The GIS Handbook

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Preface

What Is the Purpose of This Handbook?

Plummeting prices and soaring performance of personal computers has fueled the development of a wide array of new tools for data gathering, management and analysis. Computers now permeate our lives in ways that could not be imagined a decade ago. In particular, the rapid adoption of information technologies has transformed the workplace in the ways in which we work, but also in the ways in which we think about problems.

Recently, Geographic Information Systems (GIS) technology has emerged as a powerful set of tools for managing and analyzing spatial data -- maps and other data that are georeferenced, or tied to a specific point or area on the ground. Because these types of data are at the very core of many development efforts, GIS been seen as a solution to a variety of problems that confront USAID.

When compared with some of the other more common computer-based technologies, such as word processing, spreadsheets, and database technologies, the adoption of GIS is still in its infancy. This is due, in part, to the demands that GIS makes on computers in terms of speed and storage. Within the past five years, however, advances in computing speeds and storage capacities of personal computers, the development of comprehensive and manageable software packages, and an increasing awareness of GIS capabilities all have combined to make GIS increasingly common.

Rapid development has made it difficult -- if not impossible -- for managers to keep abreast of GIS technology. It is thus extremely difficult to make an informed decision about if and how GIS should be used. Here, our goal is to make better decisions by helping the manager or decision maker to make judgments about issues such as:

- Does GIS make sense for solving a specific set of problems? If so,
- What combinations of hardware and software will meet our specific needs?
- What are the budget and personnel implications?
- What institutional reordering will be required to make it work?
- How do we go about it?

This handbook is intended to serve as an introductory guide to GIS technology by addressing these types of basic questions. The handbook is not intended to advocate the technology but explain it. It suggests some common opportunities for GIS application, but also points out those areas where trouble might arise. Although it provides a snapshot of the technology at this point in time, the handbook is intended to address fundamental issues that are largely independent of technical specifics and thus less likely to become out-of-date. The handbook does not contain all the answers, but rather provides enough information and guidance to permit the reader to pursue the appropriate questions.

Who Should Use This Handbook?

The handbook is aimed at USAID mission officers who are not familiar with GIS, and who may not have any experience with computers. It thus can serve managers and decision makers outside USAID equally well, particularly those engaged in development activities that deal with infrastructure, agriculture, or natural resources management.

How Should This Handbook be Used?

The handbook is not necessarily meant to be read from beginning to end. It is organized in a general sequence of topics that might be considered when deciding whether or not to employ GIS. If the readers are unfamiliar with GIS, they should start at the beginning and read as far as they feel necessary. If the readers have some familiarity with GIS, they should read those chapters that address their specific concerns. The Appendices contain considerable detail and can be read separately, if desired. We intend this handbook to serve as a general guide that can be consulted often by a broad audience.

Acknowledgements

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Abbreviations

■	AGRHYMET	Agro-Meteorological and Operational Hydrology Center
■	AM	Automated Mapping
■	AM/FM	Automated Mapping/FacilityManagement
■	AMS	Automated Mapping System
■	APS	Area Point Sample
■	ARTS	Office of Analysis, Research, and Technical Support (USAID)
■	ASF	Area Sampling Frame
■	ASPRS	American Society of Photogrammetry and Remote Sensing
■	AVHRR	Advanced Very High Resolution Radiometer
■	CAD	Computer Aided Drafting
■	CAM	Computer Assisted Mapping
■	CCT	Computer Compatible Tape
■	CDROM	Compact Disk Read Only Memory
■	CILSS	Le Comite Inter-Etats de lutte Contre la Secheresse dans le Sahel
■	CLABS graphic	The Clark Labs for Cartographic Technology and Geo-Analysis
■	COGO	Coordinate Geometry
■	CPU	Central Processing Unit
■	DBMS	Database Management System
■	DMA	Defense Mapping Agency (United States)
■	EA	Environmental Assessment
■	EIS	Environmental Information System
■	EOSAT	Earth Observation Satellite Company
■	EROS	Earth Resources Observation System Data Center of USGS
■	ESA	European Space Agency
■	FAO	United Nations Food and Agriculture Organization
■	FAOFORIS	FAO Forestry Database
■	FARA	Division of Food, Agriculture, and Resource Analysis (USAID)
■	GAC	Global Area Coverage
■	GEF	Global Environmental Facility
■	GEMS	Global Environmental Monitoring System (a program of UNEP)
■	GIS	Geographic Information System
■	GPS	Global Positioning System
■	GRID UNEP)	Global Resource Information Database (a program of
■	GTS	Global Telecommunications System
■	HRV	High Resolution Visible
■	IGADD	Inter-Governmental Authority for Drought & Development
■	IGN	Institut Geographique National
■	ITC	International Institute for Aerospace Surveys and Earth Sciences (Netherlands)
■	IUCN	International Union of Conservation of Nature and Natural Resources

■	LAC	Local Area Coverage
■	LIS	Land Information System
■	MSS	Multispectral Scanner
■	NASA	National Aeronautics and Space Administration (United States)
■	NCGIA	National Center for Geographic Information and Analysis
■	NDVI	Normalized Difference Vegetation Index
■	NEAP	National Environmental Action Plan
■	NOAA	National Oceanographic and Atmospheric Administration
■	NRICG	National Resource Inforation Consultative Group (WRI)
■	NTIS	National Technical Information Service (United States)
■	OSS	Observatoire du Sahara et du Sahel
■	RAM	Random Access Memory
■	RBV	Return Beam Vidicon
■	RCSSMRS	Regional Center for Services in Surveying, Mapping & Re mote Sensing (Nairobi, Kenya)
■	RRA	Rapid Rural Assessment
■	SAR	Synthetic Aperture Radar
■	SARSA	Systems Approach to Regional Income and Sustainable Resource Assistance (Clark University)
■	SGS	Systematic Ground Survey
■	SPOT	Systeme Pour l'Observation de la Terre
■	SRF	Systematic Reconnaissance Flight
■	TM	Thematic Mapper
■	UNDP	United Nations Development Programme
■	UNCED	United Nations Conference on Environment and Development
■	UNEP	United Nations Environment Programme
■	UNESCO	United Nations Educational, Scientific and Cultural Organization
■	UNITAR	United Nations Institute for Training and Research
■	UNSO	United Nations Sudano-Sahelian Office
■	USGS	United States Geological Survey
■	UTM	Universal Transverse Mercator
■	WCMC	World Conservation Monitoring Center
■	WMO	World Meteorological Organization
■	WRI	World Resources Institute

Introduction

What Is a GIS?

Definitions

A Geographic Information System (GIS) can be defined as a computer-based system for the digital entry, storage, transformation, analysis, and display of spatial data. Although we often restrict our concept of spatial data to maps (e.g., land use, vegetation), spatial data also include images (e.g., satellite data), point observations (e.g., rainfall), or tabular data associated with geographic areas (e.g., census records). Thus, in addition to maps alone, a GIS must be capable of handling other types of data, all within a spatial frame of reference.

Few would disagree with this definition, but at the same time, many would arrive at a definition on their own. Their definitions would be shaped by their own interests and needs, and how the GIS is to be applied. Thus, a GIS can mean different things to different people.

GIS as an Archival System

To one large segment of the GIS community, it is the "I" in GIS that is primary. Indeed, the term itself was coined at a time when the major focus was on the use of automated procedures for the development of *information systems* for spatially referenced data. In this context, the emphasis lies with the database -- an application we might term as archival -- characterized by:

- *large, enduring, multipurpose databases*. The database is seen as an *archive* that must be built and maintained through time, and may be called upon to meet a variety of applications.
- *limited analytical needs*. Typically, archival applications are concerned largely with issues of database query, such as, "find all areas of agricultural landuse on soils associated with high erodibility." Rather than any specific output, the database itself is the primary product.

These systems have usually been associated with:

- *mainframes, minicomputers, and workstations*, because of the large amounts of data that need to be accessed. However, as microcomputer technology continues to advance, these distinctions tend to blur.

- *precise georeferencing*, or the linkage of features to well-defined positions in space, and a concern with data accuracy and integrity.

Systems such as this are often called Land Information Systems (LIS) or Multipurpose Cadastres (records of land ownership), depending upon their application. They commonly are found in agencies charged with mapping, archiving, tax assessment, and the development and maintenance of infrastructure.

GIS as an Analytical System

In recent years, a second application has emerged that has come to rival archival uses of GIS in terms of importance. This is one in which emphasis is placed on the analytical capabilities of GIS applied to specific problems. These can be described as *analytical* or *research* applications. These applications go far beyond the simple database query demands of most archival applications (see Part 1). Here the systems are characterized by:

- *small, ephemeral, special purpose databases*. Data are gathered for the specific needs of a particular research project and may not be kept after the project has been completed.
- *a strong emphasis on analysis*, particularly on modeling and statistical applications. The intent of the analytical system is to produce a better understanding of relationships among spatial phenomena.

These systems are often associated with:

- *microcomputer hardware platforms*, because of their ease of access to small working groups and modest cost.
- *simple georeferencing*, such as arbitrary plane coordinates. This does not imply casual georeferencing; only that the limited scope of many research projects does not require that the database be tied into a more general system, such as a national grid.

GIS as a Decision Support System

As the technology evolves and the need to consider environmental and natural resource information increases in a variety of settings, a very broad class of application has begun to emerge that draws on both archival and analytical orientations. In *decision support* or *action* applications, the GIS becomes a tool of the decision making process by allowing alternative outcomes to be projected, debated, and revised so that informed decisions can be taken. Decision support applications are characterized by:

- *an action orientation*. The information that is generated through data examination and analysis is intended to result in a decision that may initiate or suspend action.
- *linkages to multiple databases and models*. These can include archival databases for general reference (e.g., census, regional land use), as well as, analytically oriented databases or models that describe specific aspects of a large complex undertaking (e.g., erosion and population migration models). The intent is to place relevant information before the decision maker in a form that is readily understood.

These systems are associated with:

- *almost any computing environment*. Database creation, maintenance, and most analytical work is performed elsewhere. With an emphasis on query and simple analysis, requirements for storage and processing are modest relying instead on other systems, either through computer networks or physical data exchange (i.e., diskettes).
- *broader involvement in the decision making process*. Decision making with a GIS involves a more explicitly reasoned process of evaluating alternative courses of action, and as such requires the decision maker to be directly concerned with issues such as the choice of relevant factors and constraints, the assignment of weights, and considerations of error and uncertainty.

Application Objective

Perhaps the first and most common question that arises when considering the adoption of GIS is, "what is the best software?" Unhappily, this focus on the technology rather than the problem often leads to a mismatch of tool and task -- swatting a fly with a sledgehammer, or pushing back the tide with a broom.

As outlined in the preceding section, we may ask GIS to fill one or several different functions within a given setting. To select appropriate hardware and software, determine budget and staffing requirements, and establish valid performance criteria we cannot determine what is "best" without first answering the question, "what are we trying to do?"

The relationship of the three types of applications is described in Figure 1. Although they are often related and sometimes coexist, they are functionally distinct. To better understand their interrelationships, it is easiest to envision them imbedded in a single organization concerned with managing a large area, such as a river basin.

In this setting, one part of the organization will be charged with surveying and mapping the resources of the basin and the administrative responsibilities for how they are managed. Thus, the primary responsibility of the group will be the development and maintenance of an archive.

Other groups will have responsibilities tied to the management of specific resources (e.g., water, forests, and agriculture). They will seek to develop strategies for better resource management within the basin. This might involve developing models to determine where logging might take place by estimating yields and revenues, and balancing them against potential impacts on adjacent land uses and water quality. All of this will be based on analysis of data drawn from the archive or developed for small sample sites.

Ultimately, the executive branch of the organization will draw on the data contained in the database and apply the understanding of various resource management strategies that have been captured with models. The actions they take will be driven by politics and economics but will be constrained by the realities described in the database and the models.

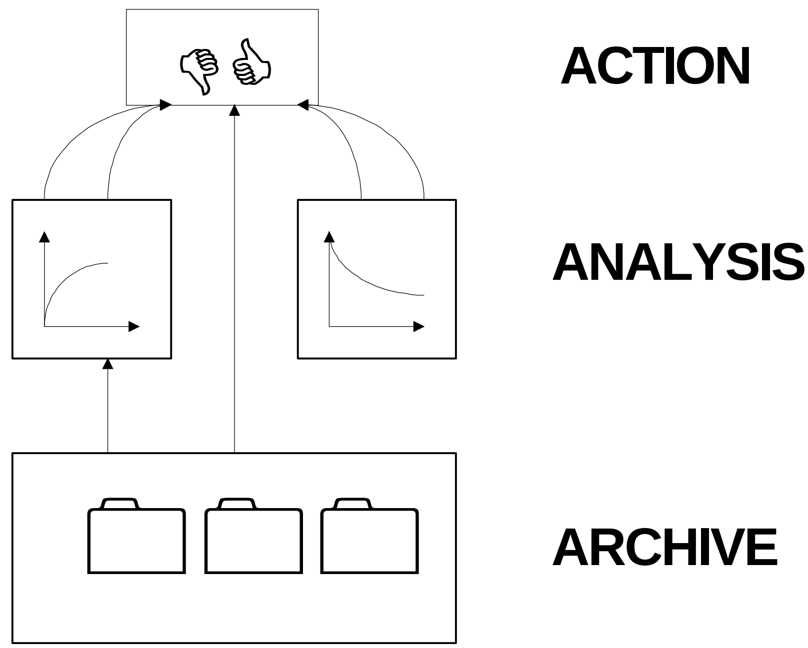

Figure 1

This "ideal" relationship of integration among the various forms of GIS application is seldom achieved. More typically, we may find only one or two applications implemented in a single institutional setting, and often these will occur in relative isolation. For example, the needs of a tax assessor or survey department will be met in an archive application because there is seldom need to proceed beyond simple queries. Or, particularly in large resource management agencies, we may find both archive and analysis applications existing together due to their sharing of data, but lacking a direct tie to the decision making process.

The ways in which archive and analysis applications feed the decision making process are in a state of flux. In the past, decision makers were provided with data and analyses by specialists on a request-driven basis. Now, with the advent of computer networks and low-cost, easily-learned GIS systems with query and low-level analytical capabilities, decision makers are able to access and analyze data themselves. However, decision makers are usually unfamiliar with the limitations of models and data sets. So it is unclear whether the exclusion of specialists from the decision support "loop" is necessarily desirable. In the face of declining budgets and rising expectations for administrative performance, it seems certain that these relationships will come under closer scrutiny.

Components of a GIS

Although we sometimes think of a GIS as a single piece of software, a GIS installation is made up of several different components. Figure 2 gives a broad overview of the software components typically found in such a setup. Not all systems have all of these elements, but to be a true GIS, a system must contain an essential group, including cartographic display, map digitizing, database management, and geographic analysis.

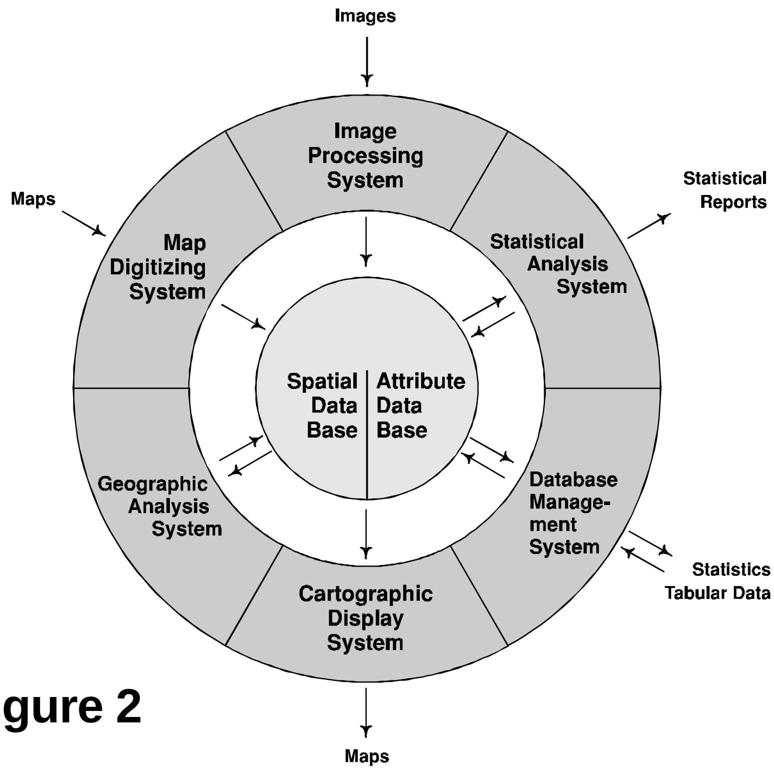

Figure 2

Spatial and Attribute Databases

Central to the system is the database -- a collection of maps and associated information in digital form. Because the database is concerned with earth surface features, it comprises two elements -- a *spatial database* describing the geography (shape and position) of earth surface features, and an *attribute database* describing the characteristics or qualities of these features. Thus we might have a property parcel defined in the spatial database and qualities such as its land use, ownership, property valuation, and so on, in the attribute database.

