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Hydrologic Engineering Center

Proceedings of a Seminar on

Variable Grid Resolution - Issues and Requirements

18 - 19 August 1977
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14. ABSTRACT
A seminar on Variable Grid Resolution - Issues and Requirements was held on 18 - 19 August 1977 at the Hydrologic Engineering Center, Davis, CA. Spatial data management techniques are rapidly becoming practical tools for use by Corps of Engineers Field offices in a variety of ways. An issue that eventually surfaces in all studies is the resolution of data capture within data variables and between data variables in the spatial data file. As an initial step in resolving this issue a small group of experience researchers and practitioners were invited to an informal seminar to explore several aspects of variable resolution data capture in spatial data management techniques.

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University of Iowa
W.E. Gates & Associates
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FOREWORD

Spatial data management techniques are rapidly becoming practical tools for use by Corps of Engineers field offices in a variety of their responsibilities. Various aspects of these techniques have been applied in traditional survey and Phase I General Design Memorandum Studies and on a rather grand scale in the Expanded Flood Plain Information studies of the Corps Flood Plain Management Services program. More than a dozen field offices have made use of the concepts and techniques of spatial data management within the past two years. A particularly knotty issue that eventually surfaces in all studies is the resolution of data capture within data variables and between data variables in the spatial data files. A seemingly simple idea of managing different data variables by varying the resolution (in effect different grid sizes), within the data files is fraught with conceptual and technical pitfalls. As an initial step in dealing with this issue a small group of experienced researchers and practitioners were invited to convene at the Hydrologic Engineering Center (HEC) for an informal seminar to explore several aspects of variable resolution data capture in spatial data management techniques. These proceedings are the papers and discussions presented at this seminar, where the participants explored a range of alternative accommodations of variable resolution concerns which, to a substantial degree, represent documentation of the present state-of-the-art. It is hoped that these proceedings will serve as a stimulus to motivate interested researchers and practitioners to actively renew or continue efforts to practically deal with this particularly interesting and difficult technical problem.

The papers and discussions are, in general, frank statements by the authors and other seminar participants and are not to be construed as official Corps documents. The views and comments expressed are those of the seminar participants, and are not intended to modify or replace official guidance or directives such as engineer regulations, manuals, circulars, or technical letters issued by the office of the Chief of Engineers.

CONTENTS

VARIABLE GRID RESOLUTION - ISSUES AND REQUIREMENTS

The Hydrologic Engineering Center is using automated geographic information systems to manage data for hydrologic, economic and environmental analysis. The current methodology consists of using grid cell information at a resolution of 0.25 - 1.53 acres, stored in a computer data bank in a multivariable format, i.e., all the information pertaining to a cell is stored in the grid cell record. The grid cell resolution has in the past been determined by the desire to capture terrain variation to enable accurate modeling of damage and erosion processes. Most applications to date have grid cell dimensions derived from the area that a computer printer character occupies on a USGS 7 1/2-minute quadrangle. A computer character which measures a 1/10th of an inch across in the X direction (200 feet on the ground) and a 1/6 or an 1/8 inch down (333.33 or 250 feet on the ground), depending on whether the printer operates at 6 or 8 lines per inch. A cell which measures 200 x 333.33 feet equals 1.53 acres (8 lines per inch) and a cell which measures 200 x 250 feet equals 1.14 acres (6 lines per inch). This rectangular cell size is used to enable the use of printer graphics for fast and inexpensive scaled displays to aid in checking data and output of modeling results.

The data variables commonly used in modeling analysis are:

1. Areal data - Watershed and subbasin boundaries, damage reaches, land use patterns, soil associations, environmental habitats, city, county, and other political boundaries, and development zoning

2. Continuous data - Topographic elevation, reference flood elevation (water surface elevation for a specific flood event), depth to ground water and topographic slope

3. Lineal data - Transportation routes and stream networks

4. Point data - Archeologic and historic sites, point source information or sampling sites

The spatial data requirements of the modeling and display programs are:

HYDPAR - Watershed identification (watershed and subbasin code), land use pattern of interest, hydrologic soil group and land surface slope

DAMCAL - Damage reach identification, land use pattern of interest, topographic elevation and reference flood elevation

RIA -Discrete variable values for distance, impact and attractiveness modeling and GRID map display.

GRIDPLOT -Plotter display of data variables or analysis results which have been preclassified into classes which have a value of 1 - 10, 23 for low cells and 25 for high cells.

Current studies make use of data banks constructed with a uniform grid cell size, that is small enough to capture the variation in the most critical variable, which is usually topographic elevation for use in damage calculations. This resolution is required for grid cells within damage reaches (the flood plain), but by using a uniform cell size throughout the entire study area, many thousands of extra grid cells are processed by modeling programs because the information is relatively over-defined in relation to the modeling requirements. Figure 1, Flood Plain Resolution, shows this difference in data requirements.

Another demonstration of the same type of problem is shown in Figure 2, Urban vs. Rural Resolution, where areas inside a city limit (or potential urban area) may need very detailed information, with less detail in the surrounding areas being more than adequate.

DISCUSSION POINTS

Given the variable grid resolution issues discussed above, how should the spatial data be stored and retrieved?

1. Create a data storage structure which allows the HYDPAR, DAMCAL, GRIDPLOT and RIA programs to retrieve the spatial data they require,

and 2. Write a short 10 - 15 page report on your solution to the problem.

The paper will be formally presented at a seminar attended by other participants asked identical questions. The paper should conform to the following requirements and outline to permit timely publication of seminar proceedings.

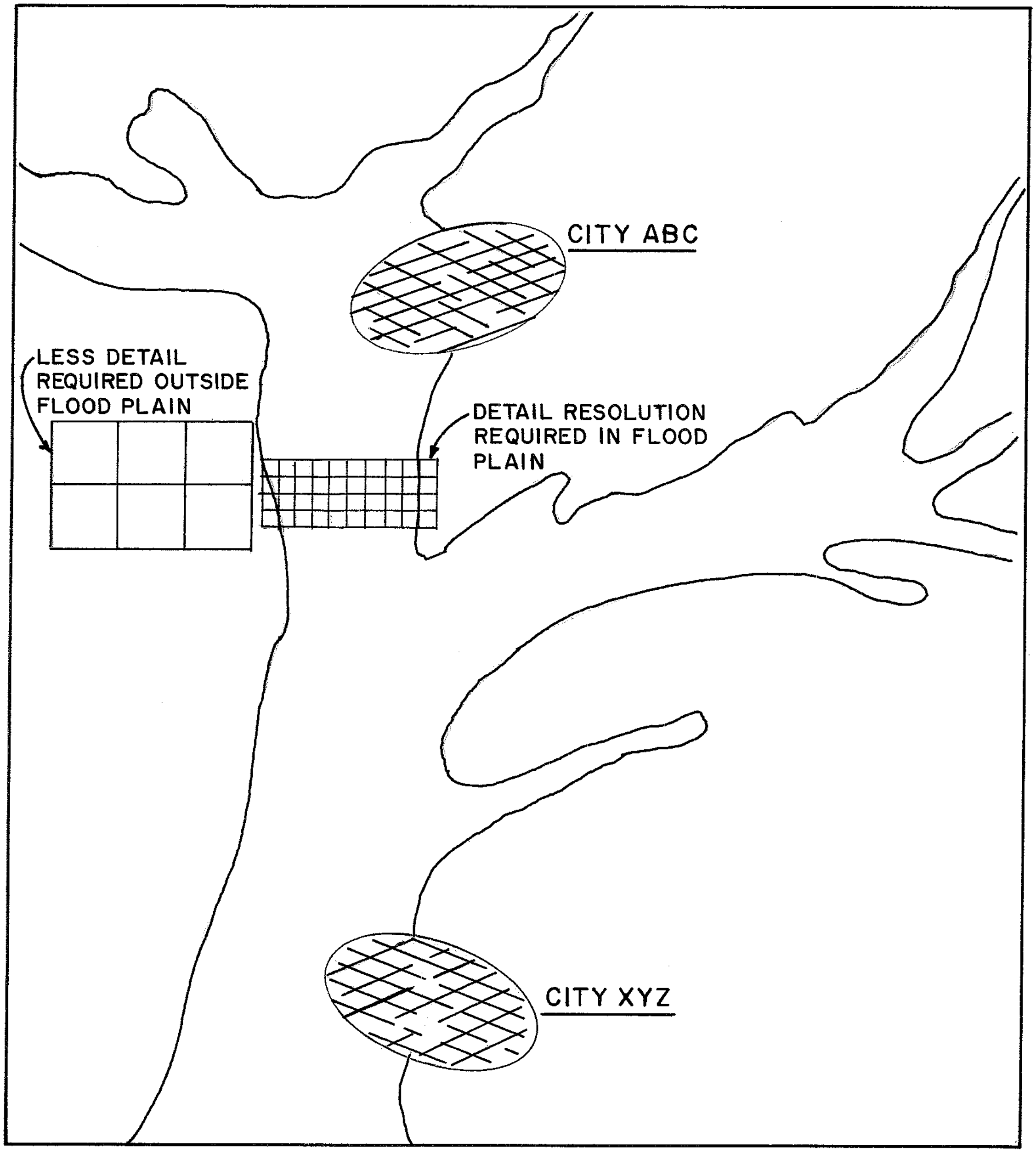

Figure 1. FLOOD PLAIN RESOLUTION

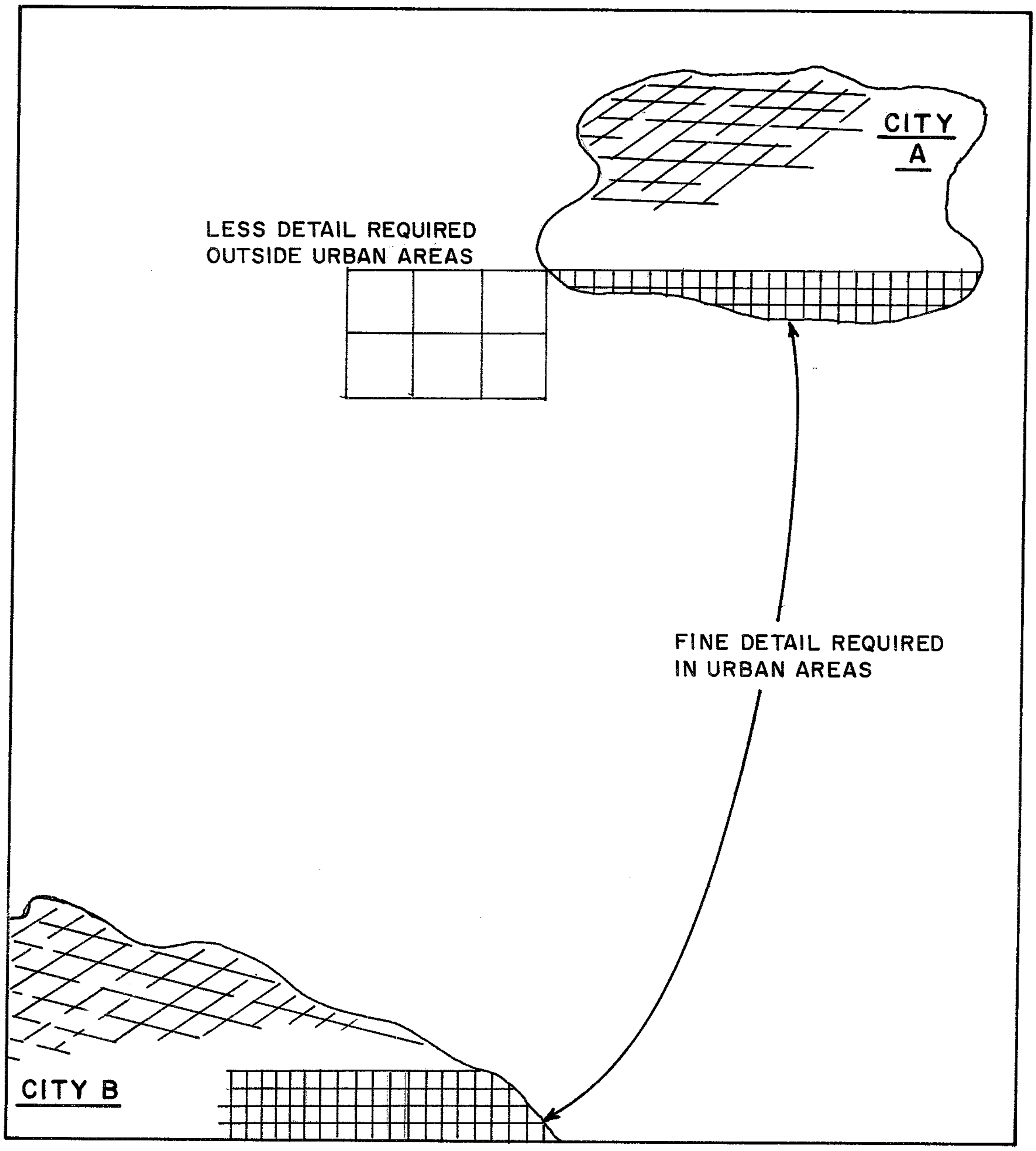

Figure 2. URBAN VS RURAL RESOLUTION

OUTLINE OF SOLUTION PAPER

I Introduction to suggested philosophy of handling spatial data.

II The data structure proposed for the storage of the spatial data.

III The data flow of information from the proposed data structure to each of the HYDPAR, DAMCAL, GRIDPLOT and RIA programs.

IV How the data structure would conform to computer graphics that are based on a single grid cell resolution (GRID and GRIDPLOT).

V Advantages and disadvantages of proposed technique vs. a single uniform grid resolution throughout the entire study area.

VI Conclusions and other observations, prognostications.

VII References

MANUSCRIPT SPECIFICATIONS

I Each paper will be typed in final form on 8 1/2 x 11 paper and will conform to the standard HEC seminar paper requirements.

II All figures and tables should be scaled so that they may be reduced to 8 1/2 x 11 pages, and still be readable.

BACKGROUND AND SEMINAR OBJECTIVES

by

Darryl W. Davis[1]

BACKGROUND

The Corps of Engineers began exploring the application of spatial data management techniques to planning studies in the late 1960's with the publication of a contract research document "A Comparative Study of Resource Analysis Methods" (1)[a/] prepared by the Department of Landscape Architecture, Harvard University, a pioneer in the development of methods of geographic data management. The Corps subsequently requested the same group to prepare a strategy for using these methods in planning recreation facilities around the periphery of Corps reservoirs. The research report "Honey Hill: A Systems Analysis for Planning the Multiple Use of Controlled Water Areas" (2) documented the strategy and illustrated its use on a small reservoir in the New England area. The Corps Institute for Water Resources, (IWR), the research manager for the investigation at that time, sponsored a field trial of the grid based spatial data management methodology in the Santa Ana river basin, near Los Angeles, California. The Santa Ana basin is some 10,000 sq. mi. in size and the planning study was comprehensive in scope. A long list of complications, subsequently documented in "The Santa Ana River Basin, An Example of the Use of Computer Graphics in Regional Plan Evaluation" (3), resulted in the trial being less than a complete success. The IWR recognized that a major shortcoming of the field trial was the lack of access by field staff to readily available Corps expertise in the area of data management technology. To overcome this basic problem the HEC was invited to investigate the concepts and methodology of the Honey Hill work and consider assuming the responsibility for its implementation in Corps studies, if appropriate; the thinking being that HEC was experienced in the development and management of computerized technology and was experienced in providing field assistance.

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[1] Chief, Planning Analysis Branch, The Hydrologic Engineering Center, Davis, California.

[a/] References are listed at the end of the paper.

HEC investigated the methodology, particularly the data management aspects and it seemed that there was great potential for useful application in many of HEC's areas of interest. The program source code for creating and managing the grid data banks and performing certain analysis and output displays was requested from Harvard, the L.A. District, and IWR. The material obtained was simply unuseable. HEC received source code listings (no decks) that were printed in the wrong character set, no documentation, and no offer of aid to bring the software up on HEC computers. The point of this background on the source code is that HEC by necessity started from scratch to acquire and/or create the computer code that now represents the currently existing HEC spatial data management capability. From this experience, HEC has developed considerable knowledge of the concepts and it has also become intimately familiar with the software/hardware aspects of spatial data management technology.

At about this same time HEC was assisting the St. Louis District in formulation of alternatives for an authorized interior flood control project. A mutual interest in applying the grid data management methods to the facility siting tasks of plan formulation resulted in HEC developing the Locational Attractiveness capability of the later more comprehensive Resource Information and Analysis (RIA) program. This capability was patterned after the basic Harvard work (2) and was applied for this investigation. A small grid cell data bank was created covering the study area with about a five acre resolution grid. The ideas for using the grid data base to perform quantitative computations for hydrologic and damage analysis were developed at this time. The grid size seemed satisfactory for the hydrologic computations but was clearly unsatisfactory to capture the terrain variation (topography) accurately enough to permit credible damage calculations to be performed. The creation of a smaller resolution (about 1.5 acre grids) data bank was initiated but to this day (late 1977) has yet to be completed. Shifting of priorities and personnel within the St. Louis District has slowed progress to a near halt. A more dynamic, enthusiastic project setting was needed and it appeared as if one had been precisely scheduled.

The Savannah District consented with the Corps headquarters to perform a pilot study that sought to establish a services posture that would be a long term commitment for advice and analytical assistance by the Crops to local communities in decisions and actions related to the floodplain. The scope of services was to be comprehensive and continuous, i.e. available on request for special assessments. HEC was asked to provide advice on the technology aspects of providing the community services planned for the pilot study. The general concept of integrated interactive use of a comprehensive gridded geographic and resource data bank was adopted and developmental efforts were begun in earnest by HEC. The use of grid data was determined to be the only spatial data management technique that offered significant analytical opportunities when compared to polygon oriented approaches. The results of the basic research and development efforts and a test application are documented in "Phase I Oconee Basin Pilot Study, Trail Creek Test" (4). The integrated data management and analysis system is specifically described in detail in "Spatial Data Management and Comprehensive Analysis System (HEC-SAM)" (5) which is reproduced in these proceedings for reference purposes. Due to the demonstrated analytical power of spatial data management techniques, other applications of the technology are being implemented in other Corps studies, such as the evaluation of structural and nonstructural flood damage reduction measures (6) and the evaluation of dredge disposal activities in the San Francisco Bay (7).

It should be noted at this point that the use of gridded data banks by HEC and users of HEC developed technology is substantially different from the use that is made by geographers and users of the Harvard type landscape analysis. The focus by HEC has been on an output product which is a step or at times two steps beyond the data bank. In other words the data bank is a means to an end, not an end in itself. The product sought is generally quantative engineering type analysis, rather than graphic displays and simple statistics as has been the more common historical use of gridded data banks. The contents of the data bank are used to calculate hard parameters for detailed hydrologic and water quality simulation models, accurately compute damages, as well as provide the more traditional geographic analysis.

Spatial data management methods have been applied in one completed Expanded Flood Plain Information (XFPI) study (8) and they are being employed in another 10 XFPI studies currently underway. HEC is assisting all studies but one. The study areas range in size from 15 to 800 square miles and the resolution of data capture varies from about one quarter acre to 4.5 acres. The odd sizes are because the cells are rectangular to permit line printer output to be undistorted. The grid cell data banks being created range from 15 variables to 30 variables. The Corps Waterways Experiment Station (WES) is performing the one remaining XFPI study which encompasses the largest area, some 800 square miles. The WES has had considerable experience over the years in creating and using gridded terrain (topography) data files in connection with military mobility research.

The grid cell size to be adopted for data capture eventually emerged in all the studies as a significant issue. On the one hand, great fidelity is required for certain analysis such as topography for erosion analysis, and topography and land use for flood damage calculations while on the other hand, considerable generalization is appropriate for some other data variables and analysis such as land use for hydrologic computations. The approach currently taken by HEC is to capture all data at the resolution needed for the most critical variable since there does not presently exist technology that will easily manage varying grid resolution within a grid cell data file.

Even though all HEC assisted studies have adopted a single uniform grid for all variables, there continues to be a feeling among field offices performing the studies that there must be a better alternative than managing all of the data at the critical resolution of a single data variable. The WES study adopted a two data bank approach - grids of about 10 acres for all variables off the flood plain and grids of about one fourth acre for selected damage related variables in the flood plain. Unfortunately, representatives of WES declined to attend this seminar and represent that particular (two data bank) approach to variable grid resolution.

OBJECTIVES

The objectives of the seminar convened are as follows:

* Sharpen our collective perceptions of the significant issues related to data capture resolution.

* Define the existing state-of-the-art in spatial data management.

* Define the issue and suggest solutions for resolution variation between data variables.

* Define the resolution issue and suggest solutions with respect to the geographic scope and cell size encompassed by the data bank, e.g. what are the limits and bounds on the mass amount of data that can be sensibly handled.

* Foster a collective sense of camaraderie among the assembled professionals to encourage sharing of ideas for the advancement of spatial data management technology.

REFERENCES

1. Steinitz et.al. A Comparative Study of Resource Analysis Methods, Department of Landscape Architecture Research Office, Graduate School of Design, Harvard University, July 1969.

2. Honey Hill: A Systems Analysis for Planning the Multiple Use of Controlled Water Areas, IWR Report 71-9, October 1971.

3. The Santa Ana Basin: An Example of the Use of Computer Graphics in Regional Plan Evaluation, IWR Contract Report 75-3, June 1975.

4. Phase I Oconee Basin Pilot Study, Trail Creek Test, The Hydrologic Engineering Center, September 1975.

5. Davis, D.W., Spatial Data Management and Comprehensive Analysis System (HEC-SAM), 21 October 1976.

6. Webb, R.P. and Burnham, M.W., Spatial Data Analysis of Nonstructural Measures, Technical Paper No. 46, The Hydrologic Engineering Center U.S. Army Corps of Engineers, Davis, California, 1976.

7. Dredge Disposal Study, San Francisco Bay and Estuary, U.S. Army Corps of Engineers, San Francisco District, September 1977.

8. Expanded Flood Plain Information Study, Upper Oconee River Basin, Ga., General Report, U.S. Army Engineer District, Savannah, May 1977.

1. Spatial Data Management and Comprehensive Analysis System (HEC-SAM)

2. Purpose of HEC-SAM

HEC-SAM was created to provide an analytical tool and analysis structure that would permit Corps of Engineers District offices to provide comprehensive planning assistance to local governmental units in decisions related to flood plain management (1).* The specific technical purpose was to provide the capability to assess hydrologic, flood damage, and environmental consequences of development situations that are reflected by alternative land use patterns and water management works. The planning environment which the system is designed to service is urban areas where development pressures are either currently significant or expected to be significant in the near future and where there exists a strong desire on the part of the local planning agencies to manage development in the best interests of the community, giving balanced considerations to flood hazard consequences of off flood plain and on flood plain development.

The general analytical strategy that comprises HEC-SAM is to 1) assemble and catalogue basic geographic and resource information into a computer data bank 2) cooperatively, with local agencies, forecast and place into the data bank selected alternative future development patterns 3) perform comprehensive assessments of the selected alternative futures and 4) document the assessment for study by the general public and community officials. Subsequent assessment services would be provided on a continuing basis at local agency request. Specific development proposals would be assessed, land use development policies analyzed and informed technical guidance provided by the Corps to the local officials.

The system is presently emerging from the pilot study stage and is being applied in several studies of the type for which it was created. It has also proven sufficiently attractive and powerful that managers of some traditional Corps Survey Investigations plan to make use of major portions of the technology in their studies.

3. System Characteristics

a. Software: The HEC-SAM system is comprised of a family of data management and analysis computer programs that service the full range of comprehensive assessments. Figure 1 presents a functional flow diagram of the analysis process and input and output results. About 1/3 of the links shown on the diagram for the Interface and Analysis programs are presently automated and these links are intended to be highly automated in the near future. Table 1 lists and briefly describes the computer software indicated on the general flow diagram.

