Integrated Environmental Planning
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CHAPTER 8

The Decision Support Perspective

Effective environmental planning demands continuous and reliable sources of information to assist in identifying problems, establishing priorities, and formulating plans. Without question, a primary activity of the planner involves "sensing" the planning area, taking in data on critical indicators of the regional system, analyzing that data, and applying the information derived from it in order to react appropriately to the needs of the community and its environment. A technology has emerged that supports the acquisition of data and guides its transformation from raw numbers and facts to meaningful information systems. This information technology is based on the computer and its ability to aid environmental decision-making (Lein, 1997). In this chapter the computer and its application in environmental planning will be examined. Beginning with a review of essential information technology concepts and information management, this chapter will explore the nature of computer assisted planning and role of geographic information systems in decision support.

The role of information technology

The planner's need for timely and reliable information concerning the planning area is not a recent phenomenon. As suggested by Kaiser et al. (1995), information represents a "strategic intelligence" that not only enables the planner and community to identify, understand, and deal with new and vexing situations, but to do so systematically in a manner that purposefully compiles, organizes, and analyzes data to realize how the community and its environment has changed. Throughout human history and certainly since the industrial revolution the ability to acquire this "strategic intelligence" has moved society from clay tablets to digital databases capable of moving information at near light speed almost anywhere over the globe. Although the volume of information available to us has grown substantially, the innate human capacity to process this information has remained essentially the same. Therefore, while having information is important, more critical is the ability to use this information and generate answers from it. Taking full advantage of the strategic potential of information has fostered the creation of new approaches to accelerate accessibility to information, enhance its processing and analysis, facilitate its storage and utilization, and perform these tasks quickly and reliably.

Information technology identifies the range of approaches that have been developed to assist with the gathering, storage, production, and dissemination of information in order to meet the needs of complex decision-making. To illustrate this point we can turn to the example provided by Lein (1997). Fifty years ago a planner seeking guidance regarding either the resource potential of land, its developmental constraints, or its general characteristics was unable to proceed without extensive field surveying and mapping followed by weeks of manual data preparation and analysis. At the dawn of the twenty-first century a satellite can gather quantities of data in a single pass over the planning area that can easily overload the cognitive abilities of its users and saturate the decision-making process. Consequently, there is a need to refine and simplify data and to produce information that can feed the decision-making process. However, information technology is not only important in its ability to store and refine information, but also by its ability to support those who use it by allowing information to be used in new ways. The challenge is that while information technology may be an integral part of planning, planners must to able to connect technology to the task and responsibilities of day-to-day practice (Moffat, 1990).

Connecting information technology to the planning process begins with a basic appreciation of the information carried by this technology and the processes that generate it. Each of us uses information continuously in our daily lives, assessing conditions and making decisions, yet most of us would be hard-pressed to define precisely what is meant by the terms or to describe how information is used (McCloy, 1995). Debons et al. (1988) have offered a simple way to categorize information in a way that relates to environmental planning:

- Information as a commodity – recognizes that information can possess economic value that will influence who controls and disseminates it.
- Information as communication – describing the condition where the exchange of information transfers understanding and meaning.
- Information as fact – explaining the general state where data devoid of context conveys no relevant meaning.
- Information as data – identifies the product of symbols organized according to established rules and conventions.
- Information as knowledge – underscores the intellectual capability to take information and with it extrapolate beyond simple facts and data to draw meaningful conclusions.

From these contrasting definitions, we can see that the term "information" can be applied to a wide range of cognitive states that suggest a range of differing functional roles. A technology dedicated to the management of information must therefore preserve critical aspects of these conditions, particularly if information is to remain useful and maintain its relevance as a resource to those who rely on it (Lein, 1997). In a slightly different context, we can also describe information as a progressive entity that begins with data and is sequentially transformed into more meaningful states of "being." Each of these states carries the implicit assumption that transformation enhances knowledge and understanding of the problem. Expressed in this way, information is one stage in the continuum that starts with data and ends with knowledge (Fig. 8.1). An information technology that "manages" information must also mirror aspects of this continuum, connecting the purely data-driven processes of information access and flow to the highly cognitive activities that envelop knowledge and wisdom (Lein, 1997).

From data to information

For the purposes of environmental planning, we may define data as the raw (unrefined or processed) observations about objects, events, or surfaces that comprise the planning area. This notion introduces the "layer cake" model as a means of conceptualizing the planning area as a series of data planes each conveying a specific theme of relevance to the planning. While such data may, at times, be used directly as information, to be useful this data must be refined or pro-

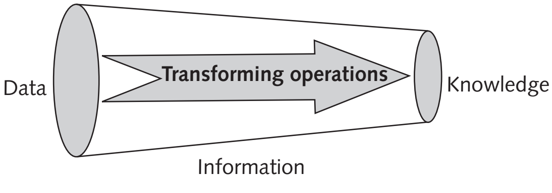


Fig. 8.1 Translating data into knowledge.

cessed in some way to make it more useful for problem-solving.

The rationale for processing data in order to create information has been summarized by McCloy and includes two important ideas. First, data pertaining to the physical attributes of the environment may be related to, but usually does not constitute the actual parameters, required by the planner. Secondly, data may be far too detailed or complex to use in its present form. Therefore, by transforming data into information, the "knowledge base" needed to guide planning decisions is created. Information technology functions to facilitate data transformation and analysis and specifically addresses procedures related to:

- Generalizing from data.
- Estimating physical parameters through data transforms.
- Filtering data to identify trends and anomalies.
- Modeling relationships in data over time and space.

Through the application of these procedures information is derived that can serve as the building blocks of a solution. Therefore, to have value, information must either enable decisions or facilitate subsequent actions by the environmental planner.

Information technology is a term loosely applied to any automated system that enhances the value of information. Generally, these technologies orbit around the nucleus of a data–information–knowledge approach to environmental planning, and define techniques instrumental to the task of representing data, information, or knowledge with an inherently geographic component. Although the techniques that form an information technology will change according to the pace of change of technology in general, their role remains constant: to support the needs of the decision-making process.

Planning and decision support

The concept of computer-aided decision support was discussed nearly two decades ago by Langendorf (1985). The basic idea then, as now, involves the design of computer systems that can support and automate critical aspects of the decision-making process. Although a simple definition of this concept has yet to be produced, a decision support system targets situations where the planner is forced to confront problems that are poorly structured or ill-defined. Problems of this variety are typically unique in the sense that they display characteristics that are highly variable, complex, and contain a high level of uncertainty. Examples might include problems encountered when conducting environmental impact studies, risk assessments, or other activities where there are a lot of different factors to consider and nothing is absolutely clear. As a consequence, unstructured problems cannot be addressed using standard operating procedures. Rather, the planner when presented with an unstructured problem relies heavily on intuition, judgment, prior knowledge, and adaptive problem-solving behavior to compensate for the extremes of uncertainty that punctuate the situation. Like the examples of environmental risk and hazard assessment, facility siting, or environmental impact assessment, there is a need to help focus judgment, support intuition, apply prior knowledge, and create an environment where adaptive strategies can be directed toward defining, analyzing, and evaluating problems. Developing an automated system to support decision-making involves the identification of tools that can supply timely and accurate information to improve the decision-making process. Therefore, the motivating force behind the concept of decision support and the development of technologies designed to aid the planning process is essentially the goal of helping planners make better decisions.

"Decisioning" and geographic information systems

Developing technologies to support decision-making begins by taking the decision-making process apart to reveal its fundamental structure. For the purposes of planning support, we can simplify the decision-making process by reducing it to its three root components:

1. Acquiring, retrieving, and selecting relevant information.

2 Structuring the decision problem to enhance the visibility of alternatives.
3 Evaluating alternatives based on their relative attractiveness.

Accepting the premise that decision-making can be reduced to these basic activities, decision support becomes a methodology that can be developed and applied to each task (Vlek et al., 1993). In this context decision support becomes a means to channel and direct the planner's cognitive processes in order to reduce uncertainty. Given the realization that most of us are limited and selective information processors capable of making simple, adaptive decisions, but poor at making complex, strategic decisions, the role of decision support becomes clear: to overcome cognitive limitations and extend the decision-maker's informal reasoning and evaluative capacities.

Understanding the types of problems where decision support can be applied is critical not only to the design of decision support systems, but also to their effective use. Five categories of problems arranged according to their relative level of difficulty have been presented by Davis (1988) (Table 8.1). In general, decision support is most effective when the problem is complex or ill-defined. Examples of such problems include situations where:

1 Objectives are difficult to determine or are conflicting.
2 Alternative actions that might be taken are difficult to identify.
3 The effect of an alternative on a given outcome (result) is uncertain.

