LANDSAT CAPABILITY ASSESSMENT USING GEOGRAPHIC INFORMATION SYSTEMS

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ABSTRACT

With the recent availability of large accumulations of detailed cartographic and other spatial data, various groups including government planners, engineering consultants, and resource managers are seeking computerized methods to store and manipulate the mapped data bases. This need has led to the development of computer-based geographic information systems (GIS) which replace the traditional overlay approach in land capability analysis (McHarg, 1969). More recent GIS software features a variety of parameter modeling procedures, color CRT display interactive capability, proximity modeling, and the ability to enter remotely-sensed data (e.g., satellite, aircraft, etc.) and input parameters.

OVERVIEW

For several years, the intense need for more effective and sophisticated methods of managing resources and assessing environmental impacts has been apparent. A fundamental requirement for effective resource management is information. To be of maximum use, the information must be accurate, timely, comprehensive, readily retrievable, and subject to a large and flexible array of analytic and interactive display approaches.

Fortunately, in the last decade, rapid advances have been made in both remote sensing and geographic information system technologies. The tools and concepts now exist to develop the required computer software and data bases.

One problem, which has always limited the application of these computer-based systems, is the high cost of establishing the digital data base files. A breakthrough in this cost is the application of techniques which permit the generation of digital land cover files from data interpreted from satellite (Landsat), aerial photography, and conventional map sources. Utilizing advanced data restoration techniques, the Landsat data can be resampled to a 50 x 50 meter cell size. Computer-assisted interpretation transforms Landsat measurements into land cover codes. This interpretation provides a fast, low-cost source for non-urban cover types, e.g., cropland, grassland, barren land, forest, nonforested wetlands, water, etc. Land use categories to be merged with the Landsat data are delineated on maps and aerial photography and digitized into the same map projection and scale as the interpreted Landsat data. The Landsat and the manually interpreted/digitized files are then merged in the computer and used as the source for map and data products.

Products resulting from this multisource procedure include: color maps and map overlays, land cover tabulations, and digital data files.

GEOGRAPHIC INFORMATION SYSTEM REQUIREMENTS

A computer-based geographic information system is basically a geo-referenced system for storing, retrieving, and manipulating mapped data (Campbell, 1981). In contrast to a conventional data base management system, the parameter data of a GIS must be related to a place or location identifier.

There are three major factors to be considered in the design of a computerized geographic information system. The first of these factors is the technique to generate and register digital files of geographic areas and resource management attributes such as topography, forest cover, land use, water type, etc. The second factor is the development of a data base management system which is used to catalog, store, and retrieve the digital file containing the resource information. The third factor is the software to be used to manipulate the data base and extract the required resources management information, and the hardware to display interim and final results. These three factors (Data Base Capture, Data Base Management, and Data Base Manipulation and Display) comprise the geographic information system.

Data Base Capture

There are many types of data to be entered into a geographic information system. Graphical information is usually presented to the system as a map. The maps can be in any number of scales and projection and will contain areal information in the form of polygons (timber type, land use, political boundaries, etc.), lines (roads, streams, etc.), and points (well known locations, topographic high or low points, bench marks, etc.). Other types of data to be entered include cellular or raster data (Landsat, digitally scanned data, etc.) and tabular data (statistics, etc.).

The most common method for the entry of graphical information is through the use of a coordinate digitizing table. Given the nature of maps used in resource management projects, the majority of the information will be digitized as polygons. Data manipulation is more easily performed with cellular data. Nevertheless, there are large advantages to storing the area data as polygons. The more advanced software packages will utilize the flexibility and compactness of polygon storage while providing the simplicity of data manipulation afforded by cellular modeling techniques. Tabular data can be viewed as single point polygonal data and can be processed using the same software as that required to manipulate the graphical data. Processed Landsat data is, of course, already in a cellular format and would be stored in that form. The software should allow the registration of these various data types, perform a polygon to raster conversion, accept geodetic coordinates (latitude, longitude), and produce a cellular data file in the specified projection and cell size. A typical data base might include data resampled to a 50 x 50 meter cell (compatible with the Landsat resolution) in a UTM projection.

Data Base Management

As data is captured, it must be indexed and catalogued for later retrieval. One of the most important decisions to be made in the evolution of an information management system is the structure and organization of the file. The design of the file structure and organization of the file. The design of the file structure is a function of the type of information desired from the data base. The file structure must be designed to permit simultaneous sorts by several attributes. Typical retrieval requirements are sorts:

- By land use category of type,
- By area (political boundaries, watersheds, etc.),
- By time period (year, month, etc.), and
- By source (satellite, aerial photography, etc.).

The structure can be hierarchial (tree structure) or matrix. For a particular resources management project, the data bases may be queried to collect the data required for manipulation.

