

GEOGRAPHIC INFORMATION SYSTEMS

OBJECTIVES

Chapter 1 presents an introduction to GIS concepts, tools, technology, and history. Given that the focus of this book is on the applications of GIS to natural resource management, what is provided in this chapter is a condensed version of these topics. Nevertheless, at the conclusion of this chapter, students should understand and be able to discuss the pertinent aspects of the following topics:

1. The reasons why GIS use is prevalent in natural resource management
2. The evolution of the development of GIS technology
3. The common spatial data collection techniques and input devices that are available
4. The common GIS output processes that are typical in natural resource management
5. The broad types of GIS software that are available

In one of the first papers on the use of **Geographic Information Systems (GIS)** in natural resource management, de Steiguer and Giles (1981) describe the potential uses of GIS. In adapting one of their introductory remarks to the present day, one finds the relevance of GIS to natural resource management:

A natural resource manager is often called upon to select an area of land to designate as critical wildlife habitat, as a potential area to implement a timber harvest, or as an area to recommend a silvicultural treatment, or to evaluate a landscape under alternative management policies. The manager describes to the GIS the characteristics of the ideal area in terms of forest structural conditions, soils, or topography. Within seconds the manager receives graphic and tabular information to locate the appropriate management areas, or to compare alternative policies.

Obviously, natural resource managers can perform the same task of identifying appropriate management areas or of analyzing policies by examining sets of paper or mylar maps, but the process becomes much more efficient and accurate when performed with GIS. Further, analyses of the impact of alternative policies are facilitated, allowing managers to consider the potential effects of various policies or actions in a more efficient manner, usually saving time and money.

For many natural resource management organizations, GIS is a necessary tool to assist in the day-to-day

management of land and other resources. The applications of GIS vary widely among organizations and range from using GIS as a mapping tool to using GIS to model policy alternatives that may impact landscape features during the next 100 years and beyond. Regardless of how a natural resource management organization plans to use GIS, understanding the potential applications of GIS to natural resource management is essential for natural resource professionals. The purpose of this text is to introduce readers to GIS concepts and principles, and to provide examples of how to apply this knowledge in a natural resource management context. Chapter 1 begins by describing the tools and technology that constitute a GIS and by explaining why GIS has become so important for many organizations. A brief history of the evolution of GIS is then provided, and the key component of any successful GIS (spatial data) is discussed.

WHAT IS A GEOGRAPHIC INFORMATION SYSTEM?

A geographic information system consists of the tools and services necessary to allow one to collect, organize, manipulate, interpret, and display geographic information. A GIS is more than just the hardware and software familiar to most people; it extends to the staff who operate the system, the **databases**, the physical facilities, and the organizational commitment necessary to make it all work. A GIS can be defined by how it is used (e.g., a land information system, a natural resource management information system), by what it contains (spatially distinct features, activities, or events defined as points, lines, polygons, or raster grid cells), by its capabilities (a powerful set of tools for collecting, storing, retrieving, transforming, and displaying spatial data), or by its role in an organization (a map production system, a spatial analysis system, a system for assisting in making decisions regarding basic geographic questions—where is it? what is it? why is it there?).

GIS can also be defined as **geographic information science (GIScience)**. GIScience involves the identification and study of issues that are related to GIS use, that affect its implementation, and that arise from its application (Goodchild 1992). In short, GIScience not only encourages users to understand the benefits of GIS technology in providing a powerful set of analysis tools but also encourages users to view the technology as part of a broader discipline that promotes geographic thinking and problem-solving strategies as being useful to society. The development of GIScience is an outgrowth of the fact that GIS technology is available to more users today than ever before and that spatial categorization and analysis is applicable to many issues and problems of society.

Regardless of how a GIS is perceived or used, it is the integration of the various tools and services that leads to a successful GIS. Although other software programs perform GIS-like tasks (e.g., database management, graphics, or computer-assisted drafting [CAD] software), a GIS is unique in its ability to allow users to create, maintain, and analyze geographic or spatial data. The term **spatial data** implies that data exist which not only describe landscape features (e.g., condition, composition, structure of forests) but also reference the location where the features can be found. A GIS allows one to manipulate spatial data and to analyze quickly a large volume of spatial data. A GIS stores spatial data in a digital database files, often referred to as themes, maps, covers, tables, layers, or GIS databases. The terminology for referring to a GIS database varies, depending on the GIS software program being used. In most GIS software programs, similar landscape features are maintained in a single GIS database. For instance, one may have a soils GIS database, which contains the soil characteristics of a landscape, or a wildlife GIS database, which contains the nest locations of a single species of animal or a group of species of animals. GIS allows the integration and simultaneous examination of multiple GIS databases through a process described as overlay analysis. Overlay analysis, described in further detail in chapter 11, represents the essence of what many consider to be a primary role of GIS in natural resource management: the ability to combine two or more GIS databases to assist in making decisions.

GIS is related to a number of other fields and disciplines, including computer-assisted drafting (CAD), computer cartography, database management, and remote sensing. In fact, GIS contains certain aspects of each of these fields and, thus, is closely related to each of them. However, the differences between GIS and these other allied fields is notable. For example, most CAD software programs have rudimentary links to a database management system, whereas GIS software programs generally have strong links to a database management system. CAD spatial modeling capabilities are also limited, whereas GIS contains a wide variety of spatial modeling capabilities that are examined in chapters 5–13 of this book. The field of computer cartography emphasizes map production, but although the databases used may be similar to those used in GIS, computer cartography generally puts less emphasis on the nongraphic attributes of spatial landscape features than does GIS. Database management software programs have the ability to store and manage the location and attribute data of landscape features but generally lack the display capabilities of GIS, CAD, and computer cartography. Finally, remote sensing-related software programs generally focus on the ability to manipulate and manage raster GIS data



In Depth

In many ways, we are all examples of a living, breathing GIS. Each day we venture from our homes, make decisions about where we are going, how we will get there, and what we will do when we arrive. For instance, a typical college student probably has a route that he or she usually takes to get to campus. Chances are, the student has designed this route over time based on experience, so that he or she can arrive at campus as quickly and easily as possible. Perhaps the student has designed a route to include a stop at a favorite coffee shop. The student may elect to drive and, depending on the time of day, might alter the usual route to avoid traffic. Road construction may force the student to alter the route for a few days or

weeks, and he or she may need to make other adjustments to avoid unforeseen delays. Once at campus, the student will have to find a parking space, then walk another route to get to his or her first class. Of course, the student might decide that the troubles with parking make riding a bike to campus more attractive, but then he or she will need to design a route for the bike trip. The choices that students make just in getting to campus require them to analyze multiple layers of spatial information about their present location, their destination, and the intervening influential factors. In short, they are acting as a GIS in solving their daily transportation challenge.

derived from satellites, scanners, or other photographic devices, and they have a limited capability to handle the vector GIS databases more common to natural resource management organizations.

A BRIEF HISTORY OF GIS

GIS is unique in its ability to process, map, and analyze spatial data. Spatial data have been collected and maintained for millennia, with records of property boundary surveys for taxation purposes in Egypt dating back to about 1400 B.C. It is only within the past 40 years, however, that society has learned how to digitally capture, maintain, and analyze spatial data. Although the term *geographic information system* was first used in the 1960s, **overlay analysis** has been demonstrated through manual techniques for over 200 years. Overlay analysis is the process of analyzing multiple layers of information at one time to address management issues. The layers represent different

types of information but are related to each other in that the information references a common landscape area (figure 1.1). GIS allows one to drape, or overlay, the layers on top of one another to examine the spatial relationships of the information contained in the layers. During the American Revolution, French cartographer Louis-Alexandre Berthier overlaid multiple maps to analyze troop movements (Wolf and Ghilani 2002). In 1854, Dr. John Snow compared the locations of cholera deaths with well locations in London to determine if well water was related to cholera infections. The first written description of how to combine multiple maps precisely through a manual overlay process appeared in a 1954 text titled *Town and Country Planning Textbook*, by Jacqueline Tyrwhitt (Steinitz et al. 1976). In 1964, Ian McHarg described how to use a series of transparent overlays to determine the suitability of areas for development in New York's Staten Island. By using a transparent overlay for each layer of interest (soils, forests, parks, etc.) and blacking-out the areas on each overlay that presented development

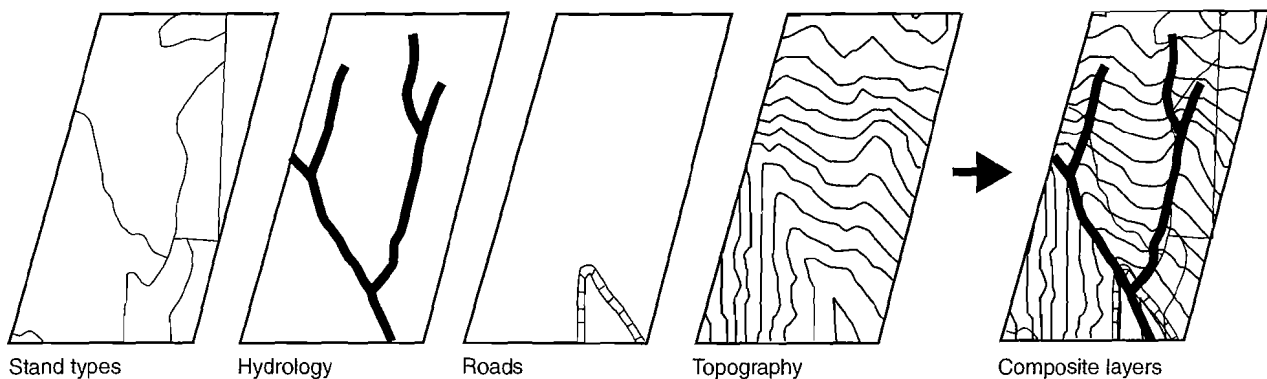


Figure 1.1 GIS theme overlay.

impediments, the layers could be overlaid and the final suitable areas defined. McHarg (1969) later published examples of his overlay techniques in his seminal book, *Design with Nature*.