In some systems, the spatial and attribute databases are rigidly distinguished from one another, while in others they are closely integrated into a single entity -- hence the line extending only half way through the middle circle of Figure 2.

Cartographic Display System

Surrounding the central database, we have a series of software components. The most basic of these is the *cartographic display system* which allows one to take selected elements of the database and produce map outputs on the screen or some hardcopy device such as a printer or plotter. Most GIS software systems provide only very basic cartographic output and rely upon the use of high quality publication software systems for the production of final negatives for printed maps.

Map Digitizing System

After cartographic display, the next most essential element is a *map digitizing system* which is used to convert existing paper maps into digital form. Map digitization can be accomplished through scanning devices. This procedure requires considerable preparation of the map data and specialized software along with dedicated hardware. As a result, digitizing is more typically done manually by a technician who traces the lines of the maps with an electronic stylus or cursor on a digitizing tablet. The lines are then stored electronically as a series of point location coordinates that, when joined, will form the lines. This element of GIS is often the most time consuming and costly phase of the GIS process.

Database Management System

The next logical component in a GIS is a *database management system* (DBMS). Traditionally, this widely-used term refers to a type of software that is used to input, manage, and analyze attribute data. It is also used in that sense here, although we need to recognize that spatial database management is also required. Thus, a GIS typically incorporates not only a traditional DBMS but also a variety of utilities to manage the spatial and attribute components of the geographic data stored.

With a DBMS, it is possible to enter attribute data, such as tabular information and statistics, and subsequently extract specialized tabulations and statistical summaries to provide new tabular reports. However, most importantly, a DBMS provides us with the ability to analyze attribute data. Many map analyses have no true spatial component, and for these a DBMS will often function quite well. For example, we might query the system to find all property parcels where the head of the household is single but with one or more children, producing a map of the results. The final product (a map) is certainly spatial, but the analysis itself has no spatial qualities whatsoever. Thus, the double arrows between the DBMS and the attribute database in Figure 2 signify this distinctly non-spatial form of data analysis.

Geographic Analysis System

Up to this point, we have described a very powerful set of capabilities -- to digitize spatial data and attach attributes to the features stored; to analyze these data based on those attributes; and to map out the results. Indeed, there are a variety of systems on the market that have just this set of abilities, some of which are termed GIS. But, useful as this is, such a set of capabilities does not constitute a GIS. The missing component is the ability to analyze data based on truly spatial characteristics. For this we need a *geographic analysis system*.

With a geographic analysis system, we extend the capabilities of traditional database query to include the ability to analyze data based on their location. Perhaps the simplest example of this is to consider what happens when we are concerned with the joint occurrence of features with different geographies. For example, find all areas of slopes greater than 30% associated with agricultural lands. This is a problem that a traditional DBMS simply cannot solve -- for the reason that slope information and landuse types necessarily do not share the same geography. Traditional database query is adequate so long as we are concerned with attributes belonging to the same individuals. But when the entities are different, it simply cannot cope. For this we need a GIS. In fact, it is this ability to compare different entities based on their common geographic occurrence that is the hallmark of GIS -- a process called "overlay" since it is identical in character to overlaying transparent maps of the two entity groups on top of one another.

Like the DBMS, the geographic analysis system is seen (Figure 2) to have a two way interaction with the database -- the process is distinctly analytical in character. Thus, while it may access data from the database, it may equally contribute the results of that analysis as a new addition to the database. For example, we might look for the joint occurrence of lands on steep slopes with erodible soils under agriculture and call the result a map of "soil erosion risk." This risk map was not in the original database; it was derived from existing data and a set of specified relationships. Thus the analytical capabilities of the geographic analysis system and the DBMS play a vital role in extending the database through the addition of knowledge of relationships between features.

While overlay is the hallmark of GIS, computer-assisted geographic analysis has matured enormously over the past decade. An outline of these capabilities is presented in the following chapter; for more detail, see Part 2. However, for now it is sufficient to note that it is this distinctly geographic component that gives a true GIS its identity.

Image Processing System

In addition to the essential elements of a GIS just described, some software systems also include the ability to analyze remotely sensed images and provide specialized statistical analyses. The *image processing system* allows one to take remotely sensed imagery (such as LANDSAT or SPOT satellite imagery) and convert it into interpreted map data according to various classification procedures. This can be a significant component of the system since computer-assisted interpretation of remotely sensed data may be an important technique for data acquisition, particularly in the developing world where current maps of many features are not available.

Statistical Analysis System

For statistical analysis, most geographic information systems offer both traditional statistical procedures as well as some specialized routines for the analysis of spatial data. Geographers and others have developed a series of specialized routines for the statistical description of spatial data, partly because of the special character of spatial data, but also because spatial data pose special problems for inferences drawn from statistical procedures.

Part 1 : Fundamentals

What Can a GIS Do?

Types of Analysis

Database Query

Database query is probably the most common type of analysis done within a GIS. With database query, we are simply selecting various combinations of variables for examination. The tools we use are largely Database Query tools (hence the name), but also include various measurement and statistical analysis procedures. The key distinguishing characteristic of this kind of analysis is that we take out no more than we put into the system. While we may extract combinations we have never examined before, the system provides us with no new information -- we are simply making a withdrawal from a data bank we have built.

Queries may be of two types -- queries of location (*What occurs in this location?*) and queries of attribute (*Where are the areas in which an attribute occurs?*). Examples of query by location include:

- What is the mean income for this area?
- What land use is at this location?

Examples of query by attribute include:

- Where are slopes greater than 20%?
- Where are the areas with population density greater than 10 people per square kilometer and average annual rainfall less than 15 centimeters?

One of the key activities in database query is pattern seeking. Typically we are looking for spatial patterns in the data that may lead us to hypothesize about relationships between variables.

Derivative Mapping

In derivative mapping, we combine selected components of our database to yield new derivative layers. For example, we might use digital elevation data to derive slope gradients, then take our slope data and combine it with information on soil type and rainfall regime to produce a new map of soil erosion potential. This new map then becomes an addition to our growing database (see Figure 3).

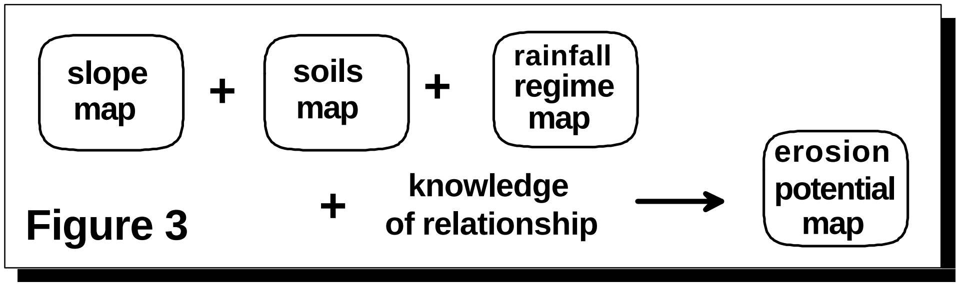

Figure 3

How is it that we can create new data from old? Unlike database query where we simply extract information that already resided in the database, with derivative mapping we take existing information and add to it something new -- *knowledge of relationships* between database elements. We can create a soil erosion potential map out of a digital elevation map, a soils map, and a rainfall regime map only if we know the relationship between those factors and the new map we are creating. In some cases, these relationships will be specified in logical terms in which we use our database query tools. An example would be creating a suitability map for industrial location based on the condition that it be on existing forest land, outside protective buffers around wetlands and on low slopes. In other cases, however, these relationships will be specified in mathematical terms, in which case we will rely heavily on map algebra tools. Regardless, the relationships that form the model must be known.

In some cases, relationship models can be derived on logical or theoretical grounds. In most applications, however, relationships are established through empirical study. Regression analysis, for example, is one common way in which empirical testing is used to develop a mathematical relationship between variables. In the soil erosion example, we might set up a series of test sites at which the soil erosion is measured in addition to slope, soil type, and rainfall data. These observations would then be used to develop an equation relating soil erosion to these variables. The equation would then be used to evaluate soil erosion potential over a much broader region.

Process Modeling

Database query and derivative mapping make up the bulk of most GIS analyses. However, there is a third area that is receiving increasing attention -- *process* or *simulation modeling.*

With process modeling, we also bring something new to the database -- *knowledge of process*. Process refers to the causal chain by which some event takes place. For example, a simple model of fuel wood demand satisfaction might run as follows:

1. *take all the wood you need from your present location,*
2. *if your demand is satisfied or if you have traveled more than 10 kilometers from home, then stop,*
3. *else move to an adjacent location not already visited and go to step 1.*

Process models have been developed and used for years, both in spatial and non-spatial applications. Such models are used in fields as diverse as meteorology (modeling the path of a hurricane), demography (modeling the migration of people given certain changes in employment availability), agricultural science (crop growth simulations) and forestry (modeling fire start potential and predicting the extent of burn). Although process modeling has not been fully exploited in GIS technology, it is an exciting and ultimately valuable analytical procedure that will become increasingly common.

Process modeling in GIS is especially enticing because it is based on the notion that our database serves as a surrogate environment, capable of being measured, manipulated and acted upon by geographic and temporal processes. Our database thus acts as a laboratory for the exploration of processes that will ultimately approach the full complexity of the true environment.

In science, we attempt to constrain or remove complexity in order to understand processes in isolation. This usually involves limiting our attention to a single factor and how it behaves -- usually through time. Often even very simple understandings yield complex patterns when allowed to interact spatially. Thus, through the use of the GIS, we seek to understand and predict how these factors behave in *space* where the full complexity of interactions with other variables is brought into play. Process modeling allows us to play out various scenarios in a fully complex spatial environment before making decisions about implementation in the real world, and can thus be an important tool for decision makers.

Examples of processes that might be modeled, given knowledge of the relationships involved include:

- What will be the effects on settlement and migration patterns given new infrastructure construction?
- What would be the differences in annual productivity over a ten year period given the adoption of various soil erosion prevention techniques?

Despite its evident attraction, process modeling is still a fairly new and uncommon activity in GIS. There are two major reasons for this. First, the relationships involved in the processes we would like to model are often complex and, as a consequence, poorly defined or not defined at all. For example, we may suspect that increasing the application of agricultural fertilizers on lands near streams decreases the fish population, but we may not have a mathematical definition of this relationship. Collecting data to empirically establish such relationships is often a time consuming and expensive endeavor.

The second reason that process modeling is not more common in GIS today is that the process itself often requires the creation of new program modules. Many analysts who might use a GIS are not comfortable with computer programming. In addition, many geographic information systems do not readily permit the incorporation of user-developed routines. As analysts become more comfortable in designing their own routines and begin to demand that systems accommodate the addition of user-developed algorithms, process modeling will become more common.

Types of Products

The types of products created during any GIS application are predictable, but the full range of their value may not always be understood.

Tables

The GIS includes a database component and thus can provide tabular summaries of all attributes. These can be produced by statistical investigations, database queries, and the like. As suggested here, the quality of tabular reports can be improved by incorporation of spatial data. These products may then become inputs to decision making processes. Tabular data, however, have lost some of their impact, particularly at the decision making level. Incorporation of spatial considerations, however, lends them a new dimension.

Maps

Customized maps may be produced at any scale showing features individually or in any number of combinations. This is one of the major stated goals of any GIS application. However, they are used by a wide variety of agencies for a number of purposes. Thus, as emphasized here, maps have an exceedingly long life. Once adopted by the responsible agency, they are assumed to represent conditions accurately and often are posted in prominent locations that lend them a respectability they may not deserve. These are probably the most public and long-lived form of publication and must thus be considered carefully.

Databases

Beyond tangible and designated end products, the implementation of a GIS often yields products that initially are unanticipated or at least underestimated. Creation of a database requires that useful data are collected, entered, and archived at a central point. Particularly in developing countries, this is a major achievement in itself. In a digital format, these data can be readily distributed, and updated easily and inexpensively. Again, in developing countries, map data are rare and difficult to acquire in hardcopy format.

When to Use a GIS

GIS is one of many tools that may be used to solve problems. Just as you would not use a financial management computer program if your problem did not involve finances, you should not choose to use a GIS unless your problem warrants its use.

The decision about whether to use a GIS is complex. There often is understandable reluctance to commit to new ways of performing old tasks. Yet, there is a countervailing tendency to go ahead and adopt exciting new technologies when they serve no purpose and may, in fact, place a crippling burden on an agency's ability to perform.

Dealing with spatial data is not always straightforward; it takes experience working both with traditional methods and GIS to be able to judge their relative appropriateness and efficiency. Even with this experience, determining when the use of GIS is appropriate involves asking at least two questions.

Is the Problem Spatial?

The term spatial here means that the *location* of the data is important. For example, you may be interested in changes in household income across the region of interest. If the geographic locations of the households are not important to your analysis, GIS is not necessary. A spreadsheet or relational database program may be all that is needed.

Despite this example, many studies that do not include a spatial component may be enhanced by adding one. For example, it might be useful to know if the areas of largest changes in household income were adjacent to changes in land uses that might affect health (e.g., absenteeism rates as a function of distance to sources of air pollution).

Part of the process of implementing a GIS in an organization involves educating members of the organization about the capabilities of the system and sensitizing them to the value of spatial inquiry. This will be discussed in detail in Part 2.

Does Automation Offer an Advantage?

Even if a problem has a spatial component, it may not require a GIS. There may be other more cost effective or appropriate procedures that should be employed. Typically, there are other manual methods for dealing with a specific problem (e.g. conventional cartography and visual analysis) or, as discussed above, there may be automated options that are quite satisfactory (e.g., electronic spreadsheets) if the problem is complex but not inherently spatial.

As in other forms of information technology, GIS has distinct cost advantages in terms of *automation* in at least three situations.

Large Data Volumes

Any time we must deal with large amounts of data, automation offers significant advantages over manual techniques. Especially in archive applications where simple queries predominate, GIS makes sense. The need for a metropolitan fire department or other emergency service to know quickly and accurately the location of street addresses and their proximity to stations is a good example. Here the need to maintain a large, fairly static database and to be able to search it quickly offers a compelling case for automation.

Routine Database Updates

Large databases usually have an equally large effort devoted to maintenance, or adding new data and deleting old. The needs of an assessor's office is an excellent example. Here, clearly, the maintenance of an accurate database on property ownership is a primary objective. However, given the complexity of updating changes in ownership and property boundaries, we might argue that the need for *current* data on property ownership is the primary driver in establishing the need for automation.

Complex Analyses

As discussed in the Introduction, there are many types of analysis that defy -- or at least confound -- manual solutions. Even the most simple form of geographic analysis -- map overlay -- is very difficult to perform manually if there are a large number of maps to be considered, or if multiple combinations are desired. More complex forms of spatial analysis present even more daunting challenges to manual approaches. For example, developing a three dimensional surface of transportation costs for a delivery service based on travel time using simply distance is a formidable task to undertake manually. If we seek to optimize this surface by establishing a network of nodes that might be served by different sizes (and costs) of vehicles, the problem becomes more difficult still. If we wish to adjust this network in "real time" in response to vehicle location and availability, it becomes essentially unworkable without automation.

What Are the Short and Long-Term Issues?

While the advantages of automation might appear clear cut, as in any other assessment of cost effectiveness, it is necessary to consider both the short-term and the long-term.