Date Manipulation

In order to have a GIS accommodate multiple users and applications, the system design should be flexible enough to accept a variety of data base parameters capable of being analyzed with a common operating procedure. Optimally the system should provide the following functions:

1. Retrieve one or more data elements from a parameter file;
2. Transform or manipulate the values in the data element retrieved;
3. Transform, manipulate, or combine the data elements retrieved;
4. Store the new data element created by the analysis in the data file;
5. Search, identify, and route a variety of different data items and score these values with assigned

weighted values (e.g., search for optimal highway routing) - the capability is highly desirable and complex;

6. Perform statistical analyses, such as multivariate regression, correlations, etc.;
7. Measure area, distance, and compare these data;
8. Overlay parameter files (e.g., census tract data with land use data);
9. Model and simulate (i.e., develop scenarios), generally in map form, to predict a future event - this is perhaps the forte of a GIS.

TYPICAL APPLICATIONS

There are several important areas where geographic information systems can aid land use planners:

1. Master plan or long-range planning;
2. Determination on the extension of utilities and public sewer/water service;
3. Siting problems, e.g., an industrial park;
4. Environmental impact assessments.

Examples of the above application areas are presented below. Data bases have been developed for Washtenaw County, Michigan and Scio Township, which is a township within Washtenaw County. The county data base contains 10 parameters while the township data base contains 25 parameters, coded on a 100 x 100 meter cell size. Thus each cell represents a surface area of 1 hectare or approximately 2.5 acres.

Many local governments, as well as private companies, develop long-range plans (which are sometimes referrered to as Master Plans) for the comprehensive planning of their respective activities. Such plans should reflect not only a consensus of the community, i.e., nontechnical factors, but also the capability of the land to support the planned use(s). As illustrated by Figure 1, only areas suitable for residential development are shown by the gray-tone pattern (lighter shades related to higher suitability). The suitability map was produced by analyzing five spatial parameters including township zoning, septic tank limitations, water well production, depth to water table, and existing land use. Moreover, the overlay of a parameter representing proposed 1990 public water mains allows the township planners to simulate development and thereby determine if the extension of the public utilities is justified.

Application two, illustrated by Figure 2, shows the areas suitable for industrial development in Washtenaw County. Five parameters were employed in the industrial development model including county land use, and proximity to expressway interchanges. The proximity parameter is an especially important capability in the GIS as it allows the planner to incorporate a gravity or distance-decay function. In addition, this application features an existing land use parameter which was developed from digitizing a map prepared from aerial photography interpretation. Landsat and other

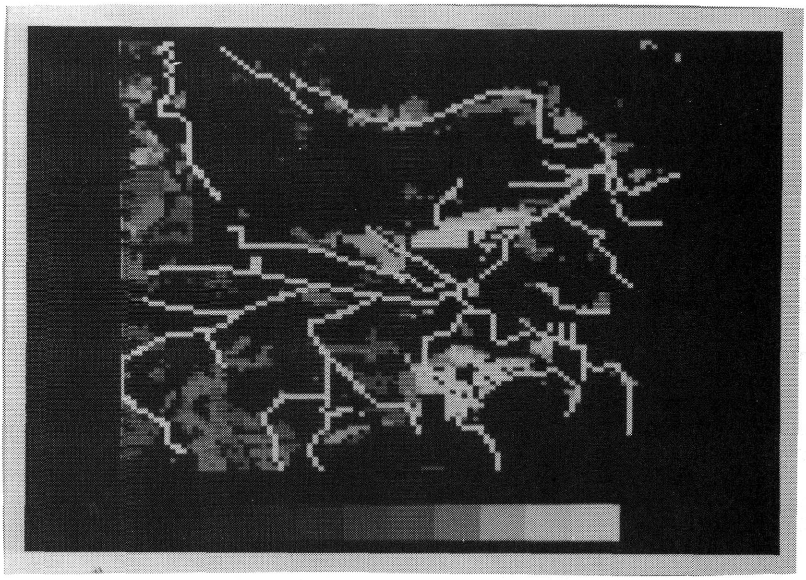

Figure 1. Suitability of Land in Scio Township for Rural Residential Development, with Overlay of Proposed 1990 Water Mains.

