GIS TECHNOLOGY IN ENVIRONMENTAL MANAGEMENT: a Brief History, Trends and Probable Future

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INTRODUCTION

Environmental management is inherently a spatial endeavor. Its data are particularly complex as they require two descriptors; namely the precise location of what is being described, as well as a clear description of its physical characteristics. For hundreds of years, explorers produced manually drafted maps which served to link the "*where* is *what*" descriptors. With an emphasis on accurate location of physical features, early maps helped explorers and navigators chart unexplored territory.

Today, these early attributes of maps have evolved from exploratory guides to physical space into management tools for exploring spatial relationships. This new perspective marks a turning point in the use of maps, setting the stage for a paradigm shift in environmental planning and management— from one emphasizing physical descriptions of geographic space, to one of interpreting mapped data and communicating spatially-based decision factors. What has changed is the purpose for which maps are used. Modern mapping systems provide a radically different approach to addressing complex environmental issues. An understanding of the evolutionary stages of the new technology, its current expression, and probable trends are essential for today's environmental policy-makers and administrators.

EVOLUTIONARY STAGES

Since the 1960's, the decision-making process has become increasingly quantitative, and mathematical models have become commonplace. Prior to the computerized map, most spatial analyses were severely limited by their manual processing procedures. Geographic information systems (GIS) technology provides the means for both efficient handling of voluminous data and effective spatial analysis capabilities (Carter 1989; Coppock and Rhind 1991). From this perspective, GIS is rooted in the digital nature of the computerized map.

Computer Mapping

The early 1970's saw *computer mapping* automate the map drafting process (Brown 1949;

McHarg 1969; Steinitz et. al. 1976; Berry and Ripple, 1994). The points, lines and areas defining geographic features on a map are represented as an organized set of X,Y coordinates. These data drive pen plotters that can rapidly redraw the connections at a variety of colors, scales, and projections. The map image, itself, is the focus of this automated cartography.

The pioneering work during this period established many of the underlying concepts and procedures of modern GIS technology (Abler et. al. 1971; Muehrcke and Muehrcke 1980; Cuff and Matson 1982; Robertson et. al. 1982). An obvious advantage of computer mapping is the ability to change a portion of a map and quickly redraft the entire area. Updates to resource maps, such as a forest fire burn, which previously took several days, can be done in a few hours. The less obvious advantage is the radical change in the format of mapped data— from analog inked lines on paper, to digital values stored on disk.

Spatial Database Management

During the early 1980's, the change in format and computer environment of mapped data was utilized. *Spatial database management systems* (SDBMS) were developed that linked computer mapping capabilities with traditional database management capabilities (Burrough 1987; Sheppard 1991). In these systems, identification numbers are assigned to each geographic feature, such as a timber harvest unit or wildlife management parcel. For example, a user is able to point to any location on a map and instantly retrieve information about that location. Alternatively, a user can specify a set of conditions, such as a specific vegetation and soil combination, and all locations meeting the criteria of the geographic search are displayed as a map.

During the early development of GIS, two alternative data structures for encoding maps were debated (Maffini 1987; Piwowar 1990; Pueker and Christman 1990). The *vector* data model closely mimics the manual drafting process by representing map features as a set of lines which, in turn, are stored as a series of X,Y coordinates. An alternative structure, termed *raster*, establishes an imaginary reference grid over a project area, then stores resource information for each cell in the grid. Early debates in the GIS community attempted to determine the universally best data structure. The relative advantages and disadvantages of both were viewed in a competitive manner that failed to recognize the overall strengths of a GIS approach encompassing both formats.

By the mid-1980's, the general consensus within the GIS community was that the nature of the data and the processing desired determine the appropriate data structure. This realization of the duality of mapped data structure had significant impact on geographic information systems. From one perspective, maps form sharp boundaries that are best represented as lines. Property ownership, power line right-of-ways, and road networks are examples where the lines are real and the data are certain. Other types of maps, such as soils, ground water flows, and steep slopes, are abstract characterizations of terrain conditions. The placement of lines identifying these conditions are subject to judgment, statistical analysis of field data, and broad classification of continuous spatial distributions. From this perspective, the sharp boundary implied by a line is artificial and the data itself is based on expert opinion or probabilistic estimates.

This era of rapidly increasing demand for mapped data focused attention on data availability, accuracy and standards, as well as data structure issues. Hardware vendors continued to improve digitizing equipment, with manual digitizing tablets giving way to automated scanners at many GIS facilities. A new industry for map encoding and database design emerged and a marketplace for the sales of digital map products emerged. Regional, national and international organizations began addressing the necessary standards for digital maps to insure compatibility among systems. This period saw GIS database development move from being expensed as individual project costs to a corporate investment in a comprehensive information resource.

GIS Modeling

As the technology continued its evolution, the emphasis turned from descriptive "geo-query" searches of existing databases to prescriptive analysis of mapped data. For the most part, the earlier eras of GIS concentrated on automating traditional mapping practices. If a user had to repeatedly overlay several maps on a light-table, an analogous procedure was developed within the GIS. Similarly, if repeated distance and bearing calculations were needed, systems were programmed with a mathematical solution. The result of this effort was GIS functionality that mimicked the manual procedures in a user's daily activities. The value of these systems was the savings gained by automating tedious and repetitive operations.

By the mid-1980's, the bulk of the geo-query operations were available in most GIS systems and a comprehensive theory of spatial analysis began to emerge. The dominant feature of this theory is that spatial information is represented numerically, rather than in analog fashion as inked lines on a map. These digital maps are frequently conceptualized as a set of "floating maps" with a common registration, allowing the computer to "look" down and across the stack of digital maps (Figure 1). The spatial relationships of the data can be summarized (database geo-queries) or mathematically manipulated (analytic processing). Because of the analog nature of traditional map sheets, manual analytic techniques are limited in their quantitative processing. Digital representation, on the other hand, makes a wealth of quantitative (as well as qualitative) processing possible. The application of this new modeling theory to environmental management is revolutionary. Its application takes two forms— spatial statistics and spatial analysis.

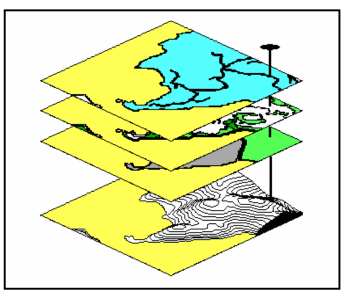


Figure 1. Conceptualization of GIS Processing. GIS processing can be conceptualized as a stack of floating maps that are geographically registered making information for any location readily accessible.

Geophysicists have used *spatial statistics* for many years to characterize the geographic distribution, or spatial pattern, of field data (Ripley 1981; Meyers 1988; Cressie 1991 and 1993; Cressie and Ver Hoef 1993). The statistics describe the spatial variation in the data, rather than assuming a typical response is everywhere. For example, field measurements of snow depth can be made at several plots within a watershed. Traditionally, these data are analyzed for a single value (the average depth) to characterize the watershed. Spatial statistics, on the other hand, uses both plot locations and the recorded measurements to generate a map of relative snow-depth throughout the entire watershed.

More recently, spatial statistics has evolved from descriptive, to predictive, to optimization models. Precision farming, for example, uses GIS modeling to investigate the spatial relationships between crop yield and soil nutrients (Berry 1996). The Global Positioning System (GPS) continuously locates a harvester in a field (Leick 1990) and, for each second, an onboard data card stores the geographic position and yield/moisture of the grain flow. The result is a yield map composed of tens of thousands of sample points throughout a field. Soil samples are analyzed for nutrient levels, such as phosphorous and potassium, then spatially interpolated into maps tracking the spatial patterns of the variations (Burgess and Webster 1980; Webster and Burgess 1980; Lam 1983). Predictive techniques from simple regression to knowledge-based modeling are used to relate the dependent (yield) and independent (nutrients) mapped variables. The derived relationship can be used to determine the optimal fertilizer rates throughout the field.