Short-term Cost Effectiveness

If the data are manageable with manual methods, there is no anticipated growth in data volume, and no need to update the data, the cost and effort required to implement a GIS may not be justified. However, it is also possible that even with small amounts of data that will not be used again, analytical requirements are such that a GIS is appropriate and in fact necessary. As suggested above, mapping multiple outcomes of a process model is an extremely time-consuming task to perform manually.

Long-term Implications

It may be true of all published data, but maps have exceptionally long lives. Studies that currently are not appropriate for GIS but anticipate the use of spatially referenced data in the future may need to incorporate a GIS from the beginning, even if the system is not fully utilized until later.

If a database is being developed that will be used in the future and will need to be updated through time, it may be cost effective in the long term to use a GIS, even if traditional cartographic methods are more cost effective in the short term. The ability to quickly and systematically update digital databases is one of the obvious advantages GIS has over traditional methods.

Another long-term consideration is the anticipated growth of data volume over time. The current project may be easily handled with manual methods but, as the amount of data increases, automation may be required at some point in the future. Time, money and effort may be saved in the long run if such an event is anticipated and the GIS built into the project design from the beginning.

In addition to changes in the volume of data that will be handled, there also may be changes in the analytical needs of the project. If these changes can be anticipated early and a GIS will be needed as analytical requirements are expanded, it may be more efficient in the long term to build the GIS into the project well before its analytical tools are needed.

Finally, as discussed in Part 3, the conversion from manual to automated methods is a massive undertaking -- not only in the conversion from one medium to another, but in the transformation of the ways in which an institution does its business. The individual and institutional obstacles that might be encountered in such a transformation should not be underestimated.

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Part 2 : Functionality

How does a GIS work?

Map Data Representation

A Geographic Information System stores two types of data that are found on a map -- the geographic definitions of earth surface features and the attributes or qualities that those features possess. Not all systems use the same logic for achieving this. Most, however, use one of two fundamental map representation techniques: *vector* and *raster* (see Figure 4).

Vector

With *vector* representation, the boundaries or the course of the features are defined by a series of points that, when joined with straight lines, form the graphic representation of that feature. The points themselves are encoded with a pair of numbers giving the X and Y coordinates in systems such as latitude/longitude or Universal Transverse Mercator grid coordinates. The attributes of features are then stored with a traditional database management (DBMS) software program. For example, a vector map of property parcels might be tied to an attribute database of information containing the address, owner's name, property valuation and land use. The link between these two data files can be a simple identifier number that is given to each feature in the map.

Raster

The second major form of representation is known as *raster*. With raster systems, the graphic representation of features and the attributes they possess are merged into unified data files. In fact, they typically do not define features at all. Rather, the study area is subdivided into a fine mesh of grid cells in which the condition or attribute of the earth's surface at each cell point is recorded. Each cell is given a numeric value which may then represent either a feature identifier, a qualitative attribute code or a quantitative attribute value. For example, a cell could have the value "6" to indicate that it belongs to District 6 (a feature identifier), or that it is covered by soil type 6 (a qualitative attribute) or that it is 6 meters above sea level (a quantitative attribute value). Although the data we store in these grid cells do not necessarily refer to phenomena that can be seen in the environment, the data grids themselves can be thought of as *images* -- images of some aspect of the environment that can be made visible through the use of a raster display. In a raster display, such as the screen on

This was taken largely from the IDRISI User's Manual, Clark University Graduate School of Geograpy, 1992.

your computer, there is also a grid of small cells called *pixels.* The term pixel is a contraction of *picture element.* Pixels can be made to vary in their color, shape or grey tone. To make an image, the cell values in the data grid are used to regulate directly the graphic appearance of their corresponding pixels. Thus in a raster system, the data directly control the visible form we see.

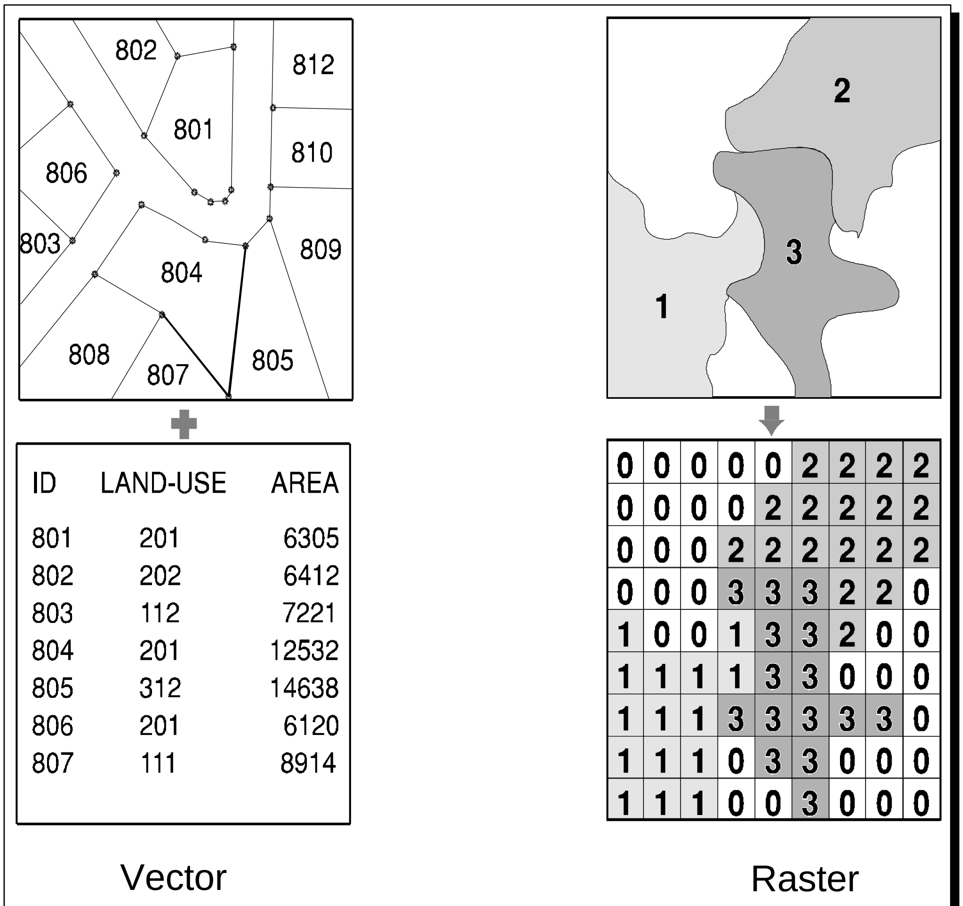

Figure 4

Raster versus Vector

Raster systems are typically data intensive (although good data compaction techniques exist) since they must record data at every cell location regardless of whether that cell holds information that is of interest or not. However, the advantage of the raster data structure is that geographical space is uniformly defined in a simple and predictable fashion. As a result, raster systems have substantially more analytical power than their vector counterparts in the analysis of continuous space and are thus ideally suited to the study of data that are continuously changing over space such as terrain, vegetation biomass, rainfall and the like. The second advantage of raster is that its structure closely matches the architecture of digital computers. As a result, raster systems tend to be very rapid in the evaluation of problems that involve various

The basic data structure of vector systems can best be described as a network. As a result, it is not surprising to find that vector systems have excellent capabilities for the analysis of network space. Thus the difference between raster and vector is less one of inherent ability as it is of the difference in the types of space they describe.

mathematical combinations of the data in multiple grids. Hence they are excellent for evaluating environmental models such as those for soil erosion potential and forest management suitability. In addition, since satellite imagery employs a raster structure, most raster systems can easily incorporate these data and some provide full image processing capabilities.

While raster systems are predominantly analysis oriented, vector systems tend to be more database management oriented. Vector systems are quite efficient in their storage of map data because they only store the boundaries of features and not what is inside those boundaries. Because the graphic representation of features is directly linked to the attribute database, vector systems usually allow one to roam around the graphic display with a mouse and inquire about the attributes of any displayed feature: the distance between points or along lines, the areas of regions defined on the screen, and so on. In addition, they can produce simple thematic maps of database queries such as, "show all sewer line sections over one meter in diameter installed before 1940."

Compared to their raster counterparts, vector systems do not have as extensive a range of capabilities for analysis over continuous space. However, they do excel at problems concerning movements over a network and can undertake the most fundamental of GIS operations. For many, it is the simple database management functions and excellent mapping capabilities that make vector systems attractive. Because of the close affinity between the logic of vector representation and traditional map production, a pen plotter can be driven to produce a map that is indistinguishable from that produced by traditional means. As a result, vector systems are very popular in municipal applications where issues of engineering map production and database management predominate.

Raster and vector systems each have their special strengths. Some GIS incorporate elements from both representational techniques. Many systems provide most functions for one technique and provide limited display and data transfer functions using the other. Which technique is most appropriate depends upon the application. A complete GIS setup may include a vector system, a raster system, or both, depending upon the types of tasks that must be done. While some applications are suitable to either vector or raster, usually one is more appropriate. Using a system that is not well suited to a particular task can be very frustrating and lead to unsatisfactory results.

Geographic Database Concepts

Organization

Regardless of the logic used for spatial representation, raster or vector, a geographic database -- a complete database for a given region -- is organized in a fashion similar to a collection of maps (Figure 5). Vector systems may come closest to this logic with what are known as *coverages*, map-like collections that contain the geographic definitions of a set of features and their associated attribute tables. However, they differ from maps in two ways. First, they will typically contain information on only a single feature type, such as property parcels, soils polygons, or the like. Second, they may contain a whole series of attributes that pertain to those features, such as a set of census information for city blocks.

Raster systems also use this map-like logic, but usually divide data sets into unitary *layers*. A layer contains all the data for a single attribute. Thus one might have a soils layer, a roads layer and a land use layer. Some raster systems can also link a feature identifier layer (a layer that contains the identifiers of the features located at each grid cell) with attribute tables. More commonly, separate layers will exist for each attribute and paper maps will be produced from a combination of map layers. (see Figure 5).

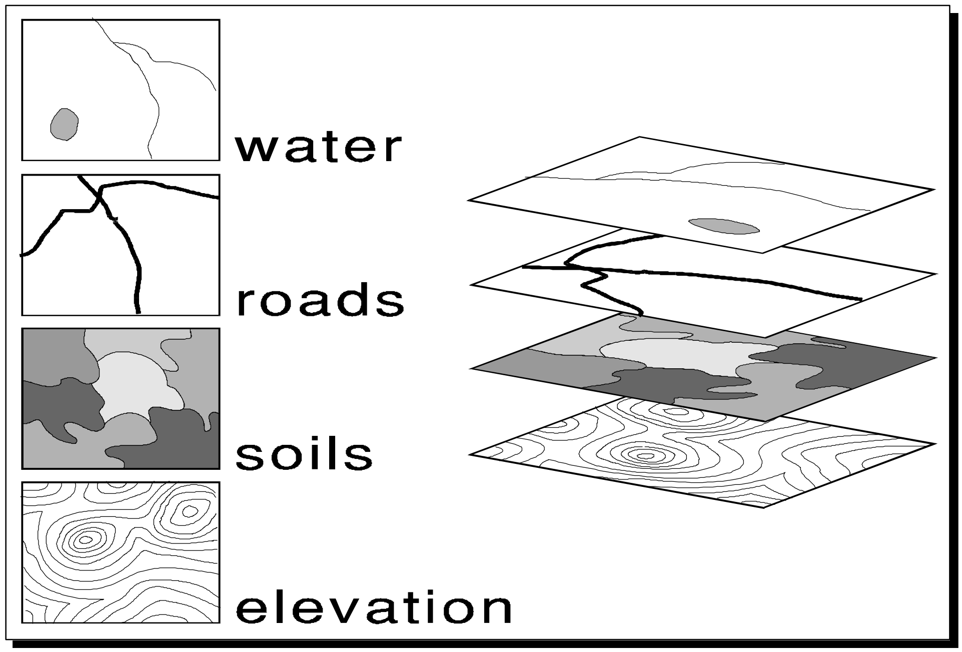

Figure 5

Although there are subtle differences, for all intents and purposes, raster layers and vector coverages can be thought of as simply different manifestations of the same concept -- the organization of the database into elementary map-like themes. However, layers and coverages differ from traditional maps in another important way. When map data are encoded in digital form (a process called digitizing), scale and projection differences are removed and data are stored in ground units. Layers can therefore be merged with ease -- a problem that has traditionally hampered planning activities with paper maps. The issue of resolution remains, however, and the results from a GIS are as much affected by the compounding of errors as any more traditional medium.

Attribute Data Storage

There are basically two ways in which attribute data are stored. Either the attributes are stored in a database and are linked, by an identifying code for example, to the spatial features, or the spatial features themselves carry the attribute data. Storing the attributes separately is very efficient in terms of storage space, and is also efficient for analyses based on attributes alone. This is the typical storage structure of vector systems. A few raster systems also allow for this structure, and storage space savings can be accomplished through compression of the feature definition files. In most raster systems the attribute values themselves are the values of the individual pixels, and thus recreate the spatial data pattern.

Georeferencing

All spatial data files in a GIS will be georeferenced. Georeferencing refers to the location of a layer or coverage in space as defined by a known coordinate referencing system. With raster images, a common form of georeferencing is to indicate the reference system (e.g., latitude/longitude), the reference units (e.g., degrees) and the coordinate positions of the left, right, top and bottom edges of the image. The same is true of vector data files, although in this case the left, right, top and bottom edges refer to what is commonly called the *bounding rectangle* of the coverage -- a rectangle that defines the limits of the mapped area. This information is particularly important in an integrated raster and vector GIS since it allows raster and vector files to be related to one another in a reliable and meaningful way. It is also vital for referencing data values to actual positions on the ground.

Analytical Tools

Database Query

The most fundamental of all tools provided by a GIS are those involved with database query. Database query simply asks to display already stored information. In some cases we query by location, -- *what land use is at this location?* In other cases we query by attribute -- *what areas have steep slopes?* Sometimes we undertake simple queries such as those just illustrated, and at other times they will be complex compounds of conditions -- *show me all wetlands that are larger than 1 hectare and that are adjacent to industrial lands.*

Single Attribute Query -- Reclassification

In most systems these query operations are undertaken in two steps. The first step, *reclassification*, creates a new map of each individual condition of interest (Figure 6). For example, if one were looking for agricultural landuse areas on steeply sloping lands, the first step would be to create a map of agricultural areas alone by reclassifying all landuse codes into only two -- a 1 whenever an area is agricultural and a 0 for all other cases. The resulting map is known as a *boolean* map since it shows only those areas that meet the condition (1 = true, it is agricultural) and those that do not (0 = false, it is not agricultural). Boolean maps are also called *logical* maps since they show only true/false relationships. They are sometimes also called *binary* maps since the image contains only zeros and ones.

Multiple Attribute Query -- Overlay

Once the agricultural map has been created, an slope map is then also reclassified to create a boolean map showing slopes associated with high erodibility. At this point we can then combine the two conditions using an operation called *overlay* (Figure 6). Overlay is the hallmark of GIS in that it is only a GIS that can combine conditions such as this that involve features with different geographies. Typically, an overlay operation in GIS will allow the production of new maps based on some logical or mathematical combination of two or more input maps. In the case of database query, the key logical operations of interest are the AND and OR relational operators, also

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It is worth noting here that the bounding rectangle is defined by the study region of interest and does not refer to the actual minimum and maximum coordinates in the data file.

known as the INTERSECTION and UNION operations respectively. Here we are looking for cases of agricultural land AND steep slopes -- the logical intersection of our two boolean maps.

