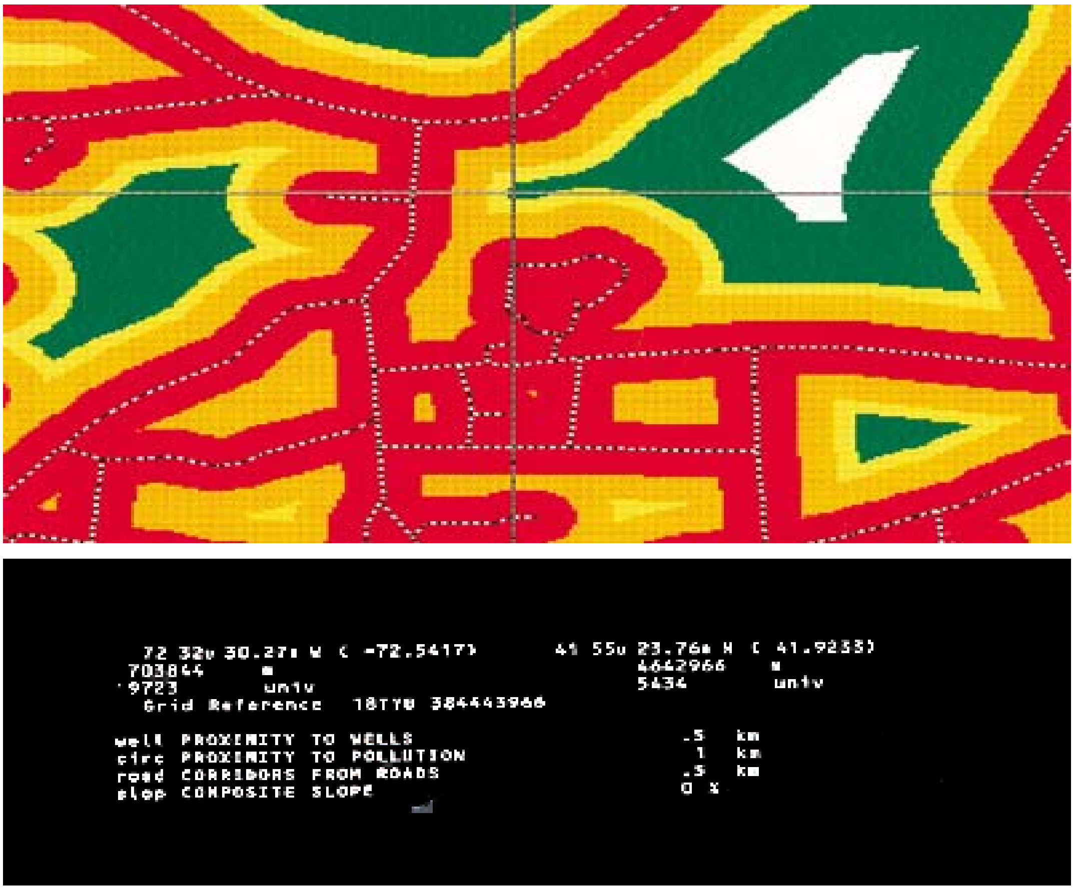


Figure 3–26 The cursor can be used to point to a location stored in an SIS and return attributes about the location such as longitude, latitude, soil type and slope

Using scanned, digital aerial photographs or satellite imagery as a visual guide, it is possible to ask an SIS about the geology or hydrology of an area, or even how close a wetland is to the end of a road. This type of analysis enables natural resource managers to derive conclusions about the wetland's environmental sensitivity.

3.4.2 Topological modelling

Using SIS technology it is possible to identify and analyse spatial relationships among mapped phenomena. Conditions of adjacency (what is next to what), containment (what is enclosed by what), and proximity (how close something is to something else) can be determined (Figure 3–27).