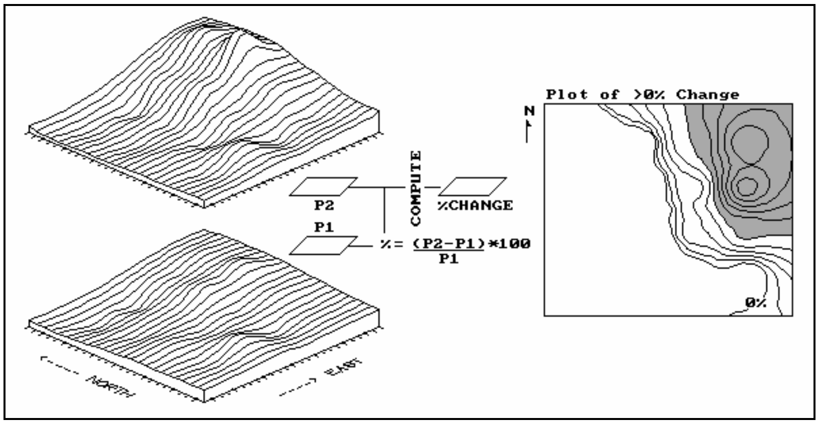
Traditional “whole-field” management involves a similar analysis, except field averages are used to derive a single application rate for the entire field. In highly variable fields, most areas receive either too much or too little fertilizer. Some farmers (encouraged by the chemical industry) hedge their bets on a good crop by applying fertilizer at a higher rate in hopes of bringing up the yield in the nutrient poor areas. The result can be over-application on more than half the field. Precision farming, on the other hand, uses “site-specific” management involving a “prescription map” derived by spatial statistics and variable rate technology. As a spray rig moves through the field, GPS locates its position on the prescription map and the injected blend of nutrients is adjusted “on-the-fly.”

Many other applications, from retail market forecasting to forest management, are using spatial statistics to relate mapped variables. The environmental sciences have a rich heritage in the quantitative expression of their systems. Spatial statistics provides a new set of tools for explaining spatially induced variance— variations in geographic space rather than numeric space. From this perspective the floating maps in Figure 1, represent the spatial distributions of mapped variables. In traditional mathematical terms, each map is a “variable, “ each location is a “case,” and each map value is a “measurement.” The GIS provides a consistent spatial registration of the numbers. The full impact of this map-ematical treatment of maps is yet to be determined. The application of such concepts as spatial correlation, statistical filters, map uncertainty and error propagation await their translation from other fields.

Spatial analysis, on the other hand, has a rapidly growing number of current resource and environmental applications (Ripple 1987; Maguire et. al. 1991a; Goodchild et. al. 1993; Ripple 1994) . For example, a forest manager can characterize timber supply by considering the relative skidding and log-hauling accessibility of harvesting parcels. Wildlife managers can consider such factors as proximity to roads and relative housing density to map human activity and incorporate this information into habitat delineation. Landscape planners can generate visual exposure maps for alternative sites for a proposed facility to sensitive viewing locations, such as recreational areas and scenic overlooks. Soil scientists can identify areas with high sediment loading potential based on proximity to streams and intervening terrain slope, vegetative cover and soil type. Similarly, groundwater and atmospheric scientists can simulate the complex movement of a release as it responses to environmental factors affecting its flow through geographic space.

Just as spatial statistics has been developed by extending concepts of conventional statistics, a mathematics supporting spatial analysis has evolved (Uwin 1981; Berry 1987a; Goodchild 1987; Ripple 1989; Johnson 1990; Maguire et. al. 1991b) . This "map algebra" uses sequential

processing of spatial operators to perform complex map analyses (Berry, 1987b; Tomlin, 1990). It is similar to traditional algebra in that primitive operations (e.g., add, subtract, exponentiate) are logically
sequenced on variables to form equations.



<u>Figure 2</u>. Percent Change Map. Algebraic equations, such as percent change, can be evaluated using entire maps as variables.

However in map algebra, entire maps composed of thousands or millions of numbers represent the variables of the spatial equation.
For example, the change in lead concentrations in an aquifer can be estimated by evaluating the algebraic expression

%change = ((new value - old value) / old value) * 100

using the average values for two time periods. Map algebra replaces the simple averages with spatially interpolated maps based on the same sets of field data used to calculate the averages. The *%change* equation is evaluated at each map location, resulting in a map percent change (Figure 2).

Areas of unusual change can be identified by the standard normal variable (SNV) expression

SNV = ((new value - %change_average) / %change_standard_deviation) * 100

This normalizes the map of changes in lead concentration, with areas of statistically unusual increase having SNV values over 100. These potentially hazardous areas can be overlaid on demographic maps to determine the level of environmental risk.

Most of the traditional mathematical capabilities, plus an extensive set of advanced map processing operations, are available in modern GIS software. You can add, subtract, multiply, divide, exponentiate, root, log, cosine, differentiate and even integrate maps. After all, maps in a GIS are just an organized sets of numbers. However, with this “map-ematics,” the spatial coincidence and juxtapositioning of values among and within maps create new operations, such as effective distance, optimal path routing, visual exposure density and landscape diversity, shape and pattern.

For example, distance is traditionally defined as "the shortest straight line between two points." Both a ruler (analog tool) and the Pythagorean theorem (mathematical tool) adhere to this strict definition. The simple definition of distance is rarely sufficient for most environmental applications. Often "…between two points" must be expanded to "…among set of points" to account for proximity, such as buffers around streams. And "…straight line" needs to be expanded to "…not necessarily straight lines," as nothing in the real world moves in a straight line (even light bends in the atmosphere). In a GIS, the concept of movement replaces distance by introducing the location of absolute and relative barriers into the calculations (Muller 1982; Elridge and Jones 1991). An effective butterfly buffer "reaches" out around a stream capturing an appropriate amount of butterfly habitat (function of vegetation cover and slope/aspect), instead of simply reaching out a fixed number of feet regardless of habitat.

Another example of advanced spatial analysis tools involves landscape analysis. The ability to quantify landscape structure is a prerequisite to the study of landscape function and change. For this reason considerable emphasis has been placed on the development of landscape metrics (Turner, 1990; McGarigal and Marks 1995). Many of these relationships are derived through analysis of the shape, pattern and arrangement of landscape elements spatially depicted as patches (individual polygons), classes of related patches (polygons of the same type/condition), and entire landscape mosaics (all polygons). The convexity index compares each patch's perimeter to its area, with an increase in perimeter per unit area indicating more irregularly shaped parcels. The mean proximity index indicates the average distance between the patches within a class as a measure of the relative dispersion. The fractal dimension of a landscape assesses the proportion of edge versus interior of all patches, summarizing whether the mosaic is primarily composed of simple shapes (circle or square like) or complex shapes with convoluted, plane-filling perimeters. These, plus a myriad of other landscape indices, can be used to track the fragmentation induced by timber harvesting and relate the changes to impacts on wildlife habitat.

This GIS modeling "toolbox" is rapidly expanding. A detailed discussion of all of the statistical and analysis tools is beyond the scope of this chapter. It suffices to note that GIS technology is not simply automating traditional environmental approaches, but radically changing environmental science. It is not just a faster mapper, nor merely an easier entry to traditional databases. Its new tools and modeling approach to environmental information combine to extend record-keeping systems and decision-making models into effective decision support systems (Parent and Church 1989; Densham 1991; Pereira and Duckstein 1993).

Spatial Reasoning and Dialogue

The 1990's are building on the cognitive basis, as well as the databases, of current geographic information systems. GIS is at a threshold that is pushing beyond mapping, management, and modeling, to *spatial reasoning and dialogue*. In the past, analysis models have focused on management options that are technically optimal— the scientific solution. Yet in reality, there is another set of perspectives that must be considered— the social solution. It is this final sieve of management alternatives that most often confounds resource and environmental decision-making. It uses elusive measures, such as human values, attitudes, beliefs, judgment, trust and understanding. These are not the usual quantitative measures amenable to computer algorithms and traditional decision-making models.

The step from technically feasible to socially acceptable options is not so much an increase in scientific and econometric modeling, as it is communication (Calkins 1991; Epstein 1991; King and Kraemer 1993; Medyckyj-Scott and Hernshaw 1993). Basic to effective communication is involvement of interested parties throughout the decision-making process. This new participatory environment has two main elements— consensus building and conflict resolution. *Consensus building* involves technically-driven communication and occurs during the alternative formulation phase. It involves the resource specialist's translation of the various considerations identified by a decision team into a spatial model. Once completed, the model is executed under a wide variety of conditions and the differences in outcome are noted.

From this perspective, a single map rendering of a environmental plan is not the objective. It is how the plan changes as the different scenarios are tried that becomes information for decision-making. "What if avoidance of visual exposure is more important than avoidance of steep slopes in siting a new haul road? Where does the proposed route change, if at all?" Answers to such analytic queries focus attention on the effects of differing perspectives. Often, seemingly divergent philosophical views result in only slightly different map views. This realization, coupled with active involvement in the decision-making process, often leads to group consensus.