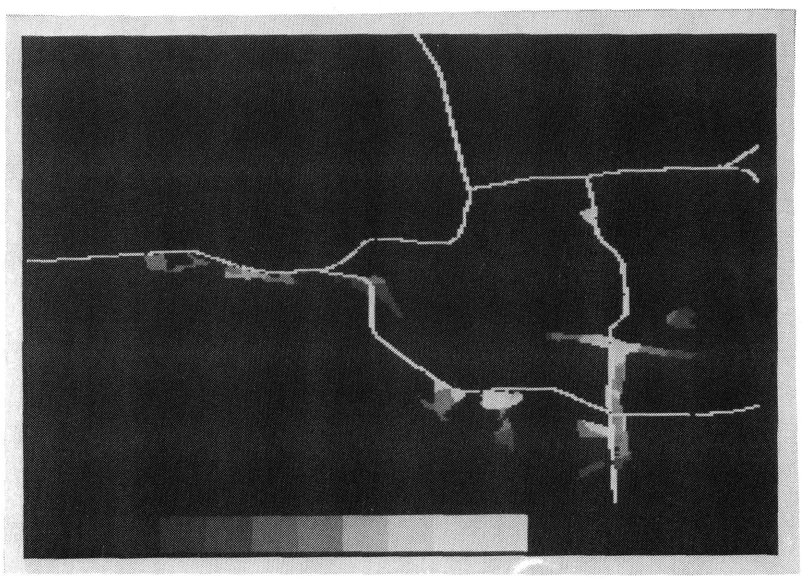

Figure 2. Suitability of Land in Washtenaw County for Industrial Development, with Major Highways Overlaid for Geographic Reference.

remote sensing platforms could also provide existing land use data.

Application three illustrates the utilization of a GIS in performing environmental impact assessments (Figure 3). Six parameters were employed in the suitability model including depth to water table, wetland type, forest type, water well production, soil type (agricultural potential), and existing recreational land use. To simulate the effect of selected environmental regulations, the wetland type and soil type parameters were assigned a weight of 2.0 whereas the remaining parameters were assigned weights of 1.0. The capability to assign weights to parameters is an important GIS feature especially when multiple suitability maps are compared.

Taking multiple suitability maps a step further, the system should be capable of generating a composite suitability map utilizing several different suitability models which pertain to a single application. For example, with regard to a hypothetical hazardous waste landfill siting model in Scio Township, three suitability maps were prepared which represent distinct planning postures: prodevelopment, neutral, and environmental/conservative. The three suitability maps were then incorporated as derived parameters in a new data base file. The resultant suitability map (Figure 4) highlights the commonality between the three alternatives. Geographic areas with high scores are cells which received high suitability values from all three simulated postures. Moreover, composite maps may facilitate concensus among planners, and can point to areas where site-specific data must be collected.

The degree to which the overall and composite nature of the future landscape is affected by alternate value systems represents the sensitivity of the land resource. By assuming a set of alternate value systems covering the spectrum of public opinion, the land use planner can generate a set of alternate land use maps, and thus assess himself of said sensitivity prior to the public hearing process. Furthermore, by submitting such a set of land use scenarios to the public forum, the land use planner can make the public hearing process a more meaningfull one from the outset.

FUTURE POTENTIAL

Recent advances in both hardware and software have opened up an exciting new area for the application of GIS technology - land assessment and resource management for areas of the world where current cartographic information does not exist or is inadequate.

The hardware advance providing this capability was the development of the TRANSIT series of satellites, allowing accurate positioning of marine vessels. In 1967, the Navy made the system available to nonmilitary users. As of 1975, six satellites were in operation in circular polar orbits at a nominal altitude of 600 nautical miles and with a nominal

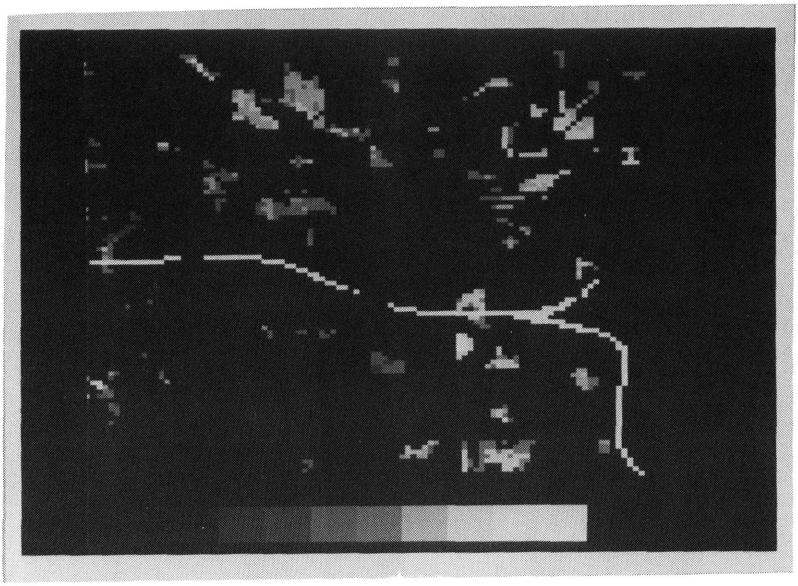

Figure 3. Suitability Map of Scio Township Showing Environmentally-Sensitive Areas.