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*References are listed at the end of the paper.

The system has three distinct functional elements: Data Bank Management, Data Bank Processing Interface, and Comprehensive Analysis. The data bank management element is comprised of the subfamily of computer programs required to process raw map or other type data to the grid cell format that becomes the general data bank. This includes a program that permits displaying data digitized in the grid cell format (GRID) (2), a program that displays data digitized in the polygon format and generates grid cell data from polygon format data (AUTOMAP II) (3), special purpose programs to create grid topographic data from digitized contour lines (TOPO, LINES), and programs to properly register polygon data to the base grid system (REGISTER) and place the grid data into the general data bank. (BANK)

The Data Bank Processing Interface element is comprised of computer programs that compile and reformat geographic and resource data retrieved from the data bank into a form processable by the general analysis computer programs. The programs service the functional analysis areas of Flood Hazard, Flood Damage and Environmental Status. HYDPAR links the data bank to the flood hazard analysis by retrieving the data variables of hydrologic subbasins, slope, soil group and land use to generate the modeling parameters required to simulate storm runoff. The link between the generated modeling parameters and the simulation analysis program (HEC-1) is currently systematic but not automated. HYDPAR also provides links to the environmental analysis by retrieving land use, soil and subbasin data from the data bank and generating modeling parameters required to simulate the quality of urban storm runoff and land surface erosion. The link between the data bank through HYDPAR to the analysis program STORM is completely automated, with the subsequent link to the general dynamic water quality simulation not presently automated. DAMCAL links the data bank to the flood damage analysis by retrieving the data variables of damage reach, land use, topography and reference flood to generate elevation-damage tables by land use category and damage index location for subsequent integrated analysis. ATODTA also serves the flood damage analysis by restructuring the DAMCAL generated data, interfacing it with hydraulic and hydrologic probability data and providing an automated link to the general hydrologic and damage analysis program HEC-1. The linkage from the data bank through DAMCAL and ATODTA to the analysis program is completely automated.

The Comprehensive Analysis element is comprised of the general simulation and analysis computer programs that perform the end product detailed technical assessments that compare the existing condition to the development condition of interest. In most instances the final analysis computer programs are standard Corps of Engineers analytical tools that have been in use a number of years and are thus familiar to potential Corps users. Some programs have been slightly modified to interface with data being generated from the data bank rather than in their usual formats. In a few instances basic modifications were made to the programs to permit or encourage a more systematic analysis process (than traditional) to take advantage of the opportunities offered by ready access to a comprehensive data bank. HEC-2 (4) has served the Corps many years in performing river hydraulic analysis and is used in its traditional form. HEC-1 (4) serves the double duty of general hydrologic simulation to forecast

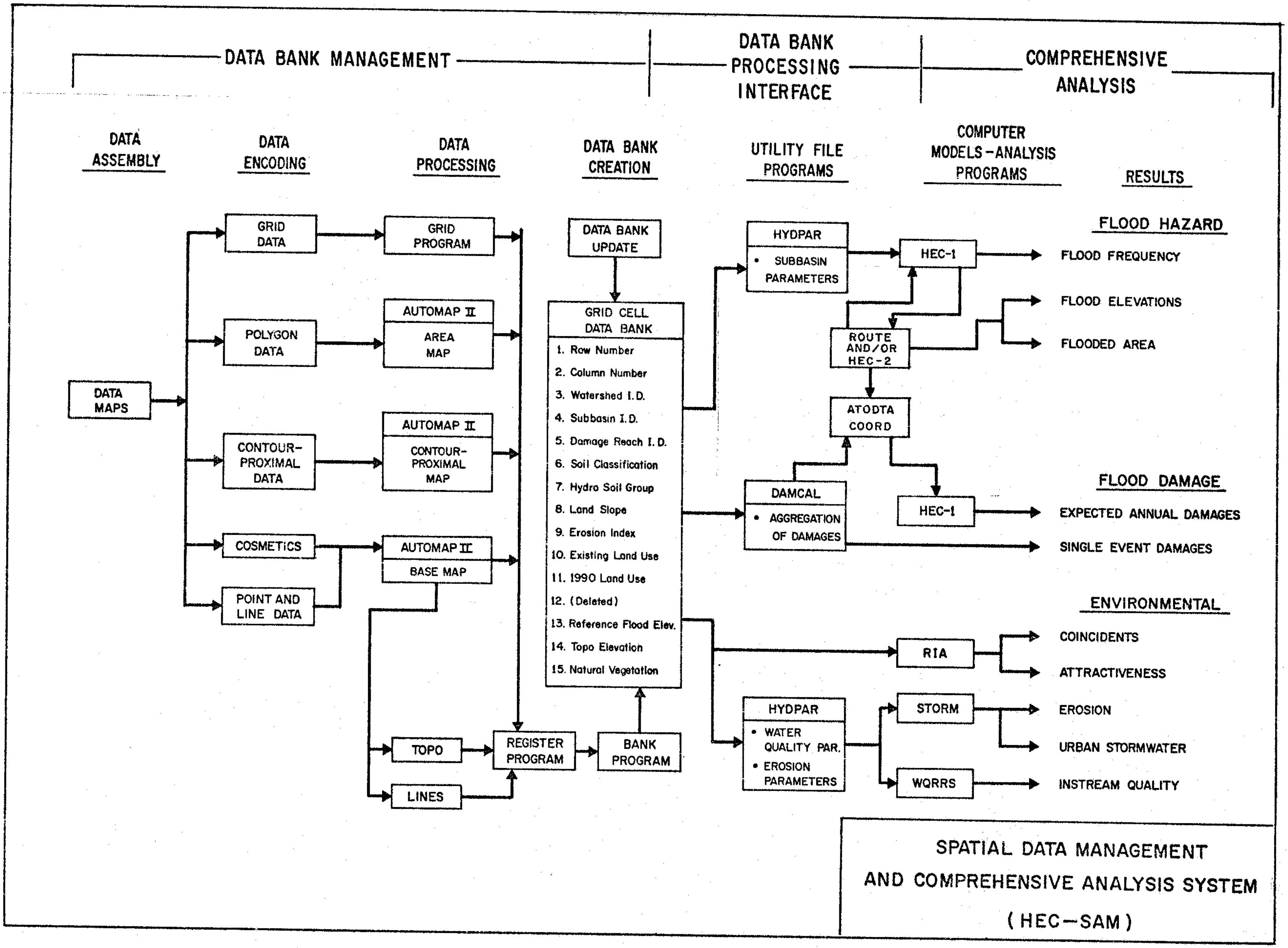
DATA BANK MANAGEMENT
DATA BANK PROCESSING INTERFACE
COMPREHENSIVE ANALYSIS
DATA ASSEMBLY
DATA ENCODING
DATA PROCESSING
DATA BANK CREATION
UTILITY FILE PROGRAMS
COMPUTER MODELS-ANALYSIS PROGRAMS
RESULTS
DATA MAPS
GRID DATA
POLYGON DATA
CONTOUR-PROXIMAL DATA
COSMETICS
POINT AND LINE DATA
GRID PROGRAM
AUTOMAP II
AREA MAP
AUTOMAP II
CONTOUR-PROXIMAL MAP
AUTOMAP II
BASE MAP
TOPO
LINES
REGISTER PROGRAM
BANK PROGRAM
DATA BANK UPDATE
GRID CELL DATA BANK
1. Row Number
2. Column Number
3. Watershed I.D.
4. Subbasin I.D.
5. Damage Reach I.D.
6. Soil Classification
7. Hydro Soil Group
8. Land Slope
9. Erosion Index
10. Existing Land Use
11. 1990 Land Use
12. (Deleted)
13. Reference Flood Elev.
14. Topo Elevation
15. Natural Vegetation
HYDPAR
• SUBBASIN PARAMETERS
DAMCAL
• AGGREGATION OF DAMAGES
HYDPAR
• WATER QUALITY PAR.
• EROSION PARAMETERS
HEC-1
ROUTE AND/OR HEC-2
ATODTA COORD
HEC-1
RIA
STORM
WQRRS
FLOOD HAZARD
FLOOD FREQUENCY
FLOOD ELEVATIONS
FLOODED AREA
FLOOD DAMAGE
EXPECTED ANNUAL DAMAGES
SINGLE EVENT DAMAGES
ENVIRONMENTAL
COINCIDENTS
ATTRACTIVENESS
EROSION
URBAN STORMWATER
INSTREAM QUALITY
SPATIAL DATA MANAGEMENT AND COMPREHENSIVE ANALYSIS SYSTEM (HEC-SAM)

Figure 1

TABLE 1

HEC-SAM SOFTWARE SUMMARY

Title	Source/Availability	Description
Data Bank Management Programs		
GRID	Harvard (2)* / HEC	Prints grey shade overprint maps of grid data.
AUTOMAP II	ESRI (3) / HEC	Prints grey shade overprint maps and generates grid data from polygon data.
REGISTER	HEC (1) (New)**	Registers polygon data sets to base map coordinates.
TOPO/INTPL	HEC (1) (New)	Generates grid topographic data from contour data.
BANK	HEC (1) (New)	Manages files comprising grid cell data bank.
Data Bank Processing Interface		
HYDPAR	HEC (1) (New)	Generates hydrologic, storm quality and erosion modeling parameters from data bank.
DAMCAL	HEC (1) (New)	Generates elevation-damage files from data bank.
ATODTA	HEC (1) (New)	Coordinates and manages economic, hydraulic and hydrologic data for modeling.
ROUTE	HEC (1) (New)	Generates hydrologic modeling data from stream geometry files.
Comprehensive Analysis		
HEC-1	HEC (Modified) (1)	Generalized hydrologic and flood damage analysis model.
HEC-2	HEC (1)	Generalized river hydraulic model converts flow to elevation.
STORM	HEC (1)	Generalized urban storm water quality and surface erosion model.
WQRRS	HEC (1)	Generalized stream water quality simulation model.
RIA	Harvard/HEC (New)	Spatial analysis package for attractiveness and impact analysis based on work done by Harvard.

* Program reference documents

** Programs labeled (New) were developed specifically for the pilot study and have not been generally released.

the hydrologic effects of development proposals and also integration of the hydrologic with economic damage data to provide the assessment of the expected value of annual damages (average annual damages) resulting from development alternatives. The RIA program operates by direct link to the data bank and performs coincident, attractiveness and vulnerability analysis and general grid mapping. The program is adapted from work by Harvard (5) and makes use of a modified version of the general grid plot program GRID (2). STORM and WQRRS (4) are recently developed Hydrologic Engineering Center computer programs that forecast urban stormwater quality and dynamic instream water quality simulations of waste loadings from treatment plants and urban storm runoff.

b. Hardware: The HEC-SAM system has been developed to operate on major computer systems. The system used most extensively for original program development work was the CDC 7600 installation at the Lawrence Berkeley Laboratories of the U. S. Nuclear Regulatory Commission (Berkeley, California). The programs are written in ANSI Standard FORTRAN IV and are thus basically portable between major computer systems. No transfer of programs has yet been made, however. Major systems with 64,000 words of core storage and 4 peripheral storage devices (tapes, discs, etc.) and standard line printer output can accommodate all system programs. The Data Bank Management and Data Bank Processing Interface programs do not require the storage and computer speed of the major programs and thus could be operated on smaller perhaps even mini computer systems. The comprehensive analysis programs require the core size and execution speed of major computer systems to be used efficiently and effectively.

c. Input, Analysis and Output: The system envisions that the data normally used during comprehensive planning studies would be encoded and processed onto a computer storage device (such as tape or disc) by application of the various Data Bank Management programs. The specific programs used would depend upon the form in which the digitized data is received; either point, grid, contour or polygon, the form being dependent upon the nature of the variable and the relative advantages and disadvantages of alternative encoding methods. The initial input data are the basic resource maps that are encoded and placed into the data bank. Analysis would be performed for a selected development condition (alternative future, e.g., a projected land use pattern with a certain flood hazard zoning policy) by processing the development into the data bank as a new variable and successively executing the Interface and Comprehensive Analysis programs. The specific executions that are performed would be dependent upon the specific nature of the alternative future that is assessed.

The comprehensive assessments require specific input data such as the hydrologic structure of the area, stream geometry, calibrated storms, relationships between land use and runoff, damage potential, storm pollutant washoff etc. The initial modeling calibration data is prepared conventionally based on observed data supplemented by parameters generated from the data bank and then the calibration data is used as the mechanism for forecasting the change in modeling data that would be caused by development alternatives.

The system output includes 1) grid map graphic displays of the data variables, attractiveness, and impact analysis results and 2) detailed numeric printout of runoff hydrographs, flow exceedance frequency relationships, expected annual damages, storm pollutographs and time traces of erosion and a range of water quality parameters for existing and the selected alternative future development patterns. The output corresponds to the complete range of technical output of comprehensive flood plain assessments.

d. Resolution and Accuracy: A major purpose in creation of HEC-SAM was to cause consistent, systematic analysis of future development to be performed in traditional functional areas and with a common data set. The level of detail and accuracy of final analysis was to be consistent with traditional methods, i.e., not permit loss of detail. For hydrologic computations, rather coarse grid sizes (4 to 10 hectares) and relatively few categories of major variables (for example 4 to 5 land use classes) are considered sufficient. General environmental analysis does not seem to be more greatly demanding in detail than required for hydrologic analysis. Flood damage calculations, on the other hand, require a rather accurate terrain resolution within the flood plain and land use category subdivision be employed. Depending upon topographic variation, grid cells as small as 1/4 hectare are necessary whereas in more gentle terrain, as large as 2 hectares could be acceptable. In any event, it appears the terrain variation and subsequent detail required for flood damage analysis dictates the appropriate grid cell size. The present state of HEC-SAM does not permit variable grid cell size being stored in the data bank so that the terrain of the study area dictates the size of the grid cells for all data variables.

4. Analysis Capabilities

The general capability of HEC-SAM is to provide a comprehensive systematic, assessment of alternative development patterns in the functional areas of flood hazard, flood damage and environmental status. A listing of the more commonly used capabilities in each of these areas would include:

a. Flood Hazard: HEC-SAM will evaluate the following prespecified alternatives for a specific storm event (such as the 100-year interval event) or for a range of storm events (development of flow and/or elevation exceedance frequency relationship) at all selected important locations within a study area.

- Changed land use patterns
- Changed drainage system
- Flood plain occupancy encroachments
- On-site water management strategies
- Engineering works of levees, channel modifications, reservoir storage and flow rerouting
- Watershed management practices

b. Flood Damage: HEC-SAM will evaluate the dollar damages for a specific event (such as the 100-year exceedance interval event) and the expected value of annual damages (average annual damages) for each designated location in the study area and each desired damage category (residential, commercial, etc.) for the following:

- Changed flood plain occupancy
- Changed watershed runoff such as from changed land use
- Changed stream conveyance such as from floodplain encroachment
- Changed structural construction practices
- Alternative development control policies
- Changed value of flood plain structures
- Modified structure damage potential such as from flood proofing
- Effects of engineering flood control and drainage works of levees, channels, reservoirs, and diversions

c. Environmental: HEC-SAM will perform a variety of environmental evaluations for the alternatives and conditions described in Flood Hazard and Flood Damage above. The evaluations that can be performed are:

- Catalogue environmental habitat changes from changed land use (coincident analysis)
- Forecast changes in land surface erosion and transport for land use and engineering work changes
- Forecast changes in runoff quality from changed land use
- Forecast changes in stream water quality
- Develop first order attractiveness and impact spatial displays
- Identify enriched habitat zones by econ-tone analysis

5. Applications

HEC-SAM was created as a part of a pilot study entitled "Expanded Flood Plain Information Study for the Upper Oconee River Basin." The study area includes Athens, Georgia and was undertaken by the Savannah District, Corps of Engineers with analytical assistance by The Hydrologic Engineering Center. A test area of the pilot study area was selected and full scale analysis performed and documented in (1). The pilot study itself has been completed and publication of the initial assessments of four alternative future land use patterns is expected in late 1976. Based on findings and encouraging results from this initial pilot study, three others have been initiated that are at various stages of completion ranging from just beginning to 50 percent complete. Six to eight new studies are programmed for initiation during FY 77.

The results of HEC-SAM applications are generated in map, tabular, and graphic format, much of which is complex and detailed and thus requires an experienced professional to interpret and display. This is especially true in the detailed water quality assessments. Selected published test results (1) have been extracted and are presented herein to illustrate the nature of the outputs.

The test area for which results are shown is the Trail Creek watershed which occupies about 12 $mi.^2$ of the pilot study area of 300 $mi.^2$ and includes a portion of the city of Athens, Georgia. The test area is presently about 10 percent urban and expected to grow to 20 to 30 percent urban by 1990. The data bank created for Trail Creek included the 15 data variables shown in Figure 1 at a grid size of approximately 0.6 hectares.

a. Flood Hazard: Table 2 summarizes the results of evaluating the alternative conditions indicated. Note that the flow rate increases for each of the specified probabilities but at a less proportionate rate for rarer events. Note also that the flow rate change for say the 100-year event is different between control points and that the change in flood elevation is not directly proportional to the change in flow. Study of the table indicates that the hydrologic consequences of land use and engineering works are complex and require careful analysis.

TABLE 2

HYDROLOGIC DATA SUMMARY

TRAIL CREEK TEST

100 YEAR PEAK FLOW AND ELEVATION

Index Station	Existing Flow (cfs)	Land Use Elevation	1990 Land Use Flow (cfs)	1990 Land Use Elevation
1	7600	627.1	9400	628.3
2	3450	656.4	3800	656.7
3	2600	711.9	2900	712.2
4	3900	650.3	5100	651.2
5	1600	694.2	1650	694.3

FLOW - EXCEEDANCE INTERVAL DATA
(cfs)

Index Station

Exceedance Interval (yr)	1 Exist	1 1900	2 Exist	2 1990	3 Exist	3 1990	4 Exist	4 1990	5 Exist	5 1990
5	2000	2800	950	1200	800	960	1100	1700	500	570
10	3000	3900	1350	1650	1100	1300	1600	2300	700	780
25	4400	5600	2000	2400	1600	1850	2300	3300	1000	1100
50	5800	7300	2650	3000	2100	2350	3000	4000	1250	1350
100	7600	9400	3400	3800	2700	3000	4000	5200	1600	1700

b. Flood Damage: Table 3 summarizes selected expected annual damage assessments for a range of conditions and land use control policy sets for damage reaches within the Trail Creek watershed that sustain significant damages.

TABLE 3
SELECTED DAMAGE ASSESSMENTS
TRAIL CREEK TEST

(Expected Annual Damage in 1000's $)

	EVALUATION CONDITION		DAMAGE REACH			
CODE	LAND USE POLICY 1/	HYDROLOGY	1	2	3	TOTAL
I	Existing	Existing (1974)	1.5	1.9	11.9	15.3
X	1990 with no development controls	1990	1033.3	350.0	32.7	1416.0
IV	1990 with new development at 1974 100-year flood level	1990	19.3	63.8	23.8	106.9
V	1990 w/new devel. @ 1974 100-year & flood proofed to ground floor	1990	16.8	18.9	4.7	40.4
VIII	1990 w/new devel. @ 1990 100-year & flood proof to ground floor	1990	11.9	16.0	2.8	30.7

1/ The 1990 land use condition is a projection based on local agency judgment. In some instances, such as Damage Reach 3, 1990 urban type development has displaced some present agricultural development.

The results are somewhat surprising and at first glance may be difficult to understand. An initial reaction might be that evaluation condition CODE IV should be similar to CODE I since the policy of no new development occurring at elevations below the 100-year event is in effect. The table shows a large increase in expected annual damages. This increase is because (1) damage does occur for new basement construction, (2) the 100-year flood for 1990 land use conditions is higher than the 100-year flood for existing land use conditions, and (3) damages are sustained by new development from events that exceed the 100-year event. Several other evaluations that include a number of alternative control and flood proofing policies are included to demonstrate the broad capability of the spatial data management technique as well as present some interesting evaluations of policies designed to manage flood losses.

c. Environmental: The environmental assessment results selected for illustration emphasize the spatial data management features of HEC-SAM. The water quality and land surface erosion assessments for the pilot study are undergoing final interpretation and are thus not available for publication.

The coincident tabulation is a first level of analysis and is comprised of a data display cataloging of change. The concept is to track changes in watershed land use coincident with an environmental interpretation of the watershed. The coincident analysis may be performed between any pairs of data in the file for any areal subdivision (such as subbasins or damage reaches). Table 4 is a coincident tabulation for the existing and 1990 land use conditions for damage reach No. 2.

The values displayed in the Table are the number of acres which are coincident with the row and column categories. The diagonal values in the matrix are the number of acres which have not changed land use classification from the existing condition to the 1990 alternative future condition. For example in row 1, 106 acres that were classified as natural vegetation under existing conditions remain so classified under 1990 conditions, 6 acres of land classified as natural vegetation under existing conditions are converted to medium density residential use, etc. The total amount of land classified as natural vegetation under existing conditions is 272 acres while the total amount of land classified as natural vegetation under the proposed 1990 condition would be 141 acres.

Attractiveness analyses for a number of potential uses within the basin were performed. The output is standard overprint grey shades indicating the relative attributes of each grid cell with respect to the others. The attractiveness display (not shown) used to illustrate the capability was for neighborhood park locations. In the display the darker shaded areas are, in a relative sense, more attractive for park development than the lighter shaded areas. The data variables of damage reaches (areas within the flood plain are preferred over areas outside the floodplain), land surface slope (flat and mild slopes are preferred over steep slopes), existing land use (natural

TABLE 4
LAND USE COINCIDENTS

UPPER OCONEE PILOT FPI
TRAIL CREEK TEST
LAND USE COINCIDENTS

DAMAGE REACH 2
COINCIDENTS MATRIX

	1	2	3	4	5	6	7	8	9	10	TOTAL
1	105.57	0.00	0.00	6.12	0.00	0.00	41.31	27.54	91.80	0.00	272.34
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	3.06	0.00	0.00	0.00	0.00	0.00	0.00	3.06
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	6.12	0.00	0.00	0.00	0.00	0.00	6.12	0.00	7.65	0.00	19.89
7	4.59	0.00	0.00	0.00	0.00	0.00	13.77	0.00	4.59	0.00	22.95
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	24.48	0.00	0.00	1.53	0.00	0.00	10.71	9.18	24.48	0.00	70.38
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	140.76	0.00	0.00	10.71	0.00	0.00	71.91	36.72	128.52	0.00	

ROW CATEGORIES ARE EXISTING LAND USE

1 NATURAL VEGETATION
2 DEVELOPED OPEN SPACE
3 LOW DENSITY HOUSING
4 MEDIUM DENSITY HOUSING
5 HIGH DENSITY HOUSING
6 AGRICULTURE
7 INDUSTRIAL
8 COMMERCIAL
9 PASTURE
10 WATERBODY

COLUMN CATEGORIES ARE 1990 LAND USE

1 NATURAL VEGETATION
2 DEVELOPED OPEN SPACE
3 LOW DENSITY HOUSING
4 MEDIUM DENSITY HOUSING
5 HIGH DENSITY HOUSING
6 AGRICULTURE
7 INDUSTRIAL
8 COMMERCIAL
9 PASTURE
10 WATERBODY

vegetation, agriculture and pasture are favored over other categories), and distance to housing (areas near the low, medium and high density residential areas are preferred to areas removed and to areas near other land uses) were used in the determination.