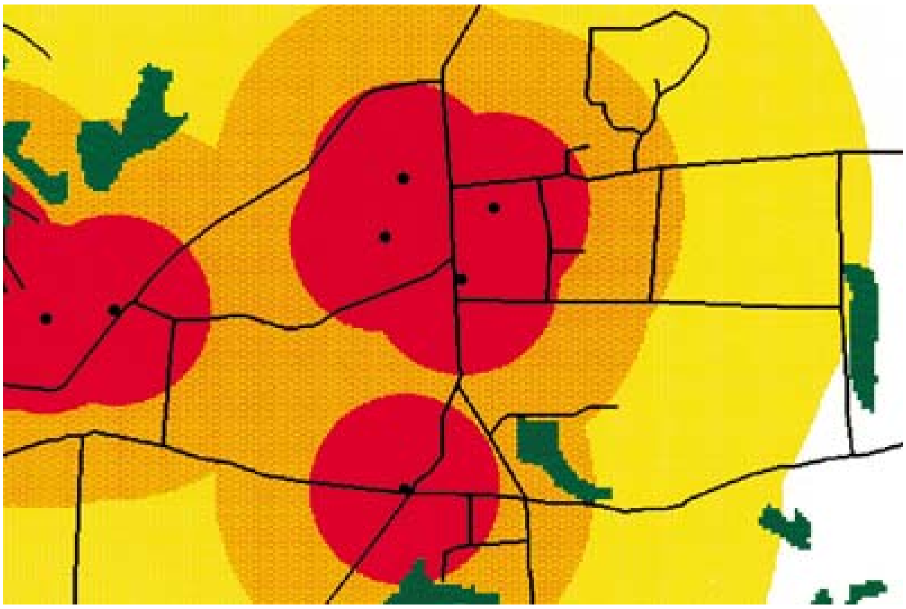


Figure 3–27 Sources of pollution are represented as points—the coloured circles show distance from pollution sources and wetlands are represented as dark green

3.4.3 Networks

When nutrients from vineyards or farmland run off into streams, it is important to know in which direction the streams are flowing and which streams discharge where. This process can be achieved using linear network functions within some SIS software programs. Additional information on water volume and speed throughout the spatial network can assist in estimating how long it will take the nutrients to travel downstream and enter a wetland area (Figures 3–28 and 3–29).

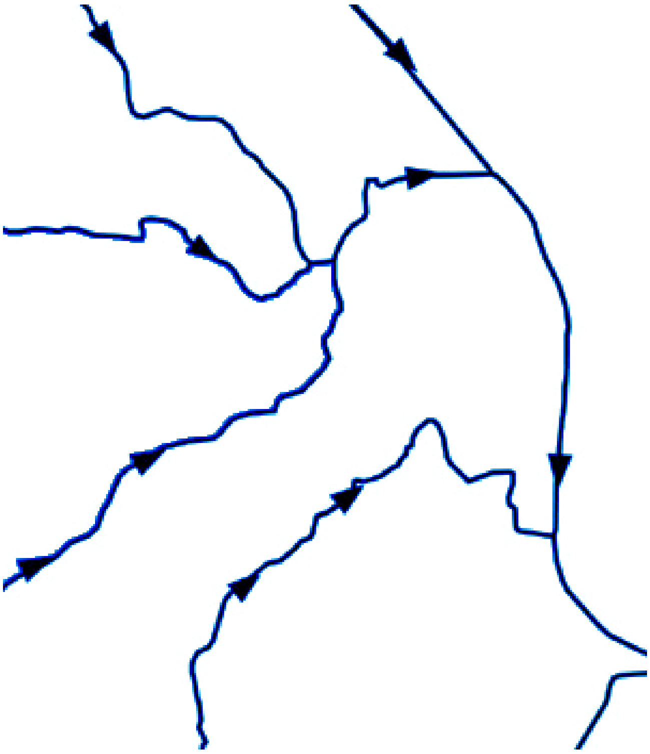


Figure 3–28 An SIS can simulate the movement of materials along a network of lines—these illustrations show the route of pollutants through a stream system

Figure 3–28 Flow superimposed on a digital orthophoto of the area

3.4.4 Overlay

Using the map layers of wetlands, slopes, streams, land use and soils with SIS technology it is possible to produce a new map or overlay that ranks the wetlands according to their relative sensitivity to damage from nutrient run-off (Figures 3–30 to 3–35).

