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DESCRIPTION OF A USER-ORIENTED GEOGRAPHIC INFORMATION SYSTEM: THE RESOURCE ANALYSIS PROGRAM

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I. ABSTRACT

This paper describes the Resource Analysis Program, an applied geographic information system. Several applications are presented which utilized soil, and other natural resource data, to develop integrated maps and data analyses. These applications demonstrate the methods of analysis and the philosophy of approach used in the mapping system.

The applications are evaluated in reference to four major needs of a functional mapping system: data capture, data libraries, data analysis, and mapping and data display. These four criteria are then used to describe an effort to develop the next generation of applied mapping systems. This approach uses inexpensive microcomputers for field applications and should prove to be a viable entry point for users here-to-fore unable or unwilling to venture into applied computer mapping.

II. INTRODUCTION

A. OBJECTIVES

There is little doubt that the technology involved with data gathering, particularly that related to advanced remote sensing systems, has far outpaced our ability to understand and integrate this data into our everyday affairs. For problems involving natural resource management and planning, more attention is now being spent on ways to integrate our basic data sources and to develop more effective means of communicating these ideas to those actively involved in affecting change on our natural resource base.

Natural resource data, for the most part, is spatial in nature and is usually depicted on maps or tabulated to support map interpretation. An example is the soil survey report. The survey document itself is physically divided into two sections: the text descriptions and interpretations and the maps. Neither one can stand on its own; only by integrating the two "data sources" can we actually extract maximum information.

Today's natural resource problems require appropriate multi-source data and also an effective means of integrating this information - and then simplifying it - so that sound management decisions can be reached.

The resource analysis system described in this report was conceived with a goal of integrating commonly available data sources. The parentage lies in applications and in the level of technical sophistication found in most users. The computer software - the Resource Analysis Program (RAP) - is a tool to implement the strategy and reflects a philosophy of approach as well as a method of analysis.

During the course of applying the system to many different types of problems, an understanding deepened as to the needs and requirements of a functional geographic information system. Applications most often involve the use of soil survey information (usually in conjunction with other data), primarily because of the fundamental importance and wide applicability of soils to our natural resource base. Functional means a mapping system that exists in the user's environment and is intended to support their routine information and problem-solving requirements.

Building upon what has been learned in the past, the next generation of applied geographic information systems is currently being developed. This effort is

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based on using readily available and inexpensive microcomputer hardware for a stand-alone system that should be affordable and sufficient for many field applications. Furthermore, this type of "low-technology" entry should prove to be most satisfactory for many of the users here-to-fore unable or unwilling to venture into applied computer mapping.

The objectives of this paper are: 1) briefly describe the Resource Analysis Program, particularly in reference to utilizing soil information, 2) describe several applications of the system, referencing the manner in which soils, and other natural resource data, are used in the RAP system approach, 3) point out some of the lessons learned during these applications relative to what a functional mapping system should be capable of doing, and 4) describe current develomental efforts in implementing a microcomputer based geographic information system.

B. DESCRIPTION OF THE RAP SYSTEM APPROACH

Program Structure. The Resource Analysis Program is a computer software system designed for analysis, integration and mapping of spatial information, with a particular emphasis on natural resource data[9, 12]. The system operates on a grid-structured data base through a series of commands (Table 1) that control the file handling, analyses and mapping options. Commands can be linked in almost any order, thus providing a "vocabulary" to tell the analytical story.

Table 1. Resource Analysis Program Commands and Their Functions.