In the early stages of the development of GIS technology, two facts were evident: there were few geographic or spatial databases to work with, and the technology to store and manipulate the data was rudimentary (by today's standards). Some may argue that GIS technology has not evolved much in the passing years; however, advancements in computer technology and the increasing availability of GIS databases indicate otherwise.

During the 1960s, organizations in the United States (including the U.S. Geological Survey and the U.S. Department of Agriculture's Natural Resource Conservation Service) began to create GIS databases of topography and land cover (Longley et al. 2001). Students and researchers began to write computer programs and design hardware devices (such as the precursor to today's digitizing table) that would allow one to trace the outlines of landscape features on hardcopy thematic maps and transfer them into a digital format. These early programs were designed to handle specific tasks and were often limited in scope. As programmers began to combine these algorithms to create more versatile and powerful software programs, the era of computer mapping applications began. Early examples of mapping programs include IMGRID, CAM, and SYMAP (Clarke 2001).

In conjunction with the development of software programs, other organizations began to assemble GIS databases. The first examples were the GIS databases created by the U.S. Central Intelligence Agency (CIA) called the "World Data Bank." Spatial features in the GIS database included coastlines, major rivers, and political borders from around the world. The U.S. Census Bureau designed a methodology for linking census information to locations in preparation for the 1970 U.S. census. The 1970 U.S. census was the first census that was mailed, and the only piece of information that was returned to reference the location of the respondent was the address. The Census Bureau, however, was faced with the challenge of matching the addresses on the responses to a map, so that the spatial distributions of the responses could be analyzed. To meet this challenge, the Census Bureau developed a system known as Dual Independent Map Encoding (DIME) which allowed them to create digital **records** of all streets and to associate addresses to street locations. The DIME system allowed the Census Bureau to understand which streets were connected to which other streets, as well as what landscape features were adjacent to each street.

The description or characterization of the spatial relationships between landscape features in a GIS database is referred to as **topology**. Topology is an important concept with respect to GIS applications and

will be discussed in more detail in chapter 2. Topology allows one to organize and analyze objects according to their location and to their proximity with other objects. The topological characteristics of data structures allow a determination, for example, of which roads in a forest are connected to which other roads and which timber stands are next to which other timber stands.

The DIME system was the predecessor of Topologically Integrated Geographic Encoding and Referencing System (TIGER) files, which were introduced by the Census Bureau in 1988 and are still used today to distribute spatially referenced census and boundary data. The availability of TIGER files was instrumental in promoting GIS use in the United States. Another important contribution to spatial data availability in the United States was made by the U.S. Geological Survey (USGS). The USGS began digitizing features from its 1:100,000 scale hardcopy maps in the early 1980s. Spatial data from these maps were made available as digital line graphs (DLGs), which, like the TIGER and DIME systems, were also stored in a file format that allowed for the topology of objects to be characterized. The file format was restructured in the early 1990s, and features from finer-resolution 1:24,000 scale maps were later made available for small portions of the country by the USGS.

To manage and analyze spatial data for their jurisdictions, Canadian and U.S. organizations began to develop software programs in the 1960s. One of the most ambitious of these systems was the Canada Geographic Information System (CGIS), which was created under the guidance of Roger Tomlinson in 1964. A chance meeting on a plane flight between Tomlinson and Canada's Minister of Agriculture resulted in Tomlinson overseeing the creation of a national effort to inventory Canada's land resources and to develop a software program to quantify existing and potential land uses. The CGIS is recognized as being the first national-level GIS; thus, Tomlinson continues to receive recognition as a GIS pioneer for his efforts. Other early landmark efforts in the evolution of GIS include the development of the Land Use and Natural Resource Inventory System (LUNR) in New York in 1967 and the development of the Minnesota Land Management System in 1969.

The success of these early systems and the need for further refinements were recognized by a group of faculty and students at Harvard University's Laboratory for Computer Graphics and Spatial Analysis. The group set forth to create a versatile GIS that would map and track locations as the DIME system does, while possessing the land measurement strengths of the CGIS. From this effort, the Odyssey GIS (containing modules named after parts of Homer's epic work *The Odyssey*) emerged in 1977 and pioneered the use of a data structure known as the arc/node or vector data structure. We will discuss the vector data structure in more detail in chapter 2; however, it is important to

note that the specifics of the Odyssey vector structure were first published by Peucker and Chrisman (1975), and the structure continues to influence the design of modern GIS software programs. Jack Dangermond, a Harvard Laboratory student, founded the Environmental Systems Research Institute (ESRI) in 1969, and ArcView and ArcInfo, the most widely used desktop and workstation GIS software programs, are based on the Odyssey vector data structure. ArcInfo, in fact, was introduced in 1981, marking the first major commercial venture into the development of GIS technology.

The 1980s also witnessed the proliferation of microcomputers, today's version of the personal computer (PC). In response, software manufacturers began to produce GIS software programs that could operate on the microcomputer (see Appendix C for a list of GIS software manufacturers). In 1986, MapInfo Corporation was formed and subsequently developed the world's first major desktop vector GIS software program for the PC. Soon afterward, raster GIS software programs, such as IDRISI, began to appear. Some software programs, such as the raster GIS program GRASS, use a software architecture developed for workstation computer platforms.

Other significant developments during the late 1970s and early 1980s were the emergence of GIS-related conferences and publications. The first AutoCarto Conference was held in 1974 and helped establish the GIS research agenda. One of the first compilations of available mapping programs was published by the International Geographical Union in 1974. *Basic Readings in Geographic Information Systems* was published in 1984, containing a collection of papers discussing GIS technology. In 1986, the first textbook written specifically for GIS, *Principles of Geographic Information Systems for Land Resources Assessment*, was published (Burrough 1986). Finally, the first GIS-related academic journal, the *International Journal of Geographic Information Science*, was published in 1987.

The history of GIS continues to evolve, with GIS users providing a number of challenges. GIS users, for example, have the ability to influence the development of GIS software program features. As new and challenging natural resource management issues arise, users identify and propose processes and functions that will make the task of analyzing potential natural resource decisions more efficient and accurate. In addition, GIS users increasingly expect support and training related to specific GIS software programs, and they expect that the software will be perfected by the time of its release to the general public. Further, because GIS databases are shared data among organizations, the need to standardize data formats is evident, as data transformations can require an extensive commitment of time and resources.

Society is fortunate today, on one hand, to have a variety of GIS software programs from which to

choose. On the other hand, evaluating which of these programs best suits the needs of a natural resource management organization is problematic. This fact posed a significant challenge in the creation of this book. Since organizations (natural resource management as well as academic) may use different GIS software programs, a decision was made to develop this book as a general reference for describing the typical types of GIS applications faced by field-level professionals associated with natural resource management organizations. Therefore, specific examples of how to address each application described in this book, those that are related to specific GIS software programs, are made available through other means (e.g., a book-related website).

WHY USE GIS IN FORESTRY AND NATURAL RESOURCE MANAGEMENT ORGANIZATIONS?

In today's natural resource management environment, it is common to see GIS used to assist natural resource managers in making decisions. For example, maps are required to be submitted to state agencies in the western United States in support of forest harvest plans, and, in most areas of North America, pesticide plans require a map to detail the proposed activity as well as the nearby homes and water resources. Although maps may still be drawn by hand in some natural resource organizations, GIS allows map production processes to be automated and repeated, reducing a lengthy drafting exercise to a few minutes. In addition, GIS allows some processes to be accomplished that would normally tax a person's analytical abilities. For example, a natural resource management organization in the southern United States considering a fertilization project, yet operating with a limited budget, may be interested in locating the forested areas (stands) that would benefit most (in terms of growth of the forest) from a fertilization application (to make efficient use of a limited budget). Further, if one assumes that the stands must be dominated by pine tree species, and located on certain soil types, one can imagine the enormous task faced by a large landowner (> 500,000 acres) when paper maps (soils and stands) are the only resource available for analysis. A process such as this could require several days to complete yet might require only a few minutes when performed within GIS.

The application of GIS in natural resource management organizations has become commonplace during the past 10 years. Part of the reason for this widespread use is due to the analytical efficiencies GIS provides, but it is also due to the continued technological advances in computer hardware and software. Computer prices, in fact, continue to decrease while processing power and storage efficiency grow. A wide variety of GIS software programs have also emerged,

and the trend in GIS software program design has been to make the programs more user-friendly.

Perhaps the primary reason for the growth of GIS use in natural resource management organizations is that collecting and analyzing Earth measurements is at the heart of many activities in these organizations. GIS allows one to work with measurement information to facilitate the mapping and modeling of landscape features or to facilitate the evaluation of management policies. For example, one might be interested in determining the extent of vegetation resources within a watershed or in evaluating the potential impacts of changes in riparian management policies. Riparian areas are land areas that are in close proximity to a stream, lake, swamp, or other water body, and often are occupied by plants that are dependent on their roots reaching the water table (Society of American Foresters 1983). An alternative definition describes riparian areas as those areas that are located where the vegetation and microclimate are influenced by seasonal or year-round water, high water tables, and soils that exhibit some wetness characteristics (Oregon Department of Forestry 1994). GIS thus facilitates an efficient exploration of the information related to natural resources.