If consensus is not obtained, *conflict resolution* is necessary. Such socially-driven communication occurs during the decision formulation phase. It involves the creation of a "conflicts map" which compares the outcomes from two or more competing uses. Each management parcel is assigned a numeric code describing the conflict over the location. A parcel might be identified as ideal for a wildlife preserve, a campground and a timber harvest. As these alternatives are mutually exclusive, a single use must be assigned. The assignment, however, involves a holistic perspective that simultaneously considers the assignments of all other locations in a project area.

Traditional scientific approaches are rarely effective in addressing the holistic problem of conflict resolution. Most are deterministic models, involve a succession, or cascade, of individual parcel assignments. The final result is strongly biased by the ordering of parcel consideration, mathematical assumptions and the assignment of discrete model parameters. Even if a scientific solution is reached, it is viewed with suspicion by the layperson. Modern resource information systems provide an alternative approach involving human rationalization and tradeoffs. This process involves statements like, "If you let me harvest this parcel, I will let you set aside that one as a wildlife preserve." The statement is followed by a persuasive argument and group discussion. The dialogue is far from a mathematical optimization, but often closer to an effective decision. It uses the information system to focus discussion away from broad philosophical positions, to a specific project area and its unique distribution of conditions and potential uses.

THE CURRENT FRONTIER

The elements for computer mapping and spatial database management are in place, and the supporting databases are rapidly coming on-line. The emerging concepts and procedures supporting GIS modeling and spatial reasoning/dialogue are being refined and extended by the technologists. There are a growing number of good texts (Star and Estes 1990; Berry 1993;

Korte 1993; Berry 1995b; Douglas 1995) and college courses on GIS technology are becoming part of most land-related curricula. What seems to be lacking is a new spatial paradigm among the user communities. Many are frustrated by the inherent complexity of the new technology. Others are confused by new approaches beyond those that simply automate existing procedures. Fundamental to the educational renaissance demanded by GIS is a clear understanding of the questions it can address.

Seven Basic Questions

Seven basic questions encompassing most GIS applications are identified in Table 1. The questions are progressively ordered from inventory-related (data) to analysis-related (understanding) as identified by their function and approach. The most basic question, "***Can you map that?***" is where GIS began over thirty years ago— *automated cartography*. A large proportion of GIS applications still involve the updating and timely output of map products. As an alternative to a room full of draftspersons and drafting pens, the digital map has a clear edge. Applications responding to this question are easily identified in an organization and the "payoffs" in productivity apparent. Most often, these mapping applications are restatements of current inventory-related activities.

Table 1. BASIC QUESTIONS GIS CAN ADDRESS

There are seven types of questions addressed by GIS technology. The first three are inventory-related; the latter four are analysis-related investigating the interrelationships among mapped data beyond simple spatial coincidence.

QUESTIONS FOR GIS	FUNCTION	APPROACH
1) Can you map that?	Mapping	(*Description*) DATA
2) Where is what?	Management	|
3) Where has it changed?	Temporal	|
4) What relationships exist?	Spatial	INFORMATION
5) Where is it best?	Suitability	|
6) What effects what?	System	|
7) What if...?	Simulation	UNDERSTANDING (*Prescription*)

Questions involving "***Where is what?***" exploit the linkage between the digital map and database management technology. These questions are usually restatements of current practices as well. They can get a group, however, to extend their thinking to geographic searches involving coincidence of data they had not thought possible. The nature and frequency of this type of question provide valuable insight into system design. For example, if most applications require interactive map queries based on a common database from a disperse set of offices, a centralized GIS provides consistency and control over the shared data. However, if the queries are localized and turnaround is less demanding, a distributed GIS might suffice. The conditions surrounding the first two questions are the primary determinants of the character and design of the GIS implemented in an organization. The remaining questions determine the breadth and sophistication of its applications. They also pose increasing demands on the education and computer proficiency of its users.

The third type of question, "***Where has it changed?***" involves temporal analysis. These questions mark the transition from inventory-related data searches to packaging information for generating plans and policies. Such questions usually come from managers and planners, whereas the previous types of questions support day-to-day operations. A graphic portrayal of changes in geographic space, whether it is product sales or lead concentrations in well water, affords a new perspective on existing data. The concept of "painting" data which is normally viewed as tables might initially be a bit uncomfortable— it is where GIS evolves from simply automating current practices to providing new tools.

"***What relationships exit?***" questions play heavily on the GIS toolbox of analytic operations. "Where are the steep areas?", "Can you see the proposed power plant from over there?", "How far is the town from the contamination spill?", and "Is vegetation cover more diverse here, or over there?" are a few examples of this type of question. Whereas the earlier types involved query and repackaging of base data, spatial relationship questions involve derived information. Uncovering of these questions within an organization is a bit like the eternal question— “Did the chicken or the egg come first?" If users are unaware of the different things a GIS can do differently, chances are they are not going to ask it to do anything different. Considerable training and education in spatial reasoning approaches are needed to fully develop GIS solutions to these questions. Their solution, however, is vital to the treatise of the remaining two types of questions.

Suitability models spring from questions of "***Where is it best?***" Often these questions are the end products of planning and are the direct expression of goals and objectives. The problem is that spatial considerations historically are viewed as input to the decision process— not part of the "thruput." Potential GIS users tend to specify the composition (base and derived maps) of "data sandwiches" (map layers) which adorn the walls during discussion. The idea of using GIS modeling as an active ingredient in the discussion is totally foreign. Suitability questions usually require the gentle coaxing of the “visceral visions” locked in the minds of the decision-makers. They require an articulation of various interpretations of characteristics and conditions and how they relate within the context of the decision at hand.

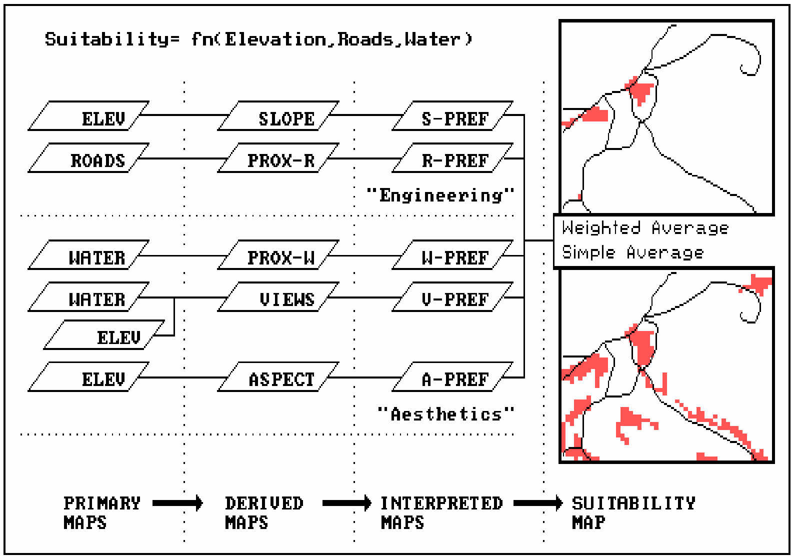
"***What effects what?***" questions involve system models— the realm of the scientist and engineer. In a manner of speaking, a system model is like an organic chemist's view of a concoction of interacting substances, whereas a suitability model is analogous to simply a recipe for a cake. Whereas suitability models tend to incorporate expert opinion, a system model usually employs the tracking of "cause and effect" through empirically derived relationships. The primary hurdle in addressing these applications is the thought that GIS simply provides spatial summaries for input and colorful maps of model output. The last 100 years have been spent developing techniques that best aggregate spatial complexity, such as stratified random sampling and the calculation of the average to represent a set of field samples. The idea that GIS modeling retains spatial specificity throughout the analysis process and responds to spatial autocorrelation of field data is a challenging one.

"***What if...?***" questions involve the iterative processing of suitability or system modeling. For suitability models, they provide an understanding of different perspectives on a project— "What if visual impact is the most important consideration, or if road access is the most important; where would it be best for development?" For system models, they provide an understanding of uncertain or special conditions— "What if there was a 2-inch rainstorm, or if the ground was saturated; would the surface runoff require a larger culvert?"

