GEOGRAPHIC INFORMATION SYSTEMS FOR RECLAMATION APPLICATIONS[1]

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Abstract. This paper presents an overview of geographic information systems technology applicable for reclamation specialists. Historically, mining applications were one of the first uses of spatial data; however, the applications were limited by hand calculation and hand graphical techniques. The demands for technically competent spatial methods by surface mining and reclamation applications were greater than the ability of spatial methods to produce results. With the development of micro-computer technology, enabling rapid calculation of spatial algorithms, geographic information systems (GIS) are presently in an enhanced position to conduct mining and reclamation investigations. This process has been labelled, "Mapematics." GIS mapematics can provide technical assistance in multi-factor applications and can generate useful spatial information that was impossible to generate in the past.

There are a variety of platforms suitable for conducting GIS projects that use MACINTOSH, DOS and UNIX operating systems and are affordable to small firms and operators. However, data input into GIS software has continued to be a limiting barrier, requiring digitizers, tape drives, and often labor intensive or cost prohibitive data input. In many instances, once the data has been placed within the computer, heuristic models and empirical models to conduct the investigation have not yet been fully developed, requiring more fundamental and applied research in model building. Consequently, the development of heuristic and empirical models is a rapidly expanding topic in GIS studies. Models can be generated to estimate the character of material deposits, predict post- mining wildlife suitability, prime farmland productivity, direct efficient placement of overburden materials, and post- mining visual quality, and assist in a wide variety of other applications. The results can be presented in a two- dimensional format, printed output, and in film format for public consumption.

This paper documents the types of output that can be generated through GIS and describes present interfaces these technologies contain with surface mining and reclamation algorithms and ecological models.

Key words: Landscape planning, ecological modeling, computer applications, spatial statistics, geostatistics.

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Introduction

Reclamation specialists have been historically concerned about spatial information, such as the area of land affected by surface mining, volumes of cut/fill, delineation of buffer zones, and the configuration of land cover types. In the past, reclamation specialists have employed hand drafting techniques to prepare maps for analysis and to determine quantities. Spatial information became mechanized when computer programmers developed mapping and analysis programs on mainframe hardware. Relatively few firms employed this mainframe technology because the hardware was prohibitively expensive and the data sets laborious to generate. However, with the development of the micro-computer, spatial information can often be inexpensively and readily processed to perform more intricate calculations quickly and often with greater accuracy and digitizing allows more efficient data entry. This spatial information is generated and processed in a technology tool termed, "Geographic Information System" (GIS).

GIS: A Definition

A Geographic Information System in its broadest definition is a collection of tools which represent and analyze spatial information. The information can be separated into elemental components, transformed and reassembled for analysis (Tomlin 1990).

Traditionally, a geographic information system was manually operated, resulting in hand drawn maps, where the medium is pen and paper or layers of transparencies (overlays), the representations of physical features are in analog form as lines, symbols and legends and the output is a drawn or printed composite 'map' (Berry 1989). It generally describes a specific location at a specific point in time.

Today GIS is most commonly associated with computer systems in which the medium is magnetic tape or optical disc, the representations of physical data are strings of digital information and the output is either an image on a screen, a photographic image or a printed 'map' consisting of numbers in sequence or translated to more 'traditional' symbolism. The focus of this paper is the computerized Geographic Information System (GIS), which is both hardware and software, and the application of GIS to reclamation projects.

GIS: The Information Challenge

Corporate mining libraries and agency reference libraries have typically and traditionally housed a diverse collection of spatial information. Formats vary from flat or folded paper maps to globes, atlases, relief models, aerial photographs and maps on microfilm (Woodson 1987). Each of these present unique problems to reclamation specialists wishing to catalog, store, preserve and provide access to them. With the development of GIS, maps not only appear in new formats, they are utilized in an entirely different manner. Several new challenges for the map reclamation specialists are thus presented.

First, the spatial information is stored digitally in databases on magnetic tape or optical discs. Second, the products of a GIS can be digital information, paper maps or textual documents, computer output microform (COM) or photographs (Monmonier 1982). Third, GIS information is produced by numerous disciplines, each of which has developed its own vocabulary and application-specific software (Burrough 1987). Fourth, the volume of information being produced by GIS world-wide rivals any form of 'traditional' maps produced to date. Fifth, and most problematic for the reclamation specialist, there does not yet exist any established uniform method of inventory or access to the volume of information that is being produced.

State of the Art: Map Making Then and Now

GIS Evolution

The first known maps were created in approximately 2500 B.C. in Mesopotamia and the Nile Valley on clay tablets (Monmonier 1982). Over the years, maps evolved and changed formats. Centuries later maps were laboriously printed by hand on paper, and were owned and used primarily by a small number of wealthy people. As with other aspects of society, map making was dramatically altered in the 15th century with invention of the printing press and subsequent improvements in printing technology. Maps were more easily reproduced and as a consequence, more readily available (Monmonier 1982). At first, maps were most frequently used for navigational purposes. It was not until the 18th century when the value of maps in identifying land ownership was realized (Burrough 1987).