6. System Running Cost

HEC-SAM is comprised of 8 major computer programs and several smaller ones. The cost of a run or analysis is therefore quite dependent upon the specific analysis performed and the computer system on which the programs are being run. In addition, computer processing involving manipulation of data bank grid information is dependent upon the number of grid cells to be processed and the number of variables included in the analysis. While a definitive schedule of costs is difficult to specify, the following Table 5 cost data resulting from processing related to the pilot study should provide a general order of magnitude estimate for comparison purposes. The processing was performed on a CDC 7600 computer system with special government rates averaging about $.12 per computing unit second (CUS).

TABLE 5

SELECTED PROCESSING COST

Data Management and Processing Interface

Operation	No. Cells or Polygons	No. Variables	CUS	Cost $
AUTOMAP II Map	18 Polygons	1	14	1.68
GRID Map	22,350 cells	1	43	3.61
RIA Attractiveness Map	11,868 cells	3	31	2.87
HYDPAR	140,760 cells	5	178	18.74
DAMCAL	140,760 cells*	4	95	$11.53

* Damage Reach cells were windowed into a mini data bank (Approximately 30,000 cells)

TABLE 5 Cont'd.

Flood Hazard, Flood Damage and Environmental

Operation	No. Subbasins	No. Index Points	CUS	Cost
System Hydro-graphs	21	5	17	$ 1.89
Flood Freq. & Ex. Ann. Damage	21	5	44	3.78
" " "	31	22	132	$13.63

7. System Implementation and Operation

The HEC-SAM system is designed to be used by Corps District offices servicing local communities in an advisory capacity. The system would either be operational on local computer equipment or access to a central computer where the system is maintained by HEC would be available. A typical study would be undertaken under the direction of a study manager, who would be a Corps planning professional, and a minimum of one each of a hydrologic engineer economist, environmental planner and data bank manager that would provide the computer system support. Local planning agency staff in parallel professional specialties would likewise be assigned, especially if the resulting data system and analysis programs were to be turned over to the local agency. A blend of private enterprise, Corps and local agency efforts would be employed to create the initial data bank. Subsequent maintenance and updates would be the joint responsibility of the particular specialty area and the data bank managers. Because of the comprehensiveness of the system capabilities, it is unlikely that any but the largest local agencies would have the capability to operate more than the simple data management features of the system. It is anticipated that after initial alternative future assessments, processing would probably be performed by the Corps as a continuing service.

The present status of HEC-SAM will require intensive training and continued consultation and support from HEC. In the longer range, perhaps 2-3 years, the system is expected to stablize sufficiently to package the elements and make the capability available on a broad basis both within and outside the Corps.

8. Future Improvements

Research and development activities to date have concentrated on assembling a working system and interfacing the functional elements into a coherent analysis package. Several items have surfaced that require further developmental work that could enhance the systems utility and capability. The list below is judged priority enhancements that are currently receiving or will soon receive research attention.

1. Automated interface between HYDPAR and HEC-1 to enhance calibration and improve efficienty of hydrologic assessments.

2. Expanded graphical output. Current system output is computer printer graphics and tabular data. Much work needs to be done to provide higher quality graphics (alternative to printer graphics), printer graphics where none presently exists, i.e., flow frequency curves, damage curves, etc, and plotter graphics where none exists, e.g., frequency curves, damage curves, etc.

3. Consolidation of software. From a services standpoint, separate software packages for grid data printer plots, polygon data printer plots, etc. is cumbersome. The graphics and other special purpose data management programs need consolidating to more serviceable packages.

4. Capability to vary grid size within a data bank for a specific variable. It is unreasonable that the least count resolution that applies in only a portion of a study area for a specific variable, such as terrain in the flood plain, dictates the remainder of the data bank.

5. Enhance automated interface with storm water and stream quality analysis.

The general state of the art analysis capability that has been captured in HEC-SAM greatly enhances the ability of planners to assess the potential effects of change. However, many technical analysis areas are still in their infancy and could benefit from basic research efforts. The most important appear to be 1) techniques to improve forecasting the hydrologic impact of urbanization, 2) analysis methods to assist in allocation of land use consistent with projections and resource capabilities, 3) improvements in erosion and sedimentation analysis and 4) development of scientific base for environmental habitat analysis.

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GEOGRAPHIC DATA HANDLING ISSUES: AN ALTERNATIVE TO VARIABLE GRID RESOLUTION

By

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INTRODUCTION TO SUGGESTED PHILOSOPHY OF HANDLING SPATIAL DATA

Grid cell encoding of data is a well established technology, which emerged from the era of unit record electronic data processing and was extended by modern computers and batch processing, where the grid format facilitated programming. Grid cell configurations became a proven technology for encoding geographic data into machine readable form. However, it must be recognized that grid cell encoding was an outgrowth of processing constraints of earlier hardware technologies. As these constraints are relaxed, we must ask whether grid cell encoding is still the appropriate technology.

In recent years batch processing has been supplemented and even replaced by the interactive minicomputer. The University of Iowa's Department of Geography and Institute of Urban and Regional Research are studying methodologies for applying interactive minicomputer technologies to geographic information systems applications. This exploration of new technologies has lead to a reexamination of existing grid cell methodologies. Within a minicomputer and coordinate digitizer environment, a team of researchers at the University of Iowa are developing a geographic encoding, storage, retrieval and analysis package, which could have application to the Corps' geographic data handling needs. The system, dubbed INFOS, has been developed to the level where its potential is clearly demonstratable. The system may be of interest to the Corps because it overcomes many of the problems of grid cell encoding and storage without resorting to a multiple resolution grid format, nor to a polygon overlay system. INFOS utilizes a scan line format, which in the present version is derived from polygon data, but which could be generated from direct raster scanning of source documents in a future version. INFOS allows the user to select resolution for overlay analysis, which precludes the need for a variable grid resolution storage system.

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Several large automated geographic information systems have been developed around grid cell data methods, including the Hydrologic Engineering Center of the U.S. Army Corps of Engineers. Although grid cell mapping represents a proven technology, there are problems inherent in a grid cell based geographic information system. The Corps is considering refinement of its current uniform grid cell system into a variable resolution grid cell data base. While this plan has merit and should be carefully evaluated, other methods for obtaining the Corps' ultimate objective, efficient and effective management of geographic data, should also be considered. This paper will briefly review some commonly available technologies and discuss the encoding, storage, retrieval, and manipulation system developed at the University of Iowa.

Common Data Storage Techniques

Grid, polygon, and topologic structuring are the most common methods of encoding and manipulating geographic data. Technicians continue to debate the relative merits of the various systems, but in fact no one system can be regarded as the preferred encoding and storage method in all situations. (2)

Grid Systems. The cell is the basic unit of grid mapping system. The matrix of grid cells is produced by applying a uniformly structured system of grid lines over the map area. Each cell which results is tagged with the predominant characteristic of the map area contained in that cell. This method of capturing geographic data is conceptually simple. Grid cell data structures can be very useful for planning and other purposes where data must be overlayed and where accuracy is not a prime consideration. In addition, map output can often be easily and inexpensively produced on line printers available at most computer installations. Originally grid mapping was motivated to facilitate programming, but its continued use is reinforced by supporting technology from satellite imagery, raster scanners, and special purpose computers. (1) Grid cell data systems can be criticized because they do not allow precise placement of boundaries and points on the map, and only the predominant characteristic of each grid cell is usually recorded.

MSDAMP (Multiple Scale Data Analysis and Mapping Program), developed by the Hard Use Analysis Laboratory of Iowa State University, has the capability for overlaying grid cell map information of coverages with different grid cell resolutions (but each coverage must have a uniform cell size). MSDAMP uses the geodetic reference sytem (latitude and longitude) and defines cell sizes in terms of seconds of arc. The geodetic system allows regional analysis at almost any scale at or above the county level. MSDAMP is noted for its high quality lineprinter maps and has been used for several major analysis projects. (5,6)

Although MSDAMP can handle coverages with varying grid resolutions, each individual coverage must maintain a uniform cell size. To get the effect of multiple resolution with one coverage, it would be necessary to subdivide the map into areas of different resolutions and then concatenate the sections for analysis.

Coordinate or Polygon Encoding. Coordinate encoding is a second common method for handling geographic data. It attempts to preserve locational integrity by recording the x,y coordinate of each significant feature on a map. The encoding of a single point, such as a well, is very straightforward: the x,y coordinate of the point is recorded along with an identifier or label. A line is encoded as a series of discrete points located at significant inflections of a line; the points are mathematically or mechanically connected on output by the computer or the plotter. Since most coordinate mapping routines connect the points with straight lines, a curve must be represented as a series of short line segments. If the intended uses of the data require an exceptionally high degree of locational accuracy, the line segments must be very short.

Polygons or areas may likewise be encoded by recording the coordinates at each significant inflection point. When digitizing polygons, however, the area is closed by giving the first and last points of the line the same coordinate location. A serious problem with polygon encoding is the necessity to digitize twice those segments which form the borders of two areas. For example, if one were digitizing the outlines of Arizona and New Mexico, the part of the outline of each state which forms a common border would have to be digitized twice.

Digitizing devices that make digitizing straightforward, efficient, and accurate are commonly available. These digitizing machines require an operator to trace the map with some type of stylus. Most digitizers allow rapid encoding of data so that even the need for double digitizing boundaries does not pose a serous problem. Computer programs to correct many small digitizing errors can be fairly straightforward. For instance, the University of Iowa system provides for both computer assisted manual editing of digitized data as well as a "join" program which allows the computer to form boundaries between separately digitized polygons.

The chief advantages of coordinate data handling systems are the rapid encoding of data and the preservation of locational integrity. Except for extremely complex coverages, coordinate data can be stored in the computer much more efficiently than grid cell data at the same level of accuracy. Outputs of coordinate maps are most accurately performed on line plotters or special cathode ray tubes. Generally the resulting maps are easier to read than grid maps.

Topologic Data Structures. A refinement of the coordinate or polygon system is the topologic data structure which represents lines and polygons as a network of nodes, or line endpoints, and boundaries connecting the nodes. Because area data can be represented as a boundary network and roads and streets can be represented as flow networks, topological data structures are useful for representing spatial relationships. In addition, logical editing of topological data structures is employed to ensure quality control. The Census Bureau's topologic DIME file is probably one of the best known geographic information systems, and its wide use has encouraged some geographic information system designs to adopt a topologic data structure.

Like coordinate systems, topologic data strutures preserve locational integrity of map features. Despite the fact that area boundaries only need to be digitized once, topologic data may be more time-consuming to produce and subject to larger amounts of digitizer error than simple coordinate data, since an identifier for both sides of each boundary line must be entered by the digitizer operator. However, topologic data structures do not usually require that lines between areas be digitized twice.

The University of Iowa's Digitizer System

The University of Iowa's Department of Geography and the Institute of Urban and Regional Research are developing methods for handling geographic data in a minicomputer environment. Iowa's "DIGIT SERIES" (4,8) is a user oriented system which has been on-line for about one year with capabilities for coordinate encoding, storage, retrieval, and manipulation of geographic data. The hardware configuration consists of two minicomputers: an IMLAC Corporation PDS-4 graphics display minicomputer and display monitor and an HP-2000 Access system. The digitizing process is machine assisted by the two minicomputers and uses a Graf/pen 3 digitizing unit. A communications link exists between the Hewlett-Packard minicomputer and an IBM 360/65 computer. This link is used primarily for batch jobs to gain access to drum plotters, line printers and other peripheral equipment attached to the 360 with the option of retrieval back to the HP. (3)

In response to the question raised by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers, the Institute of Urban and Regional Research of the University of Iowa is developing INFOS, a subsystem to DIGIT, consisting of routines for converting polygon data to a grid cell format using a simulated raster scanning algorithm. This algorithm is described and demonstrated in Appendix A. DIGIT has proven capabilities for machine-assisted encoding and editing of coordinate data; storage and retrieval of encoded geographic data; manipulation, display, and analysis of encoded data, and INFOS adds an ability for conversion from polygon to grid format allowing overlay and analysis of gridded files. The unique aspect of INFOS is the ability to create scan records from more than a single coverage, which enables generation of overlay statistics. For example, INFOS can be used to scan a land use coverage and census tract. A future extension of INFOS will make it possible to handle continuous coverages such as slope.

The chief advantage of INFOS is that analysis resolution is determined by the analyst. Data is stored in its original coordinate form and converted to a scanned file at the appropriate level of resolution at the time of analysis. This is deemed more efficient than grid storage, even with variable grid resolution, and INFOS resolution can be varied by controlling the step size in y-dimension to meet the specific analysis situation.

THE DATA STRUCTURE PROPOSED FOR THE STORAGE OF THE SPATIAL DATA

The data structure and retrieval strategy used in the Iowa system is based on hierarchical storage of coordinate files, which can be used to reconstruct the original map or can be used to perform analysis. Storage of data in the form of coordinate files gives greater flexibility in the types of analysis which can be performed and in most cases reduces storage requirements.

The hierarchical data structure of the coordinate file is shown in Figure 1.

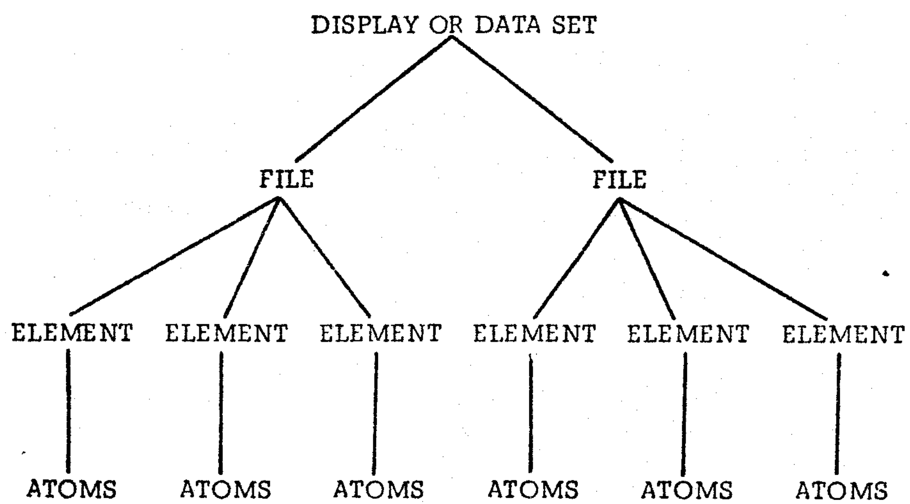


Figure 1

The "atom" is the basic unit of the DIGIT series and consists of the x,y coordinates of a single point on a map. These atoms can represent an isolated point, inflection points of a line or area boundary, or the location of a label.

Point, line, area, and text "elements" are formed from groups of atoms of the same type. In general terms, elements can represent recognizable map units such as roads (a line element), civil divisions (an area element), or a point source of pollution (a point element). Text elements portray legends such as captions and map titles. Other data is contained in an element header describing its characteristics (size, display intensity, etc.) followed by a list of atoms. Appendix B gives the precise internal format of an element.

For storage and retrieval, elements are grouped into digitized files. A file may contain any combination of point, area, line, and text elements that is convenient to the user. Usually a single file contains one complete map coverage such as all the land uses in one USGS 7 1/2 minute quadrangle, but a file may include only part of a coverage. For example, it might be useful to build one file of agricultural land uses in a given quad and put all non-agricultural land uses in another file. These two files could be analyzed separately or jointly as dictated by the analysis to be performed, or they may be combined or disaggregated to form a new file.

Once a file has been digitized and edited, several file manipulation capabilities are available:

-- One or more files may be submitted for analysis without disturbing or altering the original file.

-- One or more files may be displayed. If multiple files are used, they may be overlayed or concatenated for viewing purposes.

-- A file may be scaled to new dimensions or placed into some other coordinate system such as state plane coordinates.

-- A file can be copied to form a new file. This allows file altering procedures such as scaling to be performed on a copy of the file while leaving the original data base intact. The altered file may become a new permanent file or may be erased after the analysis has been performed.

-- Elements may be added, deleted, or edited, or a new file created. By using tic marks, precise overlays and concatenation are possible.

-- A portion of one or more files may be "windowed" on the display monitor.

-- The file may be rotated on the display monitor.

-- Coordinate files may be processed to produce scan files. The scanning may be done at any resolution appropriate to the current analysis.

-- If two or more coordinate files are scanned, overlay statistics may be generated.

-- Any coordinate or scanned file may be added to or deleted from permanent or temporary storage at any time.

THE DATA FLOW OR INFORMATION TO EACH OF THE HYDPAR, DAMCAL, GRIDPLOT, AND RIA PROGRAMS

After map data has been encoded and stored in coordinate form, it may be used in its original coordinate form or connected to a grid structure.

Information flow is illustrated in Figure 2.

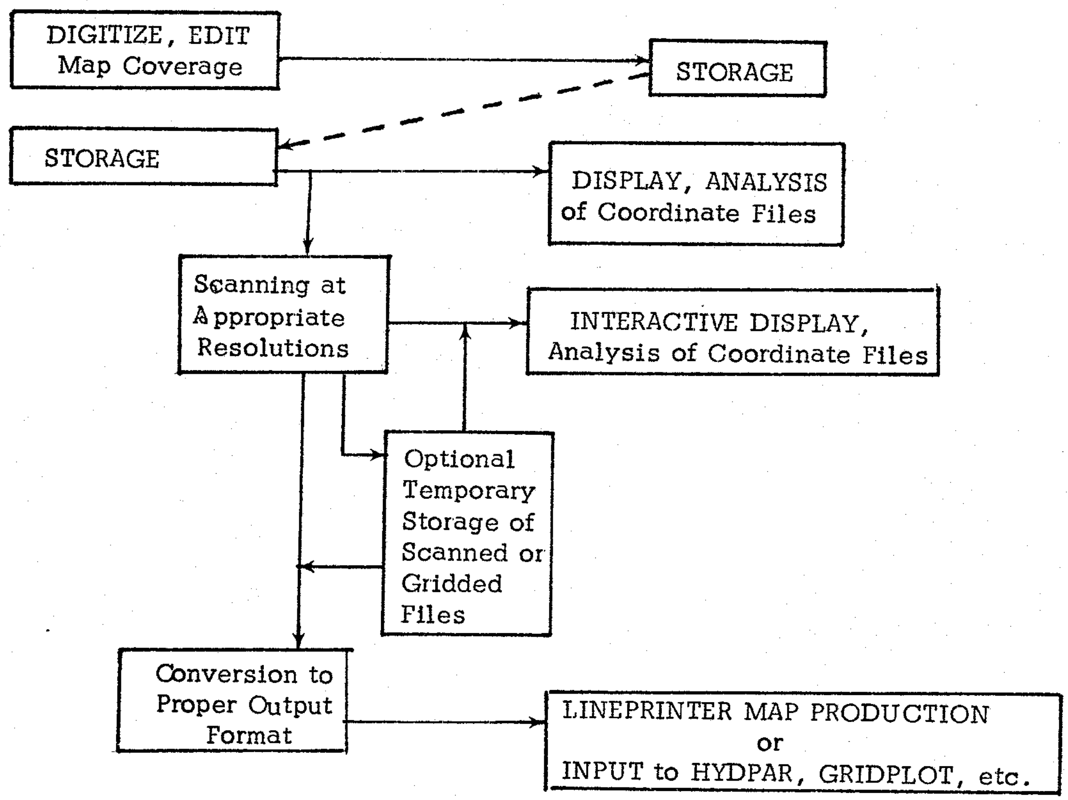


Figure 2

Some types of display and analysis can be most effectively performed using coordinate type of file structure. For other types of analysis including input into HYDPAR, GRIDPLOT, DAMCAL, and RIA, a grid file is necessary. Input to the Corps' programs would require a program to convert the INFOS generated scan file into a HYDPAR compatible input.

It is important to note that in using INFOS it may not be necessary for data to flow to HYDPAR and other Corps' programs. Most analysis and display can be performed from the scan file or coordinate files.

Accessing data on the HP-2000 minicomputer used at the University of Iowa is extremely simple. Each file must be given a unique name of up to eleven alphanumeric characters. The programs which are to use the stored files merely call for the name of each file which is to be used for input. Some type of systematic naming procedure would doubtless be required for establishing and maintaining a large map library such as that needed by the Corps of Engineers.

HOW THE DATA STRUCTURE WOULD CONFORM TO COMPUTER GRAPHICS THAT ARE BASED ON A SINGLE GRID CELL RESOLUTION

The Iowa system is primarily an interactive system built around the cathode ray tube display. The primary display unit is an IMLAC PDS-4 minicomputer and display monitor with a 21" screen and a 2048 x 2048 displayable raster. Display on the IMLAC screen is generally superior to line printer graphics. Photocopies of the display can be made on an IMLAC hard copier, measuring approximately eight inches square. It is also possible to have maps produced on 11" and 29" drum plotters, an electrostatic plotter, or a microfilm plotter.

While display on a CRT (or a photocopy of the monitor screen) is generally more readable than a map produced using line printer graphics, the latter has some useful features and are sometimes desirable. Line printer maps are usually inexpensive and easy to produce on equipment readily available at most computer centers. In addition, the Hydrologic Engineering Center has expressed an interest in producing outputs at approximately the same scale as the source USGS 7 1/2 minute quadrangle maps.

Line printer output was not an original intention in the development of the DIGIT series, but a simple software package could be developed to produce line printer compatible output from files produced by INFOS. Currently scan line data are based on a 4095 x 4095 matrix of "digitizer units" (DU) where one digitizer unit equals 1/85 inch. The user can specify the step size in DU for the y dimension. By specifying a step size of 11 digitizer units, a scan file will be produced which when printed on a line printer set at eight lines per inch would produce a map with the same y dimension and y scale as an USGS 7 1/2 minute quadrangle map. Similarly, if the user specified a step size in the y dimension of 14 DU and the map was produced on a line printer set at 1/6 inch per line, an approximately scaled USGS 7 1/2 minute quadrangle map would be produced.

The current version of INFOS has the x dimension continuously scaled rather than having discrete step sizes, as exists in the y dimension. Conversion to grid format from a continuous x axis scaling means specifying a horizontal step size similar to what is done for the y axis.

ADVANTAGES AND DISADVANTAGES OF PROPOSED TECHNIQUES VS. A SINGLE UNIFORM GRID RESOLUTION THROUGHOUT THE ENTIRE STUDY AREA AND MULTIPLE RESOLUTION DATA

The DIGIT series, particularly with the development of INFOS, is a system for machine-assisted encoding, storage, and manipulation of geographic data. It is based on coordinate data and has the capability of outputting data in a gridded format. The analyst may window in on the coverages needed, and set the resolution to any level. Overlay analysis and mapping is achieved from coordinate format data and problems inherent in the use of a uniform grid cell size are avoided. Since INFOS employs a constant scan line increment, it is in one sense analogous to a uniform grid cell size throughout an entire study area, although its increment is use determined and set at the time and for the purpose of analysis. Nevertheless, INFOS merits should be weighed against the use of a multiple resolution strategy.

In moving from a uniform grid cell resolution strategy to a multiple resolution strategy, many of the advantages of a simple uniform cell size (conceptual simplicity, ease of file maintenance, ease of overlay, and rapid processing) are lost. The rationale for sacrificing these advantages is to achieve greater detail where it is important or where coverages are more complex, through the use of windowing and then using INFOS, these same advantages can be achieved. In arriving at the INFOS scan conversion approach variable grid resolution solutions were explored and rejected.

In systems which overlay data gridded at different resolutions, problems of aggregation and prorationing are introduced. Aggregation is the combination of small areal units into larger ones. Prorationing involves dividing large areas into smaller ones while maintaining accurate representation of the data. When an area of a small grid size is overlayed with a larger grid, the two must be converted to some common cell size (the problem is analogous to the need for a least common denominator to add fractions). In most cases there is no sound analytical basis for prorationing. To maintain the theoretical significance of the data, the small cells must be aggregated to the coarser level. In this aggregation process any resolution gained by using small grid cells for one coverage is forfeited. This data loss mitigates any advantage achieved by using a multiple grid resolution format. INFOS overcomes this problem by allowing the data to be scanned at whatever resolution is appropriate for the current analysis. In addition, all data can be stored at a fairly similar high resolution since the storage requirements of polygon data are not as sensitive to the level of accuracy as the storage requirements of grid data.