In determining what GIS can do, the first impulse is to automate current procedures. Direct translation of these procedures is sufficient for the first few types of questions. As GIS moves beyond mapping to the application modeling required addressing the latter questions, attention is increasingly focused on the considerations embedded in the derivation of the "final" map. The map itself is valuable, but the thinking behind its creation provides the real insights for decision-making. From this perspective, the model becomes even more useful than the graphic output.

GIS Modeling Approach and Structure

Consider the simple model outlined in the accompanying figure (Figure 3). It identifies the suitable areas for a residential development considering basic engineering and aesthetic factors. Like any other model it is a generalized statement, or abstraction, of the important considerations in a real-world situation. It is representative of one of the most common GIS modeling types— a suitability model. First, note that the model is depicted as a flowchart with boxes indicating maps, and lines indicating GIS processing. It is read from left to right. For example, the top line tells us that a map of elevation (ELEV) is used to derive a map of relative steepness (SLOPE), which in turn, is interpreted for slopes that are better for a campground (S-PREF).



<u>Figure 3</u>. Development Suitability Model. Flow chart of GIS processing determining the best areas for a development as gently sloped, near roads, near water, with good views of water and a westerly aspect.

Next, note that the flowchart has been subdivided into compartments by dotted horizontal and vertical lines. The horizontal lines identify separate sub-models expressing suitability criteria—

the best locations for the campground are 1) on gently sloped terrain, 2) near existing roads, 3) near flowing water, 4) with good views of water, and 5) westerly oriented. The first two criteria reflect engineering preferences, whereas the latter three identify aesthetic considerations. The criteria depicted in the flowchart are linked to a sequence of GIS commands (termed a command *macro*) which are the domain of the GIS specialist. The linkage between the flowchart and the macro is discussed latter; for now concentrate on the model's overall structure. The vertical lines indicate increasing levels of abstraction. The left-most ***primary maps*** section identifies the base maps needed for the application. In most instances, this category defines maps of physical features described through field surveys— elevation, roads and water. They are inventories of the landscape, and are accepted as fact.

The next group is termed ***derived maps***. Like primary maps, they are facts, however these descriptors are difficult to collect and encode, so the computer is used to derive them. For example, slope can be measured with an Abney hand level, but it is impractical to collect this information for all of the 2,500 quarter-hectare locations depicted in the project area. Similarly, the distance to roads can be measured by a survey crew, but it is just too difficult. Note that these first two levels of model abstraction are concrete descriptions of the landscape. The accuracy of both primary and derived maps can be empirically verified simply by taking the maps to the field and measuring.

The next two levels, however, are an entirely different matter. It is at this juncture that GIS modeling is moved from fact to judgment—from the description of the landscape (fact) to the prescription of a proposed land use (judgment). The ***interpreted maps*** are the result of assessing landscape factors in terms of an intended use. This involves assigning a relative "goodness value" to each map condition. For example, gentle slopes are preferred locations for campgrounds. However, if proposed ski trails were under consideration, steeper slopes would be preferred. It is imperative that a common goodness scale is used for all of the interpreted maps. Interpreting maps is like a professor's grading of several exams during an academic term. Each test (vis. primary or derived map) is graded. As you would expect, some students (vis. map locations) score well on a particular exam, while others receive low marks.

The final ***suitability map*** is a composite of the set of interpreted maps, similar to averaging individual test scores to form an overall semester grade. In the figure, the lower map inset identifies the best overall scores for locating a development, and is computed as the simple average of the five individual preference maps. However, what if the concern for good views (V-PREF map) was considered ten times more important in siting the campground than the other preferences? The upper map inset depicts the weighted average of the preference maps showing that the good locations, under this scenario, are severely cut back to just a few areas in the western portion of the study area. But what if gentle slopes (S-PREF map) were considered more important? Or proximity to water (W-PREF map)? Where are best locations under these scenarios? Are there any consistently good locations?

The ability to interact with the derivation of a prescriptive map is what distinguishes GIS modeling from the computer mapping and spatial database management activities of the earlier eras. Actually, there are three types of model modifications that can be made— weighting, calibration and structural. *Weighting* modifications affect the combining of the interpreted maps into an overall suitability map, as described above. *Calibration* modifications affect the assignment of the individual "goodness ratings." For example, a different set of ranges defining slope “goodness” might be assigned, and its impact on the best locations noted.

Weighting and calibration simulations are easy and straight forward— edit a model parameter then resubmit the macro and note the changes in the suitability map. Through repeated model simulation, valuable insight is gained into the spatial sensitivity of a proposed plan to the decision criteria. *Structural* modifications, on the other hand, reflect changes in model logic by introducing new criteria. They involve modifications in the structure of the flowchart and additional programming code to the command macro. For example, a group of decision-makers might decide that forested areas are better for a development than open terrain. To introduce the new criterion, a new sequence of primary, derived and interpreted maps must be added to the "aesthetics" compartment of the model reflecting the group’s preference. It is this dynamic interaction with maps and the derivation of new perspectives on a plan that characterize spatial reasoning and dialogue.

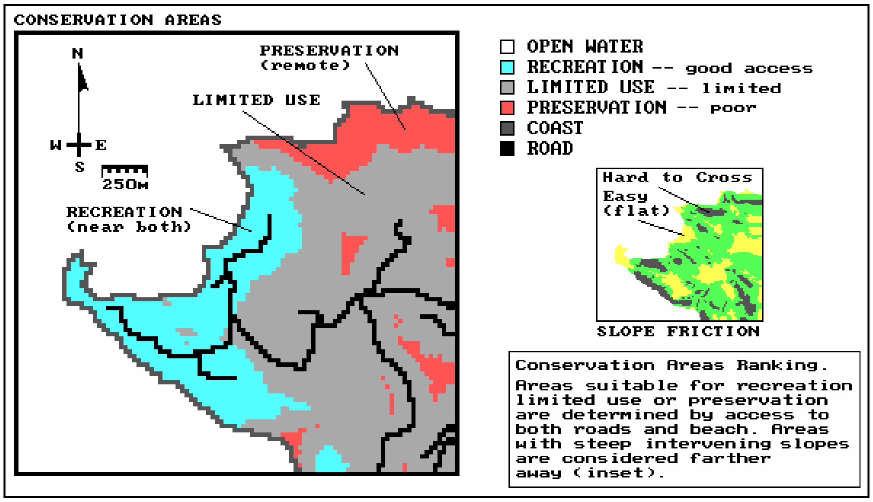
GIS IN CONCENSUS BUILDING AND CONFLICT RESOLUTION: A CASE STUDY

By their nature, all land use plans contain (or imply) a map. The issue is determining "what should go where," and as noted above there is a lot of thinking that goes into a final map recommendation (Berry and Berry 1988; Gimblett 1990). One cannot simply geo-query a database for the recommendation any more than it can arm a survey crew with a "land use-ometer" to measure the potential throughout a project area. The logic behind a land use model and its interpretation by different groups are the basic elements leading to an effective decision. During the deliberations, an individual map is merely one rendering of the thought process.

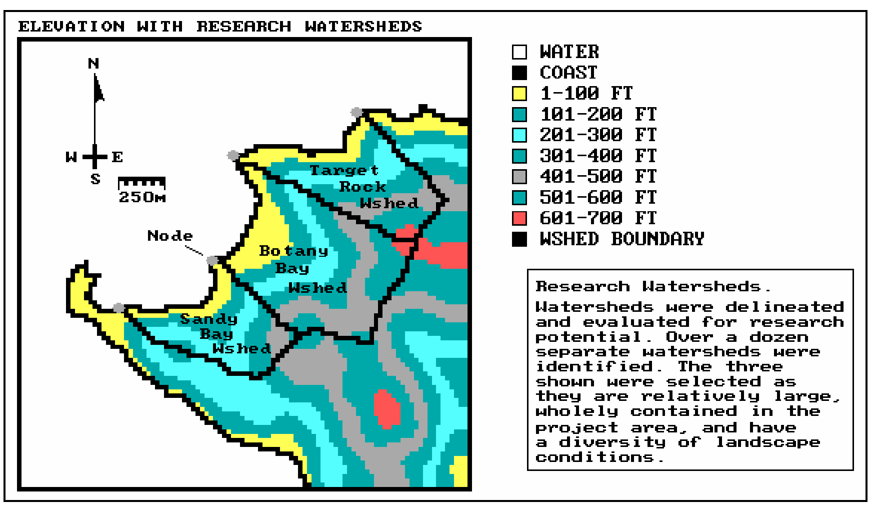
The potential of "interactive" GIS modeling extends far beyond its technical implementation. It promises to radically alter the decision-making environment itself. A "case study" might help in making this claim. The study uses three separate spatial models for allocating alternative land uses of conservation, research and residential development. In the study, GIS modeling is used in consensus building and conflict resolution to derive the "best" combination of competing uses of the landscape.