In these instances decision support is targeted at the "structurable" part of the problem. This focus paves the way for the design of "tools" to assist problem structuring.

Automated decision support defines a computerized system that incorporates functionality to collect information, formulate problems, and perform analysis to help decision-makers address situations that are ill-structured. As shown previously by Lein (1997), information collection in a decision support system involves the process of gathering data and information from the user of the system and from a repository of pertinent data. Typically this takes the form of a database. Problem recognition describes the process of refining the initial definition of the problem through a variety of data visualization techniques, data exploration tools, and models that can be embedded in the system. Analysis undertaken using an automated decision support system can mean many different things. For the most part, analysis suggests the application of specialized tools or routines to connect the collected data with "models" that aid prediction or explanation. Based on these characteristics, it can be seen that decision support systems are specifically oriented toward the types of information-processing needs demanded by the decision-making process. Thus, armed with an automated support environment, the environmental planner can manipulate large volumes of data, perform complicated computations, and investigate relationships in data that might otherwise go unnoticed. This has become the role of a geographic information system (Fig. 8.2).

Table 8.1 Levels of decision problem.

Problem type	Description
Type O	Mechanistic, non-thought-provoking problem with few alternatives.
Type A	Slightly more complex with more alternatives to consider; automation helps illuminate problem.
Type B	Requires "brute force" techniques to find best course of action, since number of objectives and possible choices are large.
Type C	Problems where the structural complexity and sheer size of the problem reduce ease of problem visualization.
Type D	Dynamic and extremely complex problems that support only a qualitative "hit or miss" approach.

A geographic information system (GIS) can be defined in several ways (Maguire, 1991). Three common views of this critical information technology include:

1 Toolbox-based definitions that characterize GIS as a powerful set of tools for collecting, storing, and retrieving geographically referenced data, and transforming and displaying that data to reveal new patterns

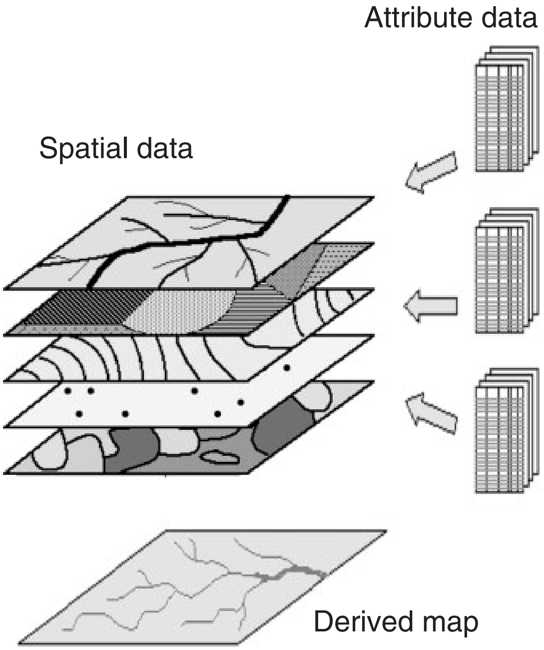


Fig. 8.2 Spatial data representation via GIS.

based on real world relationships (Burrough, 1986).

2 Database definitions that explain GIS as a database system in which most of the data is spatially indexed and upon which a set of procedures operate to answer queries about geographic entities in the database (Smith et al., 1987).

3 Organization-based definitions that describe GIS as a decision support system involving the integration of spatially referenced data in a problem-solving environment (Cowen, 1988).

Still others consider GIS a paradigm consisting of a collection of information technologies and procedures for gathering, storing, manipulating, analyzing, and presenting geographic data and information (Huxhold & Levinsohn, 1994). Although these descriptions of GIS are useful because they help us place the technology into a "problem" context, when a GIS exists in an operational setting, such as a planning department or governmental agency, we can consider GIS from an entirely different perspective.

Removing GIS from direct consideration of the software systems and hardware environments that most commentators dwell upon when discussing this technology, and focusing instead on how GIS functions within the context of decision-making, allows an alternative explanation of GIS to emerge. This considered view recasts GIS less as a technology and more as a methodology. The methodological perspective carries important implications to environmental planning and other disciplines that incorporate GIS in their day-to-day operations. As a methodology GIS represents a form of "geographic" thinking that influences how problems are conceptualized, how data is organized, how information is generated, and how knowledge is applied. Because the central feature of this methodology is its geographic focus, the manner by which spatial information supports discourse and decisions regarding population, economic, land-use, environmental, and other patterns that constitute the planning area takes precedence in formulating and analyzing planning problems. For example, if we consider the suitability assessment problem introduced in Chapter 5, applying GIS would allow the planner to identify the objectives of the problem carefully by permiting a visual examination of the factors involved, assembling the data in a "model" that could be used to create an expression of suitability, and perform an analysis that could be displayed effectively in the form of a map (Figs. 8.3a and 8.3b).

Therefore, using GIS to guide planning builds critical knowledge and support into the process by

- Describing the history and current status of critical planning variables.
- Forecasting their future status.
- Monitoring, mapping, and interpreting how these variables change.
- Diagnosing and planning, and development problems.
- Modeling critical relationships and impacts.
- Presenting information to policy-makers and the public.

GIS methodology capitalizes on representing problems and revealing solutions in a highly visual way. Examples include maps, charts,

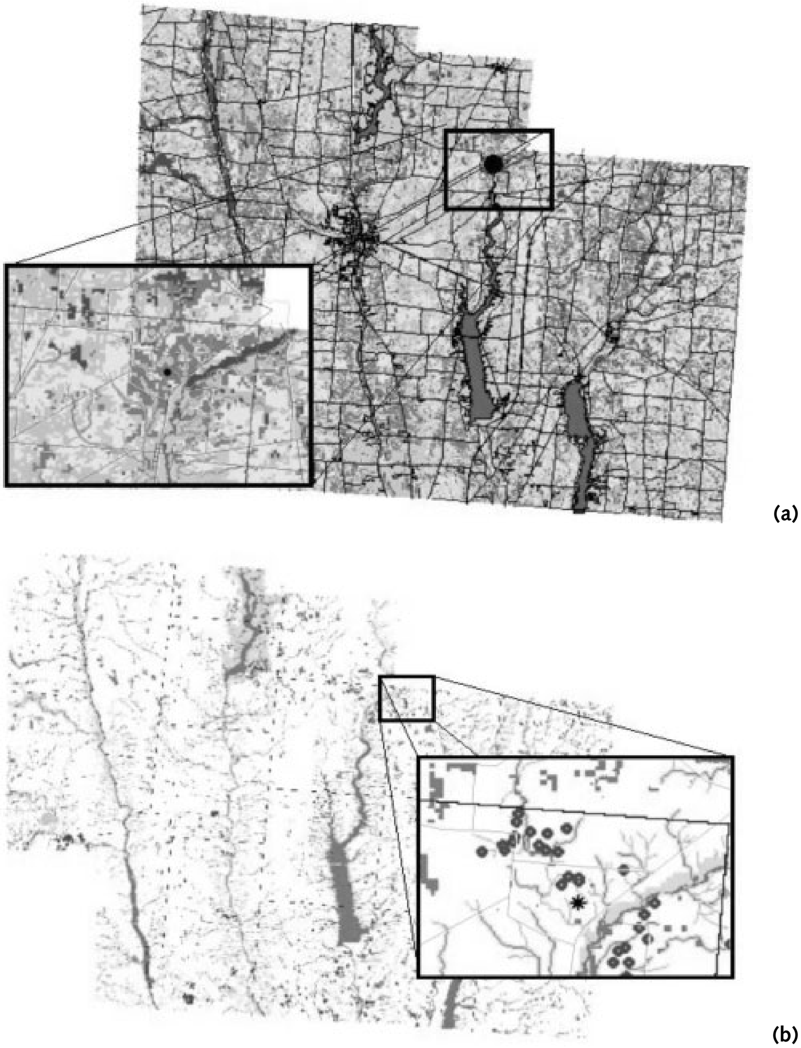
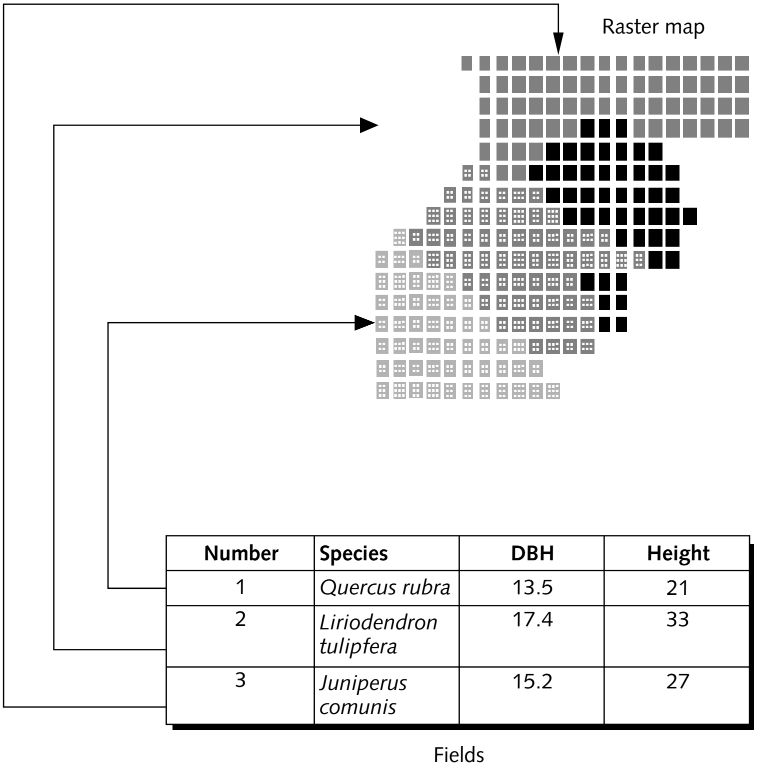