CONCLUSIONS, OBSERVATIONS AND PROGNOSTICATIONS

The Corps of Engineers is a major consumer of geographic information system technology, and have recognized the need for developing new methodologies to overcome the problems inherent in grid cell mapping. Variable grid resolution encoding represents only one of several alternatives now faced by HEC. Before investing heavily on "bells and whistles" to grid cell analysis and mapping technology, HEC should explore a broader range of alternatives, and undertake research and development to determine the best methods of achieving an effective and efficient geographic information system to support the mission of HEC.

INFOS may be representation of emerging geographic information system that rely on minicomputer technology. Interactive operation allows analysts to perform their tasks more efficiently and thoroughly. As an alternative to both uniform and variable grid resolution encoding, INFOS has been demonstrated for small coverages, but it has not yet been tested in a large data base environment. Admittedly, it is still in the research and development stage, but INFOS or a system based on a similar set of concepts could serve as the base of the next generation geographic information system for HEC.

APPENDIX A. TECHNICAL DESCRIPTION OF 'INFOS'

Table A.1 shows the list of current INFOS options used to select the major routines outlined in Figure A.1. INFOS is one of several application packages in the DIGIT SERIES.

```
    I N F O R M A T I O N   S Y S T E M   O P T I O N S :
= = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
    (1) CREATE A SCANNED FILE FROM DIGITIZED FILE(s)
    (2) DISPLAY SCANNED AREA STATISTICS
    (3) FIND AREA COMBINATIONS
    (4) PLOT AREA COMBINATIONS
    (5) SEND HARD COPY TO IBM360
    (6) STOP/EXIT
= = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
```

Table A.1. INFOS SERIES Options.

For purposes of the present discussion, the DIGIT SERIES creates, edits, and displays a graphics data file called a DIGITIZED FILE which contains labeled and unlabeled point, line, and area "elements". These elements are digitized using the GRAF/PEN digitizer and the IMLAC PDS-4 minicomputer and once produced, may be combined (overlayed), disaggregated, associated with tic mark coordinates, and scaled to any unit system. Each area polygon in these DIGITIZED FILES is scanned from top to bottom using a simulated raster scan, resulting in a "scanning record". Using a compressed grid format, these scanning records contain the width of each polygon along the scan line together with the corresponding area label. The area label may be up to 18 characters long and contain either nominal or interval data. The scanning records are stored as a subfile in the SCANNED FILE and are used to compute area statistics and combinations, and permit creation of SHADE FILES for plotting selected area combinations. Area combinations are sets of contiguous grid cells lying within one or more digitized area polygons. Plotting is accomplished directly on the IMLAC screen, in which case a photocopy may be obtained, or the SHADE FILES may be used as input to other software in the DIGIT SERIES to produce 11" or 29" CALCOMP drum plots or 35mm microfilm plots.

Create a Scanned File. Figure A.2 shows a diagram of the raster scan and scanning record produced by the routine outlined in Figure A.3. After invoking option 1, the user types a list of DIGITIZED FILE names to be overlayed and scanned simultaneously. If the IMLAC terminal is being used, these base maps are displayed on the CRT. The coordinates of each area polygon are stored on a scratch disk file (AREA COORDINATES FILE) and are used to compute the area*,

*The area is computed using the "polygon method" discussed in (7).

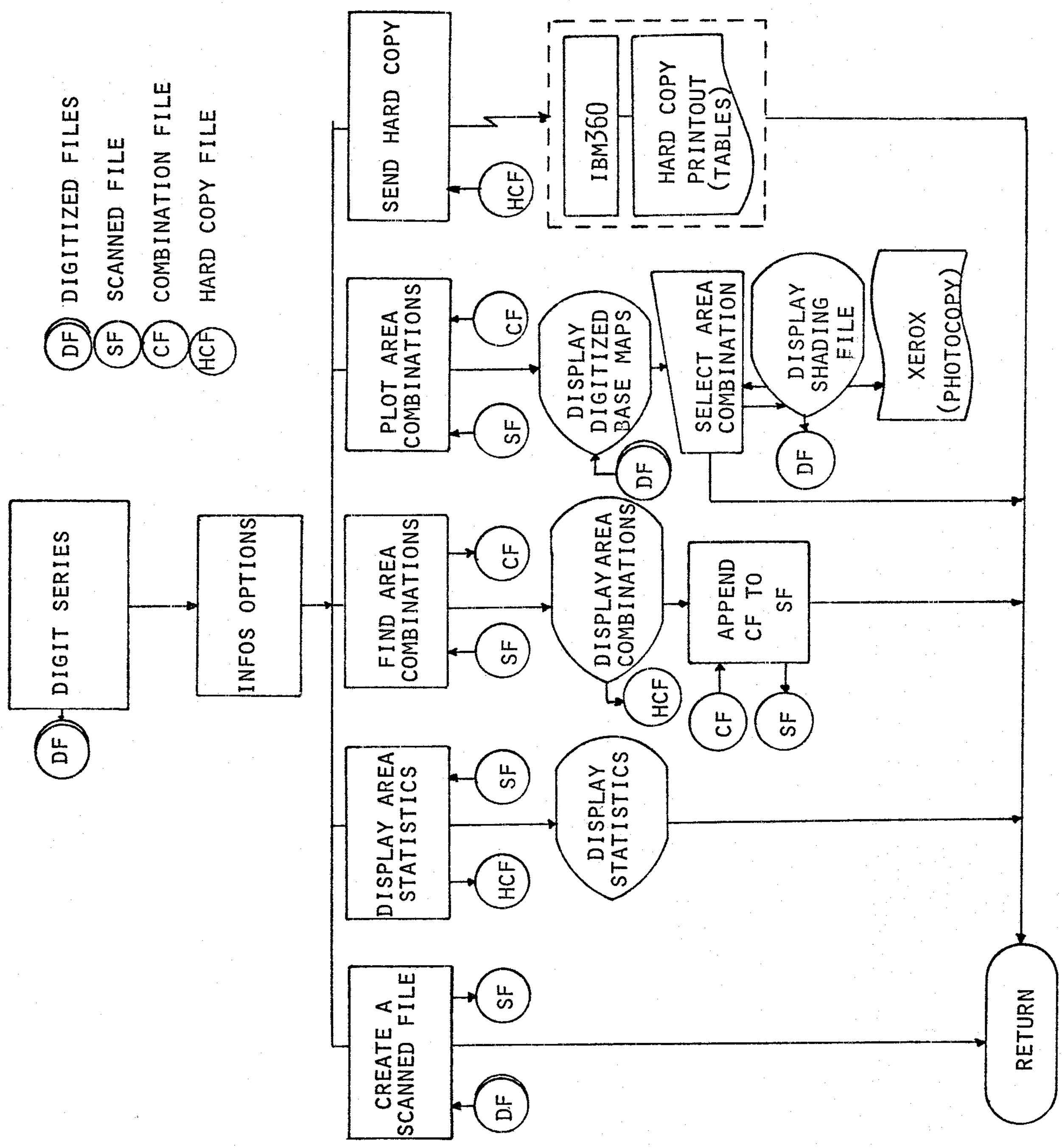
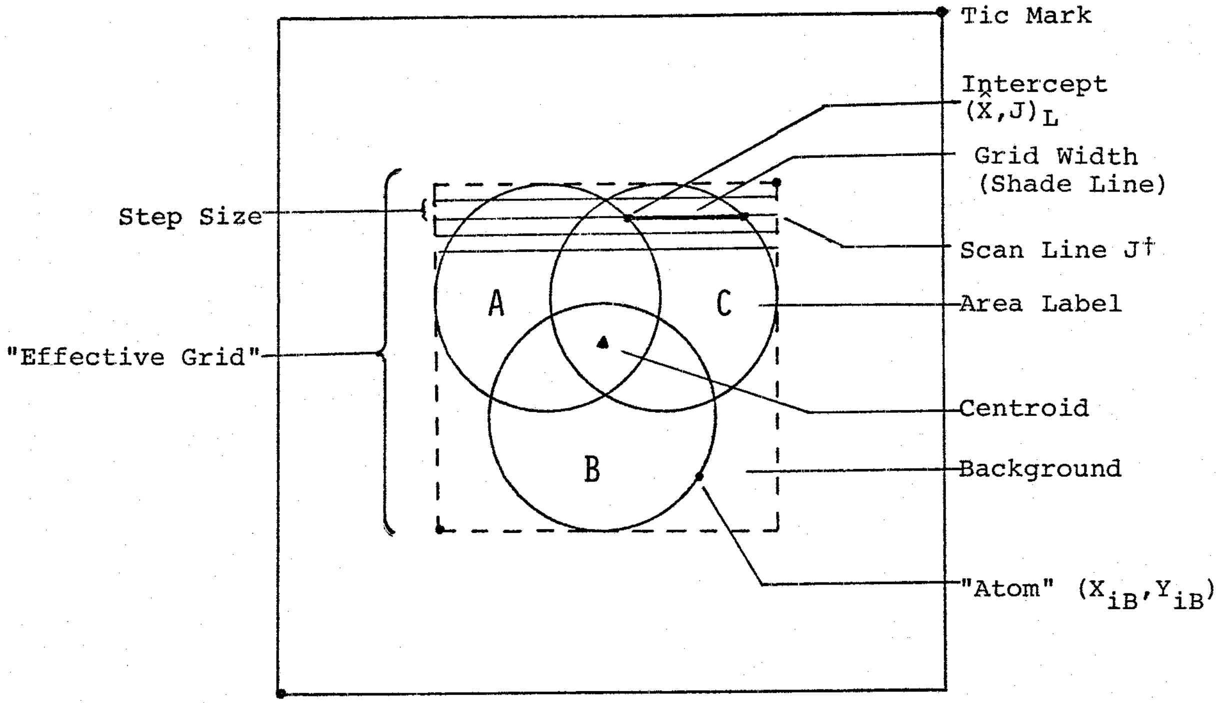


Fig. A.1. The INFOS SERIES.



†The "scanning record" for scan line J in this hypothetical example would be formatted as follows:

12X,190<A1'A'>,50<A1'A'><A3'C'>,190<A3'C'>,12X.

The width of the effective grid would be 454 DU with 12 DU background on the left and right of the scan line, 190 DU grid width of area 'A', 50 DU of areas 'A' and 'C', and 190 DU of area 'C'. A1 and A2 denote the polygon sequence numbers in the original DIGITIZED FILES. Each circle in this example is an area polygon with a radius of 126 DU residing in three separate DIGITIZED FILES ('VENNA', 'VENNB', and 'VENNC') containing 1,500 atoms each. SHADE FILES can be produced which store the coordinates of each grid width for a particular area combination.

Fig. A.2. Diagram of the Simulated Raster Scan and Scanning Record.

Fig. A.3a. Algorithm to CREATE A SCANNED FILE.

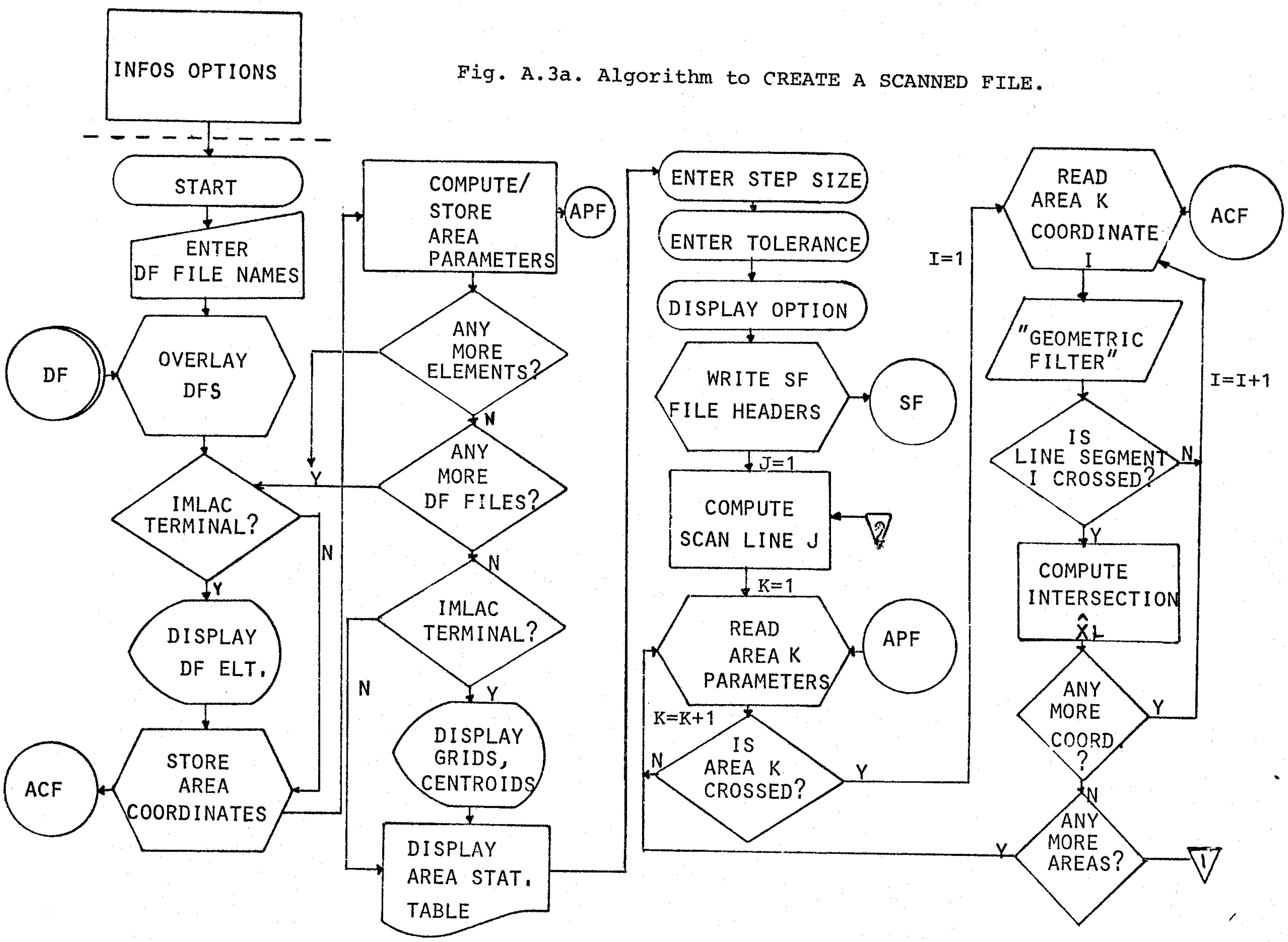
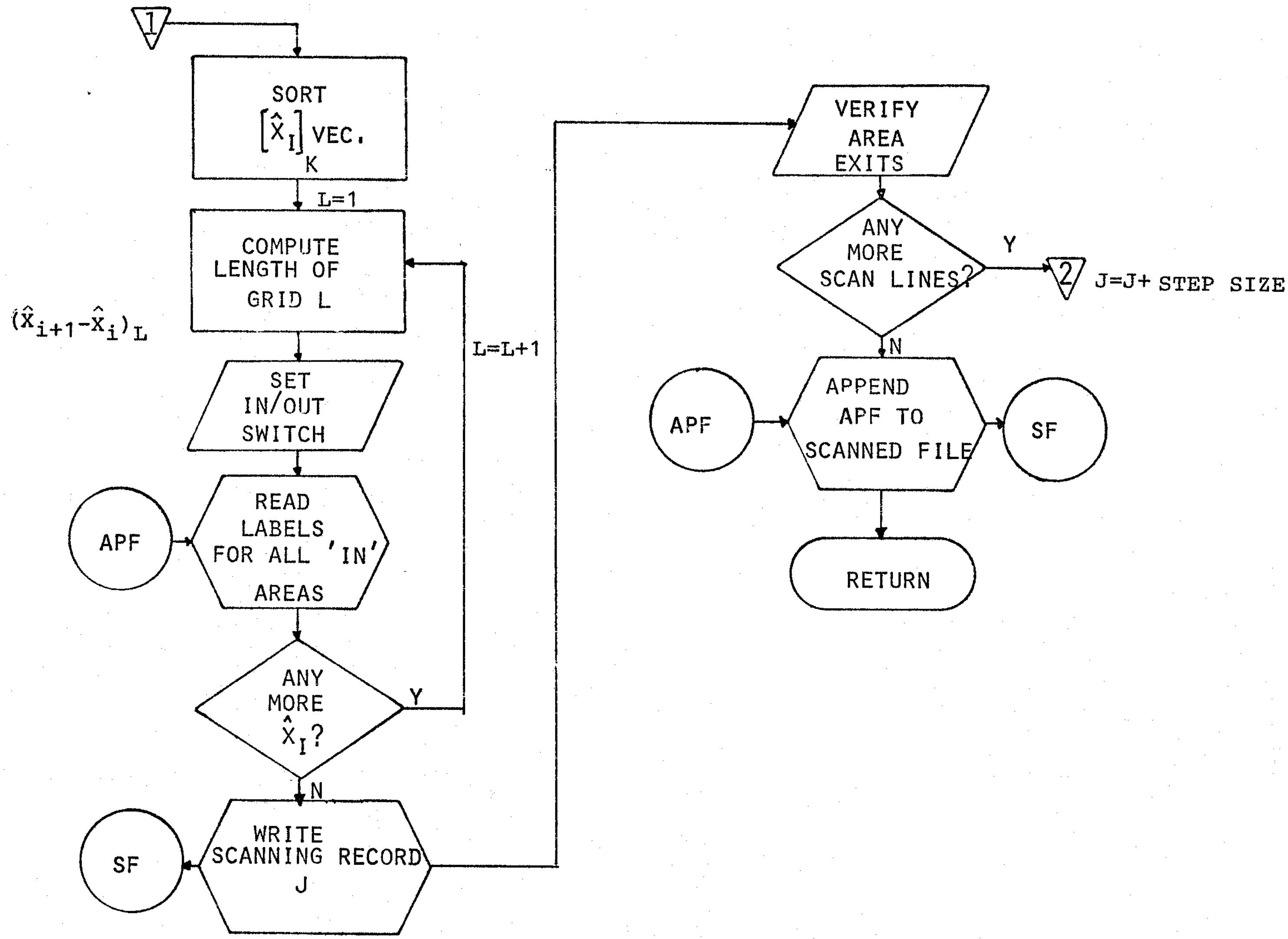


Fig. A.3b (Continued).



centroid, and the range of X and Y. Together with the area label, these parameters are stored in a second scratch file, the AREA PARMS FILE.

After displaying the DIGITIZED FILES to be scanned and storing the area parameters and coordinates on scratch files, the user is asked to supply two additional parameters: the Y-AXIS STEP SIZE and the X-AXIS TOLERANCE. The STEP SIZE and TOLERANCE guide the scanning process which is discrete along the Y-axis and continuous along the X-axis. The user may choose any STEP SIZE to a maximum resolution of 1 DU (DU = "digitizer unit" = 1/85 inch). The width of a particular area combination along a scan line, or "grid width", less than this TOLERANCE is omitted from the scanning record.

Having set these parameters, the SCANNED FILE header is written and scanning of the area polygons commences. The value of Y for scan line J is computed and the AREA PARMS FILE is read to determine which area elements are intersected by the scan line. An area is intersected if its maximum Y-coordinate is greater than J and its minimum is less than J. If intersected, the AREA COORDINATES FILE for area K is read. Corresponding to a line segment in area polygon K, each adjacent pair of coordinates, $(x,y)_i$ and $(x,y)_{i+1}$, is checked to see if it is crossed by the scan line. If crossed, the X-coordinate of this intersection, $(X_L, Y)_J$, is computed and stored together with the area identifier in vector $(\hat{X})_J$. Where:

$K = 1, \cdots$ no. of area polygons

$I = 1, \cdots$ no. of atoms in area K

J = Y coordinate of scan, incremented by STEP SIZE

$L = 1, \cdots$ no. of intersections along scan line J

After analyzing each line segment in each relevant area, the vector of intersections is sorted from smallest to largest and each intersection is then displayed on the IMLAC screen. The distance between each intersection, or the grid width $(\hat{X}_{L+1} - \hat{X}_L)_J$, is paired with the label of each polygon crossed to form the scanning record for grid row J. (See Figure A.2) The scanning record J is then written onto the SCANNED FILE and optionally displayed on the screen, and J is incremented by the STEP SIZE.

When the scanning process is completed, the AREA PARMS FILE is appended onto the end of the SCANNED FILE to produce the second subfile which is used in other options. The user is then requested to choose the next elective from the INFOS option list.

Display Scanned Area Statistics. After a SCANNED FILE is produced, summary statistics of each area scanned may be displayed. Option 2 reads the AREA PARMS subfile. For the hypothetical example in Figure A.2, the statistics may appear as follows:

```
                    A R E A   S T A T I S T I C S
= = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
SCANNED FILE:  'VENN'
= = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
SCAN OF DIGITIZED FILE(S):         'VENNA', 'VENNB',  'VENNC'
      ORIGIN:                      0000,0000
      TICS:                        0000,0000 and 1000,1000
NUMBER OF AREAS:                   3
STEP SIZE:                         25

OVER ALL AREAS
X-AXIS:                            0273 TO 0727
Y-AXIS:                            0273 TO 0727
SUM OF AREAS (POLYGON
  METHOD):                         300,000 SDUs
CENTROID:                          0500,0500

AREA 1
LABEL:                             'A'
LABEL COORDINATE:                  0410,0500
NUMBER OF POINTS:                  1500
AREA (POLYGON METHOD):             100,000 SDUs
X-AXIS:                            273 TO 525
Y-AXIS:                            400 TO 727
CENTROID:                          0400,0525

               (Table continues for other areas)
= = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
```

Table A.2. Area Statistics Table.

SDU stands for "square digitizer units" and may easily be converted to more convenient areal units such as acres or square miles. A HARD COPY of this table may also be optionally produced and submitted to the IBM360 for a printout.

Find Area Combinations. Option 3 accomplishes two primary purposes: (1) to create a temporary "combinations file" which is a direct access disk file containing the label and estimated area of each unique area combination in the SCANNED FILE, and (2) to display and produce a HARD COPY of the table of area combinations like the one in Table A.3. The first time this option is selected for a particular SCANNED FILE, this combinations file is appended onto the end of the SCANNED FILE so that these combinations need not be computed again. The combination subfile, along with the scanning record and area parms subfiles, is necessary in order to execute option 4. The estimated areas in Table A.3 are computed by a different method than those shown in Table A.2 which does not display the areas of polygon overlap. This second approach estimates the area of area combinations by summing the product of the grid widths and STEP SIZE for a particular combination.

A R E A   C O M B I N A T I O N S

REF. #	LABEL COMBINATIONS	ESTIMATED AREA
1.	'A'	100,000 SDUs
2.	'B'	100,000 SDUs
3.	'C'	100,000 SDUs
4.	'A' + 'B'	40,000 SDUs
5.	'A' + 'C'	40,000 SDUs
6.	'B' + 'C'	40,000 SDUs
7.	'A' + 'B' + 'C'	15,000 SDUs

Table A.3. Area Combination Table.

'A' is that part of area 'A' not overlapped by another area; 'A' + 'B' refers to only those grid cells lying inside both areas 'A' and 'B'. This table, which may be rather long for realistic projects, may be submitted for HARD COPY to the IBM360. Depending on the STEP SIZE, the estimated areas in this table are usually within 1% of the areas estimated using the polygon method.