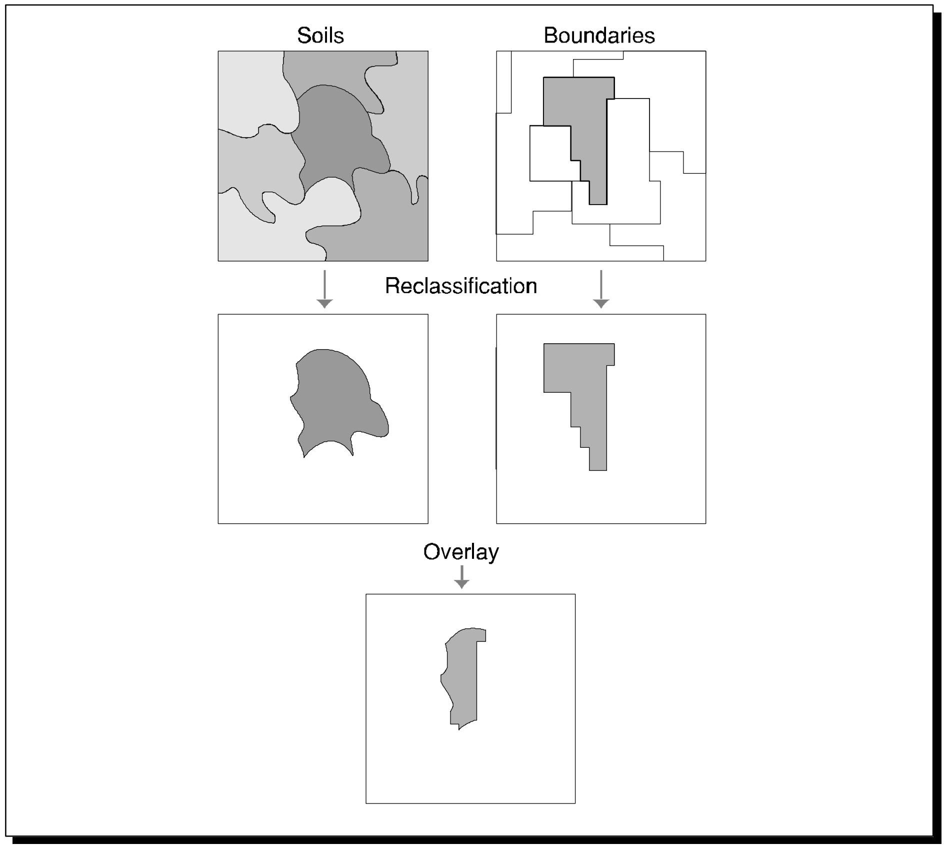

Figure 6

Tabular/Statistical Summarization

Rather than producing new images, it is possible to query the database for summary statistics that may be printed to the screen, a file, or to the printer. In this way it is possible to find for each identifier on one map the maximum, minimum, mean, etc. of these same areas on another map. For example, one might use a map of political units, such as states, then query a map of rainfall to find the range of rainfall values for each state, or a map of population might be queried to find the total population for each state.

Map Algebra

The second set of tools that a GIS will typically provide is that for combining map layers mathematically. Modelling, in particular, requires that we be able to combine maps according to various mathematical combinations. For example, we might have an equation that predicts mean annual temperature as a result of altitude. Or, as another example, consider the possibility of creating a soil erosion potential map based on factors of soil erosion, slope gradient and rainfall intensity. Clearly we need the ability to modify data values in our maps by various mathematical operations and transformations and to combine factors mathematically to produce the final result. The Map Algebra tools will typically provide three different kinds of operations :

- the ability to arithmetically modify the attribute data values over space by a constant (i.e., scalar arithmetic);
- the ability to mathematically transform attribute data values by a standard operation (such as the trigonometric functions, log transformations and so on);
- the ability to mathematically combine (such as add, subtract, multiply, divide) different data layers to produce a composite result.

This third operation is simply another form of overlay -- mathematical overlay, as opposed to the logical overlay of database query.
To illustrate this, consider a model for snow melt in densely forested areas:

$$M = (0.19T + 0.17D)$$

where M is the melt rate in cm/day, T is the air temperature and D is the dewpoint temperature. Given maps of the air temperatures and dewpoints for a region of this type, we could clearly produce a snow melt rate map. To do so would require multiplying the temperature map by 0.19 (a scalar operation), the dewpoint map by 0.17 (another scalar operation) and then using overlay to add the two results. This ability to treat maps as variables in algebraic formulas is an enormously powerful capability.

Distance Operators

The third tool group available with GIS consists of the Distance Operators. As the name suggests, these are a set of techniques where distance plays a key role in the analysis undertaken. Virtually all systems, for example, provide the tools to construct buffer zones -- areas within a specified distance of a designated feature type. Some can also evaluate the distance of all locations to the nearest of a set of designated features, while others can even incorporate frictional effects and barriers into distance calculations.

When frictional effects are incorporated, the distance calculated is often referred to as a *cost distance*. This name is used because movement through space can be considered to incur costs, either in money, time or effort. Frictions increase those costs. When the costs of movement from one or more locations are evaluated for an entire region, we often refer to the resulting map as a *cost surface.* In this case, areas of low cost (presumably near to the starting point) can be seen as valleys and areas of high cost as hills. A cost surface thus has its lowest point(s) at the starting location(s) and its highest point(s) at the locations that are farthest away (in the sense of the greatest accumulated cost).

Given the concept of a cost surface, Geographic Information Systems also commonly offer *least cost path analysis* -- another important distance operation. As the name suggests, our concern is to evaluate the least-cost path between two locations. It is the cost surface that provides the needed information that can allow this to be evaluated.

Taken from: Dunne, T., and L.B. Leopold, 1978, *Water in Environmental Planning* (San Francisco: W.H. Freeman and Co.) 480.
It should be noted here that a cost surface as just described can only be evaluated with a raster system. For vector systems, the closest equivalent would be cost distances evaluated over a network. Here we see a simple, but very powerful, illustration of the differences between raster and vector systems in how they conceive of space.

Regardless of how distance is evaluated -- by straight line distance or by cost distance, another commonly provided tool is *allocation*. With allocation, locations are assigned to the nearest of a set of designated features. For example, we might establish a set of health facilities and then wish to allocate residents to their nearest facility.

Context Operators

Finally, most Geographic Information Systems provide a variety of Context Operators (also known as *neighborhood* or *local operators*). With context operators, we create a new map based on the information on an existing map and the context in which each feature is found. One of the simplest examples of this is *surface analysis* where a digital elevation model is used to produce a slope map by examining the heights of locations in comparison to the heights of neighboring locations. In a similar fashion, the aspect (the direction of maximum downward slope) can also be evaluated.

A second good example of a context operator is a *digital filter*. Digital filters operate by changing values according to the character of neighboring values. For example, a surface of terrain heights can be smoothed by replacing values with the average of the original height and all neighboring heights. Digital filters have a broad range of applications in GIS and Remote Sensing, ranging from noise removal to the visual enhancement of images. Digital filtering may also be used in deriving several ecological measures such as diversity, relative richness and dominance.

Connectivity Operators

Connectivity operators determine whether adjacent points have the same value. These are used to group areas that have the same value into clumps, with each clump assigned a new, unique value. This is often a necessary step in determining the size of contiguous areas. The user typically has the option of specifying whether a neighbor with the same value must share an edge or only a corner point to be considered as contiguous. Some examples are viewshed and watershed determinations.

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Part 3 : Implementation

How Do We Make It Work?

The Technology Transfer Process

GIS is a relatively new information technology that supplies a set of tools to analyze and manage many types of data, both human and physical, in order to make more informed and effective decisions. Information is the end result of an analytical process that feeds into the decision making process. In order to take advantage of the capabilities of GIS, a mechanism must be put into place to sustainably transfer and implement the technology which can significantly enhance the decision making process and the way problems are addressed.

By technology transfer, we refer to the process by which technology is "injected" into an organizational and social setting and becomes part of the way the institution does its business. As a multifaceted process, there are several things that must be kept in mind. First, information is developed with some end use in mind, usually to make decisions. Second, technology is not a black box; it does not come with ready-made answers for every problem. Third, adoption of a new technology causes organizations and individuals to do things differently than they had in the past; change is difficult for organizations and individuals both. Finally, everything changes. Technology, budgets, staff, mandates, and objectives must change with time.

The complexity of the technology transfer process has not always been realized. In recent years, for example, the value of GIS technology has been called into question by the people it was intended to serve -- the decision makers. This is the result of an increasingly familiar problem in dealing with technology. At the beginning of the technology transfer process, access to the technology and development of it is often centered around technical experts who are concerned with technical issues. The decision makers who are supposed to use the information but who are not necessarily technically proficient are often excluded from defining what the system should produce and deciding where it should fit within the organization. This results in an understandable rift between technicians and decision makers, with the concentration of analysis and information largely in the hands of the technicians and the ultimate rejection of the technology by the decision makers. It is not unlike the performance of planned economies where the economic planners decide what commodities should be produced and consumers are informed that they may take it or leave it. Unfortunately, if the planners' vision does not coincide with the consumers wishes, the commodities are left on store shelves.

Being a complex technology, GIS requires properly trained staff and data analysts. Given the nature of spatial analysis, the tools in the GIS toolbox are in a state of continuous development and adaptation. Undoubtedly, it is for these reasons that the implementation process gravitates toward the GIS technicians alone. However, unless there is a dialogue between the GIS technicians and decision makers, it is difficult to identify which problems should be addressed and to select and apply the appropriate GIS tools. Guidance must come from the decision makers, but it is the technician's job to implement and adapt the appropriate tools to meet this organizational demand. Again using the market analogy, this should be viewed more as market economy in which the technician is the vendor and the decision maker is the customer. To succeed, it is worth remembering J.C. Penney's dictum that, *the customer is king*.

Within an institution, though, the customers -- or users, as defined here -- are not free to shop around. It then becomes an issue of how the relationship between technicians and decision makers is structured so the users get what they need and want. Because it shapes institutional "attitudes" toward the technology, this issue has a profound impact on whether the technology will be adopted and sustained. Obviously, it is vital that development and implementation of GIS technology be *user oriented*, and the products it generates are perceived as useful and thus the process is *demand driven*. To achieve this, we must incorporate the users into the process by having them define how to "orient" the technology or identifying how it should be used, the problems to which it is applied, and the products it generates. Borrowing from the lexicon of international development, we might call this the *participatory approach* to technology transfer.

Ultimately, technology shapes almost all aspects of *how* things are done in an organization, not just *what* is done. Thus, implementation of GIS -- like any other technology -- is not just hardware and software procurement, but ultimately adoption of a *process* that results in the technology becoming a functional part of the organization. The participatory implementation process brings together the technicians and decision makers in the development of the technology and the implementation process.

System Design

The history of GIS implementation in developing countries has followed the model described earlier. It was dominated by procurement of hardware and software, development of analytical procedures, design of database structures, and the training of personnel. Obviously, all this is part of the system design process, but is not the whole of it. Aside from the technical aspects, the GIS system design process itself must be viewed as a vehicle to improve the capability of an organization to meet its objectives, as well as to satisfy the career objectives of the individuals who comprise it. With this in mind, the system design effort should have four ultimate goals:

1. develop a system that is technically functional to meet the information needs of the organization;
2. develop a system that is intuitively accessible and exploitable by the decision makers;
3. develop a system that addresses organizational goals;
4. install a system that technicians and decision makers are motivated to use because it meets their individual needs and goals.

If the system is not designed with the human factor in mind, as addressed by the above issues, then individuals that the system is intended to serve will look elsewhere for the information they need.

Phased Participatory System Design

The system design phase of the GIS implementation is perhaps the most critical. Obviously a good deal of effort is devoted to defining system architecture, selecting equipment, and acquiring staff and training them. This requires a great deal of input from all concerned parties. Perhaps more importantly, it is also the time in which relationships are established between technicians and decision makers, and among concerned agencies that either provide data or extract information from the system. If these relationships are not established, or if they are perceived to be unequal, unfair, or unimportant, the implementation is not likely to succeed.

Traditional GIS system design, generally, has been guided by western models characterized by a structured, stepwise progression as in Figure 7. This framework is logical, but static and linear, and does not accommodate well the interactive relationships described above, or the evolution of human and organizational objectives.

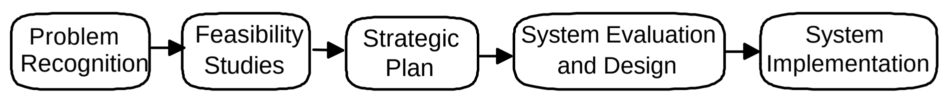

Figure 7

Alternatively, a more dynamic approach assumes that individuals, as well as organizations, evolve in terms of their needs and capabilities and that change must be accommodated within the system design (Figure 8). Moreover, as suggested above, there will be multiple players involved, and their demands and influence will also vary through time. Together, the decision makers and technical experts collaborate in the system design to support the technical, functional, and organizational goals and objectives to meet the organization's evolving demands.

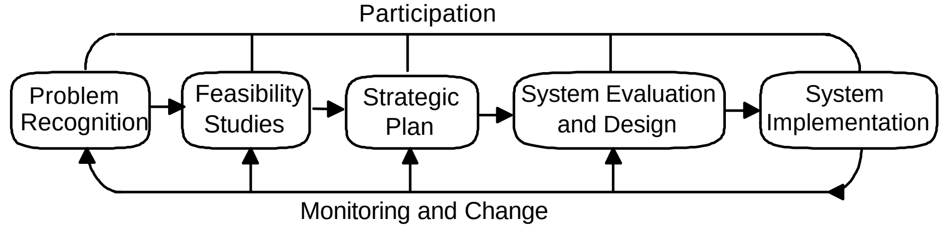

Figure 8

To facilitate this dynamic approach, this handbook advocates an incremental framework to transfer GIS technology that begins with the development of a single-purpose, *analytical* system for a small team or work group within an agency. This approach serves to develop local capacities and to demonstrate the use of the technology for solving relevant problems. A likely scenario would be to address a problem that the agency is currently facing and that the technology can readily handle. If, for example, a local agency is planning for recessional agricultural, flood modeling could facilitate likely flood plain scenarios and crop potentials.

Later, as the technology catches hold and spreads to other applications, it may lead to development of resource intensive, multipurpose *archival* systems. Ultimately, development of elaborate and extensive systems may be undertaken, but only when there is sufficient demand to support it and the appropriate institutional capacities have been developed.

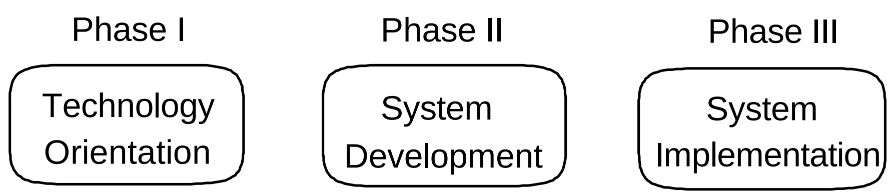

Figure 9

The phased participatory system design framework is presented in Figure 9. Although it follows closely the broad components of Figure 7, the framework must be thought of as an evolutionary process that can accommodate the dynamics of human interactions. Since no single design will fit all organizations, each phase in the process must be adapted to reflect evolving organizational objectives and human capabilities. Also, for every framework employing this design, three fundamental criteria are crucial for sustainable GIS technology transfer:

1. *Social Orientation:* Technology cannot on its own meet organizational goals. People throughout an organization must be involved, capable, and willing to use the new technology to execute tasks that lead to organizational objectives. Thus, the adoption of technology should not be centered on the technology itself, but on the social adoption process as well -- users must be able to meet their own individual functional needs in using the technology.
2. *Participatory Framework:* Benefits of the adoption process will be realized if the technology contributes to the realization of organizational objectives. The identification of these objectives and the information products needed from the technical system is a result of a collaborative process between all the relevant stakeholders having access to the technology -- staff, decision makers, technicians, and others in collaborative agencies. In the end, the organization will fully support the technology's adoption, if all relevant stakeholders are involved in the process.
3. *Phased-Evolution Process:* The introduction of new technologies will disrupt long-established organizational norms and practices. Their adoption cannot be achieved overnight. Adoption is an evolutionary learning process that acknowledges this potential for disruption. Implementation, then, should be phased and it should proceed through a series of steps, but it must also be flexible enough to ac-

commodate changes in the technology, the organization, and individuals. Establishing relationships early on, keeping lines of communication open, and responding to demands as they emerge and change will keep the process moving.

Phases of the System Design Process

Phase I - Technology Orientation

The first phase of the design process is technology orientation. The objectives are two-fold. First, to establish a baseline level of technical capability that can be used to evaluate the technology. Second, to increase general awareness regarding the technology and its potential at the decision making level. Together, these two groups can identify where and when it might make sense to employ a GIS technology.