Fig. 8.3 (a) GIS-derived developmental suitability map. (b) GIS-derived critical resource map.

diagrams, and other illustrations that permit the geographic nature of most planning problems to be visualized and examined (Fig. 8.4).

Placed into a problem-solving or policy-making role, GIS displays simplify and abstract information, conveying that information more effectively than numerical tables or written narratives. Display also offers the chance to create alternative views of information that give new insight into the spatial and contextual features of the planning area. A geographic information system has a unique but under-utilized ability to examine data and reveal associations or correlations among factors that are inherently geographic (O'Looney, 1997). This ability to "see" spatial associations gives the planner that opportunity to define problems in new ways and analyze multiple spatial data-sets. Users of GIS can pose questions via the system and operate on data. Such questions can then be taken to the next level and placed within a future context. These "what if" questions become a useful way to explore the spatial footprint created by various planning alternatives. Here, GIS can be envisioned as a conduit that not only provides a means to organize and access spatially referenced data, but also as a platform that



Number	Species	DBH	Height
1	*Quercus rubra*	13.5	21
2	*Liriodendron tulipfera*	17.4	33
3	*Juniperus comunis*	15.2	27

Fig. 8.4 Fundamental GIS data model.

encourages cross-disciplinary thinking and information sharing. In professional disciplines such as environmental planning, the "common ground" GIS provides encourages broader solutions to complex problems that allow specialists in transportation, civil engineering, geology, sociology, and others to interact. Yet, as with any applied methodology, credible answers derived from a GIS depend upon

- The integrity of the user.
- The skill of the user.
- The integrity of the data and methods used.
- Compatibility among the data sources that are being integrated into the analysis.

Developing GIS capabilities that facilitate environmental planning efforts draws on the functional capabilities of this technology. Common functions that GIS performs are illustrated in Figs. 8.5a and 8.5b and include map overlay, buffering, and specialized operations such as viewshed analysis, surface analysis, and short path analysis. By carefully considering these functional capabilities, the net benefits of GIS can be realized (Table 8.2). When these general benefits are examined in relation to the goals of environmental planning, the greatest potential for GIS lies in its ability to integrate key public values in weighing solutions to community problems (O'Looney, 1997).

Table 8.2 General benefits of GIS.

Improved quality of information
Improved timeliness of information
Enhanced information flow
Increased productivity
Reduced costs
Improved decision-making

From a local government perspective this suggests that GIS applications are driven by a deep concern for:

- Efficiency – explaining the relation between the amount of effort and the amount of return.

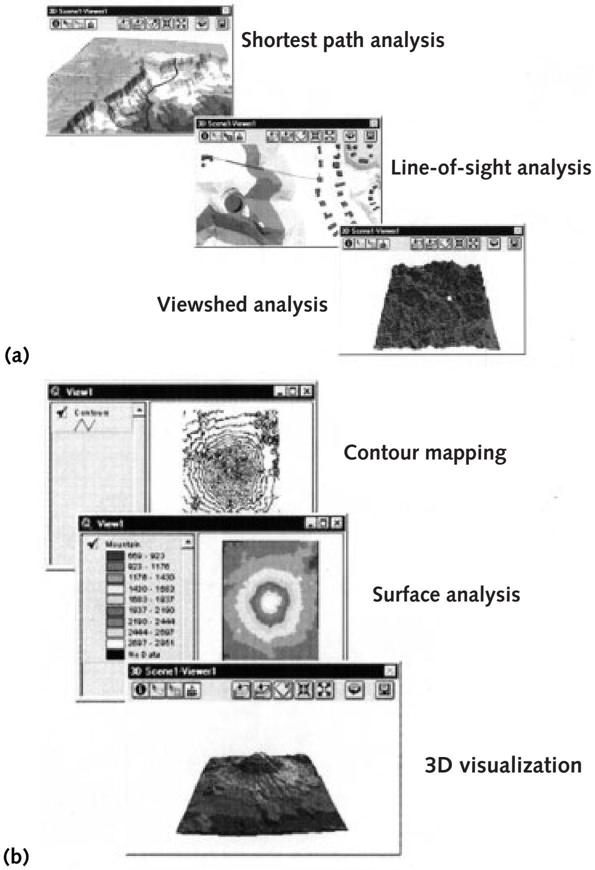


Fig. 8.5 (a) Common GIS functions: shortest path, line of site, and viewshed analysis. (b) Common GIS functions: contour mapping, surface Analysis, and visualization.

- Equity – describing the relationship between a citizen's status or effort and the social benefits they receive.
- Community viability – defining characteristics such as civic participation, cultural institutions, and activities central to a working social order.
- Environmental quality – identifying qualities of the ecosystem that provide for the long-term maintenance of life.

The manner in which GIS is used to balance these concerns has been reviewed in detail by O'Looney (1997). Overall, the success of GIS is highly dependent upon the factors that contribute to its satisfactory implementation. With respect to environmental planning, successful implementation is guided by the attention given to:

- System design and purpose.
- Data acquisition and database development.
- Analytic functionality and error management.
- Long-term management, maintenance, and modification.

Although our principal interest in this discussion is the realization of GIS as a problem-solving methodology, to understand how this method can be applied and to appreciate the significance of GIS design and implementation, a review of the fundamental components of a system must be entertained.

GIS design for environmental decision support

Geographic information systems have three important components: (1) the physical GIS comprised of computer hardware; (2) the functional GIS – consisting of sets of application software models; and (3) the organizational GIS – describing the decision-making environment in which GIS is implemented (Fig. 8.6). Each of these parts is equally important and needs to be balanced if the total system is to function according to the philosophy that encouraged its creation and design (Burrough & McDonnell, 1998).

The physical GIS

The hardware environment of the GIS describes the computer system and the related peripheral devices required to input, process, and output geographic information. While the hardware component of the GIS is extremely dynamic, with advances in computer technology introducing new capabilities in rapid succession, several devices are common:

1 **Data input devices** – such as digitizers or scanning systems that enable geographic information to be captured from its analog form as a map and recorded as digital data in the computer.

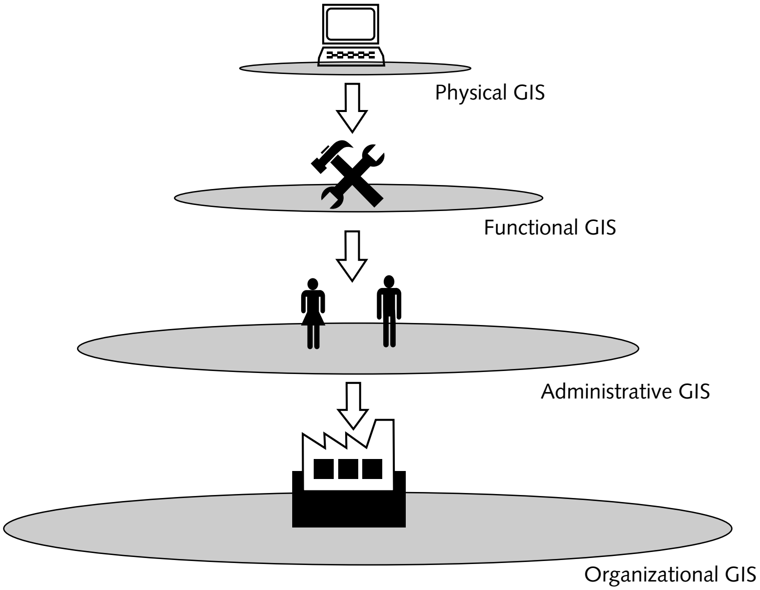


Fig. 8.6 The levels of GIS.