Plot Area Combinations. Option 4 can be selected only after the area combinations subfile has been appended onto the end of the SCANNED FILE using option 3. For each combination the scanning records are read and grid cell coordinates computed. These coordinates are then used to contruct a SHADE FILE. A SHADE FILE is a DIGITIZED FILE containing unlabeled line e lements of the scan lines contained within a chosen area combination (grid widths). The user may select one or more area combinations to be plotted. The principal steps in constructing SHADE FILES are as follows:

(1) The DIGITIZED FILES comprising the base map used in producing the SCANNED FILE is displayed on the IMLAC screen.

(2) The user selects one or more area combinations from a table to be plotted (with or without any overlap for each).

(3) Each scanning record in the SCANNED FILE is read and the coordinates of each scan line in the selected area are recorded ("shade lines").

(4) The shade lines are plotted on the IMLAC screen for all combinations chosen.

(5) The user may request a photocopy of the screen and/or store the SHADE FILE(S).

(6) The user may repeat the procedure from #2 above and optionally erase any shade lines from the screen while retaining the base map.

The SHADE FILES may be displayed together with the base map at a later time or they may be submitted to the IBM360 for a CALCOMP drum or microfilm plot.

Option 5, SEND HARD COPY TO IBM360, submits the HARD COPY FILE to the line printer. The HARD COPY FILE is cumulative in that each table listed using options 2 or 3 for any number of SCANNED FILES is appended onto the end. When the user wishes to exit from INFOS, he selects option 6, STOP/EXIT, whereby control is returned to the DIGIT SERIES.

APPENDIX B. STRUCTURE OF DIGITIZED FILES (4)

The coordinate files contain all the information necessary to display its contents including labesl, scale factors, tic marks, and origin point. The entire file is composed solely of character strings and includes (1) a "file header", (2) element file headers, (3) a list of coordinates and labels, and (4) element delimiters. The basic structure is as follows:

```
(ORIGIN), (SCALE, (TIC MARKS),                        - The "file header".
*                                                     - Element delimiter.
(ELEMENT TYPE), (ELEMENT SEQUENCE),
      (NUMBER OF ATOMS), (ATTRIBUTES),                - Element header.
*                                                     - Coordinates
.     (Next e lement)                                 - Element delimiter.
.
$                                                     - End of file mark.
```

The following example shows the structure of a typical digitized file containing an area, labeled line, labeled point, and text elements:

```
0000 0000, 0001 0001, 0000 0000 4095 0000 4095 4095 0000
4095, *, A, 1, 5, Ø 0000 0000A 3212 1203'AREA LABEL'
DL10Z03I15, 3452 3422 0023 1283 3302 1189 0083 1221 1190
1211, *, L, 2, 2, Ø 0000 0000F 0212 3122'LEFT LABEL' R 0021
1221'RIGHT LABEL' L21 Z02I10, 1232 2210 2209 0001, *, P, 3,
3, Ø 0000 0000    L21 S03 Z03I15, 1278 3223'PØINT 1',
3442 2232'PØINT 2' 0093 3432'PØINT 3', * T, 4, 1, Ø 0000
0000      L09      Z03I03, 2332 3442'TEXT ATØM', * $
```

The ORIGIN is 0,0 for X,Y, the SCALE is 1,1 for X,Y, and the four default TIC MARKS are shown in the file header. Following this, the * delimiter indicates that an element is beginning. The "A" means that the element is an area element, "1" and "5" means that it is the first element in the file and contains five atoms. The next string is composed of 95 characters, most of which are blank. The element origin, the position of the one area label and other characteristics are indicated in the "attribute string". The "D" means that the area symbol is a dashed line, and "Z03I15" denotes that the element has a label size of three with intensity 15. The five atoms (x,y,x,y,x,y,x,y, x,y,) appear of the coordinate string. In the case of labeled points and text elements, the labels are contained within the coordinate strings and delimited by apostrophes. The symbol type for point elements is indicated in the attribute string; "S01" denotes a triangle. "S02" a square, and "S03" a circle symbol. In labeled elements, the attribute string also contains the total number of characters in all labels. "L10" would indicate that the element contains a total of ten characters. All coordinate strings contain alphanumeric numbers in digitizer units relative to the element origin.

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GEOGRAPHIC DATA HANDLING ISSUES: AN ALTERNATIVE TO VARIABLE GRID RESOLUTION

DISCUSSION

Comment: The main accomplishment of this new system is that the polygons are overlayed and a multivariable file is created directly, instead of taking each polygon file separately, gridding it and then merging the grid files to form a multivariable file. This is unique. Only variables of interest need to be overlayed and grids are generated at the desired resolution independent of other overlays. The user gets to make the resolution decision A priori to each overlay analysis instead of choosing a resolution at the beginning of data collection.

Q. Can you vary the step size within a single run of an overlay?

A. We do not currently have this capability; it requires uniform steps (Y dimensions) of the variable resolution. Variable resolution can be achieved by windowing the various areas of interest.

Q. The HEC experience has been to capture data in the polygon form, create grid cell data for each and then merge the grid files to form a multivariable file and then we do engineering, economic and environmental analysis. The technique described so far seems to emphasize the creation of the multivariable file at the analysis phase.

A. (Dangermond) This is true except there is a reduction in job steps in the creation process which saves time and also when you grid all the polygons at once you get away from some of the practical problems of resolution of cartography and doing them all at once lends itself to a new file structure which is what Ray and I will discuss this afternoon.

Comment: There is an aspect of the problem which is a subtlety I (Dueker) have trouble grasping; that is the extent to which the grid cell data bank becomes the point of departure for all analysis, vs. deciding which separate coverages need to be combined for a particular analysis, and then make the decision as to the resolution needed. I guess I am saying, do the different analysis programs such as HYDPAR and DAMCAL have different data resolution requirements? If they do, then our approach would have more power than a fixed grid cell data bank.

Q. Then in the context of the objectives of the seminar, you are dealing with _between_ variable resolution and not _within_ variable resolution?

A. Yes, except for our windowing and scaling capability which allows one to do _within_ variable resolution.

Comment: (Postma) There is variable resolution from a data compaction scheme, which uses rectangles of different lengths as the mechanism to capture the variable resolution in the X direction.

Q. What kind of capability in terms of storage and processing time is involved? Is it in your best interest to continually overlay polygons prior to the analysis? In our situation it seems that gridding the data is a major expense and that we would prefer to do that as a prestep prior to any analysis and store it once than to continually do that overlay.

Another thing is that we like to do each data variable separately so that we don't have to know where everything else is.

A. Yes, there is a problem when overlays are made and the computer cost increases with the increasing complexity of the overlays. But the storage requirements do not go up because we deal with one line at a time. That is a key factor. Since we use a "mini", you can let them grind away for long periods of time fairly inexpensively. We are, however, still in an R & D mode and further work needs to be done. There needs to be an investigation of pregridding versus gridding at the time of analysis.

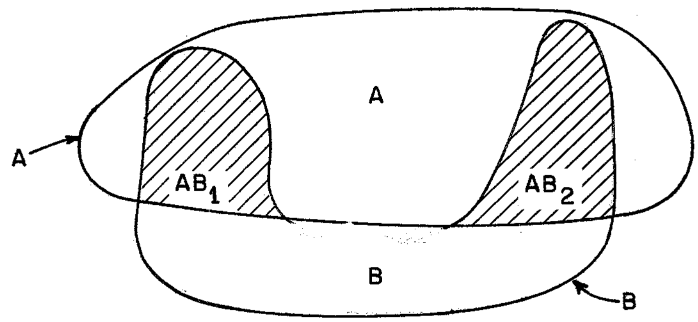
Q. Every time our organization has tried to do a cost-benefit analysis for an interactive scope or tube, to let us interactively edit files, we have always come up with the result that it is not cost effective. Is it practical for you to have interactive equipment, a production environment which digitizes thousands of complex polygons daily?

A. Our experience is more in the education side where it is very beneficial for the naive user to be able to see just what is going on. I would speculate that it would be very useful in the editing process. Much editing can be performed in batch mode (eg. join) as well as the gridding, although we have not developed the software to do this.

Q. You can't overlay complex maps on the tube with the original map. Therefore, we need a huge screen or else it is worthless.

A. I agree. (Oak Ridge National Laboratory is projecting back onto the original map from a video tape of the CRT).

Q. How are polygon intersections and neighborhood relationships determined by this system? Say there are two polygons (A and B) and they



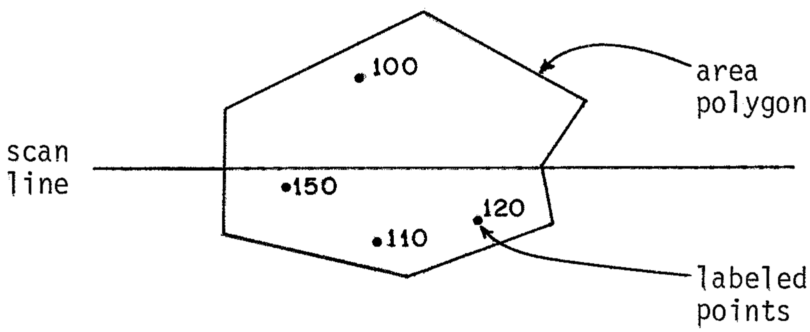
look like the Figure. There are two intersection polygons AB_1 and AB_2. Does the system know that they are actually intersections of the same polygons or do they treat them as two separate intersections?

A. The system treats each intersection separately. How important this is, I don't know.

GEOGRAPHIC DATA HANDLING ISSUES:
AN ALTERNATIVE TO VARIABLE GRID RESOLUTION

AUTHOR'S ADDITIONAL COMMENTS

1. Although the current INFOS routine scans only area polygons, the extension to include labeled lines and points is planned which will enable conversion of point and linear features to a grid format. This would be particularly useful for land use systems. The software which does the "Raster scanning" is satisfactorily developed. There are a number of potential extensions of the system which process the associated 18 byte labels (which currently store data associated with polygons). For example, contained in the label may be flags which direct processing the data in particular ways (e.g. to specify a search radius to look for adjacent point information for analysis of topographic surfaces). Such application programs must be tailored to the intended function, of course. Another extension could be the interpolation of labeled point information over a labeled area polygon to compute slopes as shown below: At intervals along the scan line, interpolations could be made from surrounding labeled points to compute the value of the interval (e.g. grid cell).



The main advantages of INFOS are as follow:

(a) Cheap, fast polygon to grid conversion, with simultaneous overlay

(b) Multivariable data stored in one file

(c) Optional interactive control/display

(d) Variable length file records

(e) Very little core required

2. Drawbacks of the current system include:

   (a) Software is somewhat hardware specific (HP - BASIC), although convertable to PL/I

   (b) Resolution maintains a constantly high level, but cannot be varied within the same run along the Y-axis without windowing or scaling as currently written

   (c) Additional software would be required to analyze slope data and many other specialized applications

   (d) Few data analysis routines have been written, except for finding the areas of polygon overlays, centroids, etc. No attempt has been made to link INFOS to hydrologic models.

   (e) Currently, data is stored in label, but label could point to other data vectors or parameters for analysis purposes.

3. HEC should begin moving away from a grid cell data bank and begin implementation of the following procedures: (minimize dependence on grid-then-store approach that fixes resolution)

   (a) Generate HYDPAR parameters directly from a digital terrain model (grid or triangular as determined by a special investigation)

   (b) Explore the use of a man-machine environment for damage calculation (DAMCAL/HEC-1). Man's judgement and computer-assistance would combine for more effective analysis: (immersion into a mini-computer/interactive environment)

      1) Select a window representing a flood plain reach for an analysis

      2) Create working files from relevant coverages for window area

      3) Compute flooded area for flood under consideration

      4) Scan-line overlay analysis to determine amount of land use, by type flooded.

4. IURR role

   (a) Further research and development of scan-line technology

   (b) Man-machine environment research

   (c) Nested land use classification research

VARIABLE GRID RESOLUTION - ISSUES AND REQUIREMENTS:

THE ADAPT SOLUTION

By

W. E. Gates and Associates[1]

INTRODUCTION

The Hydrologic Engineering Center of the US ARMY Corps of Engineers has been engaged in automated spatial data processing for purposes of hydrologic analysis and planning, utilizing a regular grid system in conjunction with a series of analysis programs and models. HEC has requested proposed solutions to the problem of incorporating a variable resolution capacity into their overall process. W. E. Gates and Associates is pleased to present what we are confident is a workable, efficient, compatible, and proven solution to this problem.

The ADAPT system, developed by personnel of WEG/A over the past five years and applied to some 50,000 square miles in five states, is a geographic information system designed primarily for use with engineering, planning, and design models, in particular where terrain considerations are important. The ADAPT system is based upon the concept of triangular cells, of varying size and shape. Each cell is defined in space by the three-dimensional coordinates of its vertices. This approach provides a geographic information system with variable resolution and excellent capacity for terrain modeling. Because of the cell orientation of the ADAPT system, models are easily interfaced with the data base. The variable resolution capacity combined with the unambiguous definition of a plane in space of the triangle cell, makes possible the terrain modeling capacity so essential for engineering use of the system. Thus, the solution of the variable resolution problem embodies within itself a solution to the terrain modeling problem. The triangulated cell system utilized in ADAPT also provides for storage and manipulation of point, line, polygon, and network data.

The cell-based organization of ADAPT is similar to that currently used by HEC in that each cell record contains within itself information on all the data variables referenced to that cell. An ADAPT file can be processed sequentially or be direct access methods, allowing great flexibility in the design of models which access the data base, and also allowing for economies in use of core storage.

Because the organization of data is similar to that utilized currently by HEC, and because ADAPT files can be processed sequentially (as are HEC files), two options present themselves:

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- the existing HEC programs operating on the regular grid cell data base could be converted (probably without major difficulty) to operate directly upon the triangle cells

or

- the triangle cells could be used to capture terrain and other highly variable resolution data, and an interface written to either insert this data directly into a regular gridded data base or allow for access from the existing HEC programs.

The ADAPT system has been described extensively in prior presentations and submittals to HEC (Reference 1). The remainder of this paper contains a brief summary of the ADAPT data structure, the proposed data flow to the HEC programs, a discussion of the computer graphics requirements/constraints of the solution, the relative advantages and disadvantages of the methodology, and a conclusion and summary.

ADAPT DATA STRUCTURE

An ADAPT data base consists of, at a minimum, two files, a triangle file, and a vertex file. Other files, such as polygon files, may be maintained, but are not strictly necessary. The triangle file is the main 'data carrier', with the vertex file being an auxiliary file used primarily in data base construction and update. The triangle file is a digital representation of the triangulated network of cells which is constructed to 'capture' the data of interest. In essence, this network partitions the area into the'least common denominator' spatial units, such that each triangle is homogeneous in all of its attributes. A triangle side marks either a change in local land slope or a change in a data attribute. In this fashion, all of the important polygons, ridge lines, streams, etc., are embedded within the triangle network as triangle sides. Within this network, triangles and vertices are numbered uniquely.

The triangle file represents this triangulated network by maintaining a single record for each triangular cell. The record contains three distinct sections, a topological section, a locational section, and an attribute section. The topological section for each triangle contains information necessary to define the neighborhood relationship of the triangle grid--in essence, this constitutes the three vertices for each triangle, and the three adjacent triangles. The locational portion contains centroid coordinates for the triangle, coordinates of the vertices, triangle area, and magnitude and direction of the gradient of the triangle. In a typical application, 25 words are used to maintain the topological and locational information. The remainder of the data record is attribute data, organized at the discretion of the user. Again for a typical application, 25 words of attribute data are made available, but this can be increased in increments of 49 words. Much of the data in the topological and locational portions of the record is 'redundant' in that it is either stored elsewhere or is directly derivable from stored data. The decision to store this redundant data within the triangle record and incur the associated 'overhead' storage charge was based upon the desire to have a user-oriented system which is easily programmed, and on the relative cost breakdown between storage and access costs on the large computers on which the ADAPT system in implemented. For these configurations, it is preferable to have all the information relating to a triangle when that triangle is processed, without incurring additional disk reads or calculations. In other configurations, a reduction in redundancy might be indicated (e.g. for a minicomputer-based system). The overhead associated with the strictly necessary data storage can be reduced to four words.

Access to the data bank is normally through the triangle record, i.e. given that I am in a certain cell, what are the attributes of that cell. However, a variety of other access methods have been devised and incorporated into the ADAPT system over the years. The use of inverted files, containing the triangle record numbers for a given attribute, eliminates much searching. Inverted files for any attribute are easily constructed with a single scan of the data base. The use of polygon retrieval, however, has largely displaced the use of inverted files. In polygon retrieval, a closed vertex chain (i.e. a closed boundary, the sides of which are all triangle sides) is identified with a given area, as, for example, a basin, or a damage reach, or political jurisdiction. This polygon is identified by a retrieval number, and stored in the polygon file. Whenever it is desired to perform an operation upon the triangular cells within that polygon, a simple subroutine call retrieves the polygon chain from the polygon file, dtermines all of the triangular cells within that polygon chain, and presents a directory of the record numbers to the main program. The advantage of this form of retrieval is significant; attributes within the cells may change over time, or with corrections to the data base. With an inverted file, the entire file would need to be scanned and the inverted file recreated--with polygon retrieval, this is not necessary, and the triangle data retrieved is always the most current. Additionally, inasmuch as it is possible to update a given triangulation pattern and add more cells, the polygon retrieval will automatically recall all of the new cells (provided that they are wholly enclosed within the polygon). The cost of calculations associated with polygon retrieval is low, and the increase in the usability of the system is quite large.

The inverse of polygon retrieval is polygon input. Data assignments can be made to all of the triangles within a given polygon, allowing for simple updating of large areas. By formatting data manipulations into input polygons and retrieval polygons, the filling of the data bank can be done in an orderly fashion.

Digitizer software developed for the ADAPT system allows the triangulated network cell system to be captured in a single digitizing pass. The associated polygons can similarly be captured from a digitizer. Thus, communication with the data base can be performed in an almost exclusively graphical framework, if desired.

It should be noted that, although the system operates with triangles as its basis, and programmers, of course, must be cognizant of the triangle cell data structure, ADAPT has evolved over the years towards a system in which the triangles become essentially transparent to the user. Communication with the system is either graphical or by specification of polygon numbers or plane coordinate locations. Only in the correction/edit phase, and in certain portions of the data insertion phase, need the user be concerned about keeping track of the internal triangle identifiers.

Within the above context of the ADAPT data structure, it is possible to discuss the ramifications of the variable resolution capacity of the system. Based on our experience, variable resolution is an extremely powerful adjunct to the manipulation of spatial data--but the existence of such a capacity creates certain problems of its own. Under a fixed resolution approach, only one decision need be made after assessing all the facts--and then you live with it. The decision, for example, to process all data at two acre grid cells is such a binary, one-time decision. With a variable resolution system, on the other hand, one is continually faced with decisions as to information cost, information value, the use of a given kind of data in a particular decision-making process, etc. All of these factors are simultaneously integrated into the decision on how big a given cell may have to be to adequately (for the purposes of the given study) define terrain, or land use, or soils. In a moderately sized study area (6000 square miles) such a decision might have to be made 45,000 to 50,000 times. The key problem with a variable resolution system is simply that because it is theoretically feasible to store data at the finest level of resolution (even if such data is appropriately handled at grosser levels), and because of the tremendous vested interest which accumulates around certain kinds of data (land use in particular), the decisions made in accord with a variable resolution capacity become overt assessments of quality/utility of various forms of data. This is not a trivial consideration, as we have learned, to our sorrow.

The essential variable resolution capacity of the data structure lies in the ability of the triangles to be modified in size and shape, providing that the grid construction rules are followed. Becasue of the variable cell size, each cell must carry with it information as to its own area and location in space (unlike the regular grid cell). Given the range and variety of situations and data types that may be captured by the triangle grid, it is difficult to give a hard and fast estimate of the relative number of cells necessary to define an area by regular grids versus triangular cells. Additionally, the ability of the triangle sides to capture the polygons defining attribute boundaries, means that the triangles themselves can provide an inherently superior representation of the actual location of the boundaries. In typical applications to date, the range of triangle sizes is roughly two orders of magnitude around the mean size. In one such application, a county of roughly 160,000 acres was represented by some 2,300 triangles. The data attributes considered in the triangulation were soils, terrain, future land use, and hydrographic boundaries. Thus, the mean triangle size was some 70 acres, with a range from less than ten acres to greater than 300 acres. A utility program within the ADAPT system provides histograms of the frequency distribution of number of triangles by area, in order that statistics on the behavior of the variable grid for different situations can be compiled and examined over time.

The average triangle size can vary significantly, depending upon the nature of the study being undertaken. In one case, a 1.6 square mile area was examined with 2,000 triangles for detailed hydrologic studies; the same area was also captured with a grid of 51 triangles, for other purposes. In a preliminary analysis of sewer design, in another study area, a density of triangulation of 200 triangles/square mile was used in the first cut; in a second round design, the density was increased to 400 triangles/square mile to obtain a better delineation of terrain variation. The triangle size range is limited only by availability of base maps at the appropriate working scale, and by computer precision. ADAPT normally stores locational information as decimal degrees of latitude and longitude, and as state plane coordinates in feet. Digitizer software is capable of resolving to within ten feet on the ground from a 7.5 minute topo map sheet source document using a digitizer of .001" resolution. The system can also be set up to use an arbitrary coordinate system, so that, if desired, even detailed 'micro' areas could be handled. In general, however, the local state plane coordinate system appears to be the most workable coordinate system for most efforts.

The inherent variable resolution capacity of the triangle framework provides the capacity to handle much of the data necessary in physical planning environments. The most variable data items are typically terrain, soils, and demographic/land use data. Terrain, as noted, is easily handled. Detailed soils surveys can be input, but for larger areas, soil association data, varying with less frequency, is adequate for many purposes. Future land use is generally presented as a broad-brush picture, and is amenable to manipulation. Existing land use, however, is frequently much more detailed--in some situations, down to individual house locations. For certain applications, as for assessment of flood damage, a good picture of detailed land use is important. Unfortunately, detailed land use data is one of the most volatile forms of spatial data, and is often out of date as soon as it is compiled. The ADAPT system was confronted with the problem of handling detailed land use data in an application involving calibration of nonpoint source models from field data. A detailed triangulation of the monitoring sites for terrain and soils was available, but inclusion of the extremely variable existing land use data directly within the triangulation framework would have required an excessive number of triangles, and would have been of limited value due to the aforementioned volatility of such data. Accordingly, a somewhat different approach was utilized; this approach provides a significant second-level variable resolution capacity, over and above that provided with the triangles themselves.

In normal applications, each triangle is considered to be homogenous in all of its attributes--there is no variation within a triangle. To handle the detailed land use data, however, this restriction was relaxed, and land use was defined as actual acreages of various land use types within a given triangle. That is, for each triangle, a set of counters is maintained--these counters accumulate the land use area for each category of interest. The data is obtained from detailed land use maps which have been digitized as variably-sized circles of a particular land use. Software then determines the relationship of the digitized detailed land use element (a circle of defined area, land use category, and spatial location) to a pre-existing triangle network, and accumulates the areas. The spatial location of each detailed land use element is known during the processing, but is not currently retained after that area associated with that element has been assigned to the appropriate triangle. The resulting data file consists of triangle records, in which certain attribute values are land use areas of a given type that lie within that triangle. In this manner, the land use mix for a given triangle does not have to be estimated/assumed from a grosser land use categorization, but rather can be directly calculated. Within this technique of detailed land use assignment, a number of approaches are utilized to minimize the search associated with assigning a land use element to a given triangle. Primary among these approaches is the use of a polygon as a basic unit against which detailed land use might be digitized. For example, a traffic zone, pre-existing as a polygon in the polygon file, might be used as the basis.