The study takes place on the western tip of Caribbean island of St. Thomas (Berry, 1991). Base maps of roads, shoreline, elevation, and current flow formed the basis of the application. Separate suitability models were developed for three alternative land uses-- conservation, research and development. The final model addressed the best allocation of land, by simultaneously considering all three potential landscape uses. The departure from "traditional" analysis is that the GISs were used in "real-time" to respond to the questions and concerns of decision-makers. In doing so, the modeling contributed to group consensus building and conflict resolution, as well as the graphic portrayal of the final plan.

A map of accessibility to existing roads and the coastline formed the basis of the *Conservation Areas Model*. In determining access, the slope of the intervening terrain is considered. The “slope-weighted proximity” from the roads and from the coastline was used. In these calculations, areas that appear geographically near a road may actually be considered inaccessible if there are steep intervening slopes. For example, the coastline might be a “stone's throw away” from the road, but if it lands at the foot of a cliff it is effectively inaccessible for recreation. The two maps of weighted proximity were combined into an overall map of accessibility. The final step of the model involved interpreting relative access into conservation uses (Figure 4). Recreation was identified for those areas near both roads and the coast. Intermediate access areas were designated for limited use, such as hiking. Areas effectively far from roads were designated as preservation areas.



<u>Figure 4.</u> Conservation Areas Map. Maps of relative accessibility to roads and the coastline formed the basis for locating various conservation uses.



<u>Figure 5.</u> Research Areas Map. Three watersheds were chosen as research areas as they are relatively large and contain a diversity of landscape characteristics.

The characterization of the *Research Areas Model* first used an elevation map to identify individual watersheds. The set of all watersheds was narrowed to just three based on scientists' preferences that they require relatively large and wholly contained areas for their research (Figure 5). A sub-model used the prevailing current to identify coastal areas influenced by each of the three terrestrial research areas.

The *Development Areas Model* determined the “best” locations for residential development. The model structure used is nearly identical to that of the development suitability model described in the section above. Engineering, aesthetic, and legal factors were considered. As before, the engineering and aesthetic considerations were treated independently, as relative rankings. An overall ranking was assigned as the weighted average of the five preference factors. Legal constraints, on the other hand, were treated as critical factors. For example, an area within the 100meter set-back was considered unacceptable, regardless of its aesthetic or engineering rankings.

Figure 6 shows a composite map containing the simple arithmetic average of the five separate preference maps used to determine development suitability. The constrained and undesirable locations are shown as white. Note that approximately half of the land area is ranked as “Acceptable” or better (gradient of darker tones). In averaging the five preference maps, all criteria were considered equally important at this step.

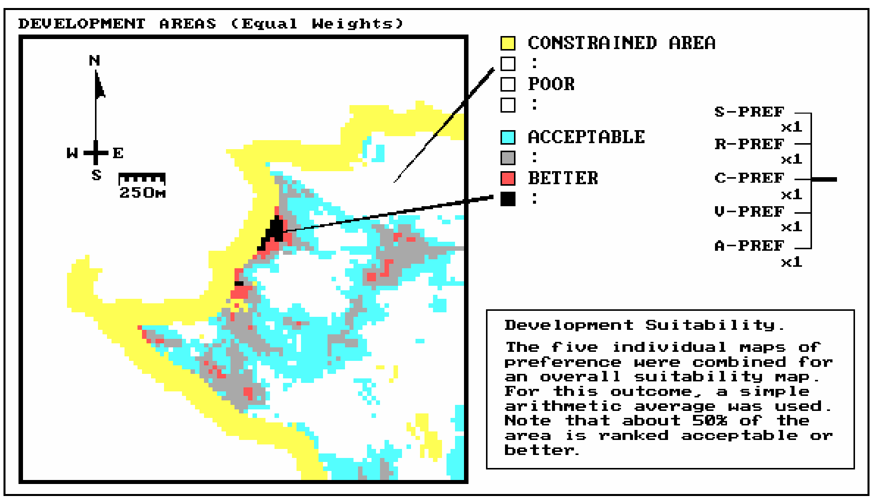
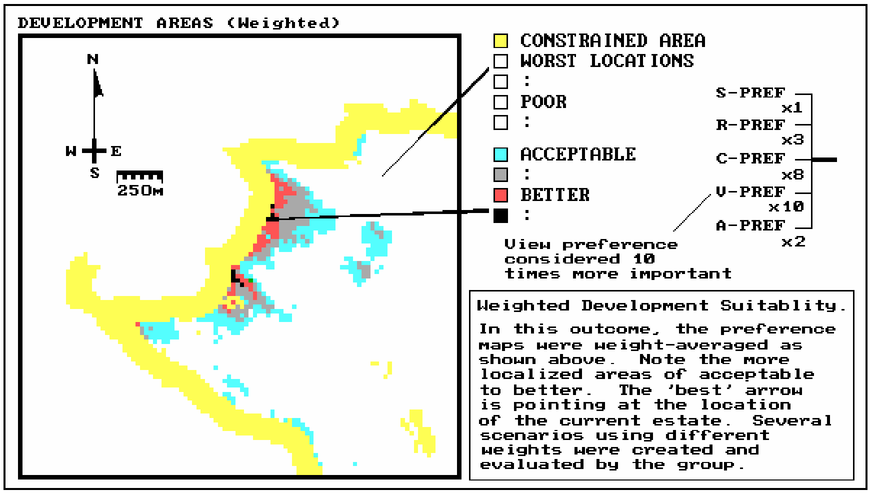


Figure 6. *Development Areas Map (Simple Average). The best areas for development were first determined through equal consideration of the five criteria.*

The analysis was extended to generate a series of weighted suitability maps. Several sets of weights were tried. The group finally decided on

- view preference times 10 (Most Important)
- coast proximity times 8
- road proximity times 3
- aspect preference times 2, and
- slope preference times 1 (Least Important).

The resulting map of the weighted averaging is presented in Figure 7. Note that a smaller portion of the land is ranked as “Acceptable” or better. Also note the spatial distribution of these prime areas are localized to distinct clusters.



<u>Figure 7.</u> Development Areas Map (Weighted Average). Weighed averaging of the maps expressing the five criteria narrowed the acceptable areas for development, reflecting the relative preferences of the group.

The group of decision-makers were actively involved in development of all three of the individual models— conservation, research and development. While looking over the shoulder of the GIS specialist, they saw their concerns translated into map images. They discussed whether their assumptions made sense. Debate surrounded the "weights and calibrations" of the models. They saw the sensitivity of each model to changes in its parameters. In short, they became involved and understood the map analysis taking place. The approach is radically different from viewing a "solution" map with just a few alternatives developed by a sequestered set of GIS specialists. It enables decision-makers to be just that— decision-makers, not choice-choosers constrained to a few pre-defined alternatives. The involvement of decision-makers in the analysis process contributes to *consensus building*. At this stage, the group reached consensus on the three independent land use possibilities.

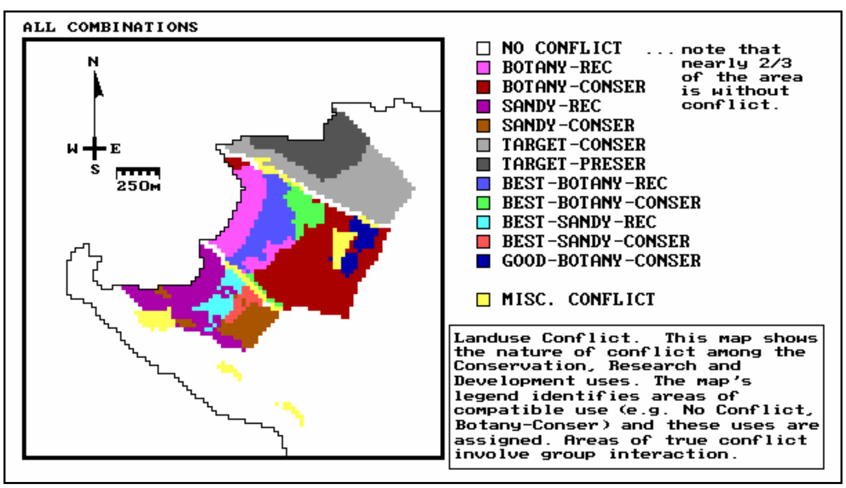
The three analyses, however, determined the best use of the project area considering the possibilities in a unilateral manner. What about areas common to two or more of the maps? These areas of conflict are where the decision-makers need to focus their attention. Three basic approaches are used in GIS-based *conflict resolution*— hierarchical dominance, compatible use and tradeoff. *Hierarchical dominance* assumes certain land uses are more important and, therefore, supersede all other potential uses. *Compatible use*, on the other hand, identifies harmonious uses and can assign more than one to a single location. *Tradeoff* recognizes mutually exclusive uses and attempts to identify the most appropriate land use for each location. Effective land use decisions involve elements of all three of these approaches.