Although many natural resource management organizations employ a GIS expert (guru, manager) at a centralized GIS office, these people are often overloaded with work and unable to offer sustained assistance to field personnel. In some cases, the experts are unaware of the common types of GIS applications in natural resource management. Add to this the fact that many natural resource management organizations want new employees to have a background in GIS, it is advantageous for those involved in natural resource management to be familiar with the potential uses of GIS and to be familiar with the processes for performing basic GIS processes, such as viewing data, calculating measurements, and making maps of features of interest.

GIS TECHNOLOGY

Operating a GIS requires working with a wide range of technology and possessing or acquiring the skills necessary to understand and manipulate the technology. Next, we will discuss the various technological components of GIS. Although it may not be important for GIS users to be considered experts in all GIS-related technologies, familiarity with the various components may help them understand how the components are integrated.

DATA COLLECTION PROCESSES AND INPUT DEVICES

Despite the rapid advance of GIS hardware and software, one of the primary challenges for organizations using GIS relates to the development and maintenance of GIS databases. Gathering spatial data, preparing the

data for GIS use, and documenting these processes continue to comprise most budgets allocated for GIS processes. Spatial data quality is central to successful GIS implementation.

Data are often described in terms of their precision and accuracy, two terms often confused. **Precision** relates to the degree of specificity to which a measurement is described. A measurement that is described with multiple decimal places, such as an area measurement of 2.6789 hectares, is considered a very precise measurement. If this measurement were derived from a property boundary where distances were gathered by counting paces, and angles were measured using a handheld compass, the measurement should not be described this precisely. Precision can also be described in terms of the relative consistency among a set of measurements. For instance, if the measurements related to a property boundary were taken multiple times through the use of a sophisticated surveying instrument, such as a total station, and the resulting variation among measurements were small, one could describe the measurements as being precise.

Accuracy is the ability of a measurement to describe a landscape feature's true location, size, or condition. Accuracy is typically described in terms of a range, or threshold of values, and attempts to answer the following question: how close are the measurements to their true value? Examples of accuracy levels include distance measurements of ± 0.5 m or angle measurements of ± 1 second. One can have measurements that are both highly precise and accurate (figure 1.2, part A), highly precise without being very accurate (figure 1.2, part B), not very precise but accurate (figure 1.2, part C), or neither precise nor accurate (figure 1.2, part D).

Accuracy and precision may also be stated in relative terms. Suppose one were to measure twice the length of a stream, with a 100-foot metal tape, resulting in measurements of 232.7 and 232.5 feet. The average length of the stream is 232.6 feet. If the metal tape was previously broken—say at the 10-foot mark—and spliced back together, reducing the effective length of the tape to 99.9 feet, the relative accuracy and precision of the measurements can be calculated. Since the tape was used about 2.3 times when measuring the stream, and the broken part of the tape was used each time, the accuracy of the measurements is about $2.3 * 0.1$ foot = 0.23 foot off of the value one might have expected with an unbroken tape. One could express the relative precision of the measurements as $(232.7 - 232.5) / 232.6 = 1:1163$ and the relative accuracy of each measurement as $0.2 / 232.6 = 1:101$. It is important that GIS users are aware of the distinction between precision and accuracy, particularly when considering the value of using a GIS database in an analysis that leads to a management decision.

There are many ways to create and collect data, and all methods require varying degrees of skill and organi-

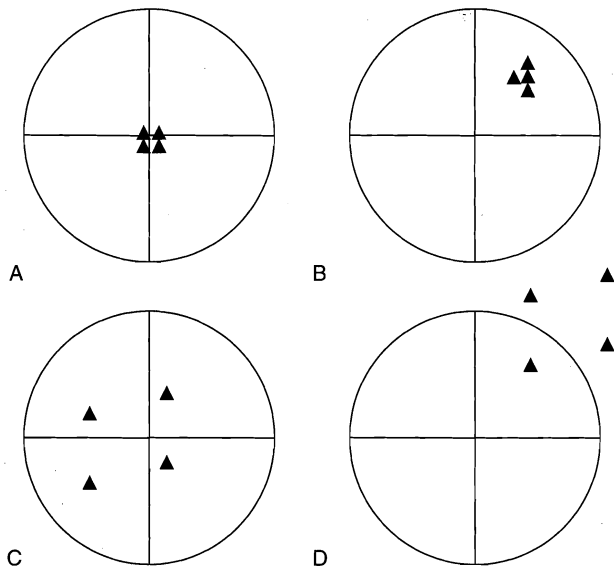


Figure 1.2 Examples of accuracy and precision.

Part A shows accurate and precise locations of data around the circle center; part B shows precise but not very accurate data; part C shows accurate but not very precise data; and part D shows neither precise nor accurate data around the circle center.

zational commitment. Next, we will examine some of the most common methods of creating GIS databases.

Manual Map Digitizing

The ability to encode vector maps manually using a digitizing table (figure 1.3) and associated software has been available since the late 1960s. Paper or mylar maps are taped down to a digitizing table, in which is embedded a fine mesh of copper wire. Known reference points on the maps are identified using the digitizing table's "puck" (similar to a computer mouse), which sends a signal to the wire mesh within the table. Once the reference points have been identified, all other landscape features can be encoded in a coordinate system and related to the reference points. For point features, this requires lining the crosshairs of the puck up with the point locations and identifying the points. For line and polygon features, it involves tracing the boundaries of the lines or polygon boundaries, noting each change in a line's direction. Features can be recorded with either "stream mode" or "point mode" referencing processes. In stream mode, the spatial location of the digitizing puck is recorded at either regular time intervals (e.g., every second) or regular distances intervals (e.g., every 0.25 inch). In point mode, the spatial location of the digitizing puck, and hence the location of landscape features, is recorded every time a button on the puck is pushed.

Manual digitizing of maps can be a tedious process and, like many other tasks that are done by hand, subject to human errors and variation. Today,

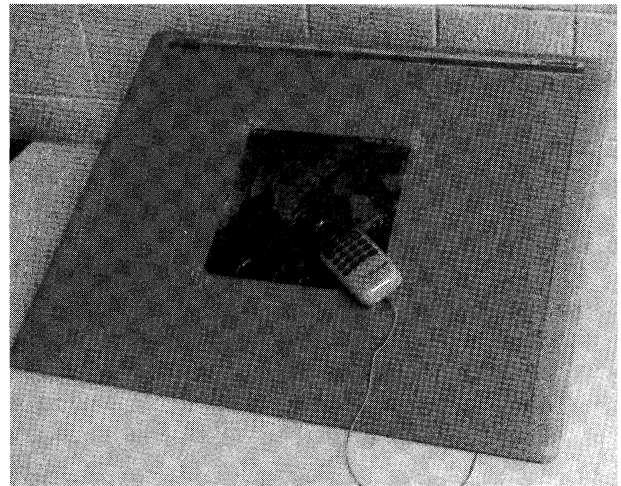


Figure 1.3 Modern digitizing table.

digitizing is still a common and necessary function for many natural resource management organizations.

Scanning

Scanning involves the examination of maps by a computer process that seeks to identify (and convert to digital form) changes in map color or tone that identify landscape features. Flat-bed scanners allow one to convert a picture or map, such as an aerial photograph or a topographic map, to digital form. The resulting images are described by the raster data structure and include pixels or grid cells that may be encoded (or attributed) differently, depending on how the scanner interprets the color or tone of each feature. Scanners (figure 1.4) generally move systematically across a picture or map, and they record for each grid cell the reflectance values of the tones or colors. Scanned images tend to look very much like the pictures or maps that were scanned, yet usually with some difference in quality due to the size of the grid cells assumed in the scanning process, the quality of the picture or map, or the quality of the scanner.

A second method of scanning involves the use of digital cameras. An array of photodetectors located within digital cameras allows one to capture and store an image. The images are saved with a raster data structure and can be transferred to a computer system and used in manners similar to the scanned images.

Remote Sensing

Remote sensing involves the use of a sensor that is not in physical contact with its subject of interest (Avery and Berlin 1992). It can include a wide variety of techniques; in fact, capturing images with a digital camera theoretically uses remote sensing technology, since the camera is not necessarily in contact with the image being collected (the landscape). However, a discussion of remote sensing technology in natural resource management frequently refers to the use of satellites or cameras

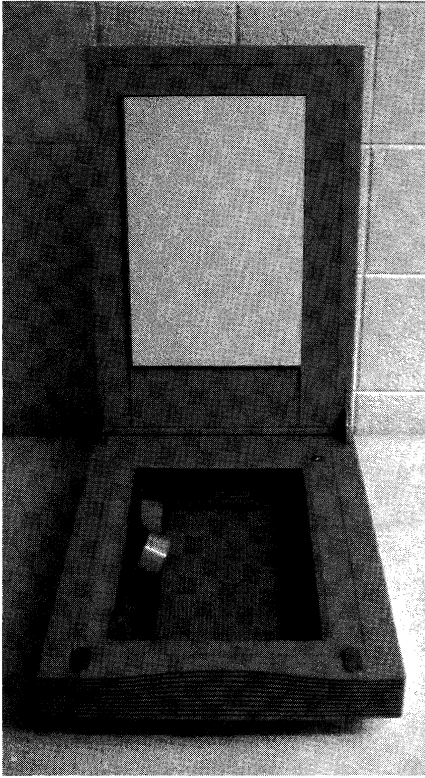


Figure 1.4 Small format scanner.

mounted on airplanes. Remote sensing devices capture electromagnetic energy, perhaps generated by the sun or another device (such as a radar transmitter), that is reflected off of landscape features. Most satellite sensors are designed to record the reflectance of light or heat from objects on the Earth's surface. These electromagnetic reflectances are recorded by the sensors in terms of their wavelength of energy, as described by the electromagnetic spectrum. The electromagnetic wavelengths are then converted to a digital format and transmitted back to a computer for processing and interpolation. Satellites such as the Landsat Thematic Mapper™ series can capture wide swaths of the Earth's surface (185 km, or 115 mi) and, thus, have the potential to record vast amounts of information over a short time period. The launch and operation of satellites for data collection has increasingly been conducted by private organizations; as a result, many forms of highly accurate and precise data are becoming available, such as the 1 m resolution IKONOS satellite data (Space Imaging, Inc. 2002). Although these advances in remote sensing technology have increased the variety of products available to consumers, the cost of acquiring and processing satellite-collected data are still prohibitive for many organizations.