A background land use of low-density residential might be assigned to this polygon. Software would then retrieve all triangles included within the polygon, and assign the appropriate background value of low-density residential. As each land use element is processed, its absolute spatial location is known from its digitizer coordinates. All of the triangles in the polygon are searched to determine which contains that absolute spatial location, and the land use element is then assigned to that triangle, as an adjustment to the previously defined background value. This form of processing allows an orderly and relatively rapid approach to what otherwise appears to be an almost intractable probelm.

As noted above, the spatial location of the land use elements is available, but is not retained. It is possible, however, to maintain this information in a special file, for later use in such situations as detailed flood damage calculations, detailed siting studies, etc.

Thus, there are two basic mechanisms for handling variable resolution data within the ADAPT data structure. One is the use of variable sized cells, in which each cell retains its homogeneity (e.g. each cell would contain area of one and only one land use). The other approach is to take advantage of the homogeneity wherever possible, but also to allow for 'inclusions' within the individual triangle. Both techniques have been fully implemented and utilized in major planning efforts, and taken together, provide what appears to be a reasonable set of tools for handling most of the kinds of spatial data encountered in land-based planning.

DATA FLOW TO HEC PROGRAMS

The ADAPT system is organized as three sets of interacting components: the data base, display modules, and applications modules. Display modules are the printer and pen plotter programs, various table, lister, and report programs, all of which operate as essentially general purpose programs on any ADAPT data base. The applications modules are programs or sets of programs performing a specific design or planning function. Among the applications programs are modules for sewer design, land application analysis, nonpoint source analysis, disaggregation of demographic data to smaller areal units, etc., etc. These programs similarly interact with the data base, and may store data in the triangle record for later output through a display program. In certain cases, display programs or applications modules are obtained from other sources. For example, three-dimensional views of the terrain surface of an ADAPT data base are produced using the SYMVU program of the Harvard Laboratory for Computer Graphics. In such cases, rather than modifying these outside source programs, an interface which extracts data from the ADAPT data base and reformats it to the appropriate input format for the program, is used.

Within this framework, two possibilities for connecting the ADAPT data base to the HEC programs exist, as noted previously. One would be to convert programs HYDPAR, DAMCAL, and RIA to applications modules, and convert GRIDPLOT to a display module (or utilize the existing printer plot capacity of the ADAPT display modules, revised appropriately). The other would be to treat the four programs as 'external' programs, and write interfaces, converting triangle cell format data into regular grid cell format data. The approach that is recommended is a mix of these two, in which the HYDPAR, DAMCAL, and RIA would be revised to work directly off of the ADAPT format data base, and an interface to GRIDPLOT would be developed. The rationale and considerations for this approach are set forth below.

The triangular cell structure utilized in ADAPT is similar to the regular cell currently used by HEC in that data is referenced to the area. As noted previously, each triangle record carries with it information as to the area referenced, and the location of the area in space, as well as all of the data attributes associated with that triangle. As such, the file can be processed in a sequential manner, analogous to current HEC processing techniques, the only exception being that data accumulations would have to be based on the variable cell area. Thus, for program HYDPAR, the data flow shown in Figure IV-2 of Reference 2 could be followed analogously. Each of the data elements would be stored in the data record. The sub basin hydraulic length, which is an exogenous input to the HEC procedure, could, in fact, be calculated from the ADAPT terrain model, as could many other hydrologic parameters related to basin morphology. The flow of information in DAMCAL, shown in Figure V-2 of Reference 2, can similarly be handled in a completely analogous fashion, but here some of the distinctions between the triangle and the regular grid cell present themselves. In paricular, elevation varies continuously over a triangle cell. Thus, it is possible, given a reference flood elevation at that cell, to calculate the actual flooded area for the cell, and adjust the land use calculations accordingly. As noted earlier, if a spatial data file of significant detailed land use points were to exist, it is a simple matter to determine whether or not any of these points lies within the flooded area of a given triangle, and incorporate this more precise delineation of land use into the procedure. In addition, the possibility exists of direct calculation of the flood elevations using the terrain model of ADAPT within HEC-1/HEC-2.

For the RIA program, it appears that processing is again on a cell by cell basis, which presents no problem. Generation of coincidents matrices is simply handled, but must be adjusted to be weighted by area for it to be meaningful. Locational attractiveness on a cell by cell basis is again a routine operation. The only potential difficulty is the assignment of a 'distance' factor to each cell, as appears to be done in the RIA example. Distance to residential land use is noted as a cell attribute, used in the locational attractiveness calcuation, but this attribute is not cataloged as belonging to the basic data bank. If this data has been input exogenously to the data bank, then the ADAPT format can be handled analogously. The calculation of inter-cell distances within ADAPT is not as straight-forward as for the regular cell, because of the variation in shape of the triangles, and because any triangle may have a variable number of neighbors (unlike the regular cell, which, if completely internal, will have eight neighbors). Thus, RIA calculations based on inter-cell distances which would need to be calculated internally within the data file would require some development of an efficient inter-cell distance capacity within the ADAPT system.

The GRIDPLOT program is not described in detail, but appears to be similar in concept to SYMAP in that it produces shaded printer plots, apparently of the entire data file, with certain statistics associated with each plot. The GRIDPLOT program appears to be intimately tied to the cell size used in the data bank. ADAPT has previously been interfaced successfully to SYMAP, and a number of printer plot programs exist within the display module of ADAPT. Accordingly, no insurmountable problems in creating an interface to GRIDPLOT are foreseen. Further ramifications of this issue are explored in the following section on computer graphics.

It is perhaps appropriate to point out at this juncture some of the essential differences between the triangular cell as a cell and the rectangular cell, which have a bearing upon the data flow. As noted earlier, the existence of a triangle itself is information-bearing within the ADAPT system. That is, a triangle side has meaning, and triangle vertices and sides are points of relatively high information content, as opposed to a set of random or regularly spaced points. The study area to be incorporated within a data bank can be seen as a continuum or surface in each of its variables (in the real world). Short of explicitly representing this surface, any cell-based representation involves some smoothing, and hence some reduction in the high-frequency variations. With a variable resolution system and cells whose shape/location itself is information-bearing, the triangle cell can capture more of the high-frequency variation than can an equivalent number of regular cells. If data stored in triangle format is then passed, through an interface, to a regular grid, some smoothing will of necessity take place, and the increased information content associated with the triangle is lost. If a large number of small regular grids are interpolated from the triangle, again the value of the triangle-based system in limiting the number of discrete cells that must be dealt with is lost. The loss of the high-frequency information in this smoothing process is non-linear in its impacts. For example, in terrain modeling, the high slope areas will generate relatively more nonpoint source pollutant; development costs on high slope areas are significantly higher. Smoothing of this terrain through either regular grids or 'large' triangles in effect filters out these high frequencies and prevents their being carried forward in the analysis. Depending upon the process being analyzed, this effect can be important.

A further feature of the triangle cell as opposed to the rectangular cell is that it is meaningful as a finite element for such processes as rainfall-runoff generation. A regular grid cell is not unambiguously defined as a terrain element, and flow patterns from adjoining cells are not defined as they are between triangular elements. This 'finite element' behavior of the triangles for hydrologic processes allows for detailed flow routing over each element, as opposed to summarizing all of the element characteristics for a basin and performing an 'average' routing, a procedure which again eliminates the important high-frequency variation which can be attributed to small impervious surfaces, high slopes, etc. In the context of dynamic analyses, it is meaningful to talk about mass balances on a triangle, accumulation, deposition, depth of flow, and other items of physical significance. Thus, the triangular cell becomes more than just a repository for data, it becomes an analog of a real-world terrain element. This capacity of the approach has been explored in only limited fashion to date, primarily in the arena of modeling of rainfall-runoff-nonpoint source generation, but it suggests the possibility of more physically-based, descriptive models of these processes than those presently available.

COMPUTER GRAPHICS

An ADAPT data base is not structured with regard to any particular output format. Data is stored in geodetic coordinates, not in relation to a printer character. As such, the ADAPT data base is essentially 'device-independent'. Because so much of the graphic data of interest to planners is mapped line data, the initial implementation of display modules for ADAPT centered upon the use of the pen plotter as an output device for graphical output. Capabilities of the pen plotter graphics display modules within ADAPT include polygon plots, contour plots, scatter plots, drainage network plots, base triangle map plots, all at continuously variable scale. Alternatively, plots can be auto-scaled to fit within a desired window, or both a scale and window can be specified. The vector plotting approach can also be used with Tektronix terminals for remote graphical access to the data base. This line plotting capability was recently augmented by a printer plot capability. The printer plot capability was introduced to the ADAPT system to provide both rapid turnaround/low cost graphical displays of the data base, for checking and orientation purposes, and to provide some graphical capacity from remote teletype terminals. Because the ADAPT system uses geodetic coordinates, these printer plot programs required the development of an interface to the grid matrix of printer plot positions. One approach uses the centroid of the triangle as a locator, and the printer plot position for the particular character associated with the data element to be plotted is located at the centroid of the triangle. That is, only a single character is produced for each triangle, independent of the size of the triangle, and that character is at the triangle centroid. An alternate approach, also implemented, actually plots triangle sides, so that the explicit boundaries are retained. It is a simple matter to modify the plot programs to print multiple points for each triangle, so that larger triangles will fill more of the spaces in the printer plot grid.

Printer plot programs currently available allow for variable scaling, variable line spacing on the printer, and selection of arbitrary windows. Symbology is currently 'hard-wired' in at 61 characters, and there is no current provision for overprinting; these two restrictions can of course be relaxed at an increase in processing cost--programs are currently set-up to be low cost, 'quick-look', rather than final product.

Perhaps the major problem with printer plots interfaced to the triangle network is simply that of resolution at a given scale. Due to the nature of the triangle cells, many individual triangles may fall at a single plot position, particularly when map scales are large. Short of defining a special symbology for overprinting, or generating maps at larger scale and then photographically reducing them, there is little adequate resolution of this problem.

In terms of interfacing with a program such as GRIDPLOT, the logical data flow would require that each triangle be either sub-divided into grid cells, or smaller triangles be aggregated up into larger grid cells. The problem of overlaying an arbitrary regular grid cell on the triangle pattern has been solved for other purposes, and could be utilized here to define an 'average' situation for each grid cell to be plotted by printer plot. From this orientation, the interface would work in the direction from the grid cell to the triangle network--that is, given a grid cell, all of the triangles falling within that cell would be determined, and the appropriate 'average' area or characteristic determined. The next grid cell would then be processed. This is distinct from an approach which would process the triangles sequentially, partitioning them into grid cells or aggregating up as necessary, which could also be implemented, following upon the pattern of the existing ADAPT printer plot programs with the modification that data could be accumulated in a single plot cell until the entire file has been processed, at which time the necessary symbology can be applied to the cumulated data in the cell.

One additional printer plot capacity not mentioned above is the opportunity to display numerical values associated with a given triangle, at the centroid of the triangle. Thus, a plot of the actual numeric centroid elevations, or soil codes, or land use codes, as opposed to a range plot represented by a symbology, also exists. This capability is implemented with a subroutine which decodes a given number in the triangle record into separate integers, and then determines the appropriate plot position for each integer. This approach is feasible because the printer plot routines of ADAPT set up a matrix in core in which each element is a print position which is filled at the appropriate plot position as each triangle is accessed. Within this framework, it is possible to interrogate the matrix as to its current value before replacing that value with another character, thus insuring that overwriting will only take place when no significant information will be lost.

ADVANTAGES AND DISADVANTAGES OF PROPOSED TECHNIQUE

It is difficult not to appear biased in discussing the advantages and disadvantages of the adoption of the ADAPT system by HEC, in view of the obvious vested interest of W. E. Gates and Associates. WEG/A is firmly of the belief that ADAPT represents state-of-the-art technology for manipulation of land-based data in conjunction with planning and design process models, and has in fact committed much of the very existence of the company to that proposition. With this declaration of bias, and under the assumption that the proposed solution would take the form of re-orientation of the existing HEC programs to work entirely off of an ADAPT data base as opposed to a regular grid cell data base, the following advantages and disadvantages (from the point of view of HEC) may be identified:

disadvantages

- need to acquire ADAPT software
- need to revise existing programs to conform to ADAPT data base system
- need to learn new system
- possible increase in system overhead associated with storing ADAPT topological/locational information
- desirability of pen plotter and digitizer availability in conjunction with ADAPT may require additional hardware resources beyond those presently available
- additional decision-making and data evaluation necessary with variable resolution storage capacity

advantages

- system provides digital terrain model, variable resolution capacity, meaningful finite elements, polygon manipulation for both data input and retrieval, geodetic coordinates
- system has proven capability to manipulate spatial data for large areas
- cell orientation means that existing HEC programs working off regular grid should be modifiable without excessive difficulty
- system provides for direct access programming, leading to possibilities for interactive and interactive graphic manipulation of spatial data for large areas
- variable resolution capacity cuts redundant data storage significantly
- existing applications/display modules of ADAPT may be of interest within HEC (nonpoint source analysis, various hydrologic estimation programs, sewer design, pen plotter routines, etc.)
- capacity to manipulate embedded drainage networks should be of value to other HEC efforts
- ADAPT system is ongoing, evolving system, with additional modules/capacities being added by WEG/A in many areas of potential parallel interest to that of HEC--thus, opportunity for HEC to obtain additional capacity for system without incurring development costs
- modular nature of system and system utilities allow for easy implementation of new applications/display modules

CONCLUSION

HEC has invested considerable effort in automated spatial analysis techniques to date, with what appear to the outsider to be at least two significant benefits--the recognition of the appropriateness and utility of coupling models and spatial data bases, and the introduction of spatial data base technology as a valid and usable technique for studies within the Corps. Having made these strides, the next levels of consideration relate to those factors associated with usability, flexibility, efficiency, and cost of such systems. As those of us who have worked with spatial data are well aware, it is almost always easy to do something in concept--doing it in reality, with tremendous pain, is another matter entirely. The effort associated with producing the Trail Creek pilot study, though not indicated in the report, must have been considerable. The payoff is the apparent acceptance of the approach within the Corps.

We know from our own experience that such acceptance is hard-bought. Initial implementation of the ADAPT system was a massive effort, involving much hand work. Once we had demonstrated the feasibility and utility of the concept, efforts over the next period of years were devoted towards making it, if not easy, at least reasonable in terms of effort. A parallel recognition was that it is all too easy to devote most of the project effort to 'managing' the data, and too little time to using the capacities of the models/spatial data base to gain insight into the processes under consideration. Accordingly, over the years, the emphasis has shifted more and more towards the position of getting to the point of having a data base to work with, in a reasonable time frame and with reasonable expenditure of effort, and then devoting the majority of time and effort to actually working with the data base, sorting and sifting, testing alternatives, etc.

HEC has obviously recognized some shortcomings of its existing approach in terms of being able to deal with large areas with little pain. The variable resolution solution of ADAPT, proposed herein, can go a long way towards lessening the pain, shortening the time necessary to get the data base on line, and allowing more real planning/engineering work to be carried out. In our pursuit of a system with these capacities, we have taken a very pragmatic approach--"if it works, use it." Thus, the ADAPT system has incorporated both cell and polygon approaches, without entering into interminable arguments. Digitizers and pen plotters are utilized because they are cost-effective. Printer plots are included because they are also valuable. Mini-computers and interactive graphics are being explored with a view to making the system more efficient, more usable. The point of all of this is not to continue to praise the merits of the ADAPT system--rather, it is to suggest that there is really no single best solution within the field of spatial analysis--the appropriate mix of tools will always contain a number of ways of doing things, and this mix will change over time, depending upon the problem at hand, the cost and availability of hardware, and the continuing evolution of the tools themselves. A pragmatic approach to achieving this mix, taking advantage of the availability of new hardware/ software, appears to be the most appropriate, certainly for those with an engineering orientation, where the solution to the problem, rather than the imposition of a technology, is the goal.

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VARIABLE GRID RESOLUTION - ISSUES AND REQUIREMENTS:
THE ADAPT SOLUTION

DISCUSSION

Q. Do all overlays, for various geographic parameters, need to be made on the same Basemap?

A. With the exception of land use, yes, all parameters are overlaid on the same Basemap. This is accomplished by direct scaling or photographically enlarging or reducing the working maps to the size of the Basemap. It is also possible to rescale the triangular grid plot to the scale of the working maps. Land use data inserted in our 'circle' format goes in from whatever scale source map is available - we produce a Calcomp triangle map at that scale and utilize the combination in digitizing.

Q. Does it require a specially trained person to determine the triangular network and do the encoding?

A. Yes, it does require specially trained personnel to lay out the triangular cell network. The triangles themselves contain significant geographic information by the very nature of their size and location, i.e. triangle boundaries are established from a detailed understanding of the terrain, soil, land use, etc. The usual rectangular grid cells do not require this additional complexity because the cells are only storage locations and the nature of the cell itself does not contain any information. Once the triangular network has been established, then it is a straight forward encoding job to digitize the X, Y, Z data for the vertices of the triangles.

Q. Why don't you capture all the geographic detail of your triangle when you are doing the terrain assignment?

A. For ease of encoding, only the triangle vertices are encoded during the first pass. Software is then used to set up the triangular grid storage system and additional geographic variables are added in successive passes.

Q. Should you start with terrain as the basis for your triangulation and then subdivide those triangles as necessary for other geographic variables?

A. Yes, good terrain representation is the foundation of our data bank.

Q. How many times is each vertex digitized?

A. As many times as there are triangles in common with it. Software is used to assign numbers to each vertex in subsequent processing of the digitized data.

Q. Are there any automatic checks on triangle encoding?

A. No, but because it is a consistent set of information, the missing triangles really stand out.

Q. How do you number the triangles and what information do you store for each triangle?

A. The triangles are numbered sequentially using the digitizer during the encoding process. The X, Y coordinate location of each vertice is determined by the digitizer and the elevation is keyed in by the operator. The identification of neighboring triangles is calculated during file establishment processing and then retained in the file.

Q. Have you used any statistical sampling techniques to determine the value of cell parameters for different geographic characteristics?

A. No, usually the dominant value is encoded. Remember, though, that triangle boundaries are originally established to identify differences in geographic characteristics.

Q. What do you do when you want to add another polygon (geographic data variable) to an existing triangle network?

A. The triangle network was originally established to represent the variation in all different geographic variables of interest. If a new variable is to be established, the easiest method would be to use the polygon shapes already represented by the existing triangles. Additional triangles could be added to existing network and this would involve an updating of the data bank.

Q. Is the triangular network particular to a special purpose?

A. Yes, it is not a generalized geographic data bank. The triangles themselves provide information by their size and shape. The emphasis is on good terrain representation.

Q. How can you add more detailed land use information to an existing triangular network?

A. We have used a percentage composition approach to capture more detailed land use information within a triangle, e.g. 10% industrial, 30% commercial, 20% residential, and 40% developed open space. Because land use is usually so irregularly distributed, the percentage composition approach has allowed us to represent this data and still maintain our basic triangular network. Another solution is to add more triangles as previously noted.

Q. Have you used the land use, soil type, surface slope, etc., characteristics of the triangles in direct computation of rainfall-runoff from each cell and then route that water downstream from triangle to triangle according to the topography?

A. Yes, we have simulated the rainfall-runoff process using the kinematic wave technique on a triangle by triangle basis. The geographic data in the triangles has also been used in an aggregate fashion to compute unit graph characteristics of subbasins. We have found the unit graph parameters to be quite sensitive to the nonlinearities associated with lumping several triangles together.

VARIABLE GRID RESOLUTION - ISSUES AND REQUIREMENTS:
THE ADAPT SOLUTION

AUTHOR'S ADDITIONAL COMMENTS

1. I have no major revisions to make to my paper at this time. I would like to re-emphasize certain of the attributes of triangles that appear to have become somewhat cloudy in the discussion of the past few days. Chief among these is that the reduction in the number of cells achieved by using the triangles provides for direct access programming techniques. That is, each cell record is immediately available to a processing program. This allows for such basic processes as profiling (finding the terrain and attribute path between two points), automated drainage calculation (through investigation of the properties of adjacent triangles), and polygon retrieval (specification of a chain, and retrieval of only the cells lying within that chain). We anticipate that this approach will further lend itself to interactive on-line modeling, and use of minicomputer based modeling/GIS technology. As modelers, we have found a number of areas in which the direct access capacity significantly enhances performance, operating mode, etc. In essence, it is no longer necessary to take a drink of water from a firehose - rather, the data base can be investigated by parts, in an almost browsing manner, which is particularly valuable for calibration of our models. Thus, the variable resolution capacity significantly reduces the number of cells, making an alternative storage methodology feasible, and providing all the attendant advantages. It seems that I did not adequately stress this aspect in either my paper or presentation.

2. In terms of apparent drawbacks, I think that most are logistical and perhaps institutional, as opposed to technical. As I have noted, we tend to rely upon a digitizer/plotter. I think that these are valuable and cost-effective general purpose tools, particularly for a shop such as HEC, but I do recognize the situation where one would desire to operate with hand-encoded data and a printer plot capacity. Inasmuch as the digitizer processing of ADAPT is an upgrade of our formerly hand-encoded procedures, I see a fairly straight-forward resolution to the encoding problem. Display, on the other hand, is still desirable through a plotter. I can see the possibility of enhancing currently existing printer plot software to make it more usable in a "no plotter" environment, but I am not sure that the quality of the product would be visually acceptable, although certainly technically adequate. It

is more an issue of form than substance here. As people have noted during the seminar, construction of a triangle grid requires some skill and training. The production people of WEG/A are currently attempting to produce a manual of procedures and training program for our own in-house purposes (to be able to hire lower cost, lower skilled technicians) - again, quality control procedures are being developed for this same purpose.

3. Keep your options open!

VARIABLE GRID RESOLUTION
HYDROLOGIC ENGINEERING CENTER

By

Jack Dangermond[1]
Raymond Postma[2]
William Hodson Ph.D.[3]

I. Introduction

The Hydrologic Engineering Center (HEC) has requested suggestions for increasing the efficiency of their automated geographic data system. Using grid cells of variable size for areas of differing resolution has been suggested as one possible solution to the problem of data management and analysis. This method is possible and workable however it would represent major changes in HEC processing procedures and software to maintain a multivariable data file of variable grid resolution.

The approach taken in this paper is to describe new ideas within the context of existing HEC software procedures, and to concentrate on the design of new file structures which can be easily interfaced with existing programs. With these policies in mind, we recommend the following:

1. Keep the existing software, with minor modifications.

2. Use data storage techniques capable of interfacing with existing programs.

3. Increase efficiency by using data compression techniques which approximate variable-size grid cells but appear to the software as a uniform grid.

4. Consider the possibility of doing several partial studies at different grid cell sizes.

This paper describes the background for these recommendations, and identifies several alternatives to each of these policies.

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II. Data Automation and Storage*

The area where it was felt that recommendations could best be directed dealt with the storage of map data. In order to best understand the data storage component a brief description of automation currently practical for HEC use is provided.

A. Data Automation

The conversion of map data into computer readable form is normally done by one of two techniques: manual recording of cell data or by use of an electronic digitizer measuring x,y coordinates.

1. Cell Encoding

The practicality and cost effectiveness of cell encoding is a subject of no little concern. The parameters for selecting a cell size and technique for encoding are poorly researched and as data is recorded on these, statistics will provide meaningful input in the design of data structures. We do know certain information. For example, when manually coding continuous data, such as elevations, the cell by cell recording technique appears to be more efficient and accurate than recording continuous lines and interpolation into a cell structure. However, if very accurate values are not required on a large portion of the study area, a more dispersed sampling could reduce the coding effort. If the sampling were done on an equal interval basis, for example every other column on every other row, the computer processing would be reduced. A surface mining operation in Australia using ESRI software achieved very acceptable results with this approach. The sampling technique in this example would reduce the coding effort by a factor of four in those areas where this resolution is adequate. By doing every fourth column on every fourth row the coding effort would be reduced to one-sixteenth

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*There are two general categories of technology associated with automative map recording, analysis and display which have been the principal focus of ESRI software development project work and information systems. These are grid cell and x,y coordinates. These two categories have unique automation techniques, analysis procedures, output types, etc., and although separate also have linkage which allow them to be interfaced as hybred systems for special applications.