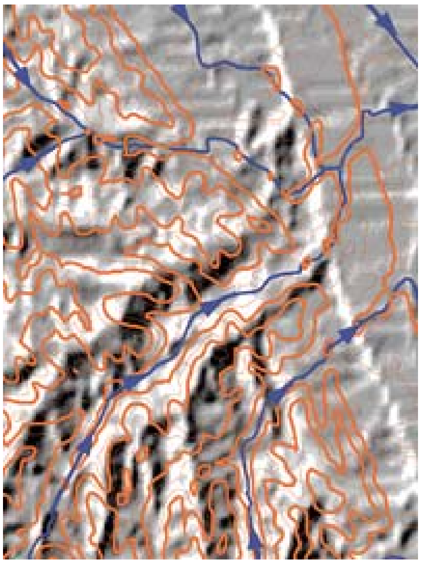


Figure 3–30 Shaded relief map and contour lines generated from a digital elevation model of the study area

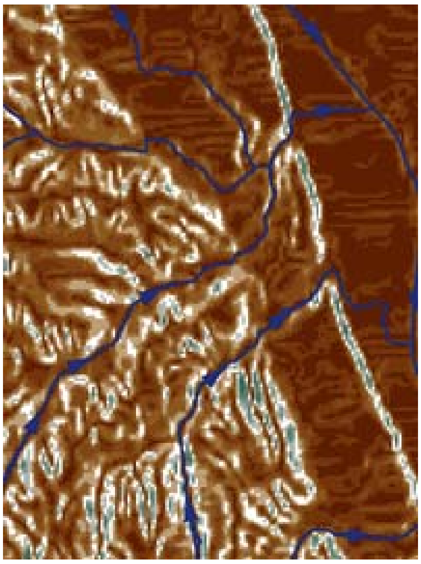


Figure 3–31 Map showing the steepness of slopes in the study area, created from the digital elevation model

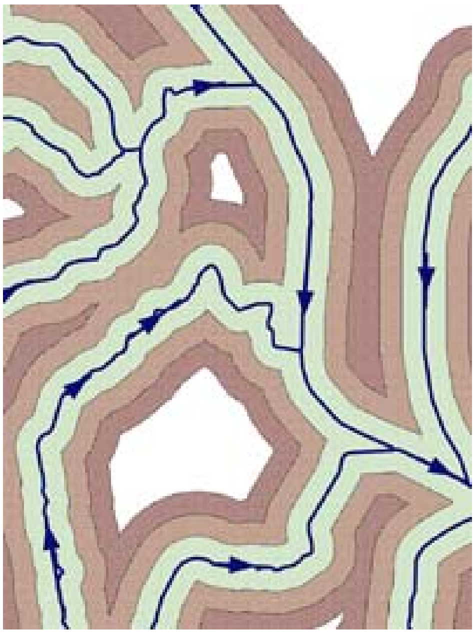


Figure 3–32 Distances to streams as measured by three 200-meter buffers derived from a digital map of hydrography

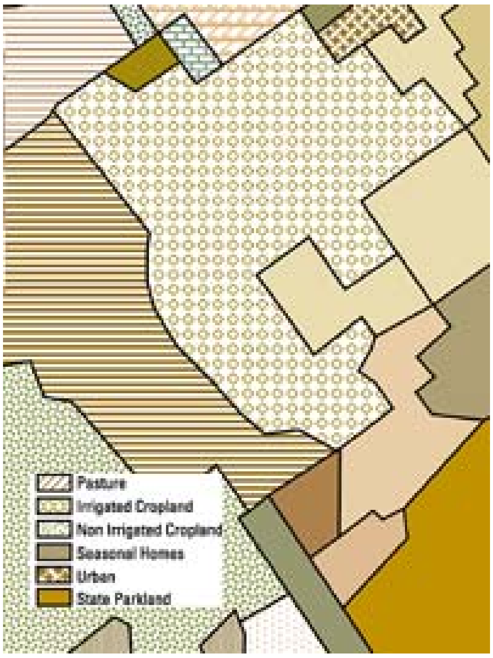


Figure 3–33 Map indicating various land uses in the study area

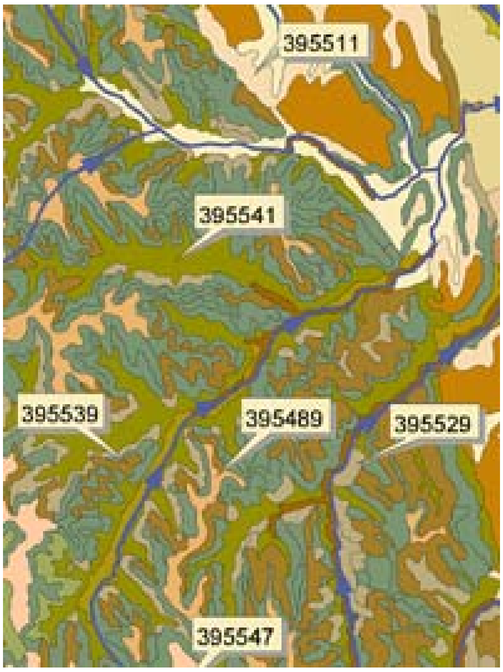


Figure 3–34 A soils map stored in an SIS database—numbers indicate the type of soil