Development of photographic techniques in the 19th century had a major influence on cartography. Surveyors began using photography to achieve a high degree of accuracy in surveying and map making (Monmonier 1982). At the beginning of the 20th century, maps were primarily utilized as inventory tools, providing representative documentation of a selected area. They were either thematic (single subject) maps or represented quantitative or qualitative data (Burrough 1987).

Much of formative development of spatial analytic methodologies can be attributed to Warren H. Manning, a landscape architect practising in the late 19th century and early 20th century (Neckar 1989). Manning developed his methodology for site development projects as well as large scale regional planning projects.

In the 1930s and 1940s, development of stereo aerial photography allowed accurate surveying and mapping of large areas (photogrammetry) (Monmonier 1982). The ability to gather and document data from a remote (not necessarily aerial) location is referred to as remote sensing. Concurrent developments in mathematical and statistical techniques allowed new ways of analyzing this data. Mathematical values were assigned to geographical points to facilitate accurate map production and interpretation. This was particularly important in the ability to "interpolate" or estimate the value of a specific unmeasured point, from measurements of surrounding points (Burrough 1987). However, there existed far too much data for manual calculation methods of analysis. Advances in analysis stalled until the 1960s when digital computer technology finally enabled cartographers and others interested in map analysis to put remote sensing, map production, mathematics and digital hardware together (Burrough 1987); the mainframe experience.

By the late 1970s, computer-generated maps in the U.S. and Europe had gained popularity. Cartographers used computers to automate manual techniques which increased the speed and accuracy of map reproduction. However, viewed simply as another production tool, early digital computers were not considered cost-effective by most cartographers (Burrough 1987) (Figure 1).

This scenario was untrue for government agencies. The military developed sophisticated techniques in remote sensing, particular satellite imagery. The U.S. Geological Survey (USGS) developed databases containing geodetic information for the United States. State and federal resource managers were developing GIS databases and evaluation techniques. All of this work was done on large mainframe computers and was inaccessible to much of the private sector.

Throughout the 1970s computer hardware improved, particularly in the production of quality graphics and software for design applications, generated primarily in the engineering fields. As computers improved in capability, they also were reduced in size and in price. As this was occurring, a new

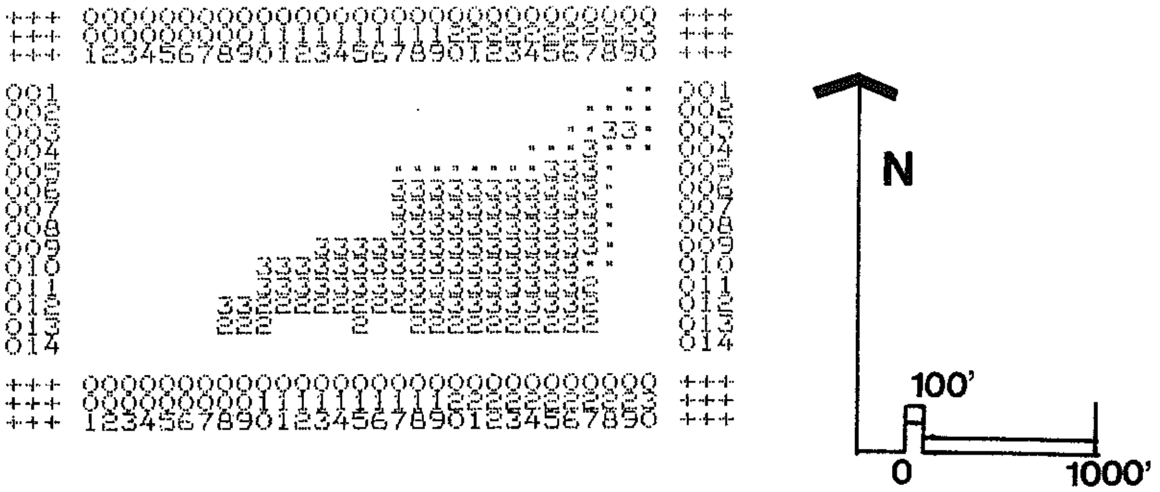

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Figure 1. GIS map typical of mainframe output. This map was produced during the time period when microcomputer output resembled mainframe output (courtesy of Burley 1988). This GIS overlay was used in predicting agricultural productivity for a reclaimed surface mine.

type of map making began to emerge. In the early 1980s, inexpensive map (spatial) analysis software began to be available which would interpret and manipulate various forms of digital data. Coupled with the proliferation of the personal computer and the availability of data, the door was finally wide open for researchers and cartographers in diverse fields to access, collect, store, retrieve, analyze, and most importantly, interactively manage map information (Burrough 1987). By 1990, "desktop mapping" had become commonplace (O'Sullivan 1990).

Geographic Information Systems have thus developed from a merger of the following six concepts assembled from diverse disciplines and sources: 'Cartography, computer-aided design and graphics, surveying and photogrammetry, spatial analysis using digital data, interpolation from point data, and remote sensing technology' (Burrough, 1987:6).