Digital cameras can be mounted on airplanes (figure 1.5), and can generally provide higher-resolution images than is provided by satellites, yet this distinc-

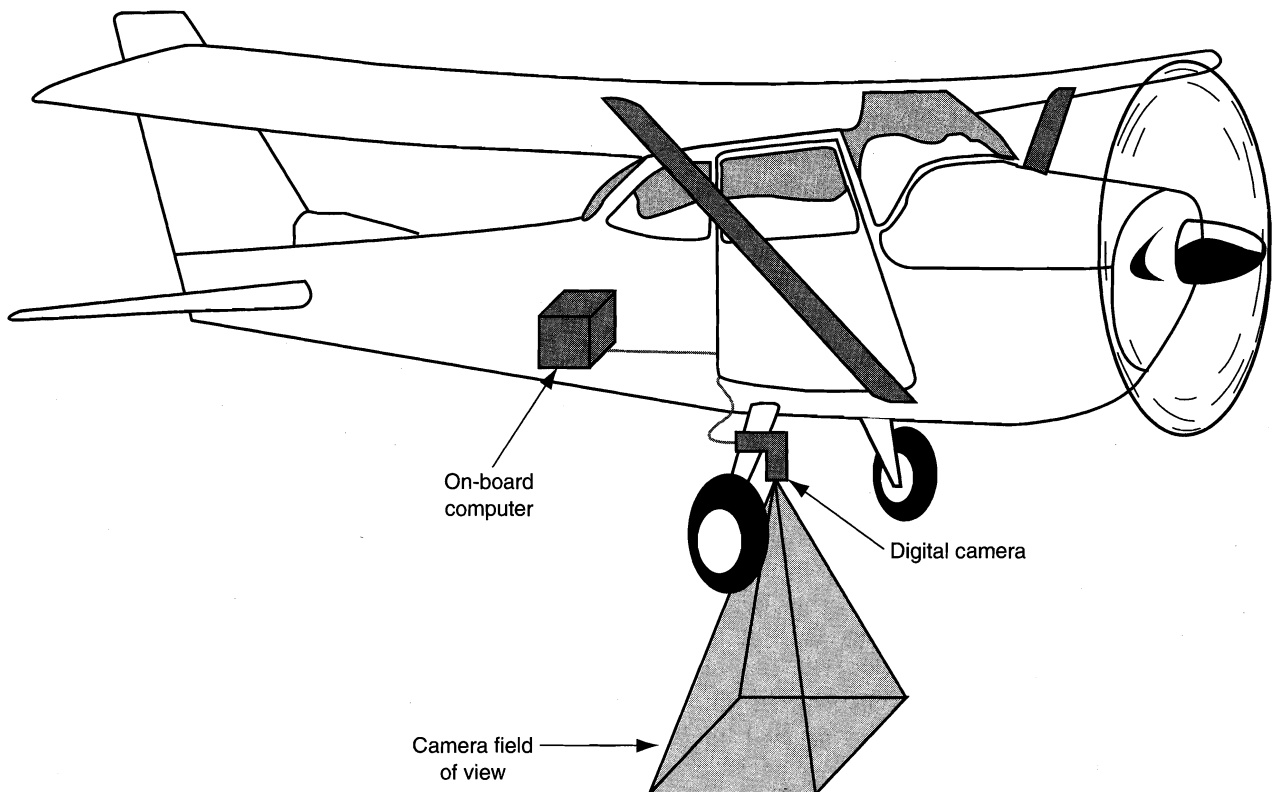


Figure 1.5 Digital camera mounted on an airplane.

(Image courtesy of Geovantage Inc., patent pending technology.)

tion is getting less clear with each passing year. A relatively new technology called light detection and ranging (LIDAR) allows for the collection of topographic or elevation data. LIDAR systems are mounted on an aircraft and include a laser, an inertial navigation system, a **Global Positioning System (GPS)** receiver, and an on-board computer for processing. The laser emits pulses of energy toward the ground surface as the aircraft travels, the pulses are reflected off the ground surface, and the return time of the energy to the aircraft is measured (figure 1.6). By comparing the return time with the speed of light, the distance to the ground can be calculated. The inertial navigation system tracks the irregularities of the aircraft's flight path and attitude (yaw, pitch, and roll), and all information is collected and processed by the on-board computer. Since the GPS receiver knows the coordinates and altitude of the aircraft, elevations can be associated with the landscape features that reflected the laser energy. The laser can generate thousands of pulses of energy per second, making it possible to collect a large amount of data very quickly. The accuracy of LIDAR databases is estimated to be in the 10–20 cm range, possibly better under certain conditions. LIDAR has shown great potential in forestry and natural resource

applications, not only in generating high-resolution digital elevation models (DEMs) but also in measuring stand structural conditions. Although the cost of acquiring LIDAR data is still prohibitive for many organizations, it is expected to become more affordable in the future.

Photogrammetry

Photogrammetry is the collection of measurements from the image of an object or a resource; it dates back to the mid-nineteenth century, soon after the first photograph was created (Wolf and Dewitt 2000). Through various techniques, photogrammetry facilitates the interpretation and measurement of features captured on photographs. It requires a firm understanding of photography, strong quantitative skills, and at times creativity, as successful interpretation sometimes becomes an art. Photogrammetry is perhaps the primary method used for the creation of spatial data in forestry and natural resource management. Within the United States, many of the products produced by the U.S. Geological Survey (USGS), including elevation surfaces and other representations of natural resources, were derived from photogrammetric techniques.

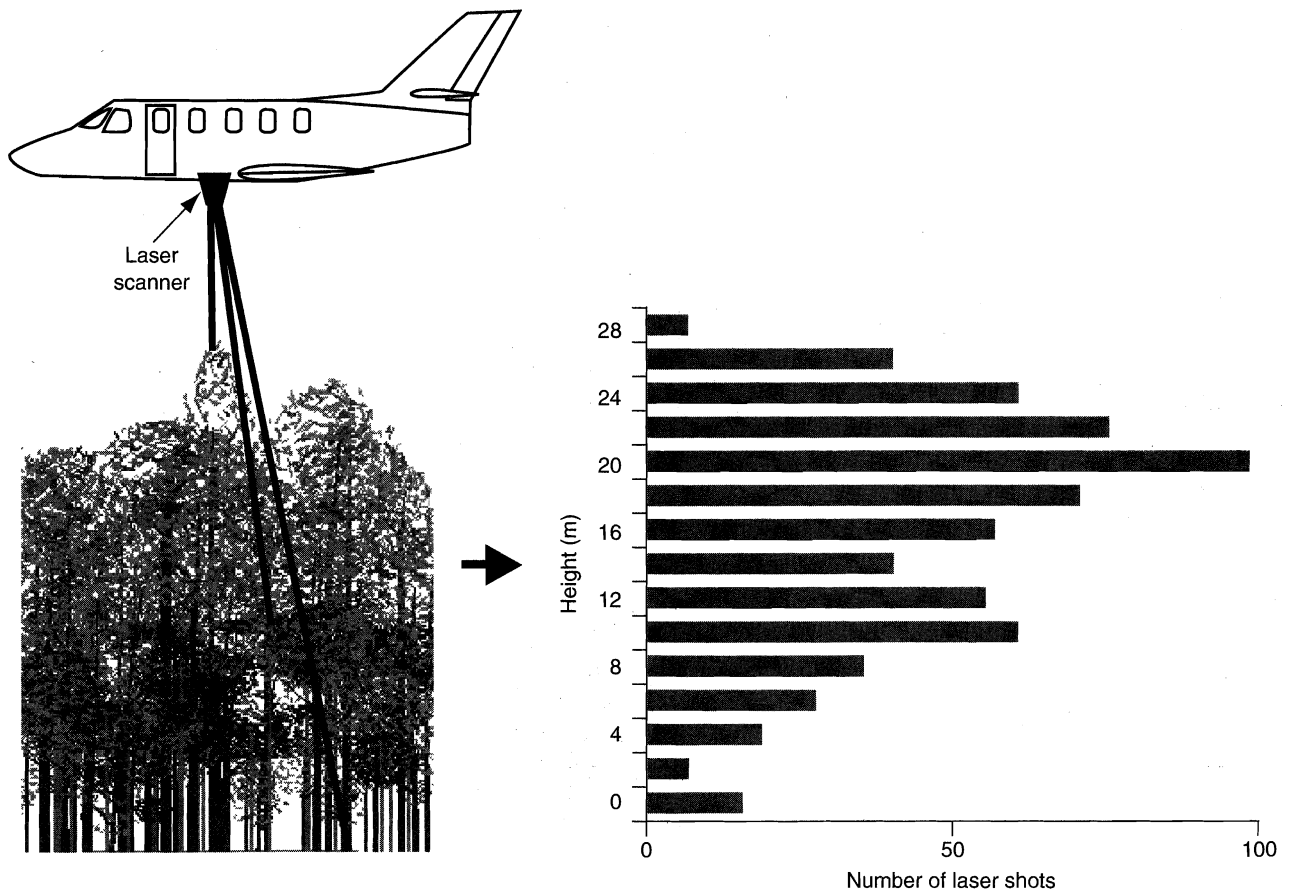


Figure 1.6 LIDAR system on aircraft.

(Courtesy Dr. Jason Drake, University of Georgia.)