In an ideal environment (i.e., experienced people, computer hardware, time, etc.) an analyst might use a combination of these tools which would be extremely sophisticated. Appendix A describes a variety of available software and how it can be linked together to create an integrated system. However, the resources necessary for taking advantage of these tools may not (at least in the short run) be available or practical to the users of the HEC system.

of the effort of doing every cell.

The point is that the mathematics of surface sampling and rough abstractions are a major consideration.

Also, when manually coding polygon line and point data our experience has been that some type of data compression is usually more efficient than coding every cell. ESRI has implemented a two-field per record, run-encoded technique which uses the value of a variable and the rightmost column for which that value applies. This technique is based on one documented by Dr. Kenneth Dueker, which has been modified and includes special control records. This has greatly reduced the manual coding effort. By including a feature to duplicate all or part of the previous row, the coding effort becomes quite small for what conceptually approaches a variable grid cell. The actual grid cells are the same size, but contiguous identical cells are grouped and coded together. By using these coding techniques, it does not seem necessary to develop some type of variable grid cell technique in order to increase coding efficiency.

2. X,Y Coordinate

Finally, the coding process is not affected by the final grid cell size if, instead of manual coding, a digitizer is used to code the areal, lineal and point data. This alternative requires a shift to using x,y coordinate recording rather than grid coding, and allows the creation of several grid data banks of differing size. Software to efficiently create and analyze data in an x,y coordinate form is developed and has been in use for several years (see Appendix A). Since HEC has traditionally used grid files in the analysis and display portions of its system, this paper considers only grid systems. ESRI normally maintains separate grid data files created from digitized data, due to the effort and expense of converting to grid form for each analysis.

B. Data Storage

In a non-compressed format the amount of data storage increases relative to the inverse square of the length of a grid cell side. By making cells 200 feet by 250 feet (1.14 acres) instead of 800 feet by 1000 feet (18.2 acres), sixteen times as much storage is required. On many computer systems the amount of data storage required for the spatial data file becomes the most important factor. This is due to two factors: The first is the cost of storage, especially on a data file that is used over a long term where storage cost may exceed processing cost. The second factor is the access time often required for use of large data files. Many systems require large data files to be off-loaded to tape, and these files need to be reloaded to on-line storage before analysis can occur. This transfer may not occur for several hours after a request is placed for use of a file. Also, the transfer cost may be considerable (as high as $50 to $100 on some installations). Finding ways to store data in a compact form is therefore an important requirement for increasing the efficiency of a system.

Grid data can be stored either as a separate file for each variable or as one multivariable file. For single variable files, a file structure similar to the coding layout usually requires the minimum amount of space. For continuous or highly heterogeneous data, the standard run-encoded data structure can require twice as much data storage as an uncompressed form, because column location must be included for each value. There are two ways to handle this problem. The first is to place these data in an additional file structure which is not run-encoded. The second alternative is to add a feature which allows switching modes between run-encoded and uncompressed data stored in the same file. When in the uncompressed mode, the column field would be used to store data. This mixed data type scheme appears to be feasible if additional logic is added in the I/O routines to enable and disable the compression mode.

ESRI software normally converts character data to binary form for faster processing. However, on some computers, such as the system at Lawrence Berkeley Labs, the storage requirement for the binary file is up to five times greater than the character file. In this case, the trade off between increased processing efficiency of the binary file and the increased data storage cost must be evaluated to find the most cost-effective approach. "Bit packing" of the binary data for the LBL system is a third alternative, but the cost of packing and unpacking the data may prove to be as costly as using a character data structure.

ESRI has purposely developed its software in a modular form so that the external data structure is nearly transparent to the analysis part of the programs. A simple replacement of the input/output subroutine library allows the existing programs to use a different data structure. One other advantage of the modular approach is that groups or blocks of data can be accessed by the user program and separated for analysis on systems where this process is not available or is done inefficiently. This increases the efficiency of transferring data from storage to analysis.

If only a few variables are analyzed at the same time, it should be possible to retain them as single variable files. Leaving the data as separate files for analysis offers several advantages. The first is that no additional effort is required to convert the data from the coding process into a multivariable form. The second advantage is that the storage space required by several separate files is normally considerably less and never greater than any composite multivariable file that could be formed. The reason composite files usually require more space is that a third dimension (variable position) must be included in the multivariable file structure. The third advantage is that only the variable(s) needed for a given analysis need be on-line. It is often possible to retain a few single variable files on-line for several days in situations where the composite file is so large that it must be stored off-line on tape. Therefore, when using few variables, it is most efficient to use single variable files.

However, there are situations where it is not possible or efficient to work with separate single variable files. This occurs, for example, when the number of files needed for a given analysis exceeds the capacity of the computer system to process them. We have found that on most systems five files is a reasonable maximum before conversion to a composite multivariable file is required. This number is not an absolute limit. We have worked with small systems which could not accept more than four files, and other systems on which as many as fifteen files have been used. It is sometimes difficult for the user to reference more than one or two files in a given analysis resulting in multivariable files being created unnecessarily. If there are only a few files that need to be used for a given analysis, attention should be given to simplifying user access to the required files, rather than creating a multivariable file with greater storage requirements.

If a multivariable file is required, more efficient techniques for its storage are possible than those which are normally used. The standard multivariable file has the row number in the first field of each record, the column number in the second field, and then the data values in the remaining fields. While some savings could be made by dropping the row and column fields, the resultant file is much less flexible. The simplest way to decrease storage requirements on this file is to add a third field which would give the final column for which all the data items apply. This allows one stored record to account for all sequential cells which contain the same data. A new multivariable record is stored whenever a variable changes in value. This technique appears well suited to situations where all the data variables are forced to be homogeneous over a sequence of several cells, such as is the case in a variable grid cell type approach. If this technique is used, all continuously changing variables and all highly heterogeneous variables must be excluded and remain as separate single variable files or no compression can occur.

Another file structure which appears to offer more flexibility and has potential for more storage efficiency uses a technique which considers each variable independently and only creates a record if a change from the previous cell occurs for that variable. Each data record has two fields rather than a complete multivariable entry. The first field indicates the variable position on a standard multivariable file and the second field has the new value for that variable. This value is used until another change occurs for that position. If any variable changes between cells a spatial identification record precedes the change which indicates the column position (normally 2) and the column number where the data change occurs. This data structure can be used on any mix of heterogeneous and homogeneous data, but it is still best to leave continuous data as separate non-compressed files if possible, because it changes with each cell, thus requiring a new record for each cell.

A current example illustrates the significance of data compression to increase efficiency of a system. Mitch Modeleski of the Association of Bay Area Governments (ABAG) has evaluated their data files to determine the space savings from data compression. He found that significant space could be saved by the methods suggested here. He also noted that a point of diminishing returns was reached where the efficiency further data compression was offset by the system requirements for accessing and manipulating the stored data. Table I lists the variables that are stored by ABAG, using the single variable run-encoded technique described earlier. The matrix size is 450 rows by 420 columns for a total of 189,000 cells. Each cell covers 500 meters by 500 meters.

Table I

Variable	Records	Cells/Run	Classification
Slope Stability	19,722	9.81	4
Geology	11,333	17.38	6
Precipitation	15,903	12.24	28
Fault Zones	4,023	53.00	56
Coast Line	3,074	72.22	4
Flood Zone	5,179	40.03	2
Well Yield	7,346	27.44	4
Soil Type	15,655	12.60	135

The ABAG data differs from HEC data in several ways. The cell size is 62 acres compared to the 1.14 acres used by HEC in its smaller grid cell. It follows that the number of cells per run would be considerably higher for a smaller grid cell size. For the same number of classifications the runs may be seven to eight times longer. Using the smaller factor, the data storage savings by using compression would range from 35 times less space for slope stability to 250 times less space for the coast line variable, because only two fields are needed to define a run. Even if a more conservative factor is used, it is obvious that the data storage reduction possible with this method is considerable.

A study that ESRI is presently working on in northern Venezuela has files for most variables at two different grid cell sizes. The data was initially converted from polygon form to grid cells with 66.67 meter sides. Then 3 by 3 groups of cells were aggregated into larger cells with 200 meter sides. This technique guarantees that the primary occurrence in a large cell is not replaced by a secondary feature. It also allows for the secondary feature to be retained as a separate file at the larger grid cell size. The 66 meter grid cell file has 767 rows and 766 columns for a total of 587,522 cells, while the 200 meter grid cell file is 256 by 256 or 65,536 cells. Table II compares five of the variables in the grid cell file. All variables are areal type data except infrastructure.

Table II

	66 Meter Cells		200 Meter Cells		Classi-
Variable	Records	Cells/Run	Records	Cells/Run	fications
Political Boundaries	3,410	172.3	1,129	58.0	6
Agricultural Districts	3,162	185.8	1,040	63.0	4
Traffic Zones	2,355	249.5	787	83.3	2
Infrastructure	83,963	7.0	20,398	3.2	127
Visual Resources	10,028	58.6	3,285	20.0	19

For infrastructure a secondary file of 4246 records and a tertiary file of 549 records were also created at the 200 meter grid cell size. Elevation data was manually coded at the 200 meter grid cell size only. Table III shows the number of records required to store the data in standard run-encoded form when the elevation readings were rounded to some multiple of meters.

Table III

Rounding Elevation to Nearest N Meters

N	Run-encoded Records	Cells/Run	Average Elevation Change
1	49569	1.32	12.27
2	42718	1.53	13.87
5	32792	2.00	18.98
10	26415	2.48	24.41
20	20065	3.26	33.44
40	14286	4.59	50.49
100	6119	10.70	117.28

The study area involved has a mixture of flat marsh land in one portion and very rugged mountainous terrain in another portion. By rounding to a large constant multiple for the whole file, detail in the marsh land is lost without affecting the mountainous area. This is normally the reverse of what is desired in a HEC flood control study.

It appears that elevation does not lend itself to run-encoding, so that the uncompressed mode technique mentioned earlier may be especially suitable for this variable. Other continuous data may, however, be rounded and still retain its usefulness. One such variable is topographic slope. Table IV shows the data compression possible by rounding. The slope file used was created by taking the greatest change in value for each cell in the elevation file.

Table IV

Slope Rounded to Nearest N Percent

N	Run-encoded Records	Cells/Run	Average Difference
1	35286	1.86	2.8
2	26420	2.48	5.0
4	18023	3.64	7.0
8	11377	5.74	10.2
Special*	17899	3.66	-

*Slope Grouped 0-1, 2-4, 5-9, 10-14, 15-24, 25-39, 40-59, 60+

The special case of uneven grouping required slightly less storage than the rounding to 4 percent even though the information retained should be much more usable. The precipitation variable in the ABAG study also used a similar grouping technique.

Another item worth comment is that several variables in the ABAG and Venezuela files have been represented in an areal form rather than in a continuous form. These include slope stability, precipitation and slope categories. For many analyses this approach is acceptable, and the data storage savings is very great. The HEC DAMCAL program requires the variables to be in continuous form, but this does not preclude using the same variables in a pseudo-areal form for the RIA program.

In order to maintain a data file compatible with the present software, and at the same time achieve data compression which approximates a variable grid size, we recommend the following types of data storage:

1. A single-variable form

c	V

where V = Value.

c = Rightmost column of row to use value V. Leftmost column to apply V is one greater than column specified in previous record. Special records using negative c values for new rows and other controls.

For switching to uncompressed data mode a special negative value could be used. Returning to run-encoded mode would be automatic after column c value is read.

2. In multivariable form

p	V

where p = Position in multivariable.

V = Value for this position.

Value applies until next record with same position.
New row when p = 1.
New column when p = 2.
No column record if no changes in other positions.

In addition, serious consideration should be given to analysis of windowed areas. Rather than working through the total data file when a particular area is being studied, a single program pass can produce a separate data file for just the study area. This is a very efficient technique when data is stored for a large area. The total data bank can then be stored off-line and only the areas of concern used on-line.

III. Data Flow to Programs

Due to the modular approach proposed here, stored data can be made compatible with the existing programs by replacing the input/output (I/O) library. The flow of data, then, would proceed in the same manner as it now does. To increase efficiency, the RIA program should be changed to accept data in the form of several single variable files, in addition to a multivariable form.

The data flow routine can be structured so that blocking and deblocking occur efficiently. That is, blocks or groups of variables are transferred from storage to the program, rather than each variable being located and transferred separately. The blocks of data are separated (deblocked) for analysis so that the program receives the data in the same manner as it does at the present time.

IV. Graphics

The data would continue to exist in a uniform cell size structure and would, therefore, be completely compatible with existing display techniques.

V. Advantages

There are three significant advantages to using a system of run-encoded data.

1. Less storage space is required due to the compression achieved by this method. Additional storage space can be saved by using single-variable files whenever possible.

2. The run-encoded analysis can be structured such that analysis occurs only when a variable changes value between two cells. Efficiency of analysis is increased by this method, because the first cell with a new value is analyzed and subsequent homogeneous cells need not be analyzed separately. A variable which is homogeneous throughout the study area need not be analyzed, while a continuous variable would be analyzed for each grid cell.

3. Because only those grid cells with new values are read into the program, fewer records are processed than at the present time. This increases the overall speed of processing.

Two disadvantages may result from adoption of this system:

1. Modification of software is required. This disadvantage is minor compared to alternative systems which require entirely new software packages.

2. A slight increase in processing may result from the routines which convert files to internal form. Again, increasing storage efficiency must be weighed against decreased efficiency of handling compressed data.

VI. Conclusion

The procedures recommended here allow HEC to maintain its present software with minor modifications. Significant increases in efficiency can be obtained by variable sampling, coding and storage techniques without revising the entire system to use a variable grid cell size.

If variable grid size is desirable, different files for different areas should be considered, using the present system.

Just as Detroit has found that for the short term it is easier to rework the internal combustion engine than to produce a completely new scheme, so the problems associated with a uniform grid size can be minimized.

VII. References

Modeleski, Mitch, "The Basis Papers", Berkeley, ABAG, October, 1976.

Dueker, Kenneth J., "Geographic Data Encoding Issues", Technical Report #43, Institute of Urban and Regional Research, University of Iowa, June, 1975 (revised).

APPENDIX A
DESCRIPTION OF ESRI SOFTWARE FOR X,Y GEOGRAPHIC ANALYSIS, CONVERSION TO GRID DATA AND GRID GEOGRAPHIC ANALYSIS

This section describes the general software systems developed by ESRI. The initial material in section 1 presents an overview of geocoding techniques and software systems. This overview is followed by a presentation of the PIOS, GRIPS, and GRID programs.

1. Software System and Geocoding Techniques Overview

As stated in the report, ESRI has developed software which utilizes geocoded x,y coordinate data. This method of geocoding involves detailed coordinate recognition of map features which are spatially identified as polygons, lines and points. This approach requires that geographic data be digitized and stored according to x,y point measurements. In case of polygons and lines, this requires a series of points defining the perimeter of each polygon or variation of each line segment. Single points are referenced by a single measurement.

The x,y coordinate technique maintains the integrity of the original data by storing the precise points which represent variations of the geographic data. Once the data is digitized according to x,y coordinates, the data file can be converted by GRIPS software to a "grid cell" format of any scale or size necessary for analysis. This capability allows the PIOS automation technique to interface the GRID System and utilize all the grid cell analysis and output advantages.

While computer transformation to grid cell matrices is normally used, manual transformation, called encoding, is also possible. Encoding to the GRID system is the same as digitizing to the PIOS system. Encoding may occur cell by cell or by groups of cells. Cell by cell encoding usually occurs when data being automated exhibits a great amount of variation. For variables where data is largely homogeneous, consolidated encoding may occur. The consolidation involves identifying for each row, beginning and ending columns. The cells interior to, and inclusive of the identified columns are inherently identified as having the same code. In either case, a numeric symbol is chosen to identify the sub-variable, such as the topographic elevation, type of vegetation, type of soil, etc., most representative of each cell. The group of cells each thus identified, then collectively represents by the total matrix. Once encoded in numerical terms, the variable can be stored within the computer as a digital data matrix. Usually, several data files are similarly created for a specific area, each file representing a different geographic variable. Once created, they can be stored separately as single variable data files, or merged into one or more multi-variable data files. The encoding procedure is similar for each variable, although special considerations may sometimes be necessary due to map scales, quality, and type of available information, etc.

Table 1 outlines the procedures and outputs of the PIOS/GRIPS/GRID scheme.

Table 1

Procedures/Outputs of the PIOS/GRIPS/GRID Scheme

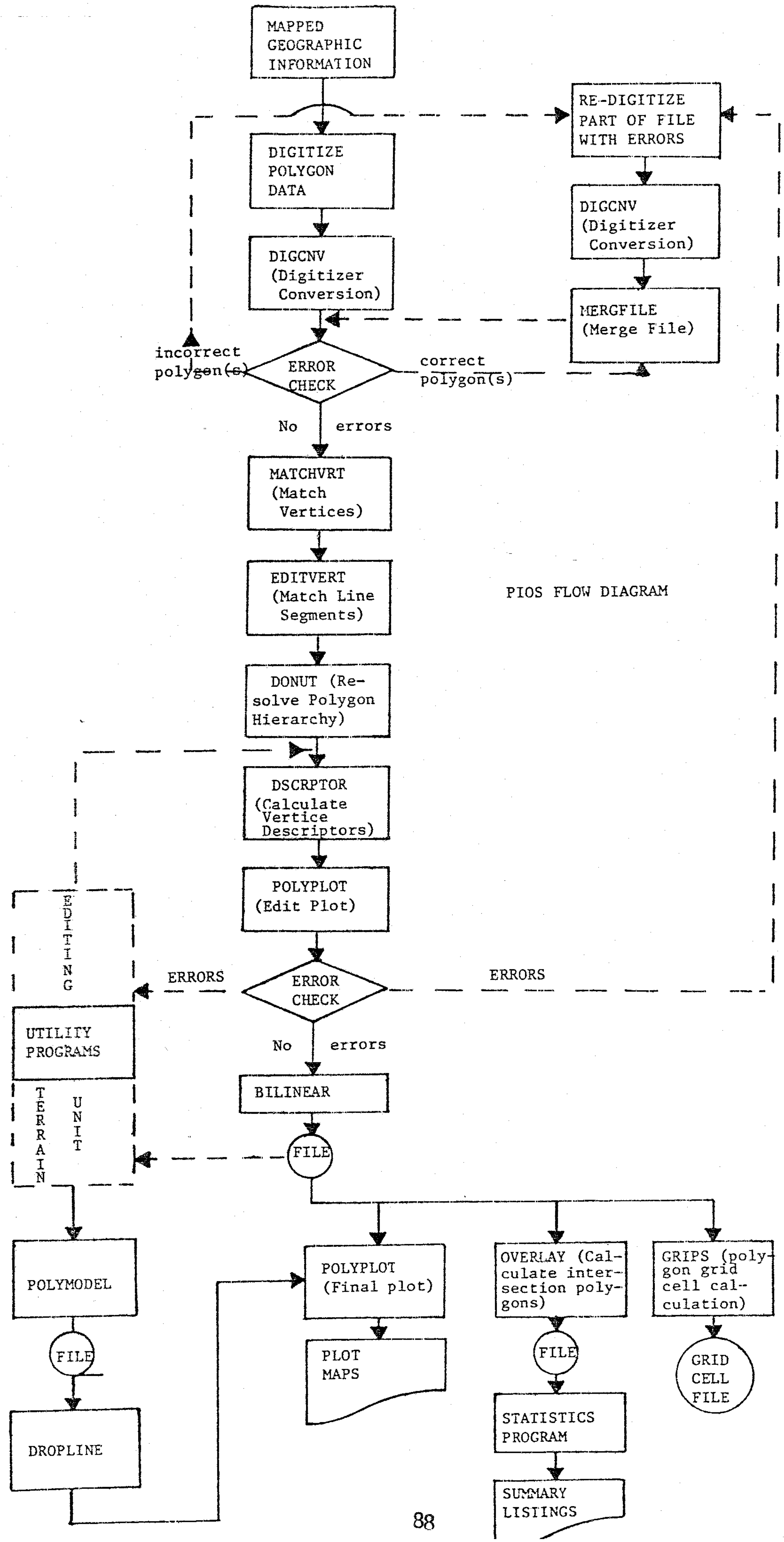
		Program or Procedure	Description
PIOS	Input Procedure	X,Y Coordinate Digitizing	A procedure used for recording x,y coordinate measurements for computer referencing of points, lines and polygons.
	Storage and File Creation	DIGITIZER CONVERSION	Converts magnetic tape computer card images of digitized data to a disc or a regular tape file in the appropriate coordinate system.
		POLYGON MERGE	Allows portions of a file which had been redigitized due to updates since initial automation, errors found in editing, etc., to be merged into the correct portion of the parent file.
		MATCH VERTICE	Consists of five programs which allow vertices of adjacent polygon borders, which were separately digitized and may not coincide, to be matched and represented by points with identical vertices.
		EDIT VERTICE	Allows strings of matchverted vertices which comprise adjacent polygon common borders to be analyzed and compatibility resolved.
		DONUT	Provides area calculation adjustments due to polygons completely contained within other polygons.
		DSCRIPTOR	Calculates the area, centroid and minimum and maximum coordinates for each polygon and transforms numeric digitized data codes to alpha codes.
		BILINEAR	Allows a digitized map to be transformed into another coordinate referencing system.