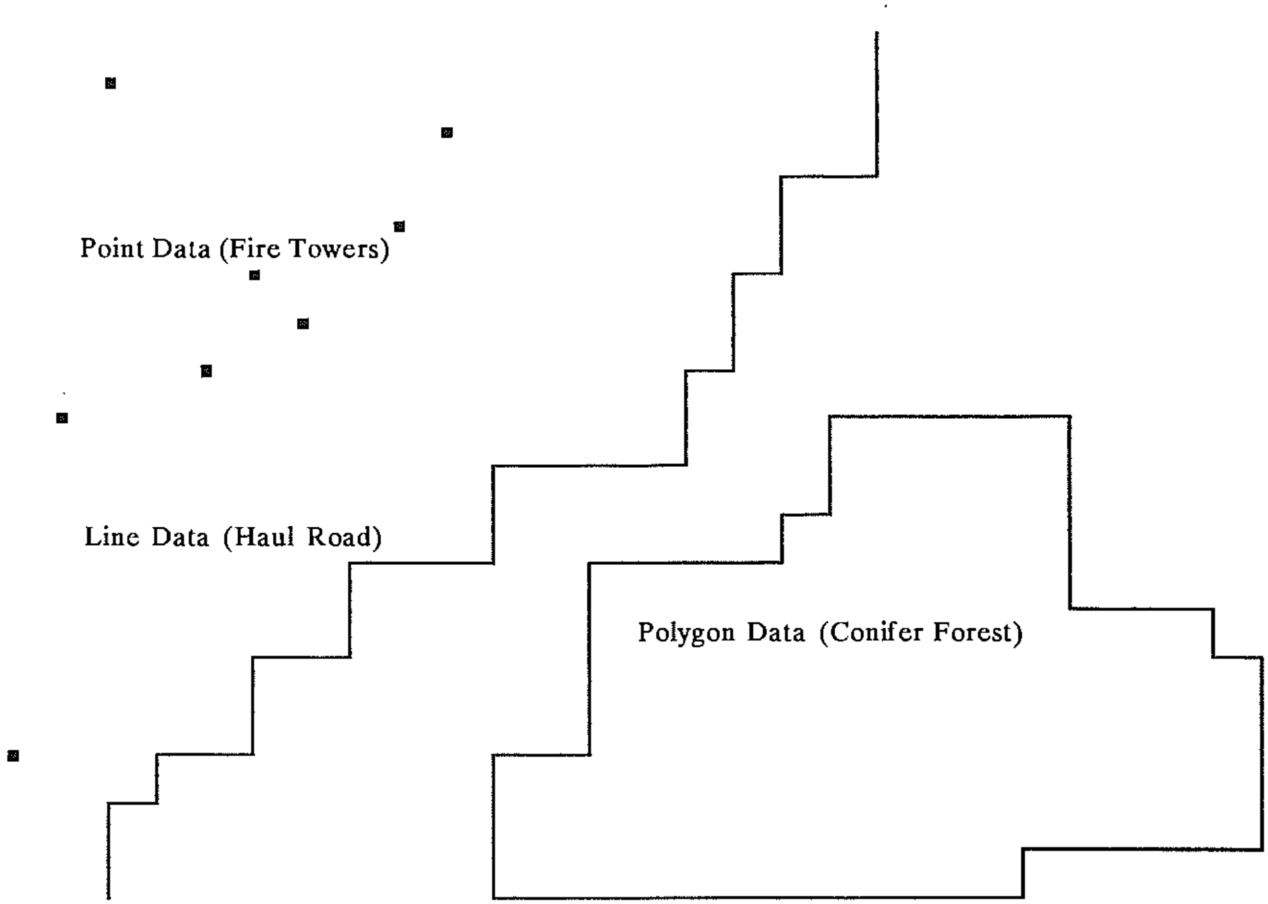


Figure 2. This map illustrates the fundamental building blocks of GIS information: points, lines, and areas (polygons). These geometric elements can be generated in Raster or Vector format; however, as microcomputer technology improves (greater resolution and computational abilities), the differences between the two formats seem to disappear. In either form, spatial resolution is an important consideration. Too coarse a resolution results in oversimplification of spatial features; while a very fine resolution may misrepresent spatial accuracy.

Westman (1985:227-252) provides a good overview of the modern principles associated with spatial landscape mapping processes and relates these concepts to environmental planning and impact assessment. In addition, Hopkins (1977) presents an excellent overview of fundamental GIS concepts that is essential reading for both practitioner and administrator. To obtain an extensive overview of methods and processes, one should read Hills (1961), Kiefer (1965), McHarg (1969), Murray et al (1971), Ward and Grant (1971), Lyle and von Wodtke (1974), Voelker (1976), Fabos et al (1978), and Omi et al (1979).

GIS: Current Features

GIS information is often displayed as either point, line or area (polygon) information (Figure 2). These points, lines or polygons have numeric attributes assigned to them by the GIS user. Each point, line or polygon is geo-referenced to a particular location, typically on the earth (although GIS can be used for other planetary bodies and 3-dimensional objects). A series of maps (overlays) can be created to represent a different set of attributes associated with a spatial location (Figure 3). These overlays comprise the GIS data base.