The initial stage of the system design involves what can be termed a "contagion" process where only a small group is exposed to the technology through training and workshops. The technology has potentials that are both positive and negative. To ensure an informed evaluation, a cadre of technicians is trained from within the organization to initially assess these potentials and assist in the development of long-term system design plans. The orientation process involves training at the introductory and advanced levels and the identification of a design team to lead a technology awareness process within the organization.

Obviously, training at a variety of levels is the major focus in the technology orientation phase. One level deals with the technology, and thus is largely analytical, conveying the principles, capabilities, and limitations of GIS technology. The training also focuses on specific trainee in-country projects in order to facilitate: (1) a quick and useful in-house demonstration project; (2) limited data collection; and (3) quick development of an in-house GIS capability.

Another level focuses on technical training and application development in an institutional setting, dealing more with organizational issues surrounding the GIS technology transfer process. Another training stage emphasizes GIS as a decision support tool rather than a technical black box. To facilitate the decision making capabilities of the technology, the GIS analysts are trained to become facilitators, for the most part, among the decision makers.

At this stage, system design becomes a major part of the training process. The trainees form provisional design teams that begin an informal process of increasing technology awareness within the organization, increasing in-house support for GIS technology, and identifying appropriate demands within the organization. This phase also allows for the formation of user-groups that will share resources and information.

Phase II - System Development

Phase II of the system design process involves the formal planning stages of the eventual GIS implementation. A permanent design team, drawn from the provisional teams, develops a formal process by which the organization can evaluate, implement and monitor these new technology systems, as well as, ensuring that the technology addresses relevant organizational problems.
The design team performs technology sensitization programs to assess the capabilities of GIS technology and its potential role for altering and enhancing current methods of

using spatial information for decision making. The initial in-country projects will assist in addressing these issues.

As awareness and support are increased within the organization, and the potential for the technology becomes apparent, the design team must concurrently enlist management support. These are the decision makers who will eventually commit funding and staff support for the technology and, ultimately, employ the information products in making decisions. As a result, this group must be involved in assessing the costs and benefits of the system.

The design team will also be responsible for the development of the *functional requirements study*, the FRS, which will become the basis for the formal GIS implementation planning document. The FRS documents this process by addressing issues that will permit implementation of the technology in a style that suits the human functional needs and capacities and fits the organization's work philosophy and practices, including:

- the information products required by decision makers;
- the frequency these products are needed;
- the data required to develop the products;
- the reliability, costs, and availability of the data;
- the staffing requirements;
- the operational GIS procedures needed to analyze the data; and
- training procedures for implementing the GIS.

Following the FRS is the development of a *strategic plan* for implementing GIS technology that will deliver these products in a timely and cost effective manner. This plan must address both the social organizational issues and the functional technical issues involved in adapting the technology to the existing organizational structure. Logistical issues are also addressed in the strategic plan such as specifying the facilities needed to house the new system and identifying who will have access to these facilities. It is crucial that management be made fully aware of the proposed implementation so they can plan the financial and human resources needed.

Once the organization's functional requirements are established, GIS systems are evaluated in terms of their abilities to meet these needs. The functionality required of the system should be weighed against costs, speed, ease of use, and the quality and capacity of support. Many peripheral systems may be required to accompany the GIS. And in most cases, because different systems have different strengths, more than one type of GIS may be required to meet the organization's needs (see Part 2). It is often necessary to develop a request for proposals for outside agencies that are willing to assist in the implementation process and software and hardware procurement, initial database development, and application development.

Phase III - System Implementation and Support

The care with which the system is planned to be both a social and technical system will be evident during implementation. The final implementation establishes a technical system that is able to support the technical demands of the organization *and* a social system that has been adjusted to exploit the technology. The planned social change now comes to fruition -- tasks are assigned and training is ongoing.
Most likely, the in-country projects and awareness programs carried out in Phase II have heightened expectations and acceptability. However, people within an organization are not always receptive to change, and the process must evolve more slowly than might be desired. It is common for the new system to run in parallel with the old work environment while it is eased into the existing organization.

A system that meets current human demands will eventually be in place within the organization. However, as a system working within a dynamic organization, it must continue to evolve after the initial implementation to meet changing objectives and human skills. It will thus need constant monitoring, evaluation, and support.

The result of the evaluation must determine if the technology addresses the demands of the organization and if it is delivering the expected results to the decision makers. Positive factors contributing to the decision making process, as well as negative barriers, are determined. Also important in the evaluation process is the system's accessibility to analysts and decision makers, user performance, and overall technical performance. In all likelihood, users will not work with the system efficiently, and may abandon it altogether, if the system is not meeting its stated and anticipated objectives. Adjustments should be expected, at the very least, due to rapidly changing technologies.

Current methods of handling spatial data within organizations often hinder decision making as a result of data being out of date, of poor quality, in varied formats, or scattered throughout the organization. Automated technology provides an alternative to rapidly acquire information, develop alternative planning scenarios, evaluate performance, and monitor projects, while increasing organizational productivity. But at the same time, implementing these technologies must be planned not only as a technical exercise, but one having far-reaching social ramifications within the organization as well. Part 3 provides the framework for such an implementation process. The extent to which each of the phases outlined above are addressed will determine the ultimate sustainability of the GIS implementation process.

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Part 4 : Resources

What does it take?

The Bottom Line

The resources required to implement and maintain a system are a predictable constraint, regardless of how the GIS is intended to be used. GIS implementations fail for a number of reasons, but perhaps the most frequent is an underestimation of the resources required to sustain it.

Costs of computer hardware, supporting peripherals, software, and even training may appear acceptable at the outset. However, if there is not a corresponding commitment of the institution to meet the continuing capital, data, personnel, and organizational needs of the undertaking, success is unlikely regardless of its justification or cost.

The purpose of Part 4 is to outline some of the resources that should be considered and the issues that surround them. As recent history shows, computer technology advances very quickly, particularly in terms of power vs. cost. Moreover, because there is a range of applications (archive, analysis, and decision support or action) as well as a range of settings in which it might be implemented (e.g. office; facility; ministry), there is no simple or single answer to the question, "What will all of this take?" What follows is more of a checklist of the types of things that should be considered rather than an inventory of what will be required.

Technical Resources

As emphasized throughout this volume, every aspect of a GIS implementation must reflect the needs it is intended to address. Although obviously driven by need, the selection of technical resources -- hardware and software -- also greatly affects the monetary, human and institutional resources that must be devoted to the undertaking. The differences in requirements for purchase, maintenance, staffing, and other overhead can vary by orders of magnitude, depending on the hardware or software systems selected.

Hardware

It is often an intimidating and confusing task to decide what pieces of hardware and in what configuration are needed for the GIS implementation you have planned. Even if the functional requirements study details the types of capabilities that are needed, often many options exist that will meet those needs. The key to making this process bearable is to take enough time and to always get second, third and fourth opinions and quotes on prices. The following section highlights some of the components that might be necessary for a system and some of the options available for each.

Computers

When choosing computers for a GIS implementation, some of the major issues to consider are:

Speed and Capacity of Calculation

Speed refers to the time it takes for the computer to execute one command and move onto the next. It is impossible to feasibly perform some operations, such as 3-D modeling on slower machines because of the sheer number of calculations required. The size of the data set being used and the complexity of the anticipated operations may rule out slower, less expensive computers. The speed and capacity of the computer is determined to a large part by the particular type of computer platform you have. It should be noted, however, that larger platforms may in some cases perform slower than their less expensive counterparts because of shared network demands.

Processor speed may be measured in a variety of ways: Mhz -- megahertz, or millions of processor cycles per second; MIPS -- millions of integer instructions per second; MFLOPS -- millions of floating point operations per second, and so on. These measures can be very confusing and are not necessarily comparable between systems. Similarly, speed can be substantially determined by basic chip design and the number of bits that can pass through the basic communications channels (the *bus*) at one time -- known as the *word* size -- regardless of the basic speed measurement. Thus, if through the system design phase, speed is identified as a critical issue, individual benchmarking should be undertaken. In general though, it is reasonable to expect that the higher the speed rating, and the larger the word size, the faster the computer should be.

Ease of Use

Each computer supplies the user with a way of interacting with it, or a *user interface*. The ease of use of computers is greatly affected by the type of user interface they have. Some computers require that sets of complex commands be typed in with little or no direction supplied to the user. Other interfaces require commands to be typed in, but the command names are descriptive and easily remembered. Both of these are known as *command line* interfaces.

Another type of user interface is *menu* oriented, with the user picking commands from a list rather than typing them. These systems are usually compatible with a mouse and are known as *graphic or icon* oriented user interfaces. Software packages also have their own user interfaces. Thus it is possible for a mouse-compatible, menu oriented software application to be run on a computer that has a command line user interface. Individuals vary in the type of interface they prefer. Many knowledgeable users find the speed of command line interfaces to be attractive. However, for new or occasional users, and those uncomfortable with typing, menu interfaces are unquestionably the more popular and productive solution.

Video Capabilities

There are two pieces of hardware that determine your video capabilities -- the monitor and the *graphics card* of the computer. Some GIS require that you have two monitors, one to enter commands and one for display. Questions to ask when you are shopping for a system are: What are the possible resolutions of the monitor-graphics card? How many colors can be displayed at the same time on the screen?

Memory

There are two basic types of memory that the computer must have. The first is its dynamic memory, known as *random access memory*, or RAM. This is the active "thinking space" for the computer. Different software packages require different amounts of RAM, as do other utilities (such as pop-up agendas or notepads) and device drivers (such as for a mouse). RAM can be added to the system later if "out of memory" problems occur. There are utilities available to help you optimize the configuration of your computer in order to use its RAM most efficiently.

The second type of memory is *disk memory* or memory in which data are stored for either short or long term. Most computers have hard disks (some early microcomputers allowed the system to operate from floppy drives). The size of hard disk you need depends on the size of the database you will work with and the applications you will be doing. Multiple hard disks may also be purchased for the same computer. Insufficient hard disk space is the most common problem experienced with computers. In general, double what you think is reasonably required.

In addition to standard magnetic hard disks installed inside the computer, there are other options for working data storage. These include removable hard disks, removable high capacity floppy systems, external hard disks and a number of optical disks (ROM = *read only memory,* you cannot write new information to the disk; WORM = *write once, read many*, you can write once and read many times, but you cannot erase what you have written; Read/Write Optical Disks allow data to be written and erased).

Platform

There are three basic families of computers that have different characteristics for each of the issues above. These three basic families are (1) *mainframes*, (2) *minicomputers* or *workstations*, and (3) *micro computers* or *personal computers*.

Mainframe computers are very large and very expensive. These computers are capable of doing many tasks simultaneously, so can accommodate multiple simultaneous users. The ability to do more than one calculation at a time is known as parallel computing. Parallel computing is very fast when the calculations are independent of each other. However, if the input for one calculation is the result of another calculation, the two cannot be done in parallel. This family of computers is generally associated with universities or large departments or ministries. They usually require one or more people to be employed as system managers and require special control of temperature and humidity conditions.

Workstations are physically much smaller and much less expensive than mainframe systems. They provide a high level of computing power and speed, yet do not normally require the kind of full-time system support that is required by mainframes. This family of computers often uses UNIX as its operating system (see below).

Personal Computers are divided into two basic families, the IBM-PC compatible family and the Macintosh family. These two personal computers are not compatible with each other. The PC family is generally less expensive and is used more worldwide, but the Macintosh family excels with certain applications, mainly graphics. The user interface for the Macintosh is very friendly and allows the user to do most activities by using the mouse. The PC user interface has historically been command-line oriented. Microsoft's *Windows* for the PC has, however, allowed for the development of Macintosh-like programs that run on the PC. Today, many graphics software programs run identically on the Macintosh and under *Windows* on the PC.

There are now a variety of sizes of personal computers in both the PC and Macintosh families. Machines that sit on or beside a desk and are too heavy to carry around on a regular basis are known as *desktop* computers. Those that can be carried easily are known as *laptop* computers, and those that are designed to be very small and lightweight are known as *notebook* computers. With the rapid advancement of computer technology, the speed, storage capacity and color video capabilities that were previously reserved for desktop machines are now available in notebook computers, though at considerable cost.

Operating System

In addition to the basic hardware components, computers also require a specialized piece of software to make the hardware elements function as a whole. This is known as the *Operating System*. In the earliest computers, operating systems were hard-wired into the computer as an elaborate set of operator switches and dials. Today, however, operating systems are distributed as software. Even so, the functioning of the Operating System is so close to that of the hardware that it should be considered as an integral part of the complete hardware package.

A variety of Opertating Systems are in use with today's computers. For microcomputers, the MS-DOS and System 7 operating systems are the most common for PC and Macintosh computers respectively. For workstations, minicomputers and mainframes, VMS, CMS and UNIX are the most common.

One of the import features an operating system provides is the user interface. Many provide both command line and graphic interface options. For example, the basic command line interfaces of MS-DOS and UNIX are supplemented by the graphical user interfaces of WINDOWS and X-WINDOWS respectively.

As of this writing, several operating systems have been or are about to be released that will run on both PC's and workstations -- selected variants of UNIX, Windows-NT and the NEXT operating system. Systems such as this offer portability between hardware platforms.

Software Compatibility

It is essential that the hardware platform you choose be compatible with the software. A software package that runs on a mainframe computer under VMS will not run on a PC using DOS. Some software packages offer different versions for different platforms. Be sure you ask what the differences in functionality are between the platform versions. If you have decided the workstation version of a software package will do what you need, do not assume that the PC version will include all the same capabilities. Also, as noted above, in order for some software packages to run, special hardware must be added onto the platform.

Warranties, Maintenance and Technical Support Service Availability

Hardware does break. Against this certainty, it is important that you have agreements in writing that spell out the warranty conditions for the equipment you intend to purchase, what is required for regular maintenance, and what kind of technical support services are available and at what cost. Is technical support offered over the phone? Are technicians able to come to the site to repair problems? Are there costs for these services that are not covered in the purchase price?

Cost

Costs range from multi-million dollar super computers to a few thousand dollars for a desktop personal computer.

Data Storage Media and Devices

There are three common types of data storage. The first is the working data storage area, where the data you are using are stored. This was discussed above.

The second type of storage to consider is backup storage. The entire system should be backed up regularly and the backup data stored in a safe place. If you are lucky, you may never need to access the data once it is backed up. But if something does happen to the active database, the information that was backed up can be recovered.

The third type of data storage is archival storage. This is for data that you want to maintain in retrievable form for long periods of time. The data may need to be preserved for legal reasons, to be used later to study change over time, or because another future study may need the information.

There are two components that make up a storage system -- the hardware device itself (e.g., a tape reader or optical disk drive) and the storage media (e.g., the tapes or optical disks). Some of the issues surrounding the selection of data storage media and devices include:

Media Capacity

The capacity of storage media is often measured in megabytes. One megabyte is one million bytes of data. How much is enough? This depends entirely on the type of applications and data you expect to be using. Determining the data storage devices and media for the system must be a part of the system design process. However, there are seldom complaints about having too much storage capacity.

Access Speed

Another criterion to consider when weighing storage device options is speed, both for backing up and restoring data. This may or may not be an issue, depending on staffing and resources. Access speed is affected mainly by whether the system has random access to the data (e.g., disk) or has to move sequentially through the media (e.g., tape) to get to the data you are looking for. Systems that use tape devices tend to be slow, since the tape must be accessed in sequential order. Disk systems tend to allow for random, and hence faster, access.

Media Longevity

Every type of medium has an expected longevity, or "shelf life." After a given period of time the media begins to degenerate and parts of the data stored will become unrecoverable. The estimated longevity of backup media must be factored into the system design process and considered in long-term funding decisions. Before the storage media reaches its critical age, copies must be made onto fresh media.

For archival storage, most media can be used, but attention must be given to the longevity of the media and replacement copies made regularly. For example, floppy diskettes have a reliability of no more than 3-5 years; backup tapes (QIC format) will generally last 5-7 years; optical disks 7-10 years and only a few special formats (such as Exabyte tapes) can achieve archival lives of 25-30 years. The climatic conditions for storing the archive copies should also be as clean and free of temperature and humidity extremes as possible.