Phase	Function
1. AGVALUE	Calculates appraised farm land values based on current market values and soil productivity.
2. CROSSTABS	Generates 1- to 3-way cross tabulation tables.
3. DELETE	Deletes map from internal Work File.
4. END	Normal termination of system.
5. EROSION	Calculates erosion susceptibility ratings based on Universal Soil Loss Equation.
6. GROUP	Combines factor values into numeric groups.
7. HISTOGRAM	Generates graphic histograms from data values.
8. INVERT	Inverts factor numeric values.
9. LIST	Lists current attributes of internal file.
10. NEWFILE	Copies internal file to external device.
11. NORMALIZE	Normalize numeric range of factor values.
12. OVERLAY	Generates comparative site indices using the map overlay technique.
13. PLOTTERMAP	Constructs variable scale maps using plotter.
14. PRINTERMAP	Constructs variable scale maps using printer.
15. SCALE	Generates comparative site indices using the multi-dimensional scaling technique.
16. SOILTABLE	Retrieves soil interpretations from system library.
17. SORT	Identifies selected features extracted from one or more maps.
18. TALLY	Summarizes factor value totals for sub-areas.
19. TITLEMAP	Constructs fixed-scale line printer maps for grid cell data graphic representation.
20. WINDOW	Creates sub-area internal data files.
21. WORKFILE	Creates internal data file from master map library.

The system places an emphasis on basic data handling functions (grouping, sub-setting, and map feature extraction) and on use of comparative site index generators. A comparative site index is a means of comparing internal map areas by using a numerical rating developed for each cell. The index is developed by integrating data from several map sources and can be either calibrated or uncalibrated, depending upon the command chosen and the data available.

Comparative site indices are an important aspect of RAP. Few formal models exist that can integrate resource data. Therefore, highly structured informal models are required[1, 2, 5]. Particularly for soils information, which is commonly available as ordinal ratings. Unique site index generators of RAP provide several alternatives of handling soil information in a definable and structured manner.

RAP has an extensive library of soil properties, ratings, and yields. The library is keyed to soil management groups, a grouping of soil series based on similar behavioral characteristics[4]. Other groupings can also be used, such as the woodland suitability groups which are published in most soil surveys.

Data File Structure. RAP uses a simple, grid-coding scheme to digitally capture data from a map. Grid coding divides the study area into a series of regular rows and columns (Fig. 1). Each grid cell has a unique row-column number address, similar to standard matrix notation.

In effect, data are coded by overlaying a grid on the map and recording the symbol occuring within each grid

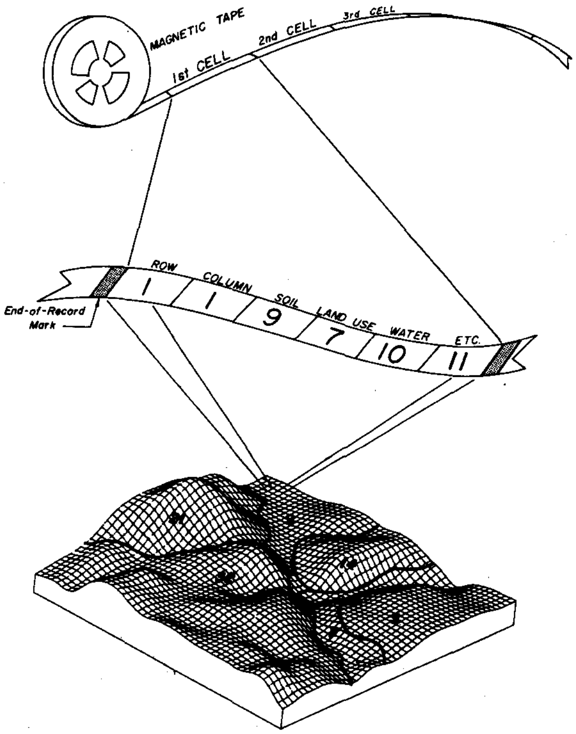

Figure 1. Schematic of the data coding scheme.

cell; either a dominant or dot sampling approach is used. The process can be repeated for different maps to create a record that contains for each grid cell the row-column coordinate and all symbols for that cell's characteristics on each map.

The system is independent of cell size, although it is recommended that the size chosen be an even increment of a standard, 640-acre section. By doing so, the cell boundaries will conveniently align with many of the cultural features shown on maps, such as section lines, roads, field boundaries, property lines, drainage ditches, etc. This alignment helps in registering the grid when coding and in locating the grid cell area in the field.

An advantage in a cell size that "fits" inside a section is most people spatially perceive the landscape using objects that are common to their experience, such as roads, field boundaries and other cultural features. Furthermore, the area enclosed by roads (at least in Michigan) tends to be thought of as a "unit" of land. It appears that mapping systems which can maintain this perception in the display of the map data greatly facilitates the use and understanding of the map products, without adverse spatial error.