In Depth

In our society, electromagnetic energy is generated by a variety of sources, including sunlamps, fires, microwaves, radio towers, radar detectors, and lasers. The most obvious natural producer of electromagnetic energy is the sun. The sun produces electromagnetic energy at multiple wavelengths, some of which are visible to human eyes. Devices or techniques for capturing this energy can be characterized as passive or active. Passive data capture techniques, such as aerial photography or Landsat TM, and record electromagnetic energy that is naturally emitted or reflected. Devices that use radar or laser technology, that transmit electromagnetic energy and record the

amount of time it takes for the energy to return, are defined as active techniques. The entire range of electromagnetic energy is known as the electromagnetic spectrum. The range of electromagnetic energy humans can see is known as the visible portion of the electromagnetic spectrum, which contains wavelengths between 0.4 and 0.7 μm . Other portions of the spectrum that are not visible to humans include the cosmic, ultraviolet, infrared, microwave, and radar wavelengths. Most digital imagery developed from remote sensing devices make use of the visible and infrared portions (0.4–0.9 μm) of the electromagnetic spectrum.

Photogrammetry offers several advantages over other data collection techniques. Using aircraft, photographs can be taken of areas at heights that might ordinarily be inaccessible by other devices. Large landscape areas can be captured, creating a permanent record of a resource at the time of data collection. Photographs can also be used for historical research, since, unlike a field survey of a resource (which generally is difficult to reproduce), it is relatively easy to reexamine a photograph. The accuracy, speed of acquisition, and cost of photogrammetric products are constantly improving; thus, photogrammetry remains a popular method for collecting spatial data and creating GIS databases. Digital methods of capturing images, however, are steadily replacing those that use photographic film.

The most crucial physical component of photogrammetry is the photographic system used. Single lens cameras are most common, and a typical frame measures 23 \times 23 cm (9 \times 9 in.). The camera lens is held at a fixed distance, or focal length, from the frame. Knowing this distance is critical in facilitating future measurements from photographs (figure 1.7). The most common focal length is 152.4 mm (6 in.), but other lengths are also used (90, 210, and 305 mm). Photographic images are captured when a shutter near the lens is opened and momentarily allows light to strike the film surface. Fiducial marks are projected onto the film during the exposure of the photograph to allow one to define the geometric center of the photograph. Fiducial marks are usually in the form of four or eight markings located in the sides or corners of the photograph margins.

Aerial photographs are described by the angle in which they were captured: vertical or oblique. A vertical aerial photograph is one in which the position of the camera axis is in a nearly perpendicular orientation to the ground surface. An oblique aerial photograph is one in which the position of the camera axis is located

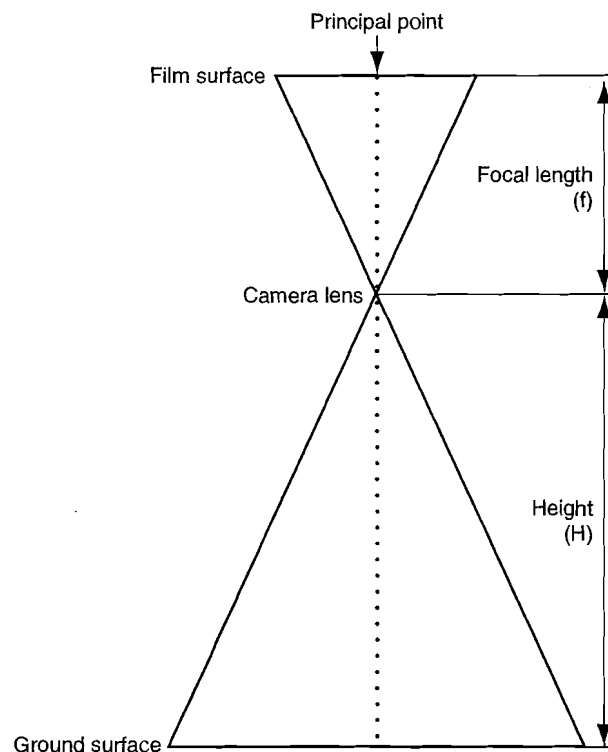


Figure 1.7 Aerial photography geometry.

somewhere between a vertical and horizontal orientation to the ground. For measurement purposes, vertical photographs (figure 1.8) are preferred by most photogrammetrists, whereas oblique photographs are more useful for interpretive purposes.

Vertical aerial photographs are usually captured along a series of locations known as a flight line, to ensure total coverage of a resource. Flight lines are usually designed so that subsequent photographs have an overlap of 60 percent. In addition, photographs captured on adjacent flight lines should have an overlap of 30 per-



Figure 1.8 Aerial photograph.

cent. An advantage of creating overlapping photographs is that one can see landscape features in stereo (with a stereoscope) when simultaneously viewing photographs captured of the same area (figure 1.9), yet from different angles. In addition, photographic mosaics can be more easily created when using overlapping photographs.

The **scale** of an aerial photograph is described by the ratio of photo distances to ground distances. A scale can be calculated for any point on a photograph by using the following formula:

$$S = \frac{f}{(H - h)}$$

where S is the scale, f is the camera focal length, H is the height of the camera above a control surface (such as mean sea level) (review figure 1.7), and h is the point's elevation. Variables f , H , and h all need to be stated in the same units of measurement. If the focal length were 6 inches, the height of the camera 2,000 feet, and the height of the point in question 450 feet, the absolute scale would be $0.5 / (2,000 - 450) = 0.000323$. Expressed as a relative scale (the inverse of the absolute scale), these measurements represent 1:3,100.

If a map is available of a photographed area, scale can be derived without using the focal length and camera height, but by measuring the photo distance and the

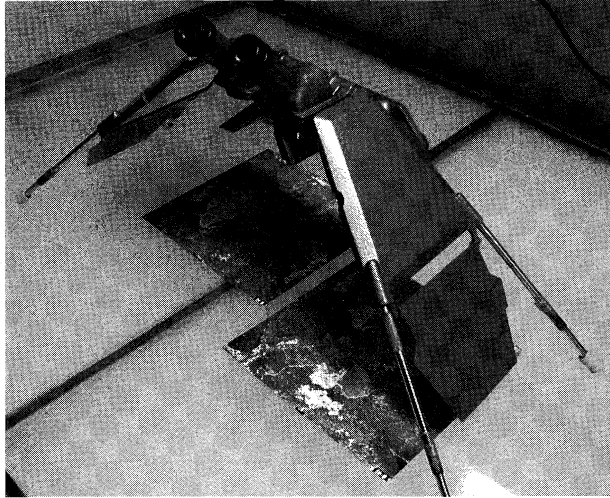


Figure 1.9 Mirror stereoscope.

map distance between two points. The following formula can then be used:

$$\text{photo scale} = \left(\frac{\text{photo distance}}{\text{map distance}} \right) * \text{map scale}$$

The distances used in this formula must be in the same units, and the photo scale will reflect the average elevation between the two points. Once the photo scale is known, photo distances can be converted to ground distances by multiplying the photo distance by the scale. For example, assume that the distance between two points on a photo distance is 2.5 inches, the distance between the same two points on a map is 4.5 inches, and the **map scale** is 1:24,000. The scale of the photo is $(2.5 / 4.5) * 24,000 = 13,333$, or a ratio of 1:13,333.

Analytical photogrammetry involves the use of mathematics to define precisely the locations of landscape features on stereo pairs of photographs. Stereoplotters are often used in analytical photogrammetry to register and measure photographs (figure 1.10). There are several types of stereoplotters, and newer models interface with a computer to increase the speed of data creation and correction. Once the photographic images are placed on the stereoplotter, lights projected from different angles are directed through them. The lights are adjusted so that a stereomodel is formed from the overlapping areas of the projected images on the photographs. Once the stereoplotter operator brings the stereomodel into focus, landscape features can be measured and mapped and a GIS database created. The accuracy of measurements obtained through analytical photogrammetry are usually expressed as a ratio of the camera height involved in the imaging process. Accuracy levels of around 1/12,000 of the camera height are typical. For camera heights of 12,000 ft, this translates into an accuracy of about ± 1 ft. A relatively recent product that is developed from aerial photographs is a

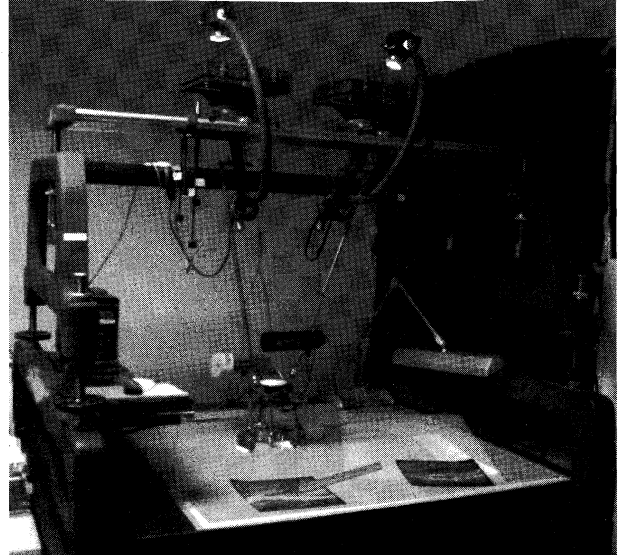


Figure 1.10 Stereoplotter.

digital orthophotograph. While an orthophotograph is derived from aerial photographs, the relief displacement inherent in the photographs is minimized, and measurements of landscape features can be taken directly from the orthophotograph without the need for displacement corrections. To create a digital orthophotograph, scanned aerial photographs and digital elevation models (DEMs) are required. Orthophotographs and DEMs are discussed in more detail in chapter 2.