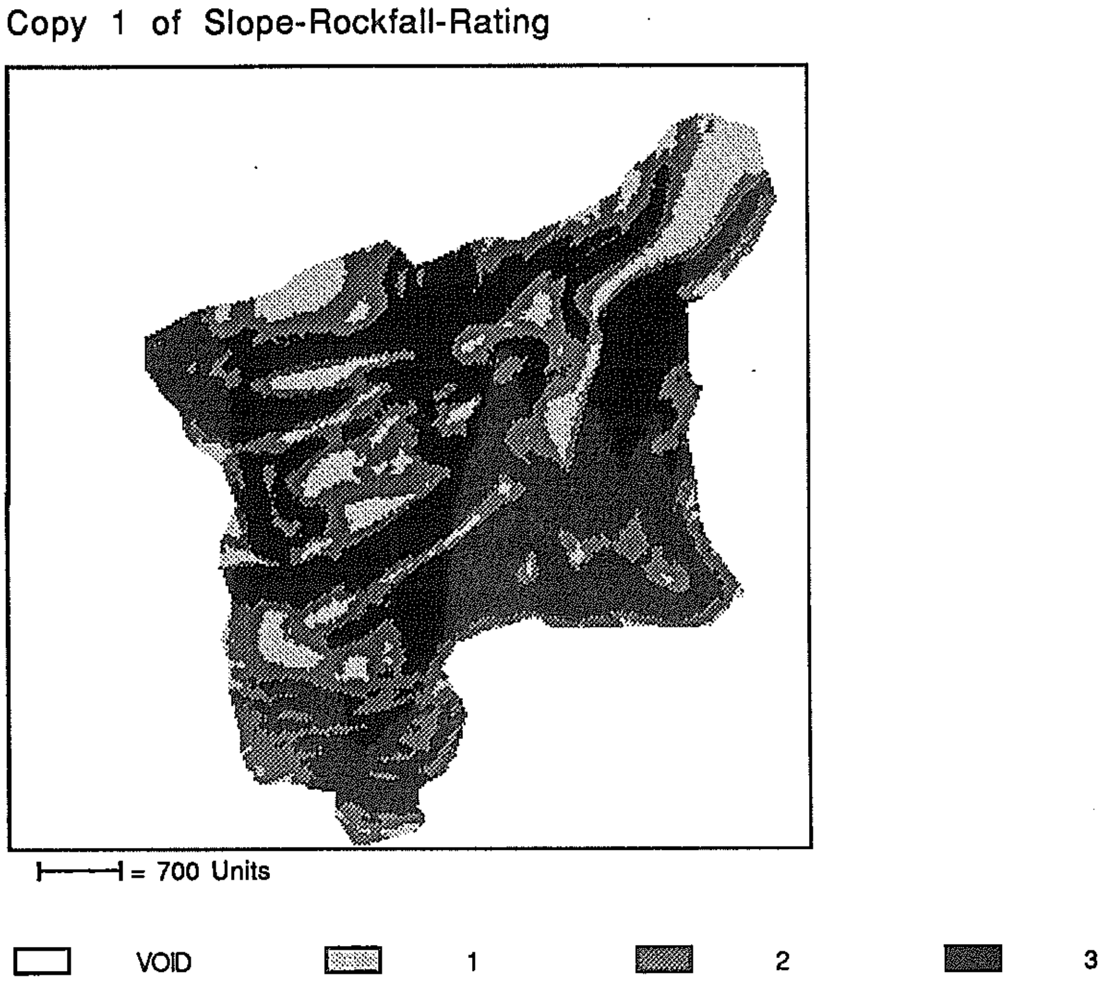


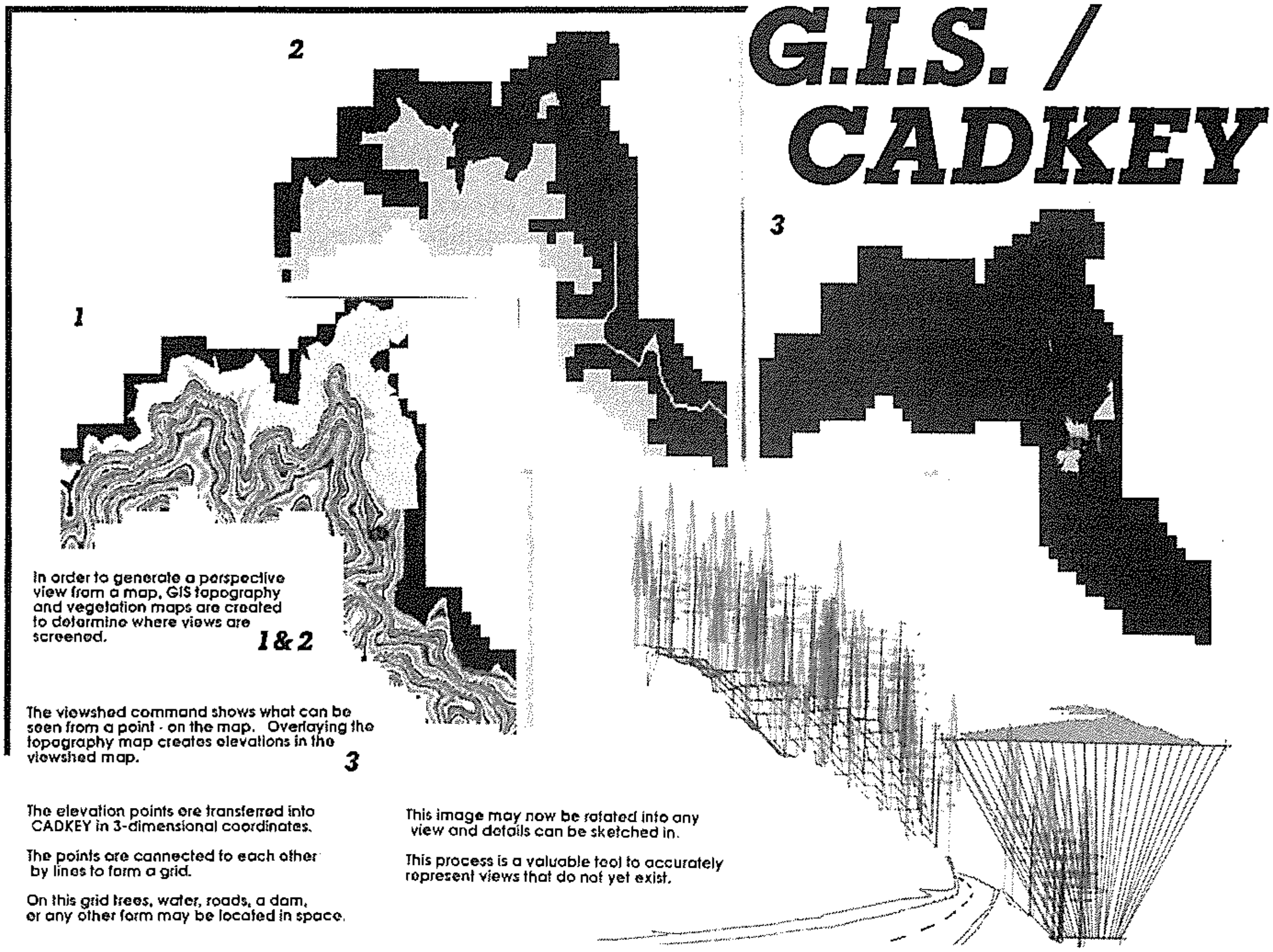
Figure 3. This map is a GIS overlay representing three catagories of slope values for a study area in the Colorado Rockies. Other overlays from this same study area represent different landscape attributes.

The overlays can be combined by applying a variety of routines to generate analytic GIS information. First, overlays can be used as maps (the standard use of cartographic information).

Second overlays can be combined in a point by point (cell by cell) fashion through standard arithmetic approaches such as adding overlays together, or through multiplication. In addition, new overlays can be created that assign values to specific combinations of attributes.

Third, overlays can be used to assess a neighborhood of values surrounding a specific location. For example, the mean topographic elevation within 300 meters of a specific point can be calculated, or all land parcels within 1000 meters of a specific polygon can be identified or polygons within a specified distance can be numerically connected together (clumped).

Fourth, overlays can be used with specific special operations such as finding the viewshed for a set of points, or finding the watershed for a specific topographic configuration, or calculating cut and fill volumes (Figure 4).



In order to generate a perspective view from a map, GIS topography and vegetation maps are created to determine where views are screened.

The viewshed command shows what can be seen from a point - on the map. Overlaying the topography map creates elevations in the viewshed map.

The elevation points are transferred into CADKEY in 3-dimensional coordinates.

The points are connected to each other by lines to form a grid.

On this grid trees, water, roads, a dam, or any other form may be located in space.

This image may now be rotated into any view and details can be sketched in.

This process is a valuable tool to accurately represent views that do not yet exist.

Figure 4. This figure illustrates some GIS output employed to study a viewshed. GIS information was then translated to a CAD system for further analysis (courtesy of Andrew Wolfe, Colorado State University).

The features of GIS can be combined into forming landscape planning/assessment/ ecological models to study alternatives and design choices. For example, Burley (1989) describes GIS technology applied to wildlife habitat modeling. Burley et al (1990) illustrate GIS modeling for investigating land-use effects upon hydrological conditions. Both of these GIS modeling applications could be employed in reclamation efforts. In the future, numerous reclamation specialists may begin to report the results of their GIS modeling efforts.

GIS Technology: Data, Storage, and Capabilities

Similar to traditional map data, GIS data is a representation of the 'real' world. It can describe objects, surface characteristics, area boundaries and spatial relationships. Unlike traditional map information, GIS data is stored in digital form. Because of this, data is not managed by moving lines and symbols on a map, but by altering the stored binary code using commands within GIS software.