From a map processing perspective, the hierarchical approach is easily expressed in a quantitative manner and results in a deterministic solution. Once the political system has identified a superseding use it is relatively easy to map these areas and simply assign the dominant use. Similarly, compatible use is technically easy from a map analysis context, though often difficult from a policy context. When compatible uses can be identified, both uses are assigned to all areas with the joint condition.

Most conflict, however, arises when potential uses for a location are justifiable and incompatible. In these instances, quantitative solutions to the allocation of land use are difficult, if not impossible, to implement. The complex interaction of the spatial frequency and juxtapositioning of several competing uses is still most effectively dealt with by human intervention. GIS technology assists decision-making by deriving a map that indicates the set of alternative uses vying for each location. Once in this graphic form, decision-makers can assess the patterns of conflicting uses and determine land use allocations. Also, GIS can aid in these deliberations by comparing different allocation scenarios and identifying the areas of change.

In the case study, the Hierarchical Dominance approach was tried, but resulted in total failure. At the onset, the group was uncomfortable with identifying one land use as always being better than another. However, the approach was demonstrated by identifying development as least favored, recreation next, and the researchers' favorite watershed taking final precedence. The resulting map was unanimously rejected as it contained very little area for development, and what areas were available, were scattered into disjointed parcels. It graphically illustrated that even when decision-makers are able to find agreement in “policy space,” it is frequently muddled in the complex reality of geographic space.

The alternative approaches of compatible use and tradeoff faired better. Both approaches depend on generating a map indicating all of the competing land uses for each location— a comprehensive *conflicts map*. Figure 8 is such a map considering the Conservation Areas, Research Areas and Development Areas maps. Note that most of the area is without conflict (lightest tone). In the absence of the spatial guidance in a conflicts map, the group had a tendency to assume that every square inch of the project area was in conflict. In the presence of the conflicts map, however, their attention was immediately focused on the unique patterns of actual conflict.



<u>Figure 8.</u> Conflicts Map. The Conservation Areas, Research Areas and Development Areas maps were overlaid to identify locations of conflict which are deemed best for two or more uses.

First, the areas of actual conflict were reviewed for compatibility. For example, it was suggested that research areas could support limited use hiking trails, and both activities were assigned to those locations. However, most of the conflicts were real and had to be resolved "the hard way." Figure 9 presents the group's “best” allocation of land use. Dialogue and group dynamics dominated the tradeoff process. As in all discussions, individual personalities, persuasiveness, rational arguments and facts affected the collective opinion. The easiest assignment was the recreation area in the lower portion of the figure as this use dominated the area.

The next break-through was an agreement that the top and bottom research areas should remain intact. In part, this made sense to the group as these areas had significantly less conflict than the central watershed. It was decided that all development should be contained within the central watershed. Structures would be constrained to the approximately twenty contiguous hectares identified as best for development, which was consistent with the island's policy of encouraging “cluster” development. The legally constrained area between the development cluster and the coast would be for the exclusive use of the residents.

The adjoining research areas would provide additional buffering and open space, thereby enhancing the value of the development. In fact, it was pointed out that this arrangement provided a third research setting to investigate development, with the two research watersheds serving as control. Finally, the remaining small “salt and pepper” parcels were absorbed by their surrounding 'limited or preservation use' areas.

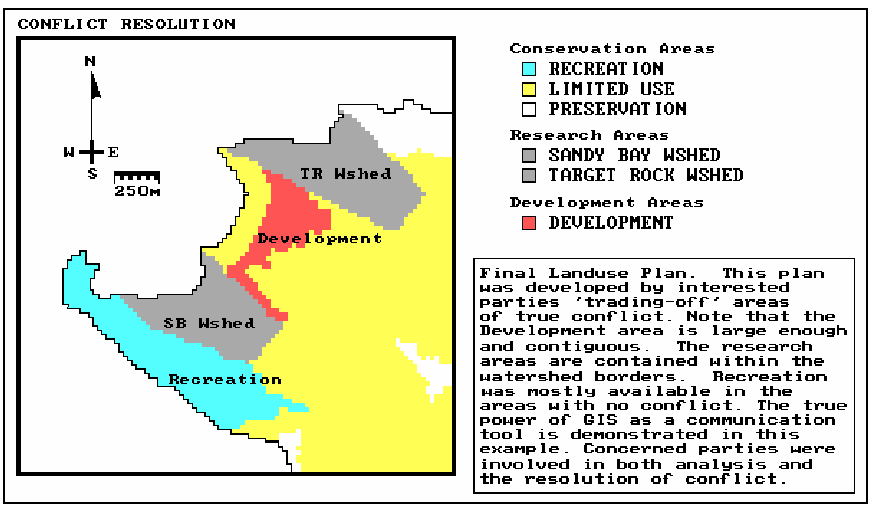


__Figure 9.__ Final Map of Land Use Recommendations. The final map was created by conflict resolution involving participatory interaction among interested parties.

In all, the group's final map is a fairly rational land use allocation, and one that is readily explained and justified. Although the decision group represented several diverse opinions, this final map achieved consensus. In addition, each person felt as though they actively participated and, by using the interactive process, better understood both the area's spatial complexity and the perspectives of others.

This last step involving human intervention and tradeoffs might seem anticlimactic to the technologist. After a great deal of rigorous GIS modeling, the final assignment of land uses involved a large amount of group dynamics and subjective judgment. This point, however, highlights the capabilities and limitations of GIS technology.

Geographic information systems provide significant advances in how we manage and analyze mapped data. It rapidly and tirelessly assembles detailed spatial information. It allows the incorporation of sophisticated and realistic interpretations of landscape factors, such as weighted proximity and visual exposure. It does not, however, provide an artificial intelligence for land use decision-making. GIS technology greatly enhances decision-making capabilities, but does not replace them. In a sense, it is both a *toolbox* of advanced analysis capabilities and a *sandbox* to express decision-makers' concerns, inspirations and creativity.

AN ENABLING TECHNOLOGY

The movement from descriptive to prescriptive mapping has set the stage for revolutionary concepts in map structure, content and use. The full potential for GIS in decision-making, however, has not been realized and is, at least in part, due to 1) the inherent complexity of a developing technology, 2) the unfamiliar nature of its products, and 3) the "user-abusive" nature of its use.

Digital maps derived through spatial modeling are inherently different from traditional analog maps, composed of inked lines, shading and graphic symbols used to identify the precise placement of physical features. The modeled map is a reflection of the logical reasoning of the analyst— more a spatial expression (application model) than a simple geo-query of the coincidence of base map themes (data sandwich). Until recently, this logic was concealed in the technical language of the command macro. The general user required a GIS specialist as a translator at every encounter with the technology. The concept of a dynamic map pedigree uses a graphical user-interface to communicate the conceptual framework of a spatial model and facilitate its interactive execution. As GIS systems adopt a more humane approach, end users become directly engaged in map analysis and spatial modeling— a situation that is changing the course of GIS technology.

A Humane GIS

Within an application model, attention is focused on the considerations embedded in an analysis, as much as it is focused on the final map's graphical rendering. The map itself is valuable, yet the thinking behind its creation provides the real insight for generating programs, plans and policy. A *dynamic map pedigree* is an emerging concept for communicating spatial reasoning that links a flowchart of processing (logic) to the actual GIS commands (macro) (Davies and Medyckyj-Scott 1994; Wang 1994; Berry 1995a). GIS users need to interact with a spatial model at several levels— casual, interactive, and developer.