Field Data Collection

Field collection techniques for the creation of GIS databases have advanced tremendously over the past 20 years and are now fully enmeshed in the digital age. Field collection techniques were once limited to manual tools that required physical skill on the part of the operator and, depending on the instrument, technical competency equivalent to that possessed by a professional land surveyor (Kavanagh and Glenn Bird 2000). Field crews used metal or synthetic tapes to measure distances between objects, and clinometers or level guns to determine gradients and elevation differences. Approximate angles could be determined from compass readings and more precise angle measurements from transits or theodolites. Measurements were recorded in field notebooks and processed in an office setting. Post-processing and adjustment of the data were almost always necessary to ensure that data collection and instrument errors were accounted for and balanced throughout the measurements. These practices are still common and appropriate today for many field crews who are involved in collecting spatial data for forestry and natural resource purposes.

Increasingly, field data collection processes are using digital data collection techniques (Anderson and

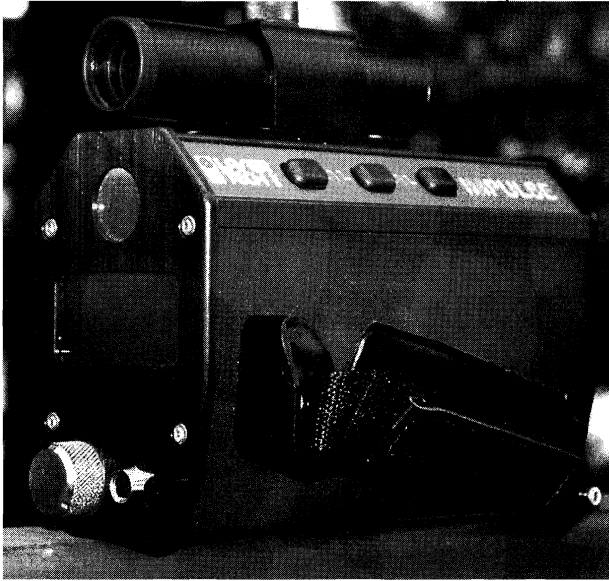


Figure 1.11 Laser range finder.

Mikhail 1998). Although technical competency with digital instrumentation and an understanding of measurement error and corrections are necessary skills for field crews using this technology, spatial data can be collected and processed with efficiency and precision that far surpass other manual field measurement techniques. Electronic distance measuring devices (EDMs) were first developed about 50 years ago and represented a major breakthrough in data collection (Wolf and Ghilani 2002). These devices measure the amount of time it takes a beam of electromagnetic energy to travel from an instrument to a reflective surface and back. With this information, a distance can be calculated. Current technology includes the ability to capture not only distance measurements but also the angles between objects. In addition, the measurements are stored in a digital database. In some cases, these measurements are highly accurate, providing positions that are within centimeters, or less, of their true values. Total stations and laser range finders (figure 1.11) are examples of tools that make it possible for field crews to sight and “shoot” distant objects. Typically, these instruments require that a reflective surface be placed on the object of interest, so that a beam can be projected onto the surface and returned for measurement. Measurements include not only horizontal distances and angles but also the elevation difference from the instrument’s position. Automatically storing the measurements within the surveying instruments eliminates errors that may arise when data recorded by hand on field forms are transferred to a GIS database.

GPS equipment has also become more affordable and useable in recent years. GPS requires that a receiver, located on the Earth’s surface, collect and record signals transmitted by a constellation of satel-

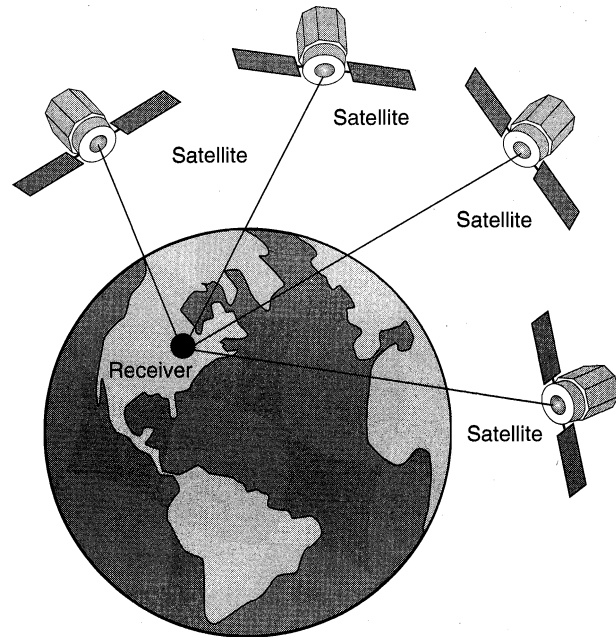


Figure 1.12 GPS schematic.

lites that orbit the Earth (figure 1.12). GPS satellites are operated by the U.S. Department of Defense (DoD) and continually transmit signals toward the Earth (Van Sickle 2001). The signals contain information about the satellite that sent the signal and the precise instant of signal transmission. GPS receivers (figure 1.13) calculate the amount of time it takes each signal to travel from the satellite. Information is also contained in the signal that allows the GPS receiver to make corrections for atmospheric disturbances that may have affected the signal’s speed. Through the process of triangulation, a GPS receiver can determine an intersection point or location. Signals received from a fourth satellite allow for the calculation of elevation and facilitate clock error adjustments. Until recently, the DoD intentionally scrambled GPS satellite signals, in the interest of national security, so that random errors prevented accurate location information from being collected. The scrambling process was known as selective availability (SA). The random errors could be removed by some of the more expensive GPS receiver software through a process called differential correction. However, recent legislation has resulted in the disabling of SA, allowing increased accuracy for all GPS receivers.

There are three broad varieties of GPS receivers. Survey grade GPS receivers are used by land surveyors and other Earth scientists to provide highly accurate and precise information. Survey grade receivers are capable of sub-centimeter data accuracy, yet the cost of this equipment is in the \$35,000 to \$100,000 range. Mapping grade GPS receivers cost about \$6,000 to \$12,000

and are capable of providing sub-meter data accuracy. Recreation grade GPS receivers can be purchased for about \$100 and provide roughly 10–30 m data accuracy.

Although many scientists, resource specialists, foresters, and engineers have turned to GPS technology for the collection of forestry and natural resource data, a number of obstacles must be overcome to use GPS technology efficiently in natural resource management.



Figure 1.13 GPS receiver, antenna, and data recorder.

Foremost among these is the GPS receiver's ability to establish and maintain signals from a sufficient number of satellites. Approximately 24 active and several spare satellites are operational at any one time. The orbital patterns of the satellites do not guarantee that a sufficient number of satellites will be in the appropriate place in the sky to allow one to triangulate a position on the ground. In addition, dense canopy cover often interferes with satellite signal reception. Relief and landforms can also block the path between the GPS receiver and satellite, and they can affect signal reception. Reception performance can be improved by using mission planning software to determine the best time frames (satellite "windows of opportunity") available for GPS signal reception. Finally, multipath errors, or satellite signals that reflect off of other objects, such as buildings or vehicles, before reaching a GPS receiver, can introduce positional errors into the measurements (figure 1.14). These errors generally must be removed manually.

Data Storage Technology

Commonly, GIS databases consist of large quantities of data that must be stored and replicated ("backed up") in a system that allows easy access for GIS managers and users at natural resource management organization field offices. Just a few years ago, magnetic tapes and magnetic disks were commonly used to store computer files on networks and personal computers (Burrough and McDonnell 1998). Today, 4 mm and 8 mm tape drives are still commonly used to transfer data among users and to back up computer systems. Some organizations still use 3.5 in. disks (1.4 Mb) for quick transfer of small GIS databases among computers and users. In fact, many of the GIS databases used in the applications described in this book are small enough to be stored on these types of computer disks. Larger-capacity "zip" disks (100–250 Mb) are also very common, and compact discs (CDs) are used by many as the standard storage technology. CDs generally can hold about 650 Mb of data, and many personal computers contain CD drives that allow users to both read and write to CDs. The read and write speeds of CDs are prohibitive for GIS users who work with large GIS databases. Recently, rapid read and write speeds (~10 ms) have been achieved by many brands of

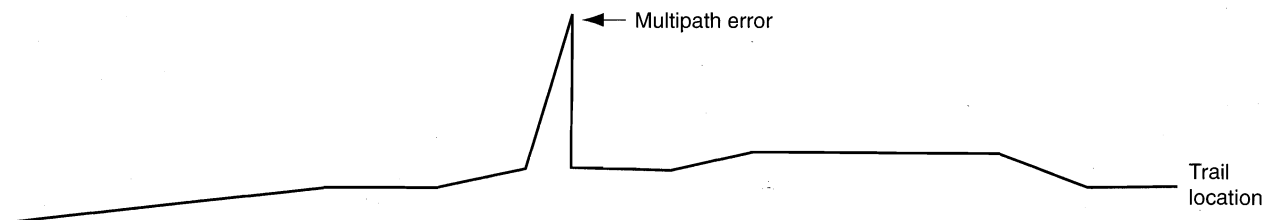


Figure 1.14 Multipath error in data collected through GPS.