The system has been used with several grid and cell sizes. Most frequent is a 10-acre cell for a township area (36 square miles). Such a file results in a grid (48 rows by 48 columns) of slightly more than 2300 cells and seems to provide acceptable resolution for applications to date.

Other file structures are compatible with the system, most notable being a standard raster scan format used with processed and classified Landsat data. Landsat data have been used as a sole source of land cover/use information and also in a unique hybrid approach between Landsat and aerial photography[11]. This type of file structure is also compatible with many polygon-to-grid conversions, such as is found with digitizers and polygon-based mapping systems.

III. SELECTED APPLICATIONS OF THE RAP SYSTEM

The following examples were selected to demonstrate the variety of applications of RAP and various techniques used in analysing commonly available resource data. In the examples, soils information played a key role in assessing the landscape capabilities and also provided a framework for integrating other map and tabular data.

A. A REGIONAL WATER QUALITY PROGRAM - THE WINDSOR TOWNSHIP PROJECT

In support of a water quality assessment program for a regional planning commission, RAP was used to demonstrate several techniques by which township areas could be evaluted in terms of potential ground-water recharge sites, areas naturally high in phosphorus and highly susceptible to erosion, and potential sites for landfill and spray irrigation waste disposal[7]. Commonly available resource data were used: soil survey, land cover/use inventory, and selected water well loss for assessing sub-surface characteristics related to groundwater recharge. A 10-acre grid cell was used to code the data.

Eleven maps (Table 2) were developed using data from the resource maps, either singly or in combination. The soil interpretation reference library was extensively used to portray soil suitabilities, general nutrient levels[6], and selected soil engineering properties. All maps were prepared on mylar using a drum plotter at a scale of 1:24,000 so they could directly overlay a standard base map.

The Potential Phosphorus Loading Source Areas map illustrates a typical 3-step analytical procedure. First, the soils map was used to retrieve the phosphorus level associated with each soil coded in the 10-acre cell.

Next, the soils map was used to obtain the coefficients required for erosion susceptibility modelling using the Universal Soil Loss Equation[10]. This model is an example of a calibrated site index; the resulting numbers have units of tons/acre/year and can be directly interpreted as a susceptibility of that site to erosion hazards. Given the resolution of the data, however, the erosion ratings were grouped into four qualitative classes: slight, moderate, severe and very severe.

Finally, the soil phosphorus level map and the erosion susceptibility map were combined in order to locate those sites that had moderate to very severe erosion hazards and medium to high soil phosphorus levels. These sub-sets of the total possible combinations were displayed using a combination of geometric symbols and symbol density.

Another example of multi-map integration is the Limitations for Sanitary Landfills map (Fig. 2). Using a site index model that permits factor weighting, data were obtained from three maps: the soil map, land cover/use, and potential ground water recharge zones (developed during a previous analysis session using RAP). The soils library was again used to retrieve important engineering properties, such as phosphorus adsorption capacity and workability.

Table 2. Maps and Data Sources Used in the Water Quality Project

		Data Source Map				
Map	Title	Soil	Slope	Land Cover/Use	Well Logs	RAP-developed
1.	Surface Topography & Natural Features		x			
2.	Land Cover/Use					
3.	Potential Ground Water Recharge Management Areas	x	x	x	x	
4.	Soil Phosphorus Availability	x				
5.	Potential On-Site Erosion	x	x			
6.	Potential Phosphorus Loading Source Areas	x				x1/
7.	Limitations for Septic Tanks	x	x			
8.	Limitations for Sanitary Landfills	x	x	x		x2/
9.	Limitations for Spray Irrigation	x	x	x		x2/
10.	Soil Stability	x				
11.	Limitations for General Agriculture	x	x	x		