GIS data is acquired using three primary methods: digitizing point data directly into the computer, scanning data directly into the computer, and receiving scanned data from remote sensing instruments via magnetic tape or telecommunications (Monomier 1982). All of this data is entered in digital format. Typical GIS software uses a combination of English and algebraic statements to correspond to operations to be performed upon the data (Tomlin 1990).

Data is stored within the computer in a database. GIS database structures vary and can be relational, hierarchical or networked (Burrough 1987). Regardless of the structure, the intent of the database is to categorize and store the data so that it may be retrieved with other data in the same category (sharing a similar characteristic), at the same location or within a specified region. The databases are similar to a system of physical 'overlays' in which each layer holds a unique characteristic. It is possible to display one layer at a time or select a number of layers to view simultaneously. These individual or grouped layers can then be analyzed, combined and re-analyzed to serve the purposes of the researcher.

This discussion identifies two primary capabilities of GIS: descriptive modeling and prescriptive modeling (Tomlin 1990).
Descriptive modeling refers to the ability of the GIS to describe or represent the real world, based on the data that has been collected and stored. This is the purpose of traditional maps of all types. However computerized systems have several advantages over manual systems, such as rapid updating and reproduction of information as well as storage and display of large amounts of data at one time (Dangermond 1984). In addition, researchers are not restricted to a single observation of existing data but can recombine the data in order to synthesize new information or look for patterns that are not clearly apparent viewing a single feature at a time. It is possible to assess a specific point or region in all layers or to view and alter points and regions in selected layers (Tomlin 1990).

The second primary capability of GIS is prescriptive modeling (Tomlin 1990). This is the ability to identify specific locations or features that will solve problems or meet objectives of the researcher (Figure 5). This prescriptive approach can best be demonstrated in a brief discussion of current GIS applications in reclamation and other areas.

Applications

Potentially, there are many uses for GIS in reclamation and surface mine operation planning. One of the earliest GIS investigations associated with mining is the work of Krige (1966). He was spatially searching for landscape types that would be suitable for further ore exploration. Land use planning for post-mining landscapes is typically considered a primary use for a GIS. This can encompass city and county zoning, locational or regional environmental impact assessment and urban planning. Vegetation production studies, crop inventories, location of soil types, wildlife population and habitat evaluation, water quality assessment and ecosystem modeling are just a few GIS applications in natural resource management with tremendous potential in reclamation planning and design. Since surface mining occurs in so many environments and conditions, the requirements of GIS packages by the reclamation community is rather large. However, the surface mining and reclamation community has published relatively little information concerning GIS investigations. One notable set of papers were published in 1987 by the University of Kentucky. While numerous firms are using GIS technology, the GIS applications are not necessarily being published (keeping firm competitiveness and fear of giving away firm trade-secrets have been cited as two reasons individuals do not publish their work).

There are GIS databases which contain information on the infrastructure of communities, counties and states as well as those which map and monitor oil and gas pipelines. Transportation departments, utility companies, and police departments are all finding pertinent data analysis facilitated by GIS (O'Sullivan 1990).

Census information is frequently in digital form and can be used for numerous population, economic and housing studies. GIS assist epidemiologists in analysis of diseases and public health issues. Weather forecasting and emergency response systems utilize GIS. Real estate agents, advertising