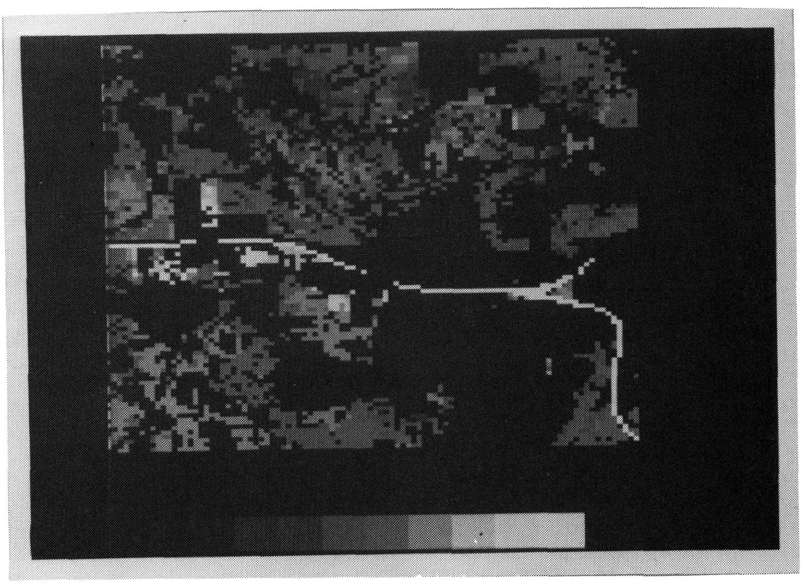

Figure 4. Composite Suitability May Showing Areas in Scio Township Suitable for Hazardous Waste Landfill.

period of 107 minutes. The number of usable passes per day range from 8 to 12 near the equator to 40 to 50 in arctic regions. To make use of the system, an observer needs a small antenna, a lightweight receiver, and a tape recorder to store the observations. Many current systems also include a microcomputer to process the data on site. By positioning these receivers at sites which are photoidentifiable in satellite (Landsat) imagery, the control points can be precisely located in latitude, longitude, and elevation. These precisely located points can then be used to geometrically correct the satellite data.

Recent software techniques have been developed for highly accurate geometric correction of Landsat satellite data. The software uses high order polynominals to map Landsat data into the desired projection, correcting spacecraft and sensor distortions in the process. The accuracy of the correction is limited by the resolution of the Landsat data and the precision with which the image and map control points are located. The desire to produce the geometrically correct imagery with as few control points as possible led to the derivation of a "model" for the Landsat spacecraft and scanner.

The "model" rigidly defines the spacecraft and sensor with a least squares fit between predicted and observed control points refining the spacecraft roll, pitch, yaw, roll rates, pitch rates, roll accelerations, and pitch acceleration. In principle, five control points can completely compensate for any attitude maneuvers performed by the satellite during the collection of the data frame (scene). In practice, 6 to 10 points are normally collected to: 1. reduce the effects and permit detection of a "bad" point and 2. permit averaging to achieve subpixel accuracy in image control point location.

The state of the art for geometric correction and digital mosaicking of Landsat data has reached a level permitting use of such data for small to medium scale mapping of poorly mapped areas. Most Landsat scenes can be geometrically corrected to national map accuracy standards at scales of 1:200,000 or smaller. Current development efforts indicate that the ultimate geometric accuracy of the Landsat MSS scanner could be as good as 25 meters RMS, meeting national map accuracy standards for 1:50,000 scale maps. The Landsat D Thematic Mapper data should be able to easily achieve this accuracy level when the appropriate correction software is developed.

The consequence for GIS technology from this ability to generate planimetric maps utilizing Landsat data is the capability to provide land resource managers with a tool to assess and control future resource utilization in areas where no viable alternative exists. The Landsat derived map becomes the base map unto which the manually interpreted data is transferred. In addition, computer-assisted land cover classification of the Landsat data may be merged with the manually interpreted data in the GIS data base.

It should be noted that the resolution of the Landsat data (50 meters) and the normal scale of the derived maps

(1:250,000) are commensurate with their utilization in areas of poor and/or nonexistent maps.

The new capability means that third world or underdeveloped countries may generate a set of maps conforming to national map standards, produce digital data bases corresponding to the map format, and produce land assessment and resource management decisions which may be referenced directly to the national map series. This ability to achieve GIS technology transfer to nations which are very much in need of the technology for a relatively low cost in a short time-frame is a most exciting aspect of the GIS picture.

REFERENCES

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