1/ Potential On-Site Erosion 2/ Potential Ground Water Recharge Management Areas

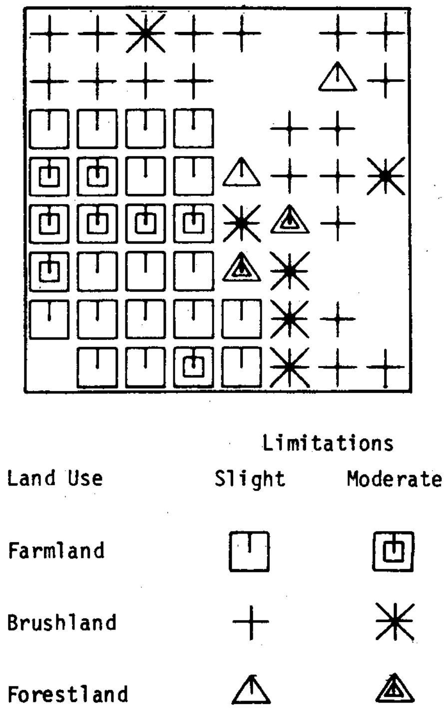

Figure 2. Limitations for sanitary landfills(section 36, Windsor Township).

Appropriate weighting values were assigned to each factor (this was a judgemental decision) and a site index was generated for each 10-acre cell ranging from 0 (a low limitation site) to 100 (a high limitation site). As in the previous example, the ratings were grouped to aid in the understanding of the results. As a final step, the land cover/use map was used to "filter" the ratings, to show only the low limitation sites that occur on farmland, brushland or woodlands.

B. AGRICULTURAL LAND ASSESSMENT - EATON COUNTY EQUALIZATION DEPARTMENT

A farmland assessment procedure, used by many County Equalization Offices in Michigan, is based on a land productivity rating by soil management group and current market values for the local area[3]. By law, the assessments must be updated annually. This application potentially represents one of the most recurring uses of soils information in the State.

The land productivity rating is developed by taking an average yield for a soil management group and normalizing it against the average yield for the most productive soils. The resulting values range from 0 (not productive) to 100 (most productive). A rating of 75, for example, indicates that the soil has an average yield that is 75% of the yield expected for the best farmland.

The current market value is derived from routine sales in the local area. Farm sales are analyzed to determine that portion of the sale price which is attributable to the land itself (total sale price minus the value of improvements). The residual land value is expressed as "number 1 equivalents", which actually is the land value normalized to the value of an acre of the most productive farmland. For example, if the residual land value is $750 per acre for a soil rated 75, then the number one equivalent value would be $1,000 per acre (100/75 x $750 = $1,000).

For each farm ownership parcel, the number of acres of the various soil types in agricultural use is determined and then the assessed value is calculated. The total assessed value for a parcel is the sum of the value derived for each soil type. It should be clear that this process, repeated for each parcel in a county, is a time consuming and labor intensive process.

This type of procedure is ideally suited for an applied mapping system and is implemented in RAP. An initial test was conducted in a township of Eaton County, Michigan, with the cooperation of the County Equalization Office[8]. The soil and land use maps were coded using 10-acre grid cells. For each cell, the soil information is used to retrieve the expected yields for the major crops grown in the county.

Only land identified on the land cover/use map as currently in agricultural is evaluated, since the resulting

```
  +----+----+----+----+   Land Value of
  I         I         I  /10-acre Parcel
  I  2388.  I  2800.  I
5 I 25 A B  I 25 C A  I — Soil Management
  I PASTURE I PASTURE I \ Unit
  I         I         I  \Land Cover/Use
  +----+----+----+----+
  I         I         I
  I  6493.  I  5971.  I
6 I 25 B A  I 25 A B  I
  I CROPLAN I CROPLAN I
  I         I         I
  +----+----+----+----+
     47        48
```

Figure 3. Estimated assessed value for land in agriculture (NE¼ of SE¼ of Section 1, Windsor Township).

assessed values do not apply to non-agricultural land. A special mapping procedure was implemented in RAP to display assessed land values, current land use and soil management group for each 10-acre cell in the township (Fig. 3).

The computer-derived assessed land values compare favorably close to those developed manually (Fig. 4). A check of approximately 25 parcels yielded a total sum difference of about 5%, with the average net difference for any single parcel being 3%, or less.