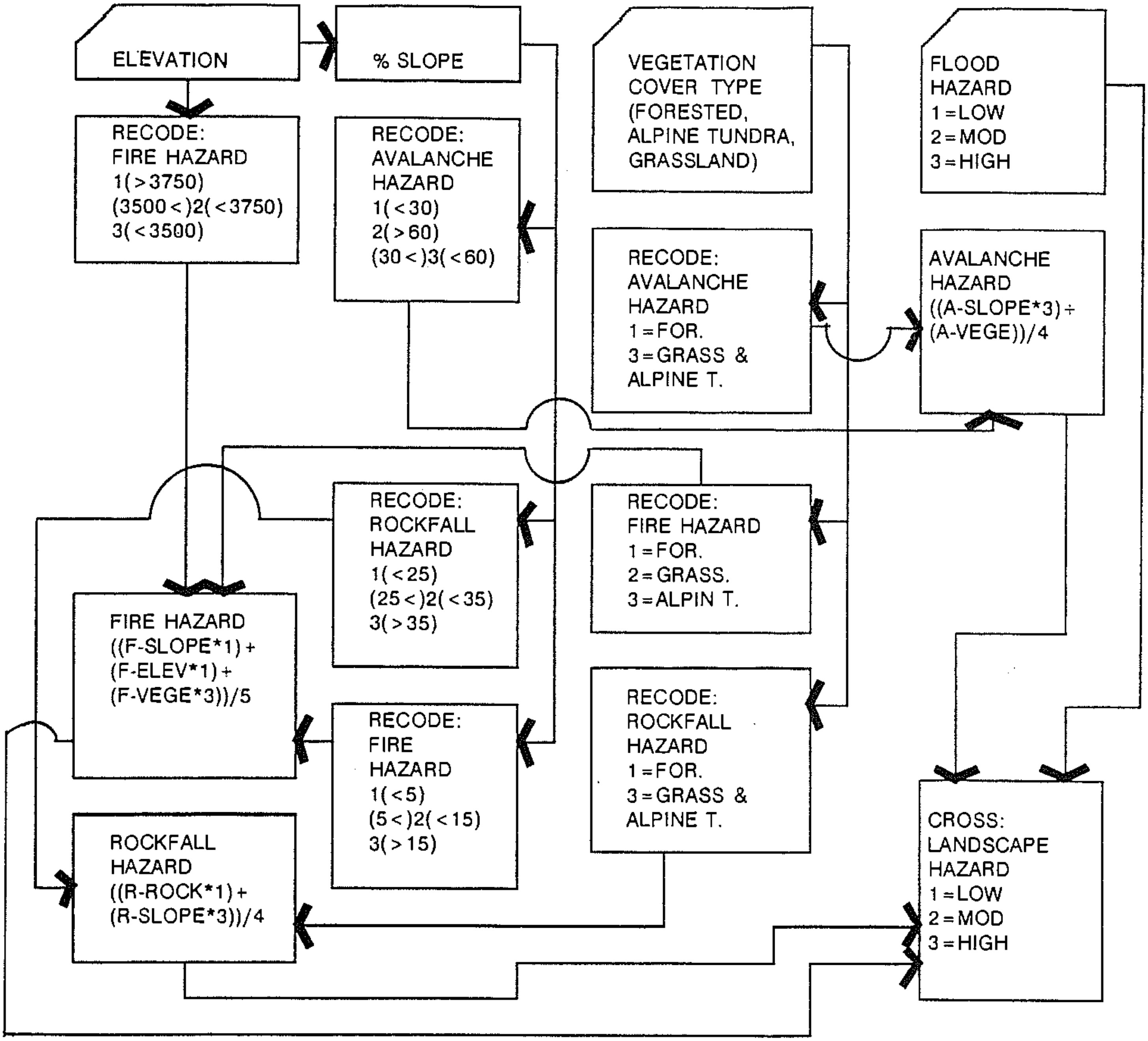


Figure 5. This illustration provides an example of the process to generate a prescriptive approach for a specific case study. While not a surface mining study, the process depicted here represents a study to examine mountainous terrain landscape hazards.

agencies and businesses may use GIS to evaluate market statistics.

With all of these diverse applications there is one very important point to keep in mind. It has always been possible with traditional maps to document existing conditions. A GIS makes it possible to take data describing diverse conditions with a geographic reference, merge it with other data, calculate mathematically and make projections about future conditions. It is possible to evaluate potential scenarios and accurately predict outcomes of intervening events. This allows the GIS user to prescribe a more appropriate course of action or solution to a problem.

Products

The physical products of a GIS can be considered to be both data and any end-result document, photograph, COM or map. Data is a valuable aspect of GIS, as many individuals can use the same data and modify it to suit a specific need. The resulting products of these various applications is in the form of new data or documents.

The GIS/Reclamation Interface

With the development of Geographic Information Systems, the usefulness of mapping has changed. Maps have evolved from descriptive tools into components of an interactive, decision-making process, in which computers as well as people examine map data for purposes of spatial analysis. The GIS map is not only an end product, it is part of the intermediary evaluative processes (Monmonier 1982). In addition, use of a GIS is not just cartography. GIS utilize theory and technology from several diverse disciplines to facilitate analysis of spatial data at a level far more complex than two dimensional maps.

As noted in the introduction, GIS technology presents a number of challenges to the reclamation specialist which may be summarized by asking the following three questions: Where is GIS information produced and stored? In what format is the information? How can it be accessed?

GIS Information Sources

At the present time, GIS data is available from several major government sources. A few examples include the National Technical Information System (NTIS), the Census Bureau (the TIGER census file structure), the Defense Mapping Agency and innumerable satellite projects (LandSat, SPOT, NOAA and more). The Earth Resources Information Centers (ERIC) are distribution points for the USGS, and also handle large databases such as Land Use and Land Cover (from NASA and the National High Altitude Program), the Digital Elevation Model and US GeoData (Sneath 1990), to name a few (George 1990). Each of these sources have developed unique methods of identification and distribution.

In addition to these vast government database sources, there are thousands of projects in research institutions, private corporations, local and state government offices and individual homes. Most of this information is documented only as projects are implemented or published. There is no referencing on a national or international basis.

In What Format Is the Information?

Until very recently, most government data was available on magnetic tape. However, most of the agencies are preparing to release information on optical discs (CD-ROM). The volume of information available through the U.S. government alone is staggering, and yet GIS is only in its infancy. In the late 1990's, NASA is expected to launch four satellites to form the Earth Observing System (EOS) which will transmit a terrabyte of information per day, just on the earth's environment (Research Libraries Group 1989). For government depository map libraries, the information inundation is only beginning.