In Depth

A GIS workstation usually includes a higher-end computer with a fast processor and large amounts of RAM and internal disk storage space. However, for the type of work performed by field foresters and natural resource managers, a typical personal computer (or even laptop computer) generally suffices to facilitate the use of desktop GIS software, such as ArcView, MapInfo, or GeoMedia. What are the desired characteristics of a personal computer that might allow one to use desktop GIS

software? Obviously, a fast processor would be beneficial: the faster the processor, the quicker a process is completed, such as buffering or overlaying. In addition, 256–512 Mb of RAM is perhaps the minimum necessary to handle large processing tasks easily. Finally, a 40–100 Gb hard drive is perhaps the minimum size necessary to store the GIS databases one might develop and use over the useful life of a personal computer (two to three years).

portable external hard drives. These external hard drives can be connected quickly to a computer's universal serial bus (USB) port, provide fast backup and recovery, and can serve as an additional hard drive if needed. Storing data on a digital versatile disc (DVD) is also becoming increasingly common. DVD discs can hold approximately 4.5 Gb of data and, like CDs and zip disks, require a separate disk drive. It would not seem unreasonable for a GIS workstation to include the following data disk drives: 3.5 in. floppy disk, CD, DVD, zip, and 4 mm tape, along with a standard 40–100 Gb internal hard drive.

Data Manipulation and Display

Personal computers and workstations are becoming synonymous, and are the mainstay of the technology needed to use GIS software programs and GIS databases. Even though the distinction between the two has been blurred over the years, they can be characterized by criteria (speed, memory, operating system) that constantly change with advances in computer technology. Workstations are usually the higher-powered devices, with more random access memory (RAM), faster central processing units (CPUs), and larger storage devices (hard drives). However, it is not uncommon to purchase a computer with a very fast CPU and only moderate amounts of RAM; thus, characterizing it as a personal computer or workstation is problematic. In terms of operating systems, most computers with uniplexed information and computing system (UNIX®) operating systems are called workstations, yet those with Windows® or Linux® systems need further clarification before settling on the type of technology they represent. UNIX® operating systems are rapidly becoming overshadowed by Windows® and Linux® systems. Many GIS software designers are also focusing their development efforts on applications related to Windows® systems rather than UNIX® systems.

The resolution and memory of computer monitors is also important for quick and clear display of GIS

databases. Video memory cards are installed in most computers to manage the level of pixel resolution of on-screen images, to display a wider array of colors, and to increase the speed at which images are displayed on a computer monitor. A below-average video card can reduce the effectiveness of an otherwise fast-processing computer. Video cards are often rated by the amount of RAM installed on the card. Currently, 32 Mb would be an adequate amount of RAM for standard GIS processes. For those working with larger GIS databases, a video card with 64 Mb or more memory should be considered.

OUTPUT DEVICES

GIS databases and the results of GIS analyses can be presented in a variety of manners, both in graphical and in tabular form. For example, when examining the impacts of alternative riparian management policies on a landscape, it may be important to present data in tabular form to describe the potential economic impacts of alternatives and in graphical form to display visually the area each policy affects. A number of the common output devices that can be used to present results of a GIS analysis are described in the next four sections (Printers and Plotters, Screen Displays, Graphic Images, Tabular Output).

Printers and Plotters

The most obvious output devices associated with GIS are printers and plotters. Fifteen years ago, line printers were common peripherals to computer systems. Their output quality was low, and the range of symbols and colors was limited. Today, a variety of color and black-and-white printers are available that can produce high-quality maps; thus, the cartographic creativity of GIS users is virtually unhindered. Printers are generally classified as laser or ink jet, depending on how ink is transferred to paper. Laser printers are more expensive (\$500 to \$2,000) than ink jet printers (< \$500), and require

TABLE 1.1 Common Sizes of Map Output from Plotters

Map Size	Dimensions
ANSI A	8.5" × 11.0" (216 mm × 279 mm)
ANSI B	11.0" × 17.0" (279 mm × 432 mm)
ANSI C	17.0" × 22.0" (432 mm × 559 mm)
ANSI D	22.0" × 34.0" (559 mm × 864 mm)
ANSI E	34.0" × 44.0" (864 mm × 1118 mm)
ANSI F	28.0" × 40.0" (711 mm × 1016 mm)
ISO A4	8.3" × 11.7" (210 mm × 297 mm)
ISO A3	11.7" × 16.5" (297 mm × 420 mm)
ISO A2	16.5" × 23.4" (420 mm × 594 mm)
ISO A1	23.4" × 33.1" (594 mm × 841 mm)
ISO A0	33.1" × 46.8" (841 mm × 1189 mm)
ISO B4	9.8" × 13.9" (250 mm × 353 mm)
ISO B3	13.9" × 19.7" (353 mm × 500 mm)
ISO B2	19.7" × 27.8" (500 mm × 707 mm)
ISO B1	27.8" × 39.4" (707 mm × 1000 mm)

ANSI = American National Standards Institute

ISO = International Standards Organization

reusable laser cartridges, yet they generally produce output products that are more stable, with regard to exposure to moisture, than ink jet printers. Ink jet printers require disposable ink cartridges, and the output products are more easily affected by exposure to moisture.

The main drawback with most printers is the format of the output, which is generally limited to 8 1/2" × 11" or 11" × 14" media. Plotters allow GIS users to produce maps of a variety of sizes (table 1.1). Plotters, however, are generally more expensive (\$5,000 to \$10,000) than printers and require special paper and ink cartridges. One way to categorize plotters is to use a vector/raster analogy. Vector plotters include those termed as flatbed or drum. Vector plotters draw lines using plotting pens of different colors and can produce some very precisely drawn maps. Raster plotters include those termed electrostatic, laser, ink jet, and warm wax. Electrostatic plotters use an array of electric contacts (> 100 per inch) that apply a charge to paper, which then comes in contact with negatively charged toner, to produce images. The technology that is used in laser and ink jet plotters is similar to that in laser and ink jet printers—each feature on the map is drawn pixel by pixel. Warm wax plotters are similar to ink jet plotters, but the resulting products have a glossy appearance. Some of these printers and plotters, in conjunction with high-quality paper, enable GIS users to produce photographic-quality output products. A thorough examination of the needs of an organization is warranted prior to making a decision regarding an investment in printers or plotters.

Screen Displays

More rudimentary output products from GIS are those related to the image displays one can view on a computer screen. These processes consist of capturing information (data or maps) displayed on the screen of a computer and temporarily storing the information in a digital database. A number of methods are available to allow GIS users to capture images displayed on a computer screen. The resolution and detail of the resulting captured image, however, depends on the method used for image capture. Screen displays are sometimes captured and saved as image files; at other times, they are simply stored in the computer's "buffer" or "clipboard" and, thus, are available for pasting into a variety of computer software programs. For example, most personal computers allow users to save what may be displayed on a computer screen by pressing (all at once) the Alt and Prnt Scrn keys on a computer keyboard. This stores the entire image displayed on a computer screen to the computer's buffer, as in copying text. Then, one can paste the captured image into a word-processing or graphics software program (figure 1.15). One potential drawback is that screen captures are raster images, even though one may be attempting to capture a representation of vector GIS databases displayed on a computer screen.

Graphic Images

In addition to screen captures, most GIS software programs allow users to directly store images viewed on the screen as an independent computer file. These products are also raster images, yet they are slightly different from the screen displays described in the section "Screen Displays" in that generally only the map image is captured and stored (figure 1.16), not everything else that may be present on a computer screen. These images can be stored in a wide variety of formats (table 1.2), depending on the availability within the GIS software program being used. However, transferring graphic images from one system (e.g., GIS) to another (graphics editing programs) or vice versa can sometimes be problematic due to format inconsistencies. In addition, the size of the resulting graphic image files will vary, depending on the format used to save the image.

Tabular Output

As one might assume, tabular output consists of tables or sets of **tabular data** (numbers, text) derived directly from a GIS database or as a result of a GIS analysis. Although maps are engaging, drawing people in and allowing them to visualize the qualities and conditions of a landscape, tabular data are also important for illustrating nonspatial information. For example, although



Figure 1.15 Screen display.

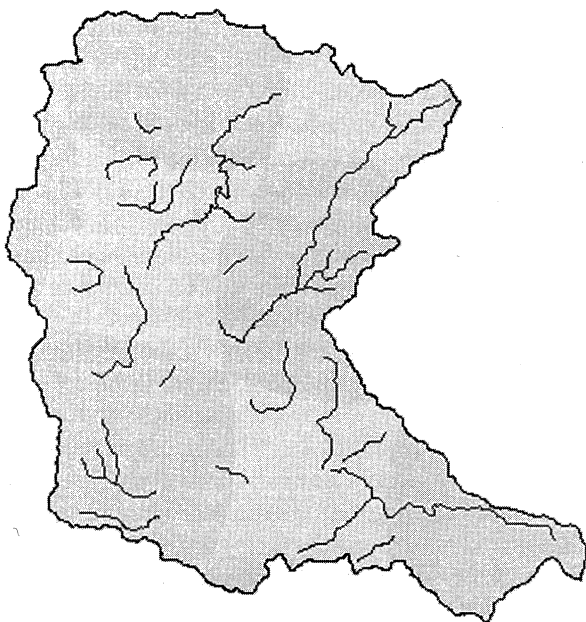


Figure 1.16 Graphic image.

TABLE 1.2 Common Types of Graphic Image Output Files

File Extension	Description
bmp	Windows® bitmap format
cdr	Corel Draw® format
cgm	Computer graphics metafile format
dxf	AutoCad® digital exchange file format
eps	Encapsulated PostScript format
gif	Graphics interchange format
jpg	JPEG file interchange format
pct	Macintosh® PICT format
pcx	PC paintbrush format
png	Portable network graphics format
tga	Targa format
tif	Tagged image file format
wmf	Windows® metafile format
wpg	WordPerfect® graphics format

developing a map of habitat quality for the spotted owl (*Strix occidentalis*) may provide an interesting and compelling view of a landscape, decision makers might also be interested in how much land of higher-quality habitat exists. Or as alternative riparian management policies are evaluated, the effect (e.g., the area or timber volume within the riparian management areas) will likely be of interest to decision makers. Tabular data from GIS analyses can be displayed directly on a map or drawn together into an independent table for incorporation within a report.