Based on these results, the Equalization Office undertook the task of manually coding the remaining 15 townships in the County. Its staff was trained in the coding process during a half-day workshop. The procedures, designed to fit in "slack" time of the staff, allowed the entire County to be completed in less than 10 weeks with an average coding time of 10 hours per township per map (soil and land cover/use).

C. TIMBER RESOURCE MANAGEMENT AND PLANNING - THE CEDAR TOWNSHIP DEMONSTRATION

A regional timber inventory, management and planning project was undertaken in Cedar Township, Osceola County Michigan. This area is within 3 miles of the proposed site of the first wood-burning electrical generating plant in Michigan. The impact on the timber resources by such a facility has aroused

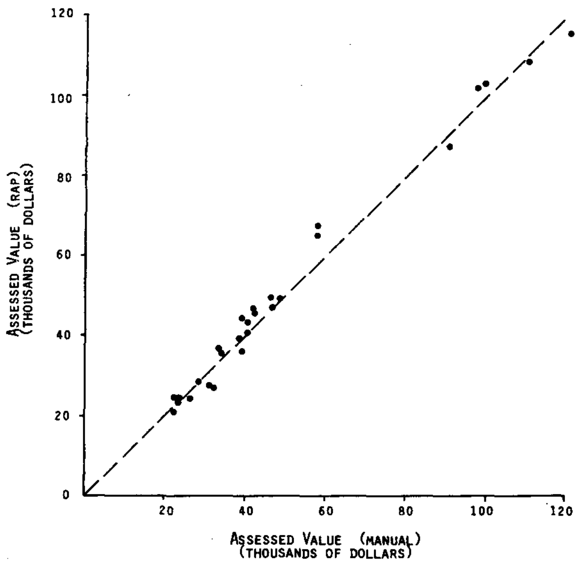

Figure 4. Assessed land values derived by RAP compared to those derived manually.

an intense public interest. The perceived competition by such a facility on the timber resource base is raising the importance of effective and practical management; given the regional nature of the project and the sheer volume of data required, a mapping system would appear to be a viable approach.

The regional planning commission provided a previously created map data base consisting of soils, land cover/use, ownership and forest type information. The soils data were summarized by woodland suitability groups, which in turn were used to access a series of interpretations stored in the RAP library. The forest type mapping units are based on a 9-category species grouping, stand size and stand stocking density. Thirteen maps and five tables (Table 3) were developed from the data.

As an example of the requirements of this project, the forest type map was used to generate interpretive maps of the major species groups, stand size, stocking density, merchantible timber and volume classes. This information was obtained by select feature extraction and assigning the appropriate graphic symbols during the mapping phase.

The timber volume map (Fig. 5) is particularly important in management studies. In general, there is limited data on which to generate volume tables, yet it is precisely this type of information that is required for map interpretation. Such a table can be used for economic planning, biomass estimations (a particularly important criteria for wood-burning electrical plants) and whole-tree harvesting.

The Cedar Township map used a very general, state-wide average volume table. There is no doubt that this information can be substantially improved through a coordinated effort of data gathering at a county or regional level.

Soils information is used to assess the harvest and replanting limitations for each 10-acre cell that has a standing timber stock. Typical interpretations are seedling mortality, plant competition, erosion hazard, equipment limitations and overall productivity index. Also, the soils information is used to evaluate site conditions for low stocking density forest stands and open land suitable for reforestation.

IV. SOME LESSONS LEARNED

Table 3. Maps and Data Sources Used in the Timber Management and Planning Project.

	Soils	Data Source Map Forest-Type	Ownership
Generalized Township Maps			
1. Generalized Forest Cover		x	
2. Forest Stand Size Classification		x	
3. Volume Classes		x	
4. Ownership			x
5. Merchantable Timber Stands		x	
6. Site Class	x		
7. Management Limitations	x		
8. Site Conditions for Forest Planting	x	x	
9. Pine plantations in Need of Thinning		x	
Detailed Section Maps			
1. Forest Stand Composition and Ownership		x	
2. Site Class, Woodland Suitability Group and Current Land Use	x	x	x
3. Volume Class and Reforestation Guide	x	x	
4. Hazards or Limitations that Affect Management of Soils for Woodland Use	x		
Summary Statistical Tables			
1. Acreage of Forest Stand Classification		x	x
2. Acres in Forest Cover Types by Size Class and Density of Stocking		x	
3. Acreage Distribution of Forest Species by Volume		x	
4. Acreage Distribution of Forest Species by Woodland Suitability Group	x	x	
5. Acreage Distribution of Forest Species by Site Class	x	x	