2 **Output devices** – such as printers, plotters, or film recorders that provide hardcopy products of the results generated by GIS analysis.
3 **Storage devices** – such as fixed disks, floppy disks, CD-roms, or tape systems that permit digital geographic data to be written and organized into files.

The functional GIS

The software component of GIS characterizes its functionality. The functional qualities of GIS can be divided into five main categories:

1 **Data input and verification** – describing a collection of software routines that guide and manage the capture of geographic information and their conversion to a standard digital form.
2 **Data storage and management** – involves the database management system that implements a specific spatial data storage paradigm (raster, vector, quadtree) and the functionality needed to control, organize, and update this database.
3 **Data output and presentation** – explains the various routines that direct the creation and display of maps, reports, and other results generated from an analysis. In a GIS information may be presented in a variety of ways including transfer to print of plotting devices and well as the direct conversion to numerous graphic file formats (gif, jpg, tif).
4 **Data manipulation and transformation** – functionality in a GIS related to this class of operations explains a set of routines that guide the removal of error and subsequent updating of data together with routines designed to perform geographic analysis. The analytical toolbox of the GIS can be rich with routines that perform data modeling, measurement, logical retrieval, and logical combination. Sets of common analytical requirements that typify GIS functionality are given in Table 8.3.
5 **User interface** – recognizing the application-specific nature of GIS, most systems provide some ability to customize and enhance how the user of the GIS interacts with the software environment. Presently most systems operate using a command language interpreter or by means of a graphical user interface (GUI). With either mode of interface, systems can be expanded functionally through the use of

Table 8.3 Typical GIS functionality.

Maintenance and analysis, spatial data	Format transformations Geometric transformations Map projections/transformations Conflation Edge matching Editing graphic elements Line thinning
Maintenance and analysis, attribute data	Attribute entry and editing Attribute query functions
Integrated analysis functions	Data retrieval, classification Measurement Overlay operations Neighborhood operations: • search • interpolation • regionalization Connectivity functions: • proximity • intervisibility • network • spread
Output formatting	Map annotation Text labels Symbolization

Table 8.4 Stages of GIS implementation.

Stage	**Tasks**
Needs assessment	Conduct interviews and examine current operational tasks, projects, and information products
Requirements analysis	Specify system philosophy, conceptual design; identify technical constraints
System design	Specify design requirements, determine optimal data model, craft prototype system
Outsource	Generate requests for proposals and evaluate, select vedor(s), establish benchmark tests, evaluate system performance
System construction	Develop pilot project, re-evaluate design, develop data encoding and conversion schedule, implement quality control program
Evaluation and enrichment	Re-evaluate needs, add capacity, modify design

simplified, formal programming languages. These macro-languages can be used to tailor GUI displays or link basic application commands together into a single command or command sequence.

The organizational GIS

When the five elements described above are assembled together they form a GIS platform that is then placed into an administrative setting. The administrative setting oversees the management, maintenance, and support needed to keep the GIS functioning according to its designed intent. Establishing this level of administration and specifying the goals of the system embodies the organizational setting in which GIS operates. This organizational context defines the arena where decision-making occurs and the structure in which GIS lends its support. At this level, concern is directed away from the physical and functional aspects of the system and attention is given to the overall rationale for using GIS, and the specific purpose and philosophy that define the system's "reason for being." It is typically at this level where GIS design and implementation begins.

A successful GIS is created to fulfill one or more goals of the organization that recognizes the advantages of utilizing "geographic" data to support decision-making. Rather than seeking a "magic bullet" in a single measure of evaluation, a practical solution involves a design process that incorporates all the concerns that influence GIS implementation (Chrisman, 1997). The general sequence of steps that direct this process is outlined in Table 8.4. Within this process the concept of "geographic" data stands as the central feature of design and the creation of a functional GIS. Geographic reference gives data new meaning by relating a name, value, quality, or condition to an object that can be visualized and treated as an entity that occupies real geographic space.

GIS design can be approached in either of two ways. One design path is referred to as the focused approach. Focused GIS design concentrates development around a well-defined and clearly articulated application or purpose. Typical applications that may encourage focused design include developing a GIS for hazard assessment and emergency management, transportation planning, growth management, or zoning administration. In each of these examples a relatively high-priority problem has been identified. With design directed toward a relatively high-priority problem or need, decisions concerning database design, functionality, and management are all predetermined by what is required to address the problem. An alternative design strategy is referred to as the panoramic approach. The panoramic approach to design is not focused on a single problem but instead envisions GIS in a broad context where the methods of GIS analysis can be applied to a range of applications. A GIS developed according to this strategy functions primarily as a dynamic store of data where the user community interacts with a limited functionality that can be expanded as the system matures. Panoramic design, therefore, creates an open-ended system that maintains a purposely broad view of GIS that allows the system to evolve in a modular fashion.

While the approach to design may vary, each requires a sustained commitment throughout the GIS lifecycle. That commitment develops out of a long-range problem whose solution, or some part thereof, can be obtained from the information derived from the GIS. From this point forward the specifics of design fall into place. Here designing the GIS involves addressing questions pertaining to:

1 The informational needs the system will be called upon to deliver.
2 The data needs users of the system will require in order to perform their jobs.
3 The software functionality that will be employed to deliver the required informational products.
4 The hardware capabilities needed to ensure optimal software and database performance.

With these considerations understood, design efforts can be directed toward the issues of data acquisition and the overall architecture of the database. The fundamental stages followed in developing the GIS database are identified in Table 8.5. As suggested by Table 8.5, development involves three primary tasks:

- The assessment of informational needs.
- The collection and evaluation of relevant data sources.
- The specification of a conceptual database design.

Because the “geographies” that comprise the planning area are inherently complex, they must be abstracted and structured into a spatial data model that not only serves as a formal device for representing their essential characteristics, but also provides for an efficient means of storage within the computer. This spatial data model is then translated into a data structure that is then encoded into the appropriate file format. Presently, GIS technology recognizes two principal ways of representing spatial data: (1) raster format and (2) vector format. Although it is common to convert data between these two structuring paradigms, during the design process the question of which mode to employ often raises confusion. Useful guidance has been offered to help resolve this issue (Burrough & McDonnell, 1998) (Table 8.6).

With the data acquisition and database design issues resolved, consideration can be given to the functional capabilities of the GIS and the analytic operations it will be called upon to perform. Approaching the question of functionality requires

Table 8.5 Stages in GIS database design.

Phase 1 – Information needs assessment
- conduct informational interviews
- review existing documents
- determine the planning area
- analyze information needs

Phase 2 – Data evaluation and collection
- collect pertinent data
- assess existing data coverage
- evaluate data quality

Phase 3 – Database specification
- develop data standards and classification schemas
- select optimal scale and resolution
- establish data input and update schedules
- design file/map manuscript system

Table 8.6 Comparison of raster and vector data models.

Raster	Vector
Advantages:	
Simple data structure	Good representation of entity data model
Location-specific manipulation of data	Compact data structure
Supports wide range of analysis	Explicitly described topology
Ease of modeling	Ease of coordinate transformations
Inexpensive technology	Accurate graphic representation
Disadvantages:	
Large data volumes	Complex data structure
Loss of information within cells	Analytic complexity
Crude graphic display quality	Simulation and modeling operations more difficult
Coordinate transformations difficult	

the adoption of a "toolbox" view of GIS. As a toolbox, GIS contains an array of routines or algorithms to process and manipulate spatial data. The tools needed to apply GIS in environmental planning have been critically reviewed by Kliskey (1995). In general, GIS software consists of two integrated components:

1. A core module of basic mapping and data management routines.
2. An application module that consists of a menu of geographic analysis routines.