For backup storage, a variety of tape formats are available including 9-track, Exabyte and quarter inch tapes. Most of the media usable for dynamic storage may also be used for backup storage, depending on the amount of data to be backed up and the frequency.

Media Standards

In addition to choosing a system that suits the needs of your particular system, there may also be times when you would like to be able to exchange data with other institutions. If this is anticipated in advance, an effort can be made to ensure that data will be exchangeable.

Warranties and Technical Support for Devices and Media

As with the computer hardware itself, warranty and technical support services must be understood and agreed upon prior to purchase.

Cost

Costs vary widely and must be balanced against the other criteria listed.

Data Input Devices

Data input devices do just that -- they allow you to enter new data into your database. There are two basic devices to consider:

Coordinate Digitizers

Digitizers allow the user to trace features on a paper map to create a digital (hence the name digitizer) version of those features. The operator simply moves a puck or pen-like stylus over the line work on a paper map that is taped to the digitizing tablet. Linework is translated into digital Cartesian coordinates. These digital coordinates can then be translated and projected into real-world coordinates such as latitude/longitude.

Tablet sizes vary from small, 12" x 12" tablets that sit on the table top to large 36" x 48" models that stand by themselves. More expensive models allow for back lighting that can be adjusted for brightness. Costs range from a few hundred to several thousand dollars. Some portable models are also available that roll up like a map or that use sonic sensors and therefore work on any flat surface.

In addition to the physical digitizing device, digitizing software must also be available. Some of the more sophisticated digitizing packages will also allow for post-digitizing editing of data and are often part of the GIS software itself.

Scanners

While a digitizer allows for the digitization of line work (vector data), a scanner is required to digitize continuous data such as aerial photographs. The page or image to be digitized is placed on the glass of the scanner and a light is moved across the page. Sensors detect the reflection of red, green and blue (or gray level) and record these as digital values for each pixel. Normally the scanner software will allow you to specify the resolution in dots per inch for the output image. These packages often produce TIF (Tagged Information Format) files, or other standard graphics file formats, that may then be converted for use in a GIS.

Data Display Devices

There are a variety of display devices available to make hard copies of your data and analysis results. They vary widely in cost from a few hundred dollars or so for simple dot matrix black and white printers, to several thousand dollars for optical film recorders.

Software that translates the data into a code that the output device can understand must be available in addition to the actual output device. These pieces of software are known as drivers and usually come with software packages. The GIS package you choose may not have a driver for every output device on the market. Choose your output device from those supported by your software. It is sometimes feasible to hire a computer programmer to write a driver to translate between a specific software package and an output device you already have, but that is not supported by the software, but this is rare since device drivers are normally very specialized hardware interface programs.

Pen Plotters

Pen plotters are widely used since they produce high quality results for vector data. The device actually picks up an ink pen and draws the features onto the paper. Sizes range from small models that sit on a desktop to very large models that either are mounted on a wall or stand alone. These devices can typically support up to eight colors automatically, though it is possible to plot multiple files onto the same paper loading different pens into the device each time. Again, software is needed to translate the data into code the plotter can understand.

Electrostatic Plotters

These are very large format raster printing devices capable of producing large map-sheet size output. These devices are very expensive, ranging from $10,000 and upwards, and are currently the only devices that allow for very large raster output.

Laser Printers

Most software allow for gray scale output of vector and/or raster data to a laser printer. This is very convenient and of high quality, especially when the office already has a laser printer for other purposes, such as word processing.

Film Recorders

Film recorders are expensive and are used for very precise mapping purposes. They use laser beams to inscribe detailed information directly onto reproduction film.

Color Raster Printers

There are a variety of color raster printers available and they have varied functionalities. Some print only 16 colors at a time while others will allow for 256 or more colors. Many require that special paper be used that interacts with the particular type of ink that is used in the device. Low end color raster printers are available for $500- $1,000. High quality color printers using ink-jet or thermal technologies are now available for less than $10,000.

Software

There is a multitude of GIS software on the market today. They range in functionality from simple database query and map output systems that run on personal computers to extremely powerful analytical packages running on both main frames and personal computers.

The functional requirements study normally associated with GIS system design will help to determine the types of packages needed. In order to choose between those packages that meet the organization's needs, you should consider many of the same questions as for hardware devices including: costs, the availability of training and training materials, the ease of use of the system and the availability and cost of technical support.

Information can be obtained from companies that provide GIS software and by attending conferences or examining trade publications then, writing or calling various companies for more detailed information. Objective review articles about individual packages or articles are also available that review a suite of packages in professional journals and trade publications. See the *For Further Reading* section at the end of this chapter for a list of relevant publications. Before making a final decision, it is a good idea to talk to actual users of the systems you might consider.

Human Resources

Staff

The GIS is often viewed simply as a means to perform existing tasks more quickly and efficiently. However, in this volume we emphasize that through the GIS we are able to perform a broad array of tasks that goes considerably beyond what was done previously and, ultimately, transforms the process by which things are done. Moreover, although the system is automated, there are still significant "front end" investments of time that must be made to train staff, establish procedures, design products, and prepare databases. There are also new routine tasks that must be performed to maintain the hardware, software, and database in addition to simply producing products.

Unfortunately, there is often an assumption that the responsibility for operating and maintaining the GIS can be given to staff positions without reassigning some part of existing responsibilities, or without reclassifying the position. This is particularly true if the concerned organization is already involved in mapping activities, and especially at the office or facility level, whatever the mission of the agency might be. This approach to staffing can lead to persistent and expensive personnel problems.

Virtually all applications will require at least one staff person dedicated to system operation and maintenance with no other responsibilities. The new technology also will create at least two new classes of staff positions where only one may have existed previously. The first will be a GIS analyst. Ideally, the person in this position will have technical skills related to the application (e.g. records manager; cartographer; forester; etc.), and may already reside in the unit. This person should receive intensive GIS training as it applies to the functions of the organization.

There is a large and growing universal demand for computer specialists which complicates staffing. The demand for GIS analysts is perhaps even greater because of their specialization. Even in developing countries, there is competition among government agencies and between the government and the private sector for these skilled people. Because of their importance to the success of the implementation and

the investment made in their training, it is imperative that the GIS technician position be raised in classification status and the pay rate adjusted upward accordingly.
A second class of staff position should be created for data entry. This might be considered clerical but requires some basic familiarity with computers and maps, and a respect for details. The classification and pay rate should also be higher than regular clerical staff for the reasons discussed above.

Even a modest archival operation will require data entry support. However, some analytical applications may justify a permanent data entry person, and most applications will require additional support periodically to deal with temporary increases in data flows.

If the implementation is large -- using a mainframe, minicomputer, a network, or even multiple micro computers -- there is need for a computer system manager who provides support in both hardware and software to keep the system operational. Although they may have a background in some other field (e.g., mathematics; electrical engineering), they should be well-schooled in computer science. As suggested above, significant investments will be made in their training, and their salaries should reflect their skill and value to the organization.

Training

Training is available from several sources. Virtually every vendor offers training on their own systems. Depending on the price of the system purchased (either hardware or software, or both) training will either be offered on-site (if the system is very expensive) or regionally (if the system is moderately priced or very popular), or at the vendor's home facility. For mainframe system managers, training at the vendor's facility is the most common.

For GIS technicians, many universities and some government agencies (such as the United Nations Institute for Training and Research -- UNITAR) also offer short term training (non-degree), on almost all systems both in-country and on their own campuses. If the system represents a fundamental transformation of a ministry, or a bureau within one, it is necessary to consider long term training leading to bachelors or advanced degrees for key personnel.

In the most common type of application -- analytical applications at the sub-ministerial level -- GIS analytical training is done best in-country. The program suggested here assumes training will be performed under conditions that exist in-country, dealing specifically with the problems to which the technology will be applied. In this way, trainees learn how to deal with actual limitations (e.g., intermittent power; poor reference data), rather than the "ideal" conditions that exist in developed countries.

Data entry personnel are best trained in-country, as well. They may be trained on-the-job by the GIS technician, but it would be desirable for them to participate in a more formal training program.

Training costs will differ according to the type and size of the implementation. Regardless of absolute costs, training will be a comparatively high proportional cost because of the initial acquisition of the considerable skills required to successfully manage a system, and the recurring need for training as hardware and software systems evolve.

Institutional Issues

It has been suggested by some that the poor performance of resource technologies (e.g., remote sensing and GIS) in developing countries has been due to the ways in which they were used initially; rather than show how they could be used to solve problems they simply showed how they worked. Clearly, the "contagion" approach to technology transfer based on demonstration is a hit and miss proposition.

However, there has been similarly poor results where the effort concentrated on developing an institutional capability rather than just demonstrate the technology. Thus, it has been suggested that information has become more of an organizational issue than a technical one.

The choice of where to install a GIS capability always presents problems because of the eternal competition for influence and scarce resources. Initial attempts to develop remote sensing and GIS capabilities often established technical centers outside traditional ministerial structures. Virtually all these failed largely because they usurped -- all or in part -- the mandates of other agencies. At the end of a project, the centers could not be sustained, politically or economically, and their capabilities were lost.

Current thinking suggests that capabilities be established within an agency and that institutional arrangements be decided by the agencies affected rather than the donor alone. This permits the necessary institutional arrangements to be worked out through conventional, though informal, interagency political means rather than imposing some arrangement from the outside.

Data Resources

Basic Considerations

Data are obviously the heart of the GIS. Data, however, are not always readily available in developing countries. Moreover, as learned elsewhere, all data are not created equal; information type, scale, accuracy, compatibility, and timeliness are concerns wherever data are analyzed. It is thus useful to consider some of the properties of spatial data that help to determine their quality and utility.

Base Maps

The existence of base maps, or highly accurate topographic maps upon which other features can be mapped (e.g., vegetation; land use), are an obvious prerequisite for developing a high quality spatial database. Reasonably accurate topographic maps for the entire world have been prepared at scales of at least 1:1,000,000, but such scales are not appropriate for anything more than general reference. Large parts of the world, though, have been mapped at scales of 1:100,000 or larger but coverage is often spotty and, more likely, not current. Although topography changes slowly, the course of rivers, the existence and location of roads, rural land uses, and the size of cities can drastically change within a decade.

Scale

There are two scale issues. The first is establishing the scale necessary to do a particular job. If topographic maps are needed to develop a grading plan for a construction project, the scale must be very large (large amount of detail) to permit an accurate estimate of the amount of material to be moved. Here, the relationship between scale and accuracy can be described in economic terms.

For many applications, there is a desire to acquire expensive large scale data when less-expensive small scale data will suffice. For example, while it would be helpful to have 1:25,000 color aerial photographs to map vegetation in a semiarid rangeland, a less accurate but acceptable map can be produced from a 1:100,000 Thematic Mapper image for considerably less. When weighed against the potential value of the resource or the type of development that might be done in the region, the smaller scale is justified.

A second scale issue is encountered when attempting to create a database at a single scale with maps of varying scale. Simply enlarging or reducing map size to bring two maps into concordance is not always appropriate, for two reasons. First, if a map is compiled at small scale, small features (e.g., ponds, small soil units, individual houses) must be deleted or the map is unreadable. If the map is enlarged, these features do not reemerge; they do not exist. Second, different maps use different mathematical projections that are incomparable. Moreover, different mapping scales have different map accuracy standards. Thus, there is no assurance that there will be agreement between maps as to the location of significant features of maps (e.g., rivers; coastlines) that were prepared with different projections or at different scales.

Currency

Often data will be available, but will be out of date. This is particularly true in many former colonies where mapping and data collection activities were more intensive and systematic prior to independence. Aside from changes that might have occurred since they were generated, these data may not be useful because of differences in reporting units, aggregation methods, or systems used for classification at that time.

Compatibility

Maps of features that are fundamental to development, such as soils, vegetation, and land use, are very rare. This is especially true when seeking coverage for an entire country. Even where they might exist, they may not be usable.

Each feature map is based on a classification system (e.g., soil; vegetation) that was developed to satisfy some purpose (e.g., range management). These systems do not always apply directly to other purposes (e.g., forest management) because they do not classify the same features in the same way, and may ignore some features altogether. For example, a map of vegetation produced by a forester might classify all grassy areas as undifferentiated "grassland." This map would be of very little use to a range manager, even though it is an acceptable vegetation map for other applications.

Some maps of the same features may be almost mutually unintelligible due to differences in classification systems (e.g. French and USDA soil classification).

Accuracy

Accuracy standards for topographic maps sometimes exist because they represent features that can be measured within some known limits. Unhappily, this is not the case with most other maps with features, such as vegetation, soil, land use, etc. As mentioned above, disagreements between maps may result from differences in classification systems. They may also result from the quality of the material (e.g., aerial photographs) upon which the map was based, or they may simply be a product of the differences in the times at which each was prepared. Also, recognition of most features is a subjective judgment (e.g., identifying boundaries of soil units, or marking that point where one moves from a forest to a woodland). Finally, there is the care with which the map is assembled.

Spatially referenced statistical data present similar problems. Government estimates of population, income, and crop production, fluctuate widely in their range of accuracy. Yet, there is often no alternative. They must be used with caution.

Once entered in a database, all data assume a new life that is often divorced from their previous one. The ability to judge the quality of the map by the attention given to detail in its preparation is largely removed after it is digitized. As a consequence, data cease to be observations, but instead become facts that are routinely used but seldom questioned. The importance of exercising care in data selection and quality assurance cannot be overemphasized. For these reasons, it is necessary to record the source of data contained in the database (*metadata*) so that the quality of it might be assessed. However, if data are unquestionably poor, it is worth considering whether they should be included in the database.

Collecting Existing Data

Assembling a comprehensive, high-quality database is a challenge, regardless of the location. The challenge is that much greater in a developing country.

The places to search locally are obvious. The ministries charged with resource management responsibilities (e.g., forests) are first. It will become apparent quickly if there are other sources, or other agencies, that might have better information.

Once found, information is sometimes impossible to extract. For example, in many developing countries it is quite common for topographic maps and especially aerial photography to be classified by the military and thus unavailable. Similarly, those agencies which gather data often consider them proprietary and are reluctant to let them go.

There are international sources of data that should also be considered. Data will vary among agencies, particularly if they have been involved in projects within a country (e.g., FAO). Overall, however, scales tend to be small because these agencies are usually involved in national or regional scale projects.

Gathering New Data

If the information needed for an application is unavailable, there are a number of options that can be considered for generating it. Here, we will consider two types of approaches. The first is survey, in which data are gathered through structured sampling but products may not include a map. The second is mapping, in which the map of a feature, or set of features, is the primary product. Although distinctions are made among these methods, they commonly are used together in a "multistage" approach to surveying or mapping.

Survey Tools

Survey tools provide for comprehensive mapping or gathering of data about some phenomenon. In some cases they will employ sampling rather than complete enumeration (such as a census). Sampling is less labor intensive and so is relatively inexpensive to use. Three are reviewed here: Ground Surveys, Land Surveys and Aerial Surveys.

Ground Surveys

Ground Surveys involve visiting a selected sample of ground locations to provide a representative mapping of the phenomenon under study. There are a wide variety of sampling techniques available that can be used to characterize a region. Some of the more common ones are described below.

Rapid Rural Assessment. Rapid Rural Assessments (RRAs) are quick, informal, relatively inexpensive surveys that are used to characterize a variety of features (e.g., land use) within an area. Surveys are semi-structured using a general outline for questions, but systematic in the area covered, and are carried out by multi-disciplinary teams in the field. They produce qualitative data but can quickly yield insight into local conditions as perceived by the inhabitants.

Informal Structured Survey. These surveys generate quantitative data through the use of informal but structured questionnaires administered in the field.

Systematic Ground Sampling. The systematic approach produces quantitative data by allocating sample points in a systematic way. Sample points can be visited and the features of interest (e.g., vegetation types) can be measured and recorded. Generally, some sort of stratified random sampling is a preferred technique in which some criterion (e.g., elevation; land use) is used to divide the study area into more homogeneous sub units. Samples are then allocated within these "strata."

Area Frame Sampling. A more formally recognized form of systematic sampling has emerged for use in very large areas. This approach also relies on spatial strata, or area sampling frames (ASFs), but they are derived from an analysis of satellite data.