Over the course of applying RAP to a variety of problems involving natural resource inventory and management issues, several recurring needs of the user have been noted. A functional mapping system must address four major needs in order to successfully survive in a user environment: data capture, interpretive data libraries, data analysis, and mapping and data display. RAP has to varying degrees been successful in meeting these needs. The strengths and weaknesses of RAP will be pointed out for each of these four areas.

A DATA CAPTURE

Many users prefer to participate in developing the digital map data base, either because of a cost-saving measure or because of their unique knowledge of local conditions. This type of participation is encouraged for several reason: 1) the user has a better understanding of the data file structure and the use of the system, 2) the user has a stronger feeling of commitment to the system, thus enhancing its chances of receiving the proper maintenance and updating, and 3) the user has more tolerance to the inevitable errors that initially occur when coding map data.

A functional mapping system should be able to provide for user participation in data capture, both for map data and creating the system library tables. This implies that the system adapt to on-site use, since the effort must be scheduled in with other staff duties. This also implies that the techniques be simple enough so that relatively untrained operators can learn the procedures quickly.

The RAP data capture procedures have usually involved manually coding the maps from different sources and at different scales using grid overlays. Although easy to learn, the process can be tedious which may introduce errors. Digitizers have also been used for grid data capture but

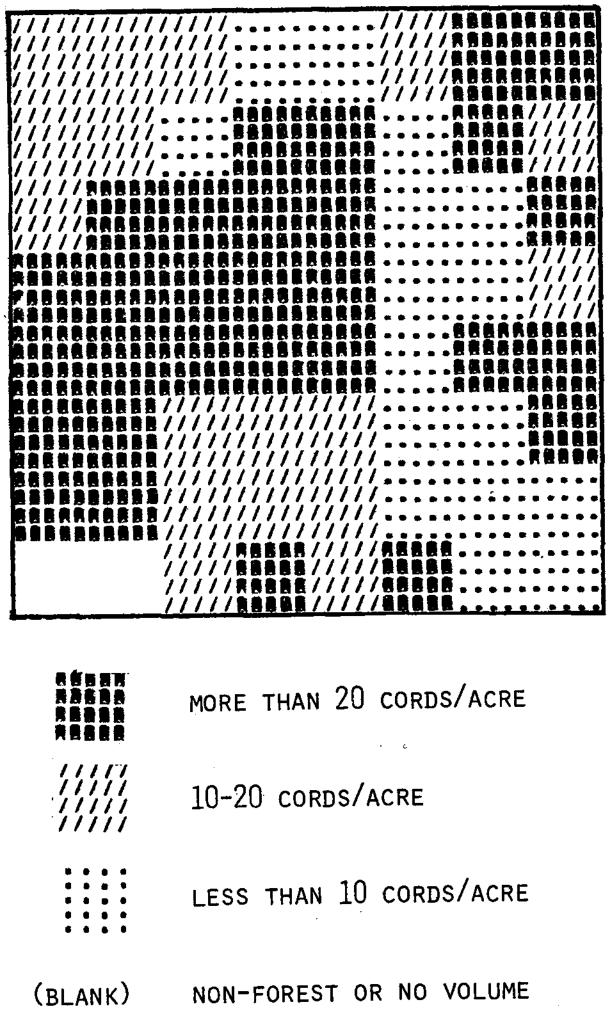

Figure 5. Timber volume classes (section 1, Cedar Township).

this requires access to the machinery, more involved data editting software, and not necessarily less time.

B. INTERPRETIVE DATA LIBRARIES

Interpretations and analyses are based on resource maps and tabular data acquired from a wide variety of sources. Some tables may be applicable to state-wide and regional areas, while others are restricted to local areas.