Because the analysis of geographic patterns and associations is the driving force behind the use of GIS in environmental planning, the ability of the system to perform geographic analysis and model fundamental geographic concepts is critical. While nearly all software systems provide tools for collecting, organizing, and displaying spatial data, their ability to perform complex analytical operations on spatial data sets varies. In the majority of cases the toolbox of a GIS consists of routines that perform overlay, dilation (buffering), neighborhood operations, reclassification, query, distance operations, tabular analysis, and display. A detailed listing of common GIS functions is provided in Table 8.7.

Table 8.7 Common GIS modeling functions.

Function	Description
Area	Measures areas associated with data
Cluster	Performs cluster analysis on data set
Cover	Superimposes one layer on top of another
Distance	Measures Euclidean distance
Euler	Determines shape or form of features
Extract	Extracts values from one layer to another
Filter	Performs data smoothing
Group	Determines contiguous groups
Histogram	Computes frequency histogram
Interpol	Interpolates continuous surface from point data
Overlay	Performs Boolean combinations
Pathway	Finds shortest path through network
Reclass	Classifies layer attributes into new categories
Surface	Performs slope and aspect calculations
Trend	Conducts polynomial trend surface analysis
View	Performs intervisibility analysis

Functionality together with the database plays an important role in specifying the design of the GIS. Of equal importance, particularly with respect to the long-term success of the system, are those factors that influence management and maintenance. Since effective planning demands accurate and timely information, capitalizing on GIS as a centralized source of data required a level of management to ensure that the system performs in a manner that keeps pace with the demands placed on it. Anticipating and planning for change is central to GIS, particularly as the system becomes operational. Four maintenance tasks are ongoing features of the GIS and should be considered early in the design process:

1. Database updating.
2. Software revisions and enhancements.
3. Hardware upgrades.
4. Application refinements and expansions.

As GIS is a data-driven environment, the accuracy, fidelity, and completeness of the database will determine how well GIS lends support to planning. The planning arena, however, is dynamic, which means that any database runs the risk of losing its utility. Thus, a detailed program must be created to plan and schedule the updating and revision of the GIS database. The specifics of this plan depend heavily on factors such as:

- The rate at which new data becomes available.
- The planner's need for timely information.
- The pace of change characterizing the planning area.

The pace of change is also a determining factor with respect to GIS software. As new innovations in information technology appear, new developments in GIS software can be anticipated. A strategy is therefore needed to help focus questions pertaining to how and when to adopt software revisions, and to critically evaluate software enhancements through detailed benchmarking to avoid adding functionality that may be unnecessary, have limited utility, or fail to support the goals and purpose of the system. A similar strategy is needed to deal with the bigger problem of hardware upgrading and replacement. In general, keeping pace with technological progress involves carefully identifying the "appropriate" level of technology needed to drive the system, maintain acceptable performance standards, meet the continuing goals and objectives of the operational GIS, and provide timely support for planning. Finally, the question of application refinement can be approached. Given the likelihood that GIS when first implemented was designed for a limited number of application areas, the need will develop to broaden the methodologies imported to the system. Here, as planners discover how GIS supports analysis, existing applications may be refined, streamlined, and customized through the creation of macros and other devices that enhance productivity. Refinement can also contribute to experimentation with new problem-solving approaches tested for GIS feasibility that may lead to their eventual adoption in day-to-day practice. Integrating GIS into the planning process and capitalizing on the support capabilities it offers is examined in the following section.

GIS-guided planning support

When connected to the planning problem, GIS defines a methodology whereby the tasks and analytical needs of the planner find their solution in the combination of data and the functional capabilities of the system. Once GIS has been installed and its components implemented, the main focus of concern shifts from design and development to the issues surrounding the system's operational use. In an often-cited study undertaken by Campbell (1994), it was shown that in the UK there was a surprising under-utilization of GIS in planning agencies. Although GIS was widely applied to automate map-making, there was comparatively little use of complex spatial analysis functions. While several reasons were offered to account for this disparity in application rigor, a major factor involved the general problem of learning how to "think " with GIS.

The question of thinking with GIS moves well beyond the case-study examples of how someone else used the system to produce a land-suitability assessment, or to establish habitat regions to protect environmentally sensitive lands. Ample case studies can be found in the GIS and environmental planning literature alike; what is uncommon is discussion detailing how those results were derived (i.e., which tools were used with what data and how). When looking only at the results, GIS remains an abstraction, a "black-box" whose inner workings are just plain mysterious. Of course, nothing could be further from the truth. When one is armed with this "nuts and bolts" information, GIS can be more fully appreciated and its ability to support environmental planning better exploited.

The value of GIS as a tool for developing planning support systems is best assessed with reference to the nature of the scientific input required at various stages in the decision-making process (Webster, 1993). A useful model that identifies where GIS fits, underscoring its potentials and limitations as a planning tool, has been introduced by Webster (1993). According to this framework, thinking with GIS begins with the information needs encountered during each stage of the planning process. From problem identification, goal-setting, evaluation of alternatives, selection, implementation, and monitoring, specific scientific support needs can be expressed.

Problem identification

This initial stage in planning can be understood to involve the measurement of demand for public goods that requires the measurement of negative externalities (Webster, 1993). Measurement can focus either on the identification of current problems or the anticipation of future problems. Two forms of scientific support are essential during this stage: description, followed by prediction. Descriptive analysis draws upon spatial data as a means to display patterns of demand together with existing patterns of key public goods. Expressing patterns implies the ability to ask questions of the data and visualize the results related to landscape features such as the location and characteristics of:

- Existing infrastructure.
- Existing demand points.
- Discontinuities related to poor allocation.
- The spatial expression of recently implemented policies.

Prediction concerns questions pertaining to the quantity, structure, and location of consuming units at some future point in time. This type of forecasting requires both a store of data and the ability to organize and model that data to produce planning scenarios that can be explored via the GIS.

Goal-setting

Setting goals can be thought of as the attachment of weights to different market or social preferences. The support required to rate, rank, and weigh preferences is highly prescriptive, with GIS analysis directed toward the aggregation of individual and group attractiveness scores using some form of implied social-welfare function (Webster, 1993).

Plan generation

In addition to the need to sample various solutions and alternative interpretations, there is a need to examine the probable geographic pattern created by planning options and study their ramifications. In this context, a given solution or recommendation expressed in the plan can be viewed as a hypothesis, where testing the hypothesis requires support to search the solution space and determine the feasibility of a given alternative. Sampling the solution space is accomplished through a form of prescriptive analysis easily conducted using GIS.

Evaluation and selection

This planning phase describes the process of narrowing down a set of feasible alternatives to a single “optimal” solution. The process, while guided by expert judgment, is another example of GIS-based prescriptive analysis where weighted goals are examined and placed into a “model” that follows some form of optimization logic. The rating and weighting process used to explain landscape variables for suitability assessments is a classic example of this procedure. In general, optimization identifies a series of procedures that will either maximize some potential surface related to the weighted goals or minimize a constraint surface.

Implementation

Implementation is a management task where specific recommendations are placed into action. Here, a series of processes and outcomes follow from a set of specific directives that require descriptive, predictive, and prescriptive support to track progress, adjust strategies, and provide feedback to policy-makers. The map that accompanies the comprehensive or environmental plan and shows where things should be, or how the planning area should evolve, is an example of this type of product.

Monitoring

Keeping pace with the driving forces that continue to shape the planning area requires the "ongoing" sensing to the landscape in order to identify new problems and trends and to track the progression of the plan. Key scientific support given by GIS includes descriptive analysis and prediction. Descriptive support is required to address fundamental "where," "what," and "how many" types of questions that will recover useful information from the database on the current status of selected indicator variables. Predictive support is needed to extrapolate trends and explore the consequence of unfolding time-dependent patterns and processes.

GIS solutions build from these scientific inputs and the types of answers required in order to satisfy basic planning questions. From this point on, analysis is simply a matter of connecting the functional capabilities of the GIS to a descriptive, prescriptive, or predictive methodology. Obtaining planning solutions using GIS therefore requires a problem-solving strategy or script. Two common strategies can be followed to transform data into the information that satisfies a planning need: a top-down strategy or a bottom-up strategy (Eastman et al., 1993). With either approach the goal is to simplify analysis and reduce uncertainty to yield a useful information product.