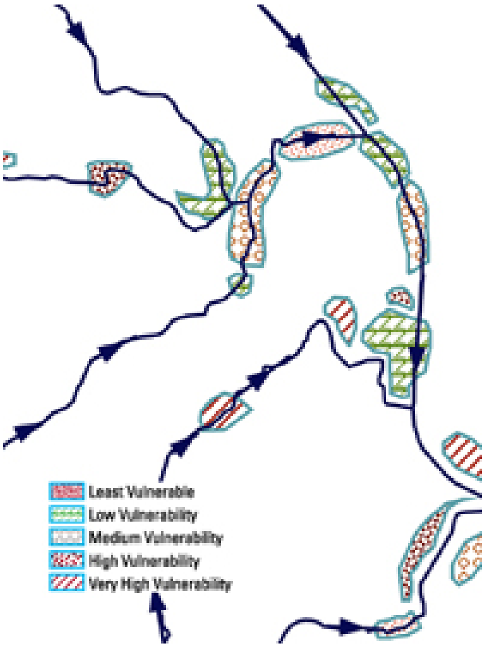


Figure 3-35 Wetlands in the study area ranked according to their vulnerability to pollution on the basis of a combination of factors evaluated by an SIS

3.4.5 Data output

One of the most critical components of an SIS is its ability to produce simple, effective visual representations though graphics, either on screen or on paper, to convey the results of analyses to people who make decisions about resources. A full range of map products covering wall maps, internet-ready maps, interactive maps and other graphics can be generated using SIS technology to assist decision makers in visualising and thereby understanding the results of analyses, simulations or potential events (Figure 3–36). The standards that support the consistent output of SIS are described in *Module 9: Map production guidelines.*

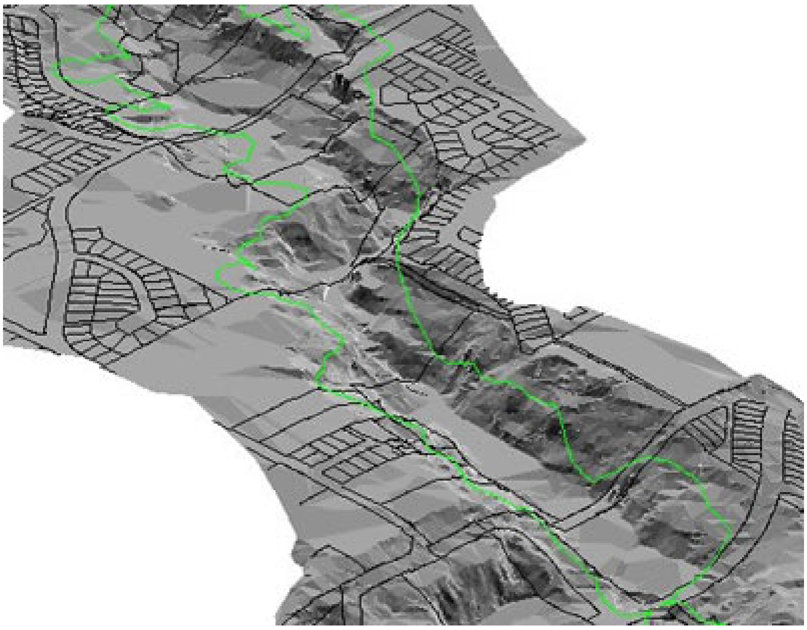


Figure 3–36 A 3-D view illustrating to property owners how a new riparian species protection law will affect them and their neighbours

3.5 Framework for cooperation and the need for planning

One of the additional benefits of introducing SIS technology into an organisation or NRM regional body is that it can encourage cooperation and communication amongst agencies and partners involved in NRM.

The collection or acquisition of data for use in an SIS is very costly and may require specialised equipment and technical expertise. Careful planning is required to ensure collection activities are well coordinated and, where possible, data can be collected once and used many times by different groups.

To be successful an SIS should not be viewed simply as a computer system but rather a tool in which the components of hardware, software, data, people and methods combine to make the system work.