How Can GIS Information Be Accessed?

At the present time there are four ways that GIS users are accessing information. The first is by tracking the various government sources, several of which were listed above. The second is through a network of informal contacts throughout the circle of academia and industry which keep people informed regarding who is doing what. Some of this is being accomplished via electronic transmission, such as over the BITNET (Lewis 1989). The third is through periodical literature in current publications. The fourth is through more formalized (local area) networking of computer facilities within specific regions, disciplines and even institutions (Hollway & Wiltshire, Cooke 1984).

The access techniques presently utilized suffer from lack of uniform vocabulary (Cooke 1984) and limited scope. Undoubtedly, much valuable information is being duplicated, lost or buried in obscure, inaccessible locations.

GIS: Computer/Human Interfacing Issues

Professional GIS work can suffer from several effects that hinder the utility of GIS generated products. First, some individuals suffer from the "Algorithm Effect," an effect noted in conversations and presentations (unpublished) with other computer-aided landscape architectural scholars. This effect is best described as an incompatibility between user expectations and the ability of the software to perform spatial procedures.

Inexperienced GIS users seem to believe that computers can perform planning and design work at levels higher than the actual performance ability of the software. Either spatial algorithms appear esoteric to the GIS user, or GIS work seems tedious, or GIS results appear too simple. In addition, the mathematical ability of some GIS software to perform simple algebraic functions is not equal to the ability of even an inexpensive scientific calculator, meaning that sometimes GIS modeling capabilities are mathematically handicapped. For example, GIS acrobatics may be required to work with very large numbers or to work with decimals. Data may require reclassifying to fit into the conformities of the software.

Related to computer technology and user expectations, some GIS users seem to have a short tolerance and low willingness to spend significant time testing procedures, verifying output, and carefully examining files. Yet these same individuals who have a low tolerance for carefully examining GIS output, could easily spend days or weeks performing the same procedures by the overlay hand drawing method, carefully testing procedures without showing any intolerance for the procedures. It seems that somehow, some GIS/computer users have been trained to expect instant results. If the instant GIS results are not readily apparent, some users seem greatly stressed and disappointed.

Learning styles also hinder GIS utility. Some professionals' learning styles depend upon memorization, meaning that they are more interested in copying the exact command line notation to perform a task, rather than learning the various approaches to accomplishing a task and developing their own analytic capabilities. Unfortunately, they prefer an exact prescription approach to computer-aided GIS. For a person dependent upon memorization and careful note taking, during lengthy demonstrations, they will often be overloaded, overstimulated and stressed in less than five minutes. GIS use requires extensive training time and a tenacious attitude toward computer use.

Some GIS users also seem to suffer from the "By-passed Process Syndrome," meaning that individuals would generate solutions without thorough programming, inventory, analysis, synthesis and concept development; instead the user would quickly attempt to generate a solution without studying alternatives or without determining the sensitivity of the models they were developing. To keep a process perspective concerning the application of GIS projects, reclamation specialists are urged to understand and to study various landscape assessment values and weighting approaches (ecological, economic, utilitarian, experiential). In addition, novice GIS users should be exposed to hand/graphical methods first and then apply these procedures to computer related technology. GIS users should develop their computer model (a set of instructions to accomplish a GIS task) carefully before even starting to digitize and analyze data. All too often GIS users start applying computer routines before developing a clear idea about the process employed to generate results that are meaningful for reclamation applications. In fact developing a consensus among surface mining interests (operator, owner, regulatory agencies, consultants, local residents) concerning the GIS process and model building, illustrating exact procedures, may take months (if not longer) and the actual GIS application may take only several days. Yet if a model is employed where there is no consensus concerning the weights and values to be applied in a GIS model, the utility of the results are greatly reduced. All too often GIS models are reported in the literature where the reporting investigator takes a "black box" approach to describing the model, because if the exact GIS modeling procedure were clearly stated to the reader, a Pandora's Box would be opened concerning the weighting procedures and the set of philosophical values employed in generating the solution. GIS users should not hide behind the technology, but should carefully employ the technology to help people study alternatives and develop solutions in an informed manner.

Conclusion

There are several measures that reclamation specialists can take to address the topics and issues associated with Geographic Information Systems:

1. Recognize the growing importance of GIS information.

2. Stay informed about availability, location and format of GIS materials.

3. Develop informal networks of GIS producers and users by actively seeking them out within your organization, community or state/province.

4. Collaborate with information specialists to develop cooperative bibliographic records and a central reference point for shared GIS data and information from diverse sources (Olson 1990).

5. Watch for opportunities to support national/international cooperative efforts.

6. Catalog everything.

7. Prepare for the increasing avalanche of digital information that will be available on-site or on-line.

8. Continue to monitor and evaluate technological advancements in GIS and consider their value and potential usefulness for the specific reclamation environment.

9. Follow developments in ecological modeling, such as watershed hydrology, habitat modeling, and vegetation production models so that the reclamation specialist can generate and apply spatial algorithms to important reclamation investigations.

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