Top-down analysis

The top-down method of GIS analysis develops from a clear and well-defined problem. Following this strategy, the problem under investigation is divided into smaller and more manageable parts. Concentrating on each individual element of the problem, each subsolution can be addressed and then their results combined at the appropriate time to produce the analytic solution to the larger question. Scripting the analysis in this manner suggests that for each subproblem a submodel is constructed whose result is an intermediate step to the larger problem. Therefore, the final expression develops from the logical combination of each submodel. To illustrate the use of this strategy consider the problem of developing an environmentally responsive zoning designation for a newly incorporated area of land. This prescriptive allocation problem can be divided into a series of subproblems based on a set of individual land uses whose suitability can be assessed with respect to the environmental constraints imposed by the site. Using GIS, important landscape variables can be examined together with the patterns of present and future infrastructure characteristic of the area. Then, on a land-use by land-use basis constraints can be identified and a potential surface can be generated to show where optimal conditions exist. Combining each of these separate models together using logical overlay techniques creates a composite profile for the area that explains a possible zoning plan. Within each zone, more detailed studies can be performed that can help determine specific developmental densities, design constraints, and other factors that can be translated into specific zoning regulations. In this example, by working on each of the smaller aspects of the problem, analysis is greatly simplified and the factors that control or influence the problem can be more easily isolated. In addition the analyst enjoys greater control over the combination of factors, their classification, and how they can be assembled to generate the solution.

Bottom-up analysis

The bottom-up strategy reflects the converse of the top-down approach. Bottom-up analysis is employed in situations where GIS is being applied in an exploratory of experimental manner. Using this approach the decision-maker begins with the smaller components of the problem or hypothesis that is being tested. Because the "big picture" may not be well understood, very little concern is given to a detailed definition of the problem. Thus, because the analyst may not know what the solution should look like, working with smaller and better-understood relationships allows a possible solution to emerge through their analytical combination. Using the GIS, facets of the problem are examined and assembled into successively larger and more complete answers based on either theory or intuition. Therefore, the GIS model builds upward toward a solution through trial and error logic. Although the bottom-up method may not be a reliable problem-solving strategy, it can prove to be useful in situations where evidence of the larger problem is uncertain or where guiding theory is absent. A good example of an environmental problem that can be approached using a bottom-up design is the question of cumulative environmental impact assessment. With respect to cumulative impact analysis the question as to how individual projects with minimal environmental significance can introduce cumulative effects that form serious adverse impacts lacks a clear and understood theory. However, taking these individual projects and aggregating their spatial pattern via GIS can gain insight into the larger question of cumulative change. Here, each smaller pattern or component builds upward to create a more comprehensive definition of the problem. Using "bottom-up" analysis, decision-makers can identify the causal processes at work and describe the geographic factors that contribute to the "big picture" of cumulative environmental change.

The decision problems to which these organizing strategies may be applied fall into four main analytical categories:

1. Single-criterion single-objective problems – here we may be dealing with the situation where one variable, such as slope, can be used to determine whether a site can support a specific type of land use.
2. Single-criterion multiobjective problems – in this case we might be able to use a factor such as slope to help illuminate several issues such as run-off, slope stability, erosion potential.
3. Multicriteria single-objective problems – these situations explain the multidimensional nature of some problems, where to form a solution it would be necessary to assemble all the variables that impart some influence. Examples might be the use of soil type, aspect, temperature, land use to explain the feasibility of reforestation efforts.
4. Multicriteria multiobjective problems – with this type of problem we find a set of controlling variables that influence or illuminate a range of problems, such as the use of demographic data to help understand key characteristics of a neighborhood.

These four classes of analysis identify the range to which GIS data may be applied and point to the methods needed to arrive at a solution. The specific GIS solution takes form as a decision rule that explains the procedures followed (required) to guide the combination of criteria taken from the database and the manner by which these data will be treated using the GIS. Thus, a decision rule will involve a particular set of operations that will be performed on the data. These operations may include setting a threshold value during a search and identifying a specific attribute, or a more complex sequence of operations that will transform, manipulate, combine, or compare data.

To the analyst/planner, decision rules become the directions that explain how a task will be conducted and which operations are needed to produce a solution. These rules or directions can be created for a variety of reasons, such as:

- The manipulation of attributes to reduce information content by grouping, isolation, classification, scaling procedures.
- The manipulation of attributes to increase the information content by ranking, evaluation, and rescaling functions.
- The combination of pairs of input values through cross-tabulation, correlation testing, principal components analysis.
- The logical combination of data through map overlay based on contributory rules, dominance rules, or interaction rules.
- The application of distance operations through buffering operations.
- The generation of surfaces through the application of neighborhood functions, statistical models, or interpolation methods.

A central feature when developing a decision rule concerns the methods used for selecting a means of "deciding." Deciding considers the overall approach that will be followed to reach a solution to the problems, and requires treatment of how the relevant data will be selected, how that selected data should be categorized, and how the data are to be logically combined. The methods for deciding can either rely on the formulation of a choice function, or a choice heuristic (Eastman et al., 1993). Choice functions are a mathematical means of comparing alternatives that employ some form of optimization that blends linear programming techniques with GIS data-processing functions. Choice heuristics define specific procedures that will be followed using GIS functionality exclusively. Because heuristics rely on tools provided within the given GIS they tend to reflect the more typical framework of GIS supported decision-making.

Formulating decision rules based on choice heuristics follows the general methodology referred to as map (cartographic) modeling (Tomlin, 1990; Berry, 1995) or map analysis (Bonham-Carter, 1994). This technique is founded upon the use of a map algebra that consists of a sequence of natural language commands or concepts that perform key data manipulation functions. With these commands mapped, data can be analyzed and a series of operations can be articulated that will create the desired derivative product. Samples of the map modeling commands common to GIS are listed in Table 8.3. With these commands, statements can be created that when followed produce a map model that depicts a geographic arrangement or relationship required by the analysis. To implement these commands effectively it is generally good practice to express the sequence of modeling operations in the form of a flow diagram

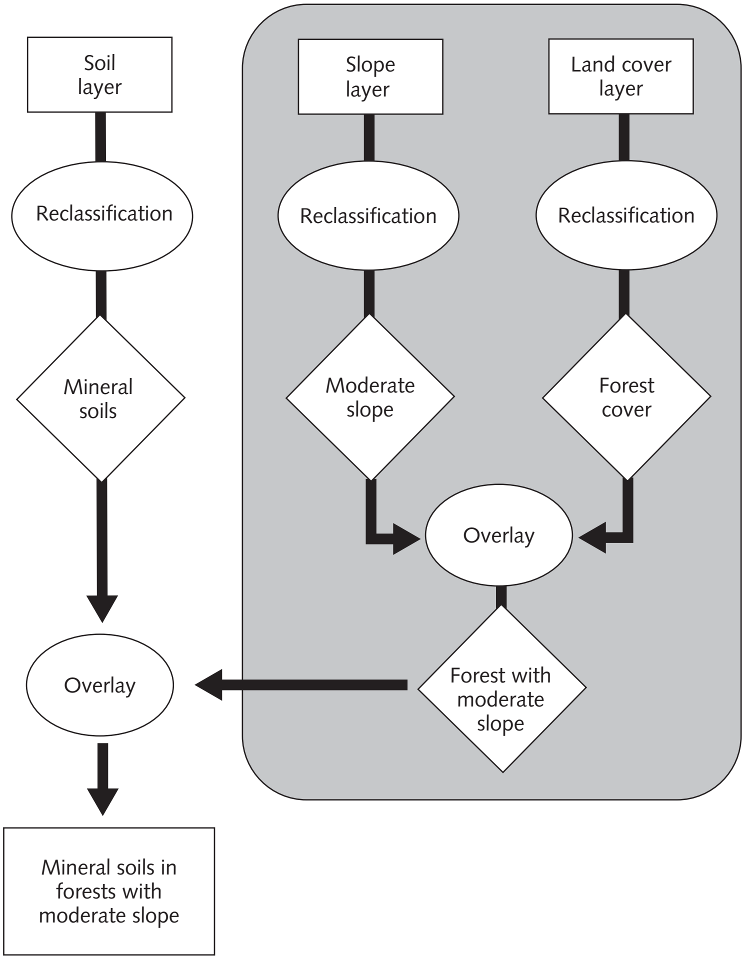


Fig. 8.7 A generalized cartographic modeling example.

(Fig. 8.7). Using this simple device, the problem can be decomposed into a number of analytical steps with the data and GIS operation specific to generating that step clearly represented. Reviewing the flow of analysis from these diagrams gives the analysis an opportunity to spot logical flaws, missing steps, or poor problem definitions prior to using the GIS. Above all, the exercise reinforces the geographic "thinking" that must precede any GIS application.