Figure 10 shows the extension of the flowchart for development siting model previously described (Figure 3) into a interactive user interface linking the flowchart to the actual GIS code and map database. At one level (casual), a user can interrogate the model's logic by mouse-clicking on any box (map) or line (process) and the specifications for that step of the model pops-up. This affords a look into the spatial reasoning supporting the application and facilitates understanding of the model.

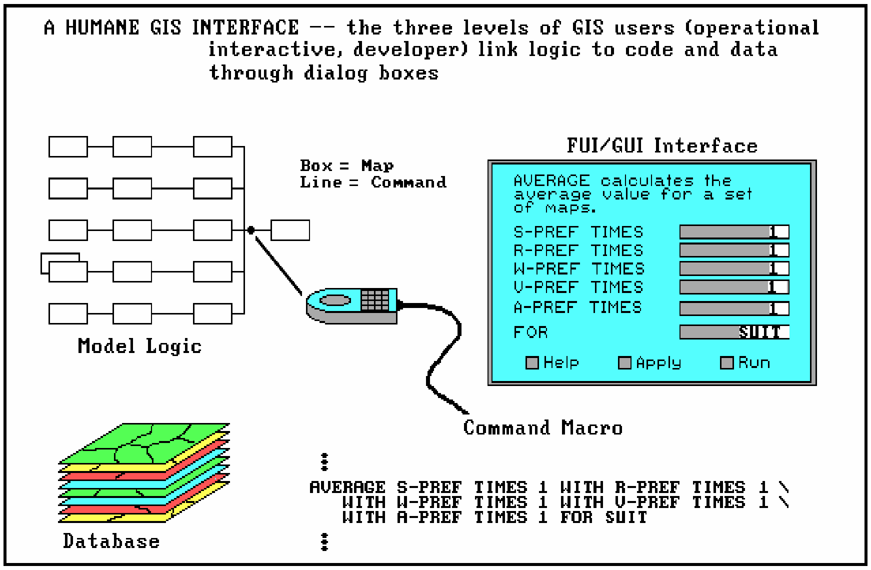


Figure 10. Dynamic Map Pedigree. The flowchart of a GIS model is dynamically linked to GIS code through "pop-up" dialog boxes at each step.

At another level (interactive), a user can change the specifications in any of the dialog boxes and rerun the model. The updated macro is automatically time-stamped and integrated into the legend of the new modeled map. This provides an intuitive interface to investigating "what if…" scenarios. For example, the processing depicted in Figure 10 shows changing the averaging of the preference maps so proximity to roads (R-PREF TIMES 10) is ten times more important in determining suitability. The suitability map generated under these weights can be compared to other model runs, and changes in spatial arrangement of relative development suitability are automatically highlighted. At the highest level (developer), a user can modify the logical structure of a model. The flowchart can be edited (e.g., cut/paste, insert, delete) and the corresponding GIS code written and/or updated.

The dynamic map pedigree provides three major improvements over current approaches. First, the graphical interface to spatial models releases users from the burden of directly generating GIS code and thereby avoiding its steep learning curve. Secondly, it furnishes an interactive stamp of model logic and specifications with each map generated. Finally, it establishes a general structure for spatial modeling that is not directly tied to individual GIS systems. In short, it provides an interface that stimulates spatial reasoning without requiring a GIS degree to operate— a humane GIS.

TRENDS, DIRECTIONS AND CHALLENGES

What began in the 60's as a cartographer's tool has quickly evolved into a revolution in many disciplines (Thomas and Huggett 1980; Goodchild et. al. 1992; Berry 1994; Maguire and Dangermond 1994; Ottens 1994; Rix 1994). As general users become more directly engaged, the nature of GIS applications change. Early applications emphasized mapping and spatial database management. Increasingly, applications are emphasizing modeling of the interrelationships among mapped variables. Most of these applications have involved *cartographic modeling*, which employs GIS operations that mimic manual map processing, such as map overlay and simple buffering around features. The new wave of applications concentrates on *GIS modeling*, which employs spatial statistics and advanced analytical operations. These new applications can be grouped into three categories: 1) data mining, 2) predictive modeling and 3) dynamic simulation.

Technological Advances

Data mining uses the GIS to discover relationships among mapped variables. For example, a map of dead and dying spruce/fir parcels can be statistically compared to maps of driving variables, such as elevation, slope, aspect, soil type and depth to bedrock. If a strong spatial correlation (coincidence) is identified for a certain combination of driving variables, this information can be used to direct management action to areas of living spruce/fir under the detrimental conditions. Another form of data mining is the derivation of empirical models.

For example, the geographic distribution of lead concentrations in an aquifer can be interpolated from water samples taken at local wells as described previously. Areas of unusually high concentrations (more than one standard deviation above the average) can be isolated. If a time series of samples are considered and the maps of the high concentrations are animated, the contamination will appear to move through the aquifer— forming an empirical ground water model. A “blob” moving across the map indicates an event, whereas a steady “stream” indicates a continuous discharge of a pollutant. The locations in front of the animated feature can be assumed to be the next most likely area to be affected. Data investigation and visualization will increasingly extend beyond the perspective of traditional map renderings.

Most *predictive modeling* is currently non-spatial. Environmental data are collected by sampling large areas, then using these data to solve a mathematical model, such as a regression equation, establishing an equation linking the variable to predict to other more easily obtainable variables. The model is applied by collecting data on the driving variables for another area or period in time, reducing the measurements to typical values (arithmetic averages), then evaluating the prediction equation. An analogous spatially-based approach was discussed within the context of precision farming in which map variables of yield and soil nutrients were used.

Another example, involves the derivation of a prediction equation for the amount of breakage during timber harvesting. Breakage is defined in terms of percent slope, tree diameter, tree height, tree volume and percent defect— with big old rotten trees on steep slopes having the most breakage. A traditional non-spatial approach ignores the geographic distribution of variation in field collected data by assuming that the “average tree on average terrain” is everywhere. Its prediction is a single level of breakage for the entire area, extended within a range of probable error (standard deviation). In a mathematical sense, the non-spatial approach assumes that the variables are randomly, or uniformly, distributed throughout a project area and that the variables are spatially independent. Both parts of the assumption are diametrically opposed to ecological theory and evidence. Most environmental phenomena coalesce into niches responding to a variety of physical and social factors.

The GIS modeling solution spatially interpolates the data into maps of each variable, then solves the equation for all locations in space. This approach generates a map of predicted breakage with "pockets" of higher and lower breakage than expected clearly identified. The coincidence of the spatial patterns of the variables are preserved, thereby relaxing the unrealistic assumptions of random/uniform geographic distribution and spatial independence. The direct consideration of the spatial patterns and coincidence among mapped data will increasingly refine environmental predictions and management actions making them more responsive to the unique conditions in a project area.

Dynamic simulation allows the user to interact with a GIS model. If model parameters are systematically modified and the induced changes in the final map tracked, the behavior of the model can be investigated. This “sensitivity analysis” identifies the relative importance of each mapped variable, within the context of the unique geographic setting it is applied. In the timber breakage example, the equation may be extremely sensitive to steep slopes. However, in a project area with a maximum slope of only ten percent, tree height might be identified as the dominant variable. A less disciplined use of dynamic simulation enables a GIS to act like a spatial spreadsheet and address “what if…” questions. Such queries address natural curiosity as much as they provide insights into system sensitivities. Both simulation versions aid decision-makers in understanding the linkages among the variables and help identify critical ranges. The use of dynamic simulation will increasingly involve decision-makers in the analysis (thruput) phase of environmental policy and administration.

Technology Versus Science

In many respects, the emerging applications of data mining, predictive modeling, and dynamic simulation have “the technological cart in front of the scientific horse.” GIS can storehouse tremendous volumes of descriptive data and overlay a myriad of maps for their coincidence. It has powerful tools for expressing the spatial interactions among mapped variables. However, there is a chasm between GIS technology and applied science. The bulk of scientific knowledge lacks spatial specificity in the relationships among variables. Now that there is a tool that can characterize spatial relationships (cart), the understanding of its expression in complex systems (horse) becomes the void.

For example, a GIS can characterize the changes in the relative amount of edge in a landscape by computing a set of fractal dimension maps. This, and over sixty other landscape analysis indices, allows tracking of changes in landscape structure, but the impact of the changes on wildlife is beyond current scientific knowledge. Similarly, a GIS can characterize the effective sediment loading distance from streams as a function of slope, vegetative cover and soil type. It is common sense that areas with a stable soil on gentle, densely vegetated intervening slopes are effectively farther away from a stream than areas of unstable soils with steep, sparsely vegetated intervening slopes. But how is effective sediment loading distances related to the survival of fish? Neighborhood variability statistics allow us to track the diversity, interspersion and juxtapositioning of vegetative cover— but how are these statistics translated into management decisions about elk herd populations?