A mapping system should be able to develop its library from whatever source is most appropriate. State-wide tables result in a conservation of effort, yet it is the local data which "tailors" the system to the user's needs. Since all of the applications of a system can seldom be identified at project onset, the system library tables should have the ability to change and grow as the needs change. A data library system should run independently of the mapping programs, so that libraries can be shared, used in other application programs, and be changed without modifying the mapping system itself.

The current RAP system incorporates the library tables within the program code (the system is written in FORTRAN). Therefore, updating or adding to the library involves knowledge usually beyond the typical field user. This arrangement also makes customized library tables more difficult to implement and more expensive for the user.

As an example, the farmland appraisal and timber management applications both would benefit from having library tables specific for the areas of application. Most county soil surveys include crop yields, timber management guides and other information pertinent to that specific county. This information is preferred over that developed for state-wide use.

C. DATA ANALYSIS

The modular, vocabulary-like design of RAP commands seems to have been a good choice. This design forces system users to thoroughly understand the analytical procedure and tends to result in a better thought-out approach without discouraging experimenting with alternatives. This design is a strong point of the RAP system.

An additional advantage of the modular design is that the system can evolve and adapt to changing requirements. A new "word" can be added to the system that takes advantage of the other program phases. This results in simpler components that can be implemented with less effort and in a shorter period of time. Also, custom analytical phases can be developed for specific user needs without major system redesign.

D. MAPPING AND DATA DISPLAY

The simple line printer maps produced by the RAP system seems to be satisfactory for most user needs. The computer maps usually take on one of two forms: standard grey-tone or symbol maps and "title" maps in which information was written directly inside a graphic presentation of the grid cell.

One lesson slow to be learned was that mapping systems seldom stand by themselves. Products developed with the mapping system tend to be integrated with other information, spatial and tabular, that were routinely used before the system was on the scene. Thus, a functional system should be able to provide its products in a form that fosters this type of data integration. In this sense, information content might very well be more important than cartographic excellence.

This need is partly met by the analytical capabilities of RAP, but also requires a flexibility in data display. Patterns, geometric symbols and grey-tone ranges can be effectively used in this manner by the line-printer maps. Also, procedures that can result in color products for overlaying with other maps are effective communication tools. Low cost graphic printers seem to offer interesting possibilities in meeting the needs.

V. A MICROCOMPUTER-BASED GEOGRAPHIC INFORMATION SYSTEM

The technology involved with microcomputers has made dramatic advances over the past few years. Complete hardware systems are now available for under $4,000 that are fully capable of supporting township and county mapping applications. Off-line data storage provide virtually unlimited access to map data, library files, and application programs. Of course, the primary limiting factor is the processing time required for very large map files.

Initial work with microcomputers indicates that many of the shortcomings found with RAP system can be overcome. In particular, the highly interactive nature of these machines, the ease of use for which they can be programmed, and the potential of the many peripheal devices on the market make a microcomputer-based mapping system a very interesting prospect.

A microcomputer-based mapping system could be a self-contained field unit. By using a standard map data file, however, the system should be able to communicate with other mapping and information gathering systems through telecommunications or other down-loading techniques. The feasibility arises of a network of mapping systems, possibly supported by a central site system for more sophisticated and involved uses.

One such application would be to use a central site for processing and classifying Landsat data. The scene would be divided into application area sub-files, and then transferred to the field units for updating the land cover information at a local level. Indeed, for small areas, several Landsat classification programs are already available for microcomputer hardware.

Such a system currently being developed. The following is provided as a brief review, with particular reference to the four needs described previously.

A. DATA CAPTURE

The highly interactive nature of microcomputers make them ideally suited for grid-cell coding. One data capture technique is played much like a video game, with the user controlling a flashing cursor that "samples" the resource map at the specified grid interval. User entries can be verified against a master library table of map symbols. This step insures the integrity between the coded map and the library system.

The data capture process is being designed for one or two operators. It uses the identical hardware as does the mapping system, so the extra expense in special equipment is eliminated. Many error checking and convenience features are being built into the program set. A data entry verification routine is being developed that uses a voice synthesizer to verbally confirm a map symbol before adding to the data file.