The question of error

As GIS methodologies find acceptance and wider application within the environmental planning community, the issues of data quality and the sources of error that can adversely affect the results of GIS analysis must temper their use in decision support. In the drive to solve problems, the question of spatial data quality can be easily overlooked, yet no map stored in a GIS is completely error free. As a consequence any analysis undertaken using GIS will not only provide useful information to guide planning, it will also contain error. The sources and treatment of error greatly influence the correctness of inferences drawn using the results produced from the GIS.

The possible sources of error in a GIS are numerous. Detailed discussions identifying the sources and treatment of error in a GIS can be found in Muller (1987), Veregin (1989), and Burrough and McDonnell (1998). When considering the quality of data used to address a planning problem it is important to remember that the data contained in the database has its origins in the planning area. From the field to the database the observations recorded have been measured, classified, interpreted, estimated, and encoded by many hands and under contrasting conditions. As a result it can be expected that this data contains errors to some degree. However, even after the data has been entered into the GIS, error can propagate and accumulate as it is manipulated and analyzed by the user. Although some users of GIS may be aware of error and how it propagates, in practice little attention is given to its significance.

Presently, much of the work related to error and error propagation in GIS remains at the research level. Nevertheless, the factors affecting the quality, reliability, and assumptions inherent to spatial data have been identified (Burrough & McDonnell, 1998). As suggested in Table 8.8, GIS analysis is no different from any other analytic technique, and the same caveats apply to GIS as they do with respect to statistical or numerical modeling. Error simply takes different forms. To illustrate this point consider the stages followed when developing the GIS database. When spatial data are entered into the GIS it is often accomplished by means of digitizing a map that had been originally drafted on some type of sable polyester film media. That map, regardless of the effort that went into its production, contains uncertainties that are duplicated in the GIS. As many planners, geographers, or other field scientists know from experience, carefully drawn boundaries and contour lines on maps are elegant

Table 8.8 Sources of error in GIS.

Accuracy of content:
- density of observations
- positional accuracy
- attribute accuracy
- topological accuracy
- linage

Data measurement:
- data entry faults
- data model generalization
- natural variation in the data
- observer bias
- processing error

Analysis and modeling:
- classification and generalization problems
- map overlay problems
- choice of analytic model
- flawed logic
- error propagation effects
- interpolation error

Reliability factors:
- age of the data
- areal coverage
- map scale/resolution
- relevance
- format

misrepresentations of changes that are often gradual, vague or fuzzy (Burrough & Frank, 1996).

The accuracy of mapped data placed into a GIS is typically expressed in three ways: (1) thematic accuracy which describes the correctness of the attributes characterizing the map theme, (2) positional accuracy which defines its precision with respect to some locational coordinate system, and (3) temporal accuracy explaining how representative that map and its patterns are as a function of time-dependent processes. Yet error can occur anywhere in the process from observation to presentation, including conditions such as:

- Errors in perception
- Errors in approximation
- Errors in measurement.

In addition to these listed, error can be introduced when data is stored in the computer because too little computer space was allocated to store the high-precision numbers needed to record data at a given level of accuracy. Then there are the situations where some data may be too expensive or too difficult to collect and inexact correlates are used with cheaper-to-measure attributes (Burrough & McDonnell, 1998). These realities of spatial data usually lead to the opinion that error and uncertainty is bad. Obviously it would be better if error did not exist, but that position is unrealistic. To the analyst applying GIS to address a problem, it can be extremely valuable to know how and where error and uncertainty occurs and to explore methods to manage and reduce its impact. By so doing, we can improve our understanding of geographic processes and the patterns they form.

One means of developing confidence in the data component of a GIS is through the implementation of a formal error assessment procedure (Dunn, Harrison, & White, 1990; Finn, 1993). Standard error assessment techniques are conducted by comparing attribute values in the database with values from known ground locations. This process of determining the "ground truth" is comparatively straightforward and can provide the decision-maker with an expression of error that effectively characterizes the thematic accuracy of the digital file (Lein, 1997). Positional accuracy, a more complex variable to measure, can be examined through the use of GPS samples taken systematically at selected ground control points and along major geographic features that trend through the area. These measurements can be used to verify and correct the geometry of the digital file.

The presence and propagation of error influence how the planner will utilize the support functions offered by the GIS. Thus, despite the promise of this technology, GIS is not a panacea (Aageenbrug, 1991). By adopting a more considered view of this mode of spatial data handling and analysis, the applicability of GIS and its limitations can be grounded in empirical evidence. When this occurs the benefits ascribed to GIS can be realized:

- Improved quality of information
- Improved timeliness of information
- Improved information flow
- Improved efficiency
- Improved productivity
- Improved decision-making.

Managing GIS projects

In a public-policy setting the potential uses of GIS are numerous. Worral (1991) lists several that are particularly relevant to the environmental planner:

- The more sensitive monitoring of change in demographic, social, economic, ecological, and environmental conditions.
- Developing a better understanding of the processes of change and the complex interactions between components of the region.
- The more accurate forecasting of the changing needs for publicly provided services.
- The more precise identification of spatial variations in living conditions as a basis for the development of social policy and the more precise targeting of local government resources.
- The more rigorous identification of target markets for the promotion of local services.
- More effective and responsive service planning by more accurately identifying the determinants of demand and by more expertly forecasting the changing pattern of need for

services as a basis for setting priorities in the deployment of resources.

- Improving statutory planning processes by developing the means for modeling and simulating alternative scenarios, and by developing the techniques to assess the suitability or conformance of developmental proposals in the context of statutory plans.
- Improving the policy-making process by developing more sensitive methods for the evaluation and analysis of policies and programs.

All of the above are possible provided GIS technology can be brought into local government and the entities involved can resolve the issues associated with justifying and managing GIS projects.

The management issues surrounding GIS have been discussed in detail by Huxhold (1991), and Huxhold and Levinsohn (1995). Three central themes have been identified that direct GIS management:

1 Evaluating geographic information needs – this management focus considers the importance of developing long-range GIS plans that are consistent with the goals of the organization and determining the geographic information needed to achieve those goals.
2 Maintaining organizational support – directs management to engage in cost/benefit studies to determine the economic value of GIS, and to conduct pilot projects to test various GIS design and application possibilities.
3 Managing the GIS project – considers the management problem associated with converting all mapped information to digital form and organizing resources for continued support and future expansion.

These management themes suggest that GIS is more that a software package installed onto a computer. Management concerns also imply that when placed into a policy-making setting GIS is also more than a problem-solving tool. Rather, placing GIS into the planning process institutionalizes the technology so that data, computer hardware and software, people, and procedures are available and dependable when they are needed (Huxhold & Levinsohn, 1995).

Perhaps the most critical aspect of the GIS management challenge is the development of a long-range GIS plan. This plan must relate to the long-range goals of the local government it is designed to serve. A comprehensive GIS plan analyzes the needs of the organization over a 5- to 10-year time horizon and attempts to identify how GIS will be used and avoid unrealized expectations and disappointment. For the decision-maker the plan allows for the careful evaluation of the system's applicability to the strategic and tactical plans initiated by local government. The plan also ensures that the appropriate resources will be available where and when they are required (Huxhold, 1991). To provide this capacity the long-range plan must address five critical programmatic needs:

1 Obtaining high-level support – not only does the long-range plan bring opportunities for improving government performance to the attention of decision-makers, but it also gives them confidence that those who advocate the new GIS technology are competent and can make the project succeed.
2 Identifying all potential application – a comprehensive long-range plan considers all of the geographic information needs of the organization and thus ensures that no improvement opportunities are omitted from consideration.
3 Prioritize applications for orderly implementation – if a long-range plan is successful at identifying all potential applications and is related to the strategic and tactical plans of local government, then it is possible to schedule or prioritize the implementation of applications in the order that will be most beneficial to the organization.
4 Obtain maximum benefits organization-wide – since one of the major features of a GIS is its ability to integrate information from a number of different sources, the long-range plan can identify information-sharing opportunities that had never before been realized as possible without a GIS. Separate functions that had never shared information before can realize improvements through geographic data integration.

5 Identifying resource requirements – one of the worst mistakes information specialists can make when advocating GIS is to surprise decision-makers later, after the project is well underway, with the need for additional unanticipated funds. Since decision-makers may not be familiar with GIS technology they place considerable trust in their technical staff to present a comprehensive and understandable proposal upon which funding decisions can be based. When costs escalate, the credibility of those in charge can be compromised.

A number of information-system planning methodologies have been introduced (Huxhold, 1991). These methodologies are designed to ensure that new technology will successfully support the long-term goals of the organization. Of the methods introduced, three of the more relevant to the implementation of GIS are: (1) business systems planning, (2) critical success factors, and (3) the Nolan–Norton stages theory. Each method listed above seeks to define the functions and other factors that are most important to an organization and then develop the appropriate information system strategy that offers the most beneficial support.