GIS SOFTWARE PROGRAMS

Many GIS software programs are available to natural resource management organizations. The comments provided in this section are general; however, a list of the common GIS software programs available is provided in Appendix C.

GIS software programs are categorized in a number of ways. One categorization is based on which of the two common data structures (raster or vector) is accommodated. Raster and vector data structures are discussed in more depth in chapter 2. GIS software programs have also been categorized by the operating system used. For example, GIS software programs developed for UNIX[®] workstations were once considered “workstation GIS software,” and GIS software programs developed for PCs were considered “PC GIS software.” This distinction has essentially faded away as workstation GIS software is now used on computers using both UNIX[®] and Windows[®] operating systems. A contemporary distinction among GIS software programs has emerged that also makes use of the term *workstation* and contrasts it with *desktop* systems. In this categorization, workstation GIS software programs are those that include the full range of GIS processes that allow one to create, edit, and analyze spatial data. Examples of full-featured workstation GIS software programs include ArcInfo and MGE Microstation. Desktop GIS software programs are thought to be scaled-down versions of workstation GIS software programs, possessing a portion of the tools or GIS processes found in full-featured workstation GIS software programs. Examples of desktop GIS software programs include ArcView, MapInfo, and GeoMedia. A primary distinction between workstation and desktop GIS programs (besides their associated cost) has been the ability to ensure that spatial relationships between locations described in GIS databases (the topology) remain true or correct. Some desktop GIS software programs are limited in their ability to maintain topological relationships without the use (and purchase) of additional software modules.

In choosing a GIS software program, purchasers need to consider the price, the GIS databases to be

managed, and the flexibility of the software to perform the likely analyses required to support management decisions. The price for most GIS software programs ranges from \$500 for a raster-based desktop GIS software program to well over \$15,000 for a full-featured workstation GIS software program. The types of **spatial databases** that are accessible by a GIS software program should be evaluated carefully. For example, if raster GIS databases will be primarily used, perhaps a raster-based GIS software program is more appropriate, as opposed to a GIS software program that focuses on the development and maintenance of vector GIS databases. Finally, a consideration of the types of GIS processes likely to be performed is important in making an informed decision regarding the purchase of a GIS software program. For example, GIS users may need to geo-reference, interpret, and classify satellite imagery, may need to create vector GIS databases (e.g., roads or streams) from measurements collected during field data collection processes, or may need to perform watershed delineation and analysis processes with a DEM.

If, after pondering these issues, the choice of a GIS software program remains unclear, perhaps choosing a GIS software program that seems to be able to expand with the needs of the organization will be preferred. Increasingly, GIS software programs are being designed in a modular manner. This design process allows users to purchase separate software modules that are intended to work with a base GIS program. Users then purchase the base GIS program and only those modules that they deem necessary.

Maintenance charges are also becoming more typical for GIS software programs and are an often overlooked budget item for natural resource management organizations. Users can either purchase annual maintenance support for a GIS software program or pay for technical support as issues arise. An annual fee is easier to predict and include in a budget, yet a per-incident fee may, in sum, result in a lower total cost (depending on the amount of support a user needs). For some GIS software programs, maintenance fees cover product upgrades; thus, as new versions of a GIS software program are released, they may be available at no additional cost to those with annual maintenance agreements. As an alternative, GIS user support groups, via the Internet, are available for users with limited access to technical support from the GIS software developer. These groups can be an inexpensive and often rapid response resource for those with software and hardware difficulties.

When evaluating GIS software programs, organizations should also consider the projected longevity of the use of the software. It is expensive to implement and maintain a GIS system. Once software has been selected, and a commitment by the organization to the software has been institutionalized, changing to a

different GIS software program is difficult and expensive. Organizations may not have a choice in this matter, as there are many examples of the obsolescence of GIS software programs and the subsequent elimination of support for GIS software programs (from the software developer) as new products are developed. Orga-

nizations should consider the length of time that a GIS developer has been in business and attempt to gauge its future prospects. Some desirable qualities of GIS software programs include: have been available for at least five years, demonstrate continually growing sales, and have well-established and active user support groups.

SUMMARY

Chapter 1 described the history of GIS development, why GIS is important in natural resource management, and the wide variety of input and output devices associated with GIS. In addition, a number of issues related to the selection and purchase of GIS software programs were outlined, to stimulate discussion among those considering the development of a GIS system within a natural resource organization. The applications of GIS to natural resource management issues

vary widely among organizations; however, understanding the capabilities and potential use of GIS is essential for natural resource management professionals. The following applications are intended to provide students with a taste of the typical types of GIS requests posed to field foresters, biologists, and other professionals familiar with GIS who work in natural resource management field offices.

APPLICATIONS

- 1.1** *Developing the specifications for a GIS system.* You have been asked by the district manager of your natural resource management organization, Jane Lerner, to develop the specifications for a computer to be purchased and used for, among other things, GIS analysis and map production in a natural resource management organization field office. Use the resources available on the Internet to design a computer system that is capable of running desktop GIS software in a forestry or natural resource field office.
- What are the specifications of the computer system that you would recommend, and how much might it cost?
 - If your budget were limited to \$2,000, how might your recommendation change?
- 1.2** *Terminology.* The district manager of your natural resource management organization, Steve Smith, is unfamiliar with a number of terms related to GIS. He has heard these terms distributed freely during staff meetings and, during one of your weekly reviews, asks you to help him understand what they mean. Briefly describe for him the following:
- GIScience
 - Topology
 - Overlay analysis
- 1.3** *Characterizing GIS software systems.* Your supervisor, John Darling, has heard the terms *workstation* and *desktop* GIS software but remains confused about how they differ. Explain to him the differences between the two types of GIS software.
- 1.4** *History of GIS.* On vacation and visiting your relatives, you find that the conversation around the dinner table has turned to the types of work you perform in your role as a natural resource manager. Describe for your relatives, many of whom have never heard of GIS, the following:
- The origin of GIS
 - How GIS has evolved into its current form
- 1.5** *A question of scale.* You measure the distance between two owl nests on a 1:24,000 scale topographic map to be 6 cm. What is the actual ground distance between the nests?
- 1.6** *Scale revisited.* You have measured the distance between two campgrounds on a topographic map to be 2 cm. From a field visit, you know that the corresponding ground distance between the campgrounds is 1 km. What is the scale of the topographic map?
- 1.7** *Data input devices.* You have been hired by the Bureau of Land Management as a forestry technician. Your supervisor is aware that you have a background in GIS and asks for your input regarding the technology that can be used to develop a vegetation GIS database. Describe three options, listing their strengths and weaknesses in terms of

collecting data and developing a GIS database.

- 1.8 *Data display options.* It is Friday afternoon in a natural resource organization's field office. As you are daydreaming about the forthcoming weekend's events, your supervisor enters your office. You determine from the

ensuing conversation that your supervisor has a meeting Monday morning with a neighboring landowner to describe the management alternatives for a portion of the forest your organization manages. A few graphics that describe the alternatives under consideration would be

beneficial to the discussion, and maps are the obvious choice of output products to engage the public. However, the color plotter in your office is not working. Describe for your supervisor three other methods for examining output from GIS that might be useful for Monday's meeting.

REFERENCES

- Anderson, J. M., and E. M. Mikhail. 1998. *Surveying: Theory and practice*. 2d ed. New York: McGraw-Hill.
- Avery, T. E., and G. L. Berlin. 1992. *Fundamentals of remote sensing and airphoto interpretation*. 5th ed. New York: Macmillan.
- Burrough, P.A. 1986. *Principles of geographic information systems for land resources assessment*. Oxford, UK: Oxford University Press.
- Burrough, P. A., and R. A. McDonnell. 1998. *Principles of geographical information systems*. Oxford, UK: Oxford University Press.
- Clarke, K. C. 2001. Getting started with geographic information systems. 3d ed. Englewood Cliffs, NJ: Prentice Hall.
- de Steiguer, J. E., and R. H. Giles. 1981. Introduction to computerized land-information systems. *Journal of Forestry* 79:734–37.
- Goodchild, M. F. 1992. Geographical information science. *International Journal of Geographical Information Systems* 6(1):31–45.
- Kavanagh, B. F., and S. J. Glenn Bird. 2000. *Surveying: Principles and practices*. 5th ed. Englewood Cliffs, NJ: Prentice Hall.
- Longley, P. A., M. F. Goodchild, D. J. Maguire, and D. W. Rhind. 2001. *Geographic information systems and science*. New York: John Wiley and Sons.
- McHarg, I. L. 1969. *Design with nature*. New York: John Wiley and Sons.
- Oregon Department of Forestry. 1994. *Oregon forest practices rules and statutes*. Salem: Oregon Department of Forestry.
- Peucker, T. K., and N. Chrisman. 1975. Cartographic data structures. *American Cartographer* 2(1):55–69.
- Society of American Foresters. 1983. *Terminology of forest science technology practice and products*. Bethesda, MD: Society of American Foresters.
- Space Imaging, Inc. 2002. IKONOS. Space Imaging, Inc., Thornton, CO. <http://www.spaceimaging.com/products/ikonos/index.htm> (accessed 1/8/03).
- Steinitz, C., P. Parker, and L. Jordan. 1976. Hand-drawn overlays: Their history and prospective uses. *Landscape Architecture* 66(5):444–55.
- Van Sickle, J. 2001. *GPS for land surveyors*. 2d ed. Chelsea, MI: Ann Arbor Press.
- Wolf, P. R., and B. A. Dewitt. 2000. *Elements of photogrammetry: With applications in GIS*. 3d ed. New York: McGraw-Hill.
- Wolf, P. R., and C. D. Ghilani. 2002. *Elementary surveying: An introduction to geomatics*. 10th ed. Englewood Cliffs, NJ: Prentice Hall.