Land Surveys

Land Surveying refers to the direct measurement of the land surface and resident features, and a subsequent mapping of those details using a locational referencing system. Several different types can be identified:

Geodetic Surveys. Geodetic Surveys are concerned with basic measurements of the earth's shape and the establishment of locational referencing systems.

Detail Surveys. Detail surveys are concerned with the measurement and location of earth surface features according to an established geodetic framework.

Cadastral Surveys. Cadastral Surveys are concerned with the specific measurement and mapping of property ownership.

Aerial surveys

Systematic Reconnaissance Flight. The Systematic Reconnaissance Flight (SRF) is widely used to estimate numbers and spatial distribution of human settlements, livestock, wildlife, and land use. It is based on a series of parallel transects flown at low altitude (e.g., 200 to 1000 m) in a light aircraft. Visual observations are recorded continuously along the flight line. Oblique (non-vertical) 35mm photographs or video images are acquired to supplement observations. Each data point can be assigned to a grid cell based on aircraft position. Grid samples can be merged with other spatially referenced datasets in the GIS such as soil, elevation models and satellite imagery.

Video/photo Reconnaissance Flight. Non-systematic variations of the SRF are routinely employed for project planning or monitoring. Oblique (non-vertical) are acquired within a study area, with zoom images of selected features. These can be used for general orientation, planning subsequent ground visits, or documenting changes or progress (e.g., road construction). Vertical 35 mm images can be acquired for mapping purposes.

Mapping Tools

Some applications require maps. A variety of data types exists that can be exploited to produce maps. Although this section concentrates on the use of remote sensing data for map production, ground data must be gathered to characterize mapping units in virtually every application. These techniques invariably rely on input from survey tools.

Remote Sensing

Remote sensing is defined as "the acquisition of information about an object without physical contact" (American Society of Photogrammetry, 1983; 1). In the context of resource information, remote sensing usually involves images of the earth's surface which provide information on the location, quality and quantity of resources. These images may be in the form of photographs or digital images collected by satellites or airborne sensors.

Remote sensing imagery is collected in many wavelengths in the electromagnetic spectrum to gain information which may not be apparent to the human eye. Imagery collected in a single band spanning several portions of the electromagnetic spectrum -- usually the entire visible range -- is called *panchromatic*. Imagery which is collected in several narrow bands is called *multispectral*. By combining individual bands, each portrayed in a different color, it is possible to create a *color composite*. Commonly, the green, red and near infrared bands are combined to create a *false color composite* -- "false" because infrared is not a "color" and thus colors are not assigned "naturally" (i.e., real world green = blue; red = green; and infrared = red).

Earth materials have different spectral properties and it is desirable to select optimum bands or band combinations to discriminate among them. To insure utility of an instrument for a variety of applications, more bands should be better than fewer. However, because the overwhelming number of applications involve vegetation assessment and monitoring, observations from the red and infrared portions of the spectrum are the most commonly used.

Temporal Resolution. The *temporal resolution* of a sensor describes the frequency where by the system can acquire an image of the same point on the earth. The AVHRR satellite images twice a day, while 16 days must pass between Landsat overpasses. Obviously, if information needs involve routine monitoring, temporal resolution is critical for at least two reasons. First, observation frequency must be high enough to ensure that changes are captured. For example, imagery of agricultural areas are normally reported every 10 days for crop condition assessments, while land use changes for planning may be required only every one to five years. Second, cloud cover or irregularities in sensor performance may cause gaps in data acquisition. Thus, even systems with high temporal resolution may face problems in regular acquisition in some environments.

Aerial Photography

Aerial photography is the oldest and most widely used method of remote sensing. Cameras mounted in light aircraft flying between 200 and 15,000m capture a large quantity of detailed information. Aerial photos provide an instant visual inventory of a portion of the earth's surface, and can be used to create detailed maps. Aerial photographs commonly are taken by commercial aerial photography firms which own and operate specially modified aircraft equipped with large format (23 cm x 23 cm) mapping quality cameras. Aerial photos can also be taken using small format cameras (35 mm and 70 mm), hand-held or mounted in unmodified light aircraft.

Camera and platform configurations can be grouped in terms of vertical and oblique. Oblique aerial photography is taken at an angle to the ground. The resulting images give a view as if the observer is looking out an airplane window. These images are easier to interpret than vertical photographs, but it is difficult to locate and measure features on them for mapping purposes.

Vertical aerial photography is taken looking straight down. The resulting images depict ground features in plan form and are easily compared with maps. Vertical aerial photos always are highly desirable, but are particularly useful for resource surveys in areas where no maps are available. Aerial photos depict features such as field patterns and vegetation which often are omitted on most maps. Comparison of old and new aerial photos can also capture changes within an area over time.

Vertical aerial photos contain subtle displacements due to relief, tip and tilt of the aircraft and lens distortion. Vertical images may be taken with overlap, typically about 60 percent along the flight line and at least 20 percent between lines. Overlapping images can be viewed with a stereoscope to create a three dimensional view, called a *stereo-model*.

Photogrammetry. The technology for obtaining precise measurements from aerial photographs is called photogrammetry. Photogrammetrists create detailed topographic maps based on a series of stereo-models and a few ground "control" points. Most modern topographic maps are created in this way and, thus, the existence of a topographic map usually means that at some time a set of aerial photos was taken. Often the date and source of the photos is included in the map legend. Much of the earth has been photographed for this purpose at some time during the past 50 years, providing a rich, unbiased, comprehensive archive of past conditions.

In addition to map products, photogrammetrists can produce geometrically corrected photographs, called *orthophotos*. Orthophotos are useful for extracting resource information, for example road networks or agricultural crop areas, since they do not contain photographic displacements. In some ways, they are more useful than maps in that they retain the all the data contained in the original photographs. However, the extraction of the information requires some interpretive skill.

Large format photography. Commercial aerial survey firms use light single or twin engine aircraft equipped with large format mapping cameras. Large format cameras, such as the Wild RC-10, use 23 cm x 23 cm film which is available in rolls. Eastman Kodak Inc. among others, manufactures several varieties of sheet film specifically intended for use in aerial photography. Negative film is used where prints are the desired product, while positive film is used where transparencies are desired. Print film allows detailed enlargements, such as large wall sized prints, to be made. In addition, print film is useful when multiple prints are to be distributed and used in the field.

The cost of a photo mission is dependent on a number of factors. One is the cost of aircraft operation, and another is the relative ease of operation. For example, if the study area is remote and far from an airport, costs can be quite high due to special logistics for positioning fuel, equipment and personnel. However, in the U.S., the cost of a custom photo mission may range between $500 for a few frames covering a small area to $30-40K for stereo coverage of several hundred square kilometers. This price includes the cost of aircraft operation, pilot, photographer, film and film processing. Purchasing prints of existing aerial photos is less expensive. Most aerial survey firms maintain a library of photographic negatives; the cost per contact print is usually about $20 from existing photography. Often, survey firms will make half tone prints which can be reproduced on a blueprint machine. Wall sized halftone enlargements can usually be purchased for under $10, while similar sized photographic prints may cost upwards of $200.

Small format photography. Small format cameras carried in chartered aircraft are an inexpensive alternative to large format aerial photography. A 35mm or 70mm camera, light aircraft and pilot are required, along with some means to process the film. Because there are inexpensive commercial processing labs in most parts of the world, 35mm systems are especially convenient.

Oblique photographs can be taken with a hand-held camera in any light aircraft; vertical photographs require some form of special mount, pointed through a belly port or extended out a door or window. Aircraft charter rates vary greatly, but a two hour flight in a single engine plane should cost less than $300.

Small format aerial photography is inexpensive but has several drawbacks. Light unpressurized aircraft are typically limited to altitudes below 4,000m and film size is small, so sacrifices must be made in resolution or area covered per frame. Because of distortions in the camera system, small format photography cannot be used if precise mapping is required. In addition, presentation quality wall size prints cannot not be made from small negatives. Nonetheless, small format photography can be very useful for reconnaissance surveys, and can be used as point samples.

Videography. Light, portable, inexpensive video cameras and recorders can be carried in chartered aircraft. Super VHS format video cassette recorders can be used with small CCD video cameras to produce high quality color aerial video. Aerial video provides continuous imagery which can be played with a VCR back over any video screen. Like small format photography, aerial video cannot be used for detailed mapping, but provides a useful overview for reconnaissance surveys, and can be used in conjunction with ground point sampling.

Satellite Imagery

In addition to the wide range of aerial photography available to resource managers, several satellite systems provide resource information on a regular basis. Moreover, some of these (i.e., Landsat) have been operating for 20 years and thus offer a significant historical archive.

LANDSAT. The Landsat system of remote sensing satellites is operated by the Earth Observation Satellite Company (EOSAT), which sells digital and photographic data and imagery commercially. There have been five Landsat satellites, the first of which was launched in 1972. The last satellite, Landsat 5, remains in operation today.

Landsat carries two multispectral sensors. The first is the *Multispectral Scanner* (MSS) which acquires imagery in four spectral bands: blue, green, red and near infrared. The second is the *Thematic Mapper* (TM) which collects seven bands: blue, green, red, near infrared, two mid-infrared and one thermal infrared. The MSS has a spatial resolution of 80 meters, while the TM can resolve 30 meters. Both sensors image a swath 185 kilometers wide, passing over each day at 09:45 local time, returning every 16 days.

EOSAT offers digital and photographic Landsat products. Digital Computer Compatible Tapes (CCTs) of full or quarter scenes are available. Photographic products of MSS and TM scenes in false color and black and white are also available.

SPOT. The *Systeme Pour L'Observation de la Terre* (SPOT) was launched and has been operated by a French consortium since 1985. SPOT carries two High Resolution Visible (HRV) pushbroom sensors which operate in multispectral or panchromatic mode. In multispectral mode, the sensor collects three bands, a green channel, a red channel and a near infrared channel, with a spatial resolution of 20 meters. In panchromatic mode, the sensor collects a single image with a spatial resolution of 10 meters, covering a swath 60 kilometers wide. The SPOT sensor has the highest resolution of any commercial satellite. In addition the SPOT sensor may be pointed to image along adjacent paths. This allows the instrument to acquire repeat imagery of any area 12 times during its 26 day orbital period. The pointing capability makes SPOT the only satellite system which can acquire useful stereo satellite imagery.

SPOT Image Inc. sells a number of products, including digital images on a choice of magnetic media, as well as photographic products. Existing images may be purchased, or new acquisitions ordered. Customers can request the satellite to be pointed in a particular direction for new acquisitions. Images range in cost from $2K to $5K per image, depending on acquisition and processing requirements.

AVHRR. The *Advanced Very High Resolution Radiometer* (AVHRR) is carried on board the current NOAA series of satellites operated by the U.S. National Oceanic and Atmospheric Administration (NOAA). It acquires data along a 2400 km wide swath each day. AVHRR collects five bands: red, two near infrared, a mid infrared, and a thermal infrared. Spatial resolution of the sensor is 1.1 km (Local Area Coverage [LAC]) but, for studying very large areas, a resampled version is also available (Global Area Coverage [GAC]) at about 4 km.

AVHRR may be "high" spatial resolution for meteorological applications, but the images portray only broad patterns and little detail. However, they do have a high temporal resolution, showing wide areas on a daily basis. Thus, AVHRR has become a tool of choice for monitoring large areas. AVHRR imagery is used by several organizations engaged in famine prediction and is an integral part of many early warning activities. AVHRR imagery is available from NOAA for less than $100 per image.

Extracting Information from Remote Sensing Imagery

Image interpretation is the process of extracting information from remote sensing imagery. Imagery may be used to detect, identify, measure, and evaluate the significance of environmental and cultural objects and their spatial relationships. Imagery can be used to create maps, or to collect statistics of the feature of occurrence, frequency and patterns, and it may be used to detect changes if images from different dates are available.

Many image interpretation tasks can be performed with a minimum of training. Roads, fields, urban areas and forested areas can be easily identified in aerial photographs and satellite imagery. For example, land use interpretations of the large number of photo sample points acquired during systematic reconnaissance flights may be done by unskilled interpreters using superimposed dot grids to estimate the area of each land use or land cover type (e.g., crop, housing, forest, plantation, road, etc.) that occur in each photograph.

More advanced tasks, such as crop identification, geological interpretation, vegetation mapping, habitat evaluation and land use mapping require disciplinary specialists who also have a background in the field of remote sensing.

Manual Image Interpretation. Manual image interpretation covers techniques of information extraction which do not rely on computer analysis. Manual techniques of interpretation are usually superior to computer techniques because a human interpreter can incorporate a combination of diverse clues and experience to identify spatial patterns easily and identify them as ground features. Tone, color, size, shape, shadow, texture, pattern, site, and association of features within an image provide a human interpreter with clues from which conclusions can be drawn.

Interpretation can be performed directly on single images. However, viewing images in three dimensions provides additional information on the height, slope and elevation of features in the image. Stereo pairs (usually 60 percent overlap) of aerial photography or SPOT imagery can be viewed with a simple device called a *stereoscope*. This device uses lenses and/or mirrors to direct a single image of the stereo pair to each eye, creating the illusion of three dimensions. The observer sees a three dimensional image where hills, trees, bridges and buildings appear to project up from the image plane. Stereo photos can be used to measure heights of objects.

An advanced device called an *stereo-plotter* can be used to make very precise height and distance measurements. Stereo-plotters systematically remove photo distortions to produce geometrically correct maps. This equipment is used by commercial survey firms and government organizations to make detailed planimetric and topographic maps using stereo photography. State-of-the-art stereo plotters typically cost upwards of $250,000 and require a skilled operator.

Digital Image Processing. Since the Landsat program of the 1970s, digital image processing systems have become common for the analysis of remote sensing imagery. As already noted, digital images are composed of a large two dimensional array of picture elements (pixels) with "brightness" numbers associated with each pixel that describes the relative gray level associated with it. For multiple-band images, there will be as many images as there are spectral bands.

Image enhancement is a common form of image processing. The goal of image enhancement is to create a more easily interpreted image through statistical processing of the image data. For example, to ensure against saturation at the upper and lower ends of instrument response, the full dynamic range of a sensor system is seldom used: there are rarely any totally "black" or "white" pixels in the original image. Thus, a frequency distribution (histogram) of the original image can be examined to determine the minimum and maximum values observed. The minimum value can then be subtracted from all pixels (sometimes called a "haze" removal operation), and the maximum observed value can be assigned the maximum allowable value (e.g., 255). Remaining pixels are reassigned values using various functions (e.g., linear; logarithmic) to achieve whatever effect is desired. This operation is called *contrast stretching* and is performed on virtually every image that will be interpreted manually. Other common image enhancement processes include *digital filtering* in which small neighborhoods of pixels (e.g., 3 x 3) are examined and values altered to enhance (edge detection) or reduce (smoothing) contrast, depending on the needs of the analyst.

Image classification encompasses a whole series of computer algorithms which are used to recognize and group pixels that are statistically similar in their spectral properties. These spectral classes can then be grouped associated with ground features (i.e., land use classes; vegetation types) using ground samples or previous knowledge. Classification is a rapid means to create a map of land cover type from satellite imagery in a semiautomatic manner. Typically, however, the classes of land cover must be very general, for example agricultural versus forested versus water.

Geo-referencing is the process of digitally matching the satellite image with the surface of the earth. Usually this is achieved by geometrically warping the image to match a map base. Geo-referencing is important for ensuring accuracy when determining the geographic location and area of features of interest. Information from a georeferenced image can be incorporated easily into a GIS, and alternatively, GIS information can be displayed on top of a georeferenced image to create an image map.

Ratios and vegetation indices are forms of image transformation in which the differences in the responses of two bands (e.g., red and infrared) are summarized in a single measure. The normalized difference vegetation index (NDVI) is the most common index currently in use. It is calculated in the following manner:

$$\text{NDVI} = \frac{(\text{Near infrared - red})}{(\text{Near infrared + red})}$$

Because of the positive correlation between NDVI response and photosynthetic activity, this index has been used extensively with AVHRR imagery to determine the condition of global vegetation, and to estimate crop conditions in West Africa. Other band ratios and combinations have been used to evaluate soil type and mineral composition of bedrock.