The most widely accepted model of computing growth in an organizational setting was advanced and refined by Nolan (1973; 1979). The model is described in detail by Huxhold and Levinsohn (1995) and serves as the GIS management centerpiece of the strategic planning process. The Nolan model uses a six-stage process to explain the growth and evaluation of computing resources in an organization.

1 Initiation – the initial stage where external technology advancements become known by users and applied to functions requiring cost containment.
2 Contagion – explaining the case where growth in applications increases significantly and users become more skilled in the technology.
3 Control – the stage of continued growth causes rising costs which attracts managements attention, and formal planning and controls are implemented.
4 Integration – as the system matures, management identifies the technology as an organization-wide resource and applications are modified to take advantage of database management capabilities.
5 Data administration – giving emphasis to shared data and systems where applications become widely integrated as a total organizational resource.
6 Maturity – the culminating stage where applications are designed to follow the flow of information through the organization, and computing technology is accepted and used as a strategic resource by users as well as managers.

Accordingly, the Nolan model assumes that the new technology enters an organization and is adopted at the user level where it becomes popular. However, different planning agencies and local governments are most likely to be in different Nolan stages; consequently, they are also likely to progress through these stages at different rates. This observation helps to explain why the adoption of GIS technology has not been more widespread than expected (Huxhold & Levinsohn, 1995).

Managing the work required during the operational phase of a GIS consists of defining projects, developing a work plan to apply resources to the projects and schedule their completion, and preparing a budget to make certain that the financial, machine, and human resources will be available to complete the project. A project can be defined as any work activity that requires GIS resources to produce an end-product of value. In general, GIS projects can be categorized as direct or indirect. Direct projects have a beginning and an end with specific time limits attached and understood. Indirect projects are less well defined, often last an entire work-year, or are very repetitive. Based on the nature of a project, a work plan will be needed to determine the resources that it will require and to facilitate accurate budgeting. Several factors are important to this work plan, including:

- An estimate of how many staff hours will be required to complete the project.
- An estimate of the total cost of the project

including staff time, software, hardware, and other relevant costs.

- An estimate of when the work on the project will begin and when it is scheduled to be completed.

This information is critical to the success of the GIS project management system and to effective budgeting for GIS operations. The information provided in the work plan also forces the planner to realize that GIS planning support exists within the constraints of the capital budgeting programs of local government, Thus, while GIS has demonstrated potential, there can be a gap between what is possible and what is practical when GIS is placed into day-to-day operation. Effective project planning together with a more considered view of GIS technology helps to narrow that gap.

Beyond conventional GIS

At the outset of this chapter, GIS was characterized as a dynamic and adaptive problem-solving methodology. However, the question remains as to whether GIS has been applied to its full potential, or if it alone is sufficient to provide the technical support required by the planner (Holmberg, 1994). In response to this question the concept has emerged of a planning support system that employs the best available GIS technology as its technical core, and then branches beyond GIS to incorporate IT environments that provide more specialized forms of a planning assistance. Recently, there have been several examples where GIS has been reconfigured to serve as the nucleus of a planning support system (Faust, 1995; Zhu, 1998; Shiffer, 1995; White et al., 1997; Batty, 1997). These extensions beyond conventional GIS grow out of a new dynamic between science and technology that encourages a change in the manner by which environmental information is managed and analyzed (Stafford et al., 1994). At issue is the observation that the design, implementation, and operation of information systems to support planning are inflexible. Many of the deficiencies surrounding GIS have been attributed to defects in handling, representing, visualizing, and communicating diverse forms of geographic data. Overcoming these support deficiencies has contributed to the design of hybrid systems based on advances in multimedia/hypermedia systems, knowledge-based systems, virtual environments, and web-based technologies. Although still very much in the development state, these emergent technologies are likely to redefine the concept of GIS and the reshape the future of computer-assisted planning.

Multimedia extensions

The term multimedia has been defined as the communication of information in a variety of formats including text, graphics, images, animations, video, and audio. Multimedia systems promote the use of integrated media in a highly interactive format that (1) makes digital information more directly accessible and (2) places the user of digital information in a more active role. Thus, the incorporation of multimedia capabilities in a planning support system encourages access to new data sources (images, video, sound), introduces enhanced visualization and manipulation capabilities, and fosters creation of more intuitive multimedia interfaces.

The main characteristics of multimedia systems that contribute to the design of hybrid GIS are those that influence the assimilation and presentation of information to the user:

- Nonlinear data access – multimedia designs are highly interactive and based on the principle of permitting users to move through data in a nonlinear way.
- Interactivity – interactivity is the characteristic principle of multimedia technology. Interactivity is achieved by means of hypertext where words or images can be connected with other information that can be accessed by use of pointing devices. This technique permits a very simple and immediate ability to navigate through data.
- Ease of navigation – navigation describes the user's movement through the multimedia application by means of the interactive instruments employed in the systems design. The greater the range of interactive instru-

ments, the greater and more flexible the navigation. Ideally, navigation implies that movement through the system is not rigidly structured, but as random and possible.
- Substituting speech for text – text often becomes overwhelming and difficult to comprehend fully on the computer screen. Integrating maps and images with speech can give detailed descriptions that may allow users to concentrate more on the visual interpretation of data.
- Use of animation – animation consists of giving movement to a scene or a figure on a fixed background. Such a technique can permit easier consultation of thematic maps and aerial images where animation can be used to highlight important information that might make complex phenomena easier to understand and visualize.
- Use of morphing – morphing is the method used to transform an object into another by means of animation. This technique can be instrumental in representing dynamic events and give planners a way to vary the descriptive characteristics of an object over a continuous range.

Intelligent systems and applied AI

Since the early development of computers there has been a strong interest in finding ways to make these machines smarter. Over the past decade the prospects of designing intelligent information systems based on Artificial Intelligence concepts have been explored (Lein, 1997). AI technologies, such as the expert system, can contribute to the development of decision tools that can

- Learn or understand from experience.
- Interpret ambiguous or contradictory information.
- Use reasoning strategies to solve problems.
- Respond to new situations.
- Deal with complex situations.
- Acquire and apply knowledge.

A detailed literature examining the use of expert systems in environmental planning has emerged (Hushon, 1990; Kim et al., 1990, Wright et al., 1993). Application areas that show promise for the design of intelligent systems include environmental impact analysis, developmental suitability mapping, and zoning (Lein, 1989; Geraghty, 1992; Han & Kim, 1989). However, the most promising work to date has been in the development of knowledge-based spatial decision support systems (Kirkby, 1996; Zhu, Healey, & Aspinall, 1998).

Virtual planning environments

The prospects for developing computer systems that can produce representations of a problem in the form of a mental context-model that can be experienced within the machine environment are both tremendous and challenging (Raper et al., 1998; Faust, 1995). Although true virtual geographic or planning support systems have yet to be implemented, several requirements have been identified that will be instrumental in creating true virtual systems:

1 vicarious travel
2 multimedia
3 three-dimensional modeling
4 virtual reality.

Developed with these capabilities, an interactive three-dimensional virtual reality GIS would have to deliver a very realistic representation of the planning area, provide a means to permit free movement within the selected geographic area, perform all normal GIS functions employing a three-dimensional database, and view the results from any vantage point, integrating visibility functions into the user interface. To date, creating virtual environments has proved to be difficult primarily because the data sets from which the applications are created must be collected firsthand and the software environments must be developed from scratch for each application.

Summary

In this chapter the computer and its realization as a form of planning support was examined. Key concepts from the field of decision support were explored in this context, and the role of the computer as a decision support environment was described. Decision support was discussed with an emphasis on the prospects for automating key decision problems and facilitating problem structuring when issues are ill-defined and require novel solutions. The nature of geographic information systems was a central theme in this discussion. Because GIS has become an essential part of the planner's toolbox, its design and implementation, together with its role in data analysis and communication, are key elements in supporting planning decisions. Yet GIS is not a panacea and the concerns surrounding error and its propagation where noted. The chapter concluded with a review of newly emerging information technologies that offer new capabilities to represent and study environmental planning problems.

Focusing questions

Discuss the concept of decision support with reference to planning problems that are ill-defined.

How can an understanding of the error inherent to GIS analysis influence a more considered use of this technology?

Where can decision support be applied in environmental planning?

Discuss the factors that influence GIS implementation.

How does GIS change how environmental planning is conducted?