A successful SIS operates according to a well-designed implementation plan and business rules, which form the models and operating practices unique to each organisation**. As with all organisations and NRM regional groups dealing with sophisticated technology, new tools can only be used effectively if they are properly integrated into the entire business strategy and operation.** This is achieved using relational databases which, once connected to geo-locational data, enable the display of data stored in external databases and spreadsheets. Many organisations have large spatial relational data holdings such as thematic datasets with address locations. In this scenario it could be possible to link the thematic data from the external dataset to an SIS layer based on address locations.

To do this properly requires not only the necessary investments in hardware and software, but also the training and/or hiring of personnel to utilise the new technology in the correct organisational context. **Failure to implement an SIS without giving consideration to proper organisational commitment will result in an unsuccessful system.**

It is simply not sufficient for an organisation or NRM regional group to purchase a computer and some SIS software, hire an enthusiastic individual and expect instant success.

Module 11: Partnerships and working together – the potential for collaboration has additional information.

3.6 Additional support

This guideline provides an overview of the issues and functionality of an SIS. The focus is on practical issues aimed at those with limited understanding of spatial information systems. Considerable additional support material is available on all of the issues identified including the following sources and references.

Wiley Publishers: http://www.wiley.com/ has a number of very good SIS/GIS reference books suitable for use in the establishment of regional centres. An example of its collection is a recent publication 'The Design and Implementation of Geographic Information Systems' by Harmon and Anderson, May 2003.

> *The Design and Implementation of Geographic Information Systems provides a unique nuts-and-bolts perspective of enterprise GIS design, a geographic information system that meets the needs of numerous users across multiple units in an organisation. This hands-on guide offers in-depth, up-to-date material on issues of spatial data when designing and implementing enterprise GIS, along with insightful, illustrative examples.*
>
> *From the predesign planning stages dealing with assessment, requirement analysis, organisational issues, and cost analysis, to integrating legacy MIS systems and preparing for future developments in database design, this user-friendly book addresses all the*

fundamental aspects of the design and implementation of GIS, regardless of software or hardware. It offers helpful 'decision trees' to assist in strategic planning, as well as proven strategies for application development, interface design, and enabling web-based access. Numerous case studies and examples from the private and public sectors demonstrate how these strategies and approaches play out in the real world.

As GIS becomes increasingly integrated with traditional MIS/IT database systems, GIS practitioners and MIS/IT managers will find The Design and Implementation of Geographic Information Systems a reliable, go-to resource.

OnWordPress: http://www.onwordpress.com/ also has a number of software specific and general reference SIS/GIS support books. An example of its collection is the publication 'GIS Solutions in Natural Resource Management' by Delmar Publishers.

GIS Solutions in Natural Resource Management enables readers to explore how diverse datasets may be applied to specific areas of study, ranging from sustainability to the incorporation of economic, demographic, and cultural indicators into resource management models. Central to the book are case studies that depict social and life scientists combining efforts to utilise GIS to respond to, and solve, today's socio-political challenges such as: Protecting endangered species, Preventing famine, Managing water and land usage, Transporting toxic materials, Locating scenic trails through public and private lands. Sections I and II introduce a progression of technique developments and requirements for current resource management applications. Section III enables readers to delve beyond these traditional approaches and their requirements to translate GIS resource technology into social and economic terms. Each chapter of the book is written in tutorial style to convey its central ideas. (Keywords: Introduction to GIS)

Other appropriate titles can be discovered by entering GIS in the product search function of the above websites.

Also of interest are a number of web-based newsletter type services that specialise in SIS/GIS activities. The following are examples of such websites:

Geocommunity: http://spatialnews.geocomm.com. This group offers many speciality channels including a book service at: http://search.geocomm.com/search.phtml?query=books

GIS Café: http://www.giscafe.com/

Directions Magazine: http://www.directionsmag.com/.

Similarly, many software vendors have useful reference material and newsletters. A sample collection of material available from bookstores maintained by software vendors can be found at the following locations. The list is provided simply to assist regional centres to discover information available from software vendors and is not meant to be comprehensive. Note: Listing of any company does not constitute an endorsement of that company.

MapInfo: http://www.mapinfo.com.au/

Intergraph: http://www.intergraph.com/au

ESRI: http://gis.esri.com/esripress/display/index.cfm

ESRI Australia: http://www.esriaustralia.com.au/ .