For Further Reading

GIS Hardware and Software

Trade Publications

GIS World
GeoInfo Systems
The GIS Source Book

Professional Publications

International Journal of GIS
International Journal of Remote Sensing
Remote Sensing of Environment
Photogrammetric Engineering and Remote Sensing

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Appendix I

GIS Application Demonstrations

Accompanying the handbook is a diskette containing two illustrations of the use of GIS. The first case study is a raster multi-criteria/multi-objective landuse allocation problem. This study outlines the procedures for using GIS in a decision making process for land allocation to three competing development areas -- agriculture, industry, and residential.

The second case study illustrates vector analysis and mapping. The study uses a GIS to generate information products to help planners assess current land cover and landuse in order to determine how a proposed road would impact the local environment.

The demo runs on any PC-compatible computer with a 3½" floppy disk drive and a VGA display. Follow the instructions on the diskette.

Appendix II

Glossary

The following entries give some details on concepts and terms used in this manual and otherwise encountered when reading literature related to GIS. They are arranged in alphabetical order.

ARC

Also known as a *chain* -- an uncrossed line segment, the ends of which are known as *nodes*. Arcs are bounded on each side by *polygons.* A simple example would be a city street. The ends of the street (where it meets other streets) are the nodes. On each side of the street we have a different city block (polygons). Because of this special relationship between 0-dimensional nodes, 1-dimensional chains, and 2-dimensional polygons, the arc is the most fundamental element in vector geographic information systems.

ASCII

ASCII (pronounced "ask-ee") is an acronym for American Standard Code for Information Interchange. The standard presents an almost universally recognized system for coding characters (letters of the alphabet, numerals, symbols, etc.). Data files that contain characters in this coding system are often called ASCII files, although they are also commonly known as "text" files. The coding system uses groups of 8 binary digits to represent the numbers 0 through 255. Each of these numbers stands for a character. For example, number 65 stands for the capital letter A. Because of the importance of these 8-bit groups, they are given a special name, as a measure of memory storage. An 8-bit group is known as a byte. Thus each ASCII character requires one byte of memory for storage.

There are clearly more codes than letters of the alphabet, numerals, etc. Some of the codes represent messages to the digital device (like line feed, form feed, or return), and some are reserved for specifying special character sets. Since the ASCII coding system is universally recognized, it is the system most commonly used for transporting data between computer systems. It is not, however, the most efficient way of storing numeric data. For example, the integer number 30,000 requires 5 bytes when stored as ASCII characters, and only 2 bytes when stored as an integer number recoded into a binary system (111010100110000) with each binary character requiring only one bit.

ATTRIBUTE

Since each cell in an image represents a rectangular portion of space, the attribute of that cell is the characteristic or quality we find at that location. Height, land use, and vegetation type are all attributes.

This text was adapted from the IDRISI User's Guide, Version 4.0, Clark University Graduate School of Geography, 1992.

AUTOCORRELATION

Autocorrelation is the propensity for data values to be similar to surrounding data values. In a raster image, this describes the degree to which values in any cell will be similar to the cells surrounding it. A common measure of autocorrelation is Moran's I, with a range from -1 to +1. A value close to 1 indicates a smooth surface, with each cell containing a value very similar to the cell next to it. A value close to -1 indicates a very rough or fractured surface, with each cell quite different from its neighbors. When autocorrelation is measured for the adjacent neighbors of a cell, it is called first lag. Subsequent lags refer to increasingly distant neighbors.

BINARY (image)

An image where the attribute of any cell can only be an integer 1 or 0. A binary image is also known as a *logical* image or *Boolean* image.

BINARY (file)

A data file format in which numbers are stored in their binary representation. Binary files are more efficient than ASCII files for storing numeric data.

BIT

A contraction of the words "binary digit". A bit is represented as an on/off circuit in computers, and can store the numbers 0 or 1. Larger numbers can be formed through the use of a base-2 arithmetic system. The binary number 101 represents the decimal number 5.

BYTE

A measure of digital storage. A byte represents an 8-bit group. Digital storage is commonly measured in kilobytes (K). A kilobyte is 1024 bytes. Thus, a computer whose memory is said to be 256 K actually contains (256 x 1024) = 262,144 bytes.

C

A popular high level programming language.

CARTESIAN COORDINATES

Named in honor of Rene Descartes ("I think therefore I am"), cartesian coordinates use an arbitrary grid with an origin (0,0) in the lower left and increasing x and y axes. The x axis runs horizontally, the y axis vertically, and locations within the plane are described using (x,y) pairs. The x value describes the horizontal location of the point, and the y value describes the vertical location.

Cartesian coordinates are sometimes called plane coordinates because they describe point locations in a plane. See also PROJECTION.

CARTOGRAPHIC DISPLAY SYSTEM

A cartographic display system allows for the production of map products from information stored in a spatial and attribute database.

CATHODE RAY TUBE (CRT)

A commonly-used technology for the production of computer screens. With a cathode ray tube, a beam of electrons is moved in raster fashion over the face of screen covered with phosphor dots. Depending upon the strength of the beam, dots struck by this beam will glow with varying intensity. The most common form of CRT is the *refresh* CRT where the dots gradually fade. To maintain intensity, the screen is scanned repeatedly (e.g., 30-60 times per second) to refresh the dots which should not be allowed to disappear. With color screens, three cathode ray guns are used to direct separate beams to each of the dots in triplets of red, green and blue producing phosphors.

CD-ROM

An acronym for *Compact Disk* - *Read Only Memory* -- an optical recording medium capable of storing large quantities of information.

CELL

A rectangular division of space which is considered to have uniform characteristics. Raster images are composed of cells (see also PIXEL and RASTER).

CENTRAL PROCESSING UNIT (CPU)

The central processing unit is the computational heart of the computer. On the PC-compatible computers the CPU will be one of a family of chips originally designed by Intel Incorporated. The oldest and slowest are the 8088 and 8086 chips. Newer and faster variants are, in order, the 80286, 80386, and 80486 (with the 80586 under development).

CHAIN

see Arc.

CLASSIFICATION

Any technique whereby data are grouped into a more general number of integer categories is known as a classification. In remote sensing, a classification is a procedure whereby data cells are assigned to one of a broad group of landcover classes according to the nature of the specific reflectances found at that place.

COLOR SPACE

A color production system can usually be described by a small number of *dimensions* along which variations produce the full gamut of colors possible. By analogy, these dimensions thus describe a space within which all possible colors reside. For example, color monitors use varying strengths of the additive primaries (red, green and blue) to produce their full gamut. If one were to imagine these as physical dimensions, red would form one axis, green another, and blue a third. The space described would thus be a cube. Color spaces commonly used in computer graphics include RGB (using the red, green and blue additive primaries), CMY (using the cyan, magenta, and yellow subtractive primaries), and HLS (hue, lightness and saturation, arranged in a double hexcone form). RGB describes well the colors produced by graphics monitors; CMY describes the colors produced by most hardcopy devices and HLS describes the phenomenological characteristics of color.

COMPILER

A computer program that can translate the instructions of a high-level language, such as PASCAL, into the binary instruction format of a particular computer (or operating system).

COMPUTER AIDED DESIGN

Abbreviated CAD, computer aided design describes programs used as "electronic drafting boards" to help designers, architects and planners do their work.

CONCATENATE

Concatenate means to join together (mosaic) two or more images into a single image, usually by placing the images next to each other.

COVERAGE

A term commonly used to indicate a data set pertaining to a single theme. For example, an image consisting only of vegetation type codes could be referred to as a vegetation coverage. A coverage is also known as a *layer*.

DATABASE MANAGEMENT SYSTEM

Abbreviated DBMS, Database Management Systems are used to store and manage information. The information for each entity are known collectively as a record. A record is in turn made up of fields -- attributes concerning those entities. Thus, for example, a database may consist of records for each of a set of property parcels, each of which contains information for the fields "owner", "land use", "valuation", and so on. In, the name *Database Management System* is commonly understood to mean the software that manages the attribute data for a set of features.

DIGITIZER

A term commonly used to refer to a device for encoding vector graphic data (point locations) into plane (X,Y) coordinates. However, the term equally applies to various types of scan digitizers that encode raster images.

DIGITAL ELEVATION MODEL (DEM)

A term used to refer to an image that stores data that can be envisioned as heights on a surface. Although the grid structure breaks up the surface into cells of uniform character, the data are considered to come from an underlying continuous surface. Often abbreviated DEM. A special case is the DTM (Digital Terrain Model), where the heights are heights above mean sea level on the land surface. The United States Geological Survey distributes a standard format DEM for much of the United States.

DIGITAL LINE GRAPH (DLG)

Abbreviated DLG, the United States Geological Survey distributes digital data for hydrogeography, hypsography, roads and other features for much of the United States, in vector form in a standard format they call a Digital Line Graph.

DIGITAL TERRAIN MODEL (DTM)

See DIGITAL ELEVATION MODEL.

FIELD

A related set of characters that supply some element of information. In Database Management Systems, a field is one piece of information within a record, such as an address or land use designation. (see RECORD and FILE).

FILE

A related set of data records, stored under one name on a computer disk or tape.

GENERALIZATION

Any process whereby data are reduced to a more general form. With map data, generalization may be undertaken either for reasons of information processing or for accommodation to scale reduction.

GEOGRAPHIC INFORMATION SYSTEM

Often abbreviated GIS, a system (usually computer-assisted when this term is used) for the input, storage, retrieval, analysis and display of interpreted geographic data. The data base are typically composed of a large number of map-like spatial representations (called "coverages" or "layers").

GEOREFERENCING

Georeferencing refers to the location of an image or vector file in space as defined by a known coordinate referencing system. With raster images, a common form of georeferencing is to indicate the reference system (e.g., latitude/longitude), the reference units (e.g., degrees) and the coordinate positions of the left, right, top and bottom edges of the image. The same is true of vector data files, although the left, right, top and bottom edges now refer to what is commonly called the *bounding rectangle* of the coverage -- a rectangle which defines the limits of the study area.

GLOBAL POSITIONING SYSTEM (GPS)

Abbreviated GPS, a global positioning system calculates the range (distance) to a set of simultaneously viewable satellites to intersect a position according to a specified geodetic referencing system.

GROUND TRUTH

Ground truth refers to any verification of mapped data against true ground conditions.

HALFTONE

A technique for producing apparent shades of a color when only solid color can be printed. By printing small dots of ink within a region, the balance between the amount of ink and the amount of white paper in that region will yield variable perceptions of intermediate tones.

IMAGE

A representation of some rectangular portion of space.

IMAGE PROCESSING SYSTEM

A set of analytical routines designed for the restoration, enhancement and computer-assisted interpretation of digital images, most particularly of remotely sensed data.

INTEGER

A number having no fractional part (i.e., a whole number, such as 1, 2, 3, etc.), also known as whole numbers. Integer data is usually stored with two bytes per number. This allows for a range of -32768 to +32767.

INTERPRETER

A computer program that can translate high-level language instructions into binary machine instructions. BASIC is a language that commonly uses an interpreter.

Programs that require interpreters generally run more slowly than those which have been translated by a compiler before being run. See COMPILER.

K (kilobyte)

A measure of digital storage. A kilobyte represents 1024 bytes (see BYTE).

LAYER

A term commonly used to indicate a data set pertaining to a single theme. Also known as a coverage. See COVERAGE.

M (megabyte)

A measure of digital storage. A megabyte represents 1,048,576 bytes (see BYTE).

MAP DIGITIZING SYSTEM

Any digitizing system when applied to cartographic data can be called a map digitizing system. Special features for digitizing cartographic data sometimes include the creation and location of control points and the assessment of locational error.

NDVI

Normalized Difference Vegetation Index **--** an index derived from reflectance measurements in the red and infrared portions of the electromagnetic spectrum to describe the relative amount of green biomass from one area to the next.

PROJECTION

Projection refers to the representation of one surface onto another. In the mapping sciences it is understood to refer to the representation of a somewhat spherical earth onto a flat medium such as paper or a computer screen. Since it is physically impossible to flatten a globe without distortion, scale will vary across the projection surface with consequent distortions in distance, area and angular relationships. Fortunately, it is possible to engineer this distortion such that specific properties (such as the preservation of areal or angular relationships) are maintained within certain constraints.

RAM

An acronym for "Random Access Memory" **--** the internal memory within the computer that is available for storing programs and the data required by those programs. Computer memory is typically measured in kilobytes (K) or megabytes (M). .

RANDOM-ACCESS (file)

A disk file access technique where the elements do not need to be accessed in a particular order, but in any order.

RASTER

Technically, a raster is a pattern of horizontal scan lines, as traced by an electron beam in a CRT (from the German word for rake). It is commonly used as a term to describe a system of representing images, where the image is composed of small, internally uniform cells arranged in a grid. The order of image storage is typically by scanlines, progressing from left to right along scan lines, and then from top to bottom from one scan line to the next.

RECORD

A related set of data fields. Typically a record consists of all the information pertinent to a single entity within a data file.

REFLECTANCE

In this manual, reflectance refers to the non-directional diffuse reflection of the sun's energy by earth surface materials. Remote Sensing devices measure the amount of reflectance reaching the sensor from the earth's surface in specific areas or *bands* of the electromagnetic spectrum . A high reflectance indicates that much of the energy in that band was reflected from the surface of the earth, while a low reflectance indicates that much of the energy was absorbed or transmitted and not reflected. See also REMOTE SENSING.

REMOTE SENSING

Information about the environment that is acquired without being in direct contact with it, is traditionally called remote sensing. Examples range from aerial photography to multispectral scanning to radar.

RMS Error

The root-mean-square error -- a measure of the variability of measurements about their true values. The RMS error is estimated by taking a sample of measurements and comparing them to their true values. These differences are then squared and summed. The sum is then divided by the number of measurements to achieve a mean square deviation. The square root of the mean square deviation is then taken to produce a characteristic error measure in the same units as the original measurements. The RMS error is directly comparable to the concept of a standard deviation.

SCANLINE

A horizontal group (a row) of image cells (pixels) spanning the entire image.

SCANNER

A device used for the direct collection of raster data. In remote sensing, a scanner moves (points) an electro-optical measuring device in a raster fashion over a visual scene. Regular measurements of reflectance are then taken along each row to form the data cell values. Various hardcopy scanning devices are also available.

STATISTICAL ANALYSIS SYSTEM

A set of computer programs designed for the statistical analysis of data. In some GIS, a statistical analysis system is provided that can characterize both the spatial as well as non-spatial aspects of the geographic database.

STRING

In computing, the term *string* is usually understood to refer to a group of characters. Attribute values files can have string fields to store the names of coded regions.

SUPERVISED CLASSIFICATION

Supervised Classification is a technique for the computer-assisted interpretation of remotely sensed imagery. The operator *trains* the computer to look for surface features with similar reflectance characteristics to a set of examples of known interpretation within the image. These areas are known as *training sites*.

TESSELATION

A tesselation is the complete division (or *tiling*) of a space into regular repeating cells. The word comes from *tessera*, a small tile used in mosaics. The raster data structure is an example of a tesselation.

TEXT (file)

Another term for an ASCII file. (see ASCII).

TIFF (file)

A commonly-used raster file format developed by the Aldus Corporation. There are 32 TIFF formats that have undergone 5 revisions. As a result, virtually no programs can read or write all TIFF formats.

UNSUPERVISED CLASSIFICATION

Unsupervised Classification is a technique for the computer-assisted interpretation of remotely sensed imagery. The computer routine does so by identifying typical patterns in the reflectance data. These patterns are then identified by undertaking site visits to a few selected examples to determine their interpretation. Because of the mathematical technique used in this process, the patterns are usually referred to as *clusters*.

VECTOR

Technically, a vector is any variable quantity that can be described as having magnitude and direction and which can be resolved into components. In computer-assisted cartography, complex lines can be described by a series of smaller line segments, each having magnitude (length) and direction. The term is frequently used to signify all graphic data that can ultimately be decomposed into point locations described by absolute coordinates (e.g., plane coordinates X and Y). This would include points, lines (a logically related set of points that can be joined to produce the line) and areas (a line which joins up to itself to produce a polygon). When used to refer to a GIS, the term describes systems that make use of vector representations in data storage and analysis.

WORD

The number of bits that are stored or retrieved as a unit in a given computer architecture. Most micro-computers today use 16- or 32-bit words.