The mechanics of GIS in integrating multiple phenomena is well established. The functionality needed to relate the spatial relationships among mapped variables is in place. What is lacking is the scientific knowledge to exploit these capabilities. Until recently, GIS was thought of as a manager's technology focused on inventory and record-keeping. Even the early scientific applications used it as an electronic planimeter to aggregate data over large areas for input into traditional, non-spatial models. The future will see a new era of scientific research in which spatial analysis plays an integral part and its results expressed in GIS modeling terms. The opportunity to have both the scientific and managerial communities utilizing the same technology is unprecedented. Until then, however, frustrated managers will use the analytical power of GIS to construct their own models based on common (and uncommon) sense.

The direct engagement of general users will increasingly question the traditional concepts of a map and its use. To more effectively portray a unified landscape, GIS must step beyond its classical disciplines. Traditional concepts of a map 1) distort reality of a three-dimensional world into a two-dimensional abstraction, 2) selectively characterize just a few elements from the actual complexity of the spatial reality, and 3) attempt to portray environmental gradients and conceptual abstractions as distinct spatial objects. The imposition of our historical concept of a map constructed of inked lines, shading and symbols thwarts the exploitation of the full potential of mapped data expressed in digital form.

The concepts of “synergism,” “cumulative effects,” and “ecosystem management” within the environmental and natural resources communities are pushing at the envelope of GIS's ability to characterize a unified landscape. Historically, system models have required a discrete piecemeal approach, however, a unified landscape is by nature a holistic phenomena. For example, consider how a hiking trail which maximizes cover type diversity might be identified. An *atomistic* approach would begin at the trailhead, test the neighborhood around each location and step to a different cover type whenever possible. This approach, however, could commit to a monotonous path after the first few diverse steps. However, if a few seemingly sub-optimal steps where made at the start it might have lead to a much more diverse route.

A *holistic* modeling approach requires the assimilation of an entire system at the onset of an analysis. Conventional mapping and GIS modeling approaches characterize the landscape in an atomistic fashion. GIS can benefit from the advancements in holistic modeling made by artificial intelligence, chaos theory and fuzzy logic. These approaches attempt to account for inference, abrupt changes and uncertainty. Instead of a deterministic solution with a single map portrayal, they establish the “side-bars” of system response. If applied to GIS these emerging map-ematical techniques might provide a more realistic description of a system “whose whole is greater than the sum of its individual parts.”

Equally important is the recognition of *perception* as an additional element of a landscape. Each individual has a unique set of spiritual, cultural, social and interpersonal experiences which form their perspective of a landscape. The ability to map these considerations requires a closer marriage between GIS and the social sciences. As the future of GIS unfolds, maps will be viewed less as a static description of the landscape and more as an active process accounting for inherent variability in perception, as well as spatial descriptors. To move from tool development to a true discipline, GIS needs an infusion of ideas from a wealth of “neo-related fields” not traditionally thought of as its bedfellows, such as the social sciences.

CONCLUSION

Environmental policy and administration have always required information as their cornerstone.

Early information systems relied on physical storage of data and manual processing. With the advent of the computer, most of these data and procedures have been automated during the past two decades. As a result, environmental information processing has increasingly become more quantitative. Systems analysis techniques developed links between descriptive data of the landscape to the mix of management actions which maximizes a set of objectives. This mathematical approach to environmental management has been both stimulated and facilitated by modern information systems technology. The digital nature of mapped data in these systems provides a wealth of new analysis operations and an unprecedented ability to spatially model complex environmental issues. The full impact of the new data form and analytical capabilities is yet to be determined.

Effective GIS applications have little to do with data and everything to do with understanding, creativity and perspective. It is a common observation of the Information Age that the amount of knowledge doubles every 14 months or so. It is believed, with the advent of the information super highway, this periodicity will likely accelerate. But does more information directly translate into better decisions? Does the Internet enhance information exchange or overwhelm it? Does the quality of information correlate with the quantity of information? Does the rapid boil of information improve or scorch the broth of decisions?

GIS technology is a prime contributor to the landslide of information, as terra bytes of mapped data are feverishly released on an unsuspecting (and seemingly ungrateful) public. From a GIS-centric perspective, the delivery of accurate base data is enough. However, the full impact of the technology is in the translation of “where is what, to so what.” The effects of information rapid transit on our changing perceptions of the world around us involve a new expression of the philosophers’ view of the stages of enlightenment— data, information, knowledge, and wisdom. The terms are often used interchangeably, but they are distinct from one another in some subtle and not-so-subtle ways.

The first is data, the "factoids" of our Information Age. *Data* are bits of information, typically but not exclusively, in a numeric form, such as cardinal numbers, percentages, statistics, etc. It is exceedingly obvious that data are increasing at an incredible rate. Coupled with the barrage of data, is a requirement for the literate citizen of the future to have a firm understanding of averages, percentages, and to a certain extent, statistics. More and more, these types of data dominate the media and are the primary means used to characterize public opinion, report trends and persuade specific actions.

The second term, information, is closely related to data. The difference is that we tend to view information as more word-based and/or graphic than numeric. *Information* is data with explanation. Most of what is taught in school is information. Because it includes all that is chronicled, the amount of information available to the average citizen substantially increases each day. The power of technology to link us to information is phenomenal. As proof, simply "surf" the exploding number of "home pages" on the Internet.

The philosophers' third category is *knowledge*, which can be viewed as information within a context. Data and information that are used to explain a phenomenon become knowledge. It probably does not double at fast rates, but that really has more to do with the learner and processing techniques than with what is available. In other words, data and information become knowledge once they are processed and applied.

The last category, *wisdom*, certainly does not double at a rapid rate. It is the application of all three previous categories, and some intangible additions. Wisdom is rare and timeless, and is important because it is rare and timeless. We seldom encounter new wisdom in the popular media, nor do we expect a deluge of newly derived wisdom to spring forth from our computer monitors each time we log on.

Knowledge and wisdom, like gold, must be aggressively processed from tons of near worthless overburden. Simply increasing data and information does not assure the increasing amounts of the knowledge and wisdom we need to solve pressing environmental and resource problems. Increasing the processing "thruput" by efficiency gains and new approaches might.

How does this philosophical diatribe relate to GIS technology? What is GIS's role within the framework? What does GIS deliver-- data, information, knowledge or wisdom? Actually, if GIS is appropriately presented, nurtured and applied, it can affect all four. That is provided the technology's role is recognized as an additional link that the philosophers failed to note.

Understanding sits at the juncture between the data/information and knowledge/wisdom stages of enlightenment. *Understanding* involves the honest dialog among various interpretations of data and information in an attempt to reach common knowledge and wisdom. Note that understanding is not a "thing," but a process. It is how concrete facts are translated into the slippery slope of beliefs. It involves the clash of values, tempered by judgment based on the exchange of experience. Technology, and in particular GIS, has a vital role to play in this process. It is not sufficient to deliver spatial data and information; a methodology for translating them into knowledge and wisdom is needed.

Tomorrow's GIS builds on the cognitive basis, as well as the spatial databases and analytical operations of the technology. This new view pushes GIS beyond data mapping, management and modeling, to spatial reasoning and dialogue focusing on the communication of ideas. In a sense, GIS extends the analytical toolbox to a social "sandbox," where alternative perspectives are constructed, discussed and common knowledge and wisdom distilled.

This step needs to fully engage the end-user in GIS itself, not just its encoded and derived products. It requires a democratization of GIS that goes beyond a graphical user interface and cute icons. It obligates the GIS technocrats to explain concepts in layman terms and provide access to their conceptual expressions of geographic space. In turn, it requires environmental professionals to embrace the new approaches to spatial reasoning and dialogue. GIS has an opportunity to empower people with new decision-making tools, not simply entrap them in a new technology and an avalanche of data. The mapping, management and modeling of spatial data is necessary, but not sufficient for effective solutions. Like the automobile and indoor plumbing, GIS will not be an important technology in environmental policy and administration until it fades into the fabric of the decision-making process and is taken for granted. Its use must become second nature for both accessing spatial data/information and translating it into the knowledge/wisdom needed to address increasingly complex environmental issues.

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