B. INTERPRETIVE DATA LIBRARIES

The library function will be supported by a completely separate data base management system implemented on the microcomputer. The system is capable of maintaining a library file set that is integrated into, and accessible by, the mapping programs. A central library can be maintained from which local users may draw information. This will be augmented by local library development and maintenance through the provisions of the data base management system. This capability will be one of the major improvements over the larger, mainframe-bound, version of RAP.

For example, approaches are being discussed for implementing a timber harvest monitoring system that will develop regional and sub-regional timber volume tables. Creating volume tables with current empirical data, in effect, becomes the system's "learning center" for improving its accuracy of interpretation and opening up new possible applications. This type of system "learning" will be crucial in future timber management applications and the concept can be applied to non-forest data as well.

C. DATA ANALYSIS

The modular approach to analytical and mapping commands in the initial version of RAP will be maintained in the microcomputer version. The modularity is particularly suited for the small memory capacity of micros. Smaller application programs make room for larger data files. Most applications will be able to bring the map, or maps, into the computer's memory. Memory operations are much faster than disk operations, so the in-memory data buffering significantly decreases run time.

D. MAPPING AND DATA DISPLAY

Under direct computer control, a low-cost graphic printer can produce a wide variety of patterns (stripes and cross-hatching, among others), symbols (geometric and descriptive, such as standard swamp and water symbols), and complete grey-tone ranges. The density ranges of a graphic printer is particularly interesting. The startling realism of the now-common computer portraits and posters is an example of pictorial image representation by a graphic printer.

Techniques are being developed to use graphic output from the microcomputer mapping system to create color overlays to other map information. One inexpensive technique suitable for small size maps involves copying the map onto a overhead transparency using standard office copying machines. The transparency is then used to expose color diazo film in order to make the colored overlay. The resulting overlays are very effective and can be used in overhed projectors for group viewing.

VI. ACKNOWLEDGEMENTS

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VII. REFERENCES

1. Butler, K.S., et al., "Use of a computer-based resource data system to evaluate on-site waste disposal alternatives," Journal of Soil and Water Conservation, 32:214-219, 1977.

2. Cox, T.L., "Integration of land-use data and soil survey data," Photogrammetric Engineering and Remote Sensing, 43:1127-1133, 1977.

3. Michigan Tax Commission, State Assessors Manual), Lansing, Michigan, 1972.

4. Mokma, D.L., "Soil management units and land use planning," Ext. Bull. E-1262, Michigan State University, East Lansing, Michigan, 1964.

5. Nichols, J.D., and L.J. Bartelli, "Computer-generated interpretive soil maps," Journal of Soil and Water Conservation, 29:232-235, 1974.

6. Robertson, L.S., et al., "Test levels in soil profiles of Michigan corn fields," Mich. Agr. Exp. Sta. Res. Rep. 281, East Lansing, Michigan, 1975.

7. Tilmann, S.E., "A resource management portfolio for Windsor Township, Eaton County, Michigan," Remote Sensing Project, Michigan State University, East Lansing, Michigan, 1976.

8. Tilmann, S.E., "A computer-assisted farmland assessment procedure for property tax assessment," Remote Sensing Project, Michigan State University, East Lansing, Michigan, 1977.

9. Tilmann, S.E., "Resource Analysis Program: A user's guide to RAP," Remote Sensing Project, Michigan State University, East Lansing, Michigan, 1978.

10. Tilmann, S.E. and D.L. Mokma, "Soil management groups and soil erosion control," Mich. Agr. Exp. Sta. Res. Rep. 310, East Lansing, Michigan, 1976.

11. Tilmann, S.E., et al., "A procedure for mapping land cover/use data from Landsat, aerial photography and map sources: Compatibility, accuracy and cost," 2nd Annual Pecora Memorial Symposium, Sioux Falls, South Dakota, 1976.

12. Tilmann, S.E., et al., "A computer software system for integration and analysis of grid-based remote sensing data with other natural resource data," 1977 Annual Meeting of the American Society of Photogrammetry, Washington, D.C.

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