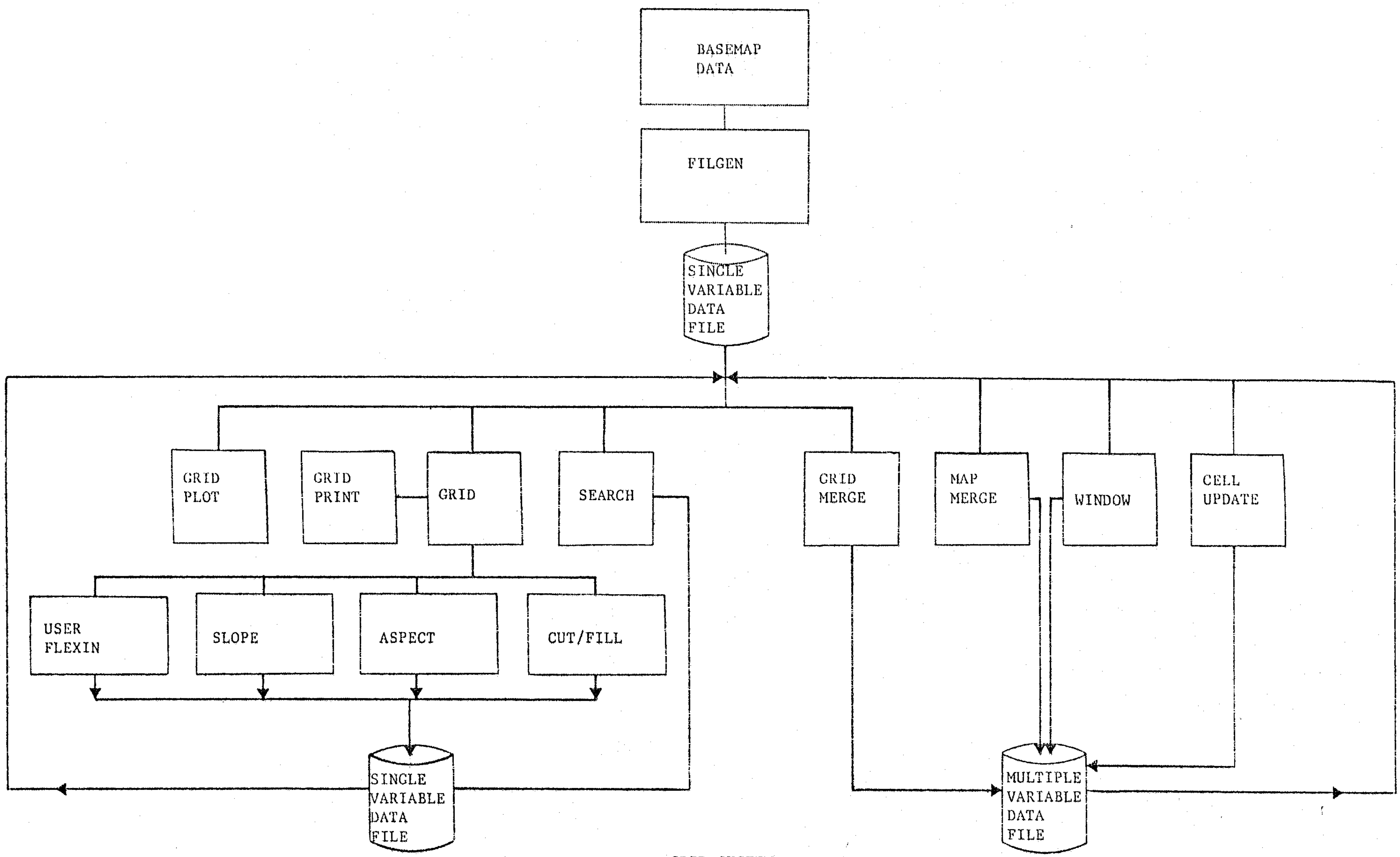
		Program or Procedure	Description
PIOS	Data Manipulation	OVERLAY	Calculates intersection coordinates of polygons overlayed on other polygons, thus identifying newly created polygons.
		STATISTICS	Various programs for calculating area statistics for polygons.
		POLYMODEL	A program that allows the user to perform flexible overlays and rescaling/weighting procedures to model polygon oriented data.
	Utility Programs	DIGITIZER FILE GENERATION	A transition program to enhance the transformation of digitized data for input to the DIGCNV Program.
		LIST VERTICE	A program used to create a list of vertices for editing digitized data or a file of selected data for partial plotting.
		CHANGE VERTICE	Allows the user to manipulate point data to correct errors made during the digitizing process.
		DELETE AND SHIFT VERTICES	A program to shift vertices and to eliminate one of two identical vertices within the same polygon resulting from the MATCHVRT Program.
		SINGLE OVERLAY	A program to create an overlay file when the subordinate (minor) variable area to be summarized is contained entirely within a single polygon of the dominant (major) variable.
		IDENTIFIER FILE GENERATION	A program to create a concise file of PIOS automated data which contains identification records of each polygon minus the vertice coordinate data describing the polygon perimeter.
		POINT REVERSE	A program to reverse the order of a string of digitized points.

		Program or Procedure	Description
PIOS	Utility Programs	CODE FIND	Allows the user to select specific codes for generating selected characteristic plots.
		UTM CONVERSION	This program calculates UTM coordinates from latitude and longitude coordinates.
		TERRAIN UNIT EXPANSION	Enables a user to expand the normal PIOS 16 digit ID record up to 40 digits.
		SPLIT IDENTIFIER	Allows a user to split the Terrain Unit Expansion File into unique variable components.
		ADD VARIABLE	Allows variables to be added to a file after the Terrain Unit Expansion and Split Identifier Programs have been run.
	Display Out-put Programs	POLYPLOT	Creates computer drawn plots of digitized information.
		DROPLINE PLOT	Allows the elimination of common boundaries between adjacent terrain unit polygons when similar components have the same code.
GRIPS	File Creation	GRIPS	A program used to convert x,y coordinate data to a grid cell format (gridded information from polygons).
GRID	File Creation and Manipulation	FILE GENERATION	Program used to generate an unformatted, sequential single variable data file from a cell by cell data encoding technique.
		RECORD GENERATION	A program similar to FILGEN, except a consolidated data encoding technique is used and windowing and updating are possible.

		Program or Procedure	Description
GRID	File Creation and Manipulation	GRID MERGE	Allows the user to merge one or more single variable files into a multi-variable file.
	Data Manipulation	GRID MODEL	A program that allows the user to perform flexible overlays and re-scaling/weighting procedures to model gridded geographic data.
		SEARCH	Allows the user to accomplish frequency/distance analyses.
		TOPOGRAPHIC ANALYSES	A group of programs used to perform various calculations for a) slope b) aspect c) sun intensity d) grading e) visual exposure.
		SPECIAL ANALYSES	Programs to perform various calculation and analysis problems such as a) time/distance search b) gravity models c) diffusion models d) area calculation e) frequency calculation f) aggregation analysis g) statistical analysis, including standard deviation, mean et al. h) sort/cross tabulations.
	Utility Programs	CELL UPDATE	Program used to update cell or area data.
		WINDOW FILE	A program used for identifying a portion of a data file for selected area analyses.
		RECORD GENERATION	Accomplishes both of the above.
	List Information Output	CELL LIST	Allows the user to list the inventory of a given cell.
		WINDOW LIST	This program summarizes the inventory of specified polygon or variable area.
		LINE LIST	A program which summarizes the inventory of a specified linear zone of data.

<table>
<tr><td rowspan="6">GRID</td><td rowspan="6">Display/Output Programs</td><th>Program or Procedure</th><th>Description</th></tr>
<tr><td>GRIDPRINT</td><td>A program which allows the user to generate "line printer" maps.</td></tr>
<tr><td>GRIDPLOT</td><td>A program which generates "pen plotter" maps.</td></tr>
<tr><td>ELECTROSTATIC GRIDPLOT</td><td>A program which generates electro-static plotter maps.</td></tr>
<tr><td>GRIDVIEWS</td><td>A program to generate a non-continuous display of 3-D grid data.</td></tr>
<tr><td>VIEWS</td><td>A program to display a continuous 3-D surface.</td></tr>
</table>


MAPPED GEOGRAPHIC INFORMATION
RE-DIGITIZE PART OF FILE WITH ERRORS
DIGITIZE POLYGON DATA
DIGCNV (Digitizer Conversion)
DIGCNV (Digitizer Conversion)
MERGFILE (Merge File)
incorrect polygon(s)
ERROR CHECK
correct polygon(s)
No errors
MATCHVRT (Match Vertices)
EDITVERT (Match Line Segments)
PIOS FLOW DIAGRAM
DONUT (Resolve Polygon Hierarchy)
DSCRPTOR (Calculate Vertice Descriptors)
POLYPLOT (Edit Plot)
EDITING
ERRORS
ERROR CHECK
ERRORS
UTILITY PROGRAMS
No errors
BILINEAR
TERRAIN UNIT
FILE
POLYMODEL
POLYPLOT (Final plot)
OVERLAY (Calculate intersection polygons)
GRIPS (polygon grid cell calculation)
FILE
PLOT MAPS
FILE
GRID CELL FILE
STATISTICS PROGRAM
DROPLINE
SUMMARY LISTINGS


BASEMAP
DATA
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PRINT
GRID
SEARCH
GRID
MERGE
MAP
MERGE
WINDOW
CELL
UPDATE
USER
FLEXIN
SLOPE
ASPECT
CUT/FILL
SINGLE
VARIABLE
DATA
FILE
MULTIPLE
VARIABLE
DATA
FILE

GRID SYSTEM

2 PIOS Software

The primary purpose of PIOS is to create an automated, geographic oriented, multi-variable data file of polygon, point and line data which can be used individually or in overlay combinations for various analyses and graphic outputs.

Various component programs comprise PIOS and, following the digitizing of the data, can provide the user the above capabilities.

These component programs are summarized in the following section.

2.1 Digitizer Conversion - DIGCNV

The Digitizer Output Conversion Program (DIGCNV) converts digitized data from magnetic tape to a disc or tape file in various formats. The program has the capability to edit the identifiers associated with each digitized polygon or line. A list of the identifiers and the coordinates associated with each polygon may be produced by this program.

Conversion to another referencing system is possible. This is provided for by digitizing at least three tic marks with coordinates relative to the coordinate system into which the data is to be transformed (i.e., State Plane, Universal Transverse Mercator, etc.). This is accomplished just prior to digitizing the map. The DIGCNV program calculates the appropriate factors for this transformation for various pairs of digitized tics and selects the pair to be used, based on several user supplied options.

2.2 MERGE FILE (MERGFILE)

Sometimes a portion of the digitized data is not satisfactory and must be redigitized. The merge file (MERGFILE) program allows up to two of these digitized files to be merged. Various features are available to edit, delete, or insert the polygons from the redigitized data file into the original data file.

2.3 MATCH VERTICE (MATCHVRT)

The purpose of the match vertice portion of PIOS is to eliminate sliver underlaps and overlaps of double digitized data points (vertices). Slivers sometimes occur because each vertice is digitized twice, once for each polygon encompassing the common border. Due to such dual automation, the digitized points may not exactly coincide. The match vertice portion of PIOS utilizes five programs in consonance with a user specified tolerance distance between matching vertices to resolve this. It should be noted that programs 2 and 4 are standard system sort routines and are not controlled by the user as are 1, 3, and 5. Sometimes consecutive points on a line segment fall within this specified tolerance and are matchverted. This creates two points with the same coordinates. For subsequent processing efficiency (such as for the EDITVERT program), the matchvert programs eliminates duplicate points, also.

2.4 EDIT VERTICE (EDITVERT)

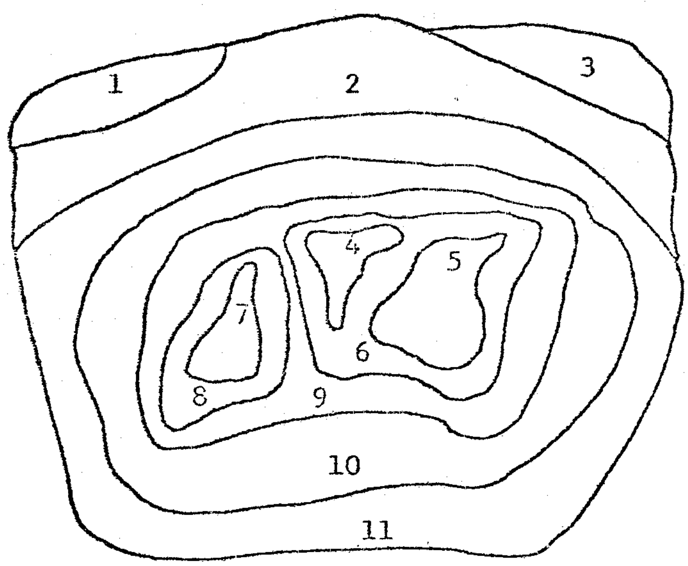
The Edit Vertice (EDITVERT) portion of PIOS is composed of 5 computer programs. These programs are used to edit interfacing line segments (i.e., the double digitized series of vertices) which represent the overlapping boundaries of adjacent polygons. Selected polygons or an entire file may be edited with EDITVERT. EDITVERT changes vertices as needed to correct the original PIOS file. Two types of changes are made: 1) a point is added; 2) two points are averaged. A point is added when a series of double digitized vertices representing a line segment between adjacent polygons contains an unpaired vertice. The unpaired vertice is added in the proper position in the otherwise identical line segment. This may be accomplished only within a string of matched line segment vertices, not at either end.

Averaging two vertices occurs when two unpaired vertices, one from each of the two adjacent polygons, exist within matching line segments, in the same position in the otherwise paired strings. These similarly positioned unpaired vertices may be averaged when they are within a preset tolerance of each other.

2.5 DONUT

As mentioned in the digitizing portion of this documentation, the DONUT program is used to manipulate the coordinates for specially digitized polygons which completely surround other polygons. These are called donut polygons because holes are left in the surrounding polygons when the areas of the surrounded polygons are deleted.

A maximum of five levels of donuts may be used with this program. Level one is the outside polygon and the level increases by one until the innermost polygon is reached. Polygons which do not contain other polygons and are not contained themselves are given a level "0" classification. The order in which the polygons are digitized is important. Figure 46 shows the correct level of the various polygons and the order in which the polygons must be digitized.



Poly #	Poly Type
1	0
2	0
3	0
4	5
5	5
6	4
7	5
8	4
9	3
10	2
11	1

FIGURE 46

The program automatically creates new sets of polygon coordinates with the donut coordinates inserted in counter clockwise order after the first point of each appropriate surrounding polygon. The branch is then back to the first point to create a hidden line. This is continued for each donut area before continuing clockwise around the vertices of the surrounding polygon. The procedures mentioned assure that the proper status of each polygon is considered when statistical runs, such as area calculations are made.

2.6 DESCRIPTOR (DSCRPTOR)

The coordinate descriptor calculation program (DSCRPTOR) is used to calculate the area, centroid, and minimum and maximum coordinates for each polygon. Prior to final plotting, DSCRPTOR is used as an edit step. The area calculation portion of DSCRPTOR provides this edit (i.e., if an area calculation for a polygon yields a "0", the polygon is not defined by a "closed" path, that is digitizing did not return to the origin; if the area calculation is negative, the polygon was digitized backwards when it should not have been). For final plotting, the 16 digits of the identification records are split into the appropriate identifiers and converted to alpha characters, as in the case of the land use polygons. These polygon identifiers are then output to form a new file structure acceptable to the overlay, plotting, and statistical printout programs.

2.7 POLYGON PLOTTING (POLYPLOT)

High quality graphic representations are a basic output of the PIOS system. The POLYPLOT program is used to create, edit, and produce final computer drawn plots of the polygon outlines at various scales with optional title data for map identification. Plotted polygon labels may be either numeric or alpha, such as is used for land use. The reference tic marks are also plotted to show the relation to another coordinate system, such as state plane.

2.8 DROPLINE PLOTTING

DROPLINE is a plotting program with card input data similar to the Polyplot program. Sometimes, polygon coding (and subsequent plotting) involves the same assigned code for contiguous polygons. This often occurs when dealing with terrain units where the second ID record for a polygon encompasses several codes. When plotting one variable represented by a specific code location within the terrain unit expansion ID, two contiguous polygons for that variable may have the same code. Thus, one homogeneous area is represented by two polygons. Sometimes this is visually misleading and may not be desirable. DROPLINE creates plots where the common boundary between the two identically coded polygons has been eliminated.

The DROPLINE process actually begins by running the EDITVERT sequence of programs on the desired data file. The output file from the second sorting step (EDITVERT program 4) is then stored (using JCL). This EDITVERT processing step is normally <u>in addition to</u> a prior EDITVERT submission which was used to "clean" the file. This second EDITVERT run creates strings of vertices (points), identified by association with the polygon on the left and the polygon on the right. The program check the codes of the polygons on either side of point strings interior to the study area and plots only the strings where these codes are different. For vertice strings which correspond to the map borders, only one of these polygons exists. These border strings are always plotted.

2.9 BILINEAR

The digitizing process generates an automated computer readable copy of a map which is the same size as the base map original. The BILINEAR computer program is used to transform this map into another coordinate system such as UTM or state plane coordinates.

This bilinear transformation is possible because digitizer coordinates are measured for four locations called "TIC" marks for which coordinates in the new system are known. Since measurements in both systems are known for these points, all digitizer measurements can be transformed to the new referencing system. The new coordinate system eliminates distortion which existed on the original map, allows accurate area calculations, and, because of referencing separately digitized maps with a common system, provides a method of joining adjacent maps.

2.10 OVERLAY

The OVERLAY program calculates the coordinates of the intersection polygons resulting from mathematically laying the polygons from a dominant (major) map on top of the polygons of a subordinant (minor) map.

Point-in-polygon and line intersection techniques are used to construct the coordiantes of the intersection polygons. The dominant polygon identifier is added to that of each subordinate polygon or portion thereof to form the identifier for each intersection polygon.

The output file of the OVERLAY program is in the same format as the two input polygon files and may be thus used as input to perform a subsequent overlay.

2.11 STATISTICAL PRINTOUTS

The STATISTICAL PRINTOUT portion of the PIOS system consists of five programs, each designed to produce one or two specifically formatted area calculation printouts. The programs are used in conjunction with files identified by means of job control cards. Input specifications apply to files so identified. The first program produces area calculation listings by individual minor polygon codes. The second two programs produce area calculation listings by major polygon(s) showing individual minor polygon codes. The last two programs produce area calculation summaries based on a consolidated code, such as residential land uses aggregated for "R-1", "R-2", and "R-3" into one consolidated residential land use code of "R". Each program is described briefly below based on the output which each program produces.

1. Minor Polygon Summary - Produces basic (or selected) area summary listings by individual minor polygon.

2. Minor Polygon Summary - One Overlay - Produces area summary listings by individual minor polygon for polygons associated with one overlay (e.g., land use polygons by census tract).

3. Minor Polygon Summary - Two Overlays - Produces area summary listings by individual minor polygon for polygons associated with two overlays (e.g., land use polygons by census tract and General Plan Area).

4. Minor Polygon Summary (Consolidated Code) - One Overlay - Produces area summary listings for minor polygons aggregated by code type, for polygons associated with one overlay (e.g., consolidated land use by utility service district).

5. Minor Polygon Summary (Consolidated Code) - Two Overlays - Produces area summary listings for minor polygons aggregated by code type for polygons associated with two overlays (e.g., consolidated land use by utility sub-region showing area in national forest).

2.12 Utility Programs

The PIOS system also contains twelve programs whose purpose are to enhance data through various updating, editing, and manipulating capabilities. A brief summary follows:

1. DIGITIZER FILE GENERATION (DIGFILGN) - Transforms digitized data for imput into the DIGCNV program. No data manipulations are associated with this program.

2. CHANGE VERTICES (CHVERT) - This program allows the user to modify polygons already on the data file or to add additional polygons to the data file. The user may modify existing polygons by changing vertice coordinates, deleting vertice coordinates or adding coordinates. Also, by giving a string of vertices, the user may create a new polygon.

3. LIST VERTICE (LTVERT) - LTVERT allows the user to create a list of x,y coordinates for polygon, line or point data. The selection of polygon, line or point sequence numbers is at the discretion of the user. The list generated is used for editing the vertices of all or of a selected number of polygons, lines or points. Data selected for listing often depends upon apparent errors such as contiguous polygons with sliver errors, extra lines in the automated data, etc. Based on an edit of generated listings, changes are subsequently made.

This program may also be used to create a temporary output file to plot selected polygons, lines or points.

4. Delete and Shift Vertices (DASHVERT) - The Delete and Shift Vertices (DASHVERT) program allows the user to eliminate one of two identical vertices within the same polygon resulting from the Match Vertice program. This only applies to consecutive vertices digitized for a single polygon which happen to occur within the Match Vertice tolerance; it does not eliminate double digitized vertices for contiguous polygon "shared" borders. This purpose of DASHVERT is seldom used since MATCHVERT does this automatically. The DASHVERT program also allows the coordinates of the data file to be shifted to facilitate and assure coincidence with another variable for use by the overlay program. Since coordinate recordation is accomplished using a cartesian system, a subtractive shift is required to change the coordinates and approximate a move of the data file toward the origin.

5. Single Overlay (SINGLOVL) - This program allows the user to create an overlay file when the subordinate (minor) variable area to be summarized is contained entirely within a single polygon of the dominant (major) variable.

6. Identification File Generation (IDFILGN) - The Identification File Generation (IDFILGN) program allows the user to create a concise file of PIOS automated data. This concise file consists of the identification records of each polygon minus the vertice coordinate data describing the polygon perimeter. Creation of this identification record file is for efficiency purposes. It is used by the statistical summary programs, and data manipulations (e.g., record sorts) are much faster and easier since the coordinate value "strings" do not enter into the processing procedures.

7. Point Reverse (PTREVRSE) - The Point Reversal program is used to reverse the order of the digitized vertices describing the outline of a polygon. This needs to be done if the vertices for a polygon were erroneously digitized in a counter clockwise order. Since the DSCRPTOR program assumes clockwise order for area calculation, a negative area sometimes flags a polygon with counter-clockwise points. The point reverse program allows this to be corrected.

The reversing operation is performed only on specified polygons. Polygons which contain the estimated centroid as the last vertice are identified so the centroid is not included in the point reversal. Only a portion of the vertices may be reversed, as in the case of reversing only the vertices for a donut polygon after the digitized points were run through the donut polygon program.

8. Code Find - This program reads either a two or a three record PIOS structured file. Pre-determined linear or polygon data codes specified by the user are read and their associated PIOS data are output to a temporary file. Normally, this newly created temporary file is input to the POLYPLOT program to create a plot of selected characteristics.

9. UTM Coordinate Calculations (UTMCONV) - The UTMCONV program calculates and converts coordinates from latitude and longitude inputs. Conversely, it calculates latitude and longitude from UTM inputs. The calculations occur using specific points called TIC marks, for which either latitude/longitude or UTM coordinates are known.

10. Terrain Unit Identifier Expansion (TUEXPAND) - Polygons automated using the PIOS system are most often described by two records; one is a 16 digit record of identifiers which specifies among other things, the map number, the polygon sequence number and the polygon code; the other is a record of coordinates which define the identified polygons outline. For most applications, the four to six digits (of the total sixteen) allowable for the polygon code in the record of identifiers is sufficient. This is because a polygon is normally associated with only one type of variation (i.e., a type of vegetation or a type of soil or a type of geology, etc.). However, the advent of terrain unit mapping generated polygons with multi-variable characteristics (i.e., a type of vegetation and a type of soil and a type of geology, etc.) each characteristic possibly requiring a four to six digit code. Thus, the four to six total digits normally allowable for a polygon code identifier in the first record is not adequate.

In fact, up to forty digits may be required to sufficiently identify the multiple characteristics associated with terrain unit polygons.

For this reason, a second identification record may be generated to allow additional description capabilities. The second identification record lists (as a character string) the multiple characteristics which describe a polygon (or polygons). This unique sequence of characteristics is in turn assigned a numeric terrain unit code. Referencing this terrain unit code in the first identification record (where the four to six digit variable code is normally placed for a single variable polygon) links the first identification record to the second identification record.

Whether the first identification record is used by itself, or in conjunction with this second identification record, the coordinate record remains the same.

If a second identification record is required, the Terrain Unit Identifier Expansion Program generates this second record for each polygon.

11. Split Polygon Identifiers (SPLITIDS) - The SPLIT IDENTIFIER program is used to restructure terrain unit data files for use by the POLYMODEL program.

The TERRAIN UNIT EXPANSION program was the first step toward providing PIOS modeling capabilities. It linked unique sequences of geographic characteristics (listed in a table of possible variations such as sequence 1 = soil x_1, vegetation y_1; sequence 2 =

soil x_1, vegetation y_2, etc.) to polygons in a terrain unit polygon data file. Each polygon was thus assigned a set of geographic characteristics which identified its internal variation. The assigned characteristics were stored either as an expansion identifier record (in addition to the normal 16 digit identifier record and the coordinate record) or as an independent file. The expansion identifier record was an integral part of each polygon description. The independent file, when accessed, related to the original file simply by association on a one to one basis (i.e., the first expansion ID relates to the first polygon, etc.). For efficiency, both TERRAIN UNIT EXPANSION output files used the character (alphameric), versus the binary (numeric) computer storage concept. The expansion identifier was thus a continuous string of characters. A specific variable could thus be accessed only by identifying the beginning and ending digits which recorded the associated variation (i.e., digits 7-10 of the 40 digit expansion ID reflect vegetation type). While the character string storage concept is efficient, character storage does not directly adapt to arithmetic processing, and identifier strings are continuous (i.e., vegetation cannot be addressed as, say, variable 5, or variable 17, it must be addressed as digits 7-10, or digits 26-29, etc.).

The SPLIT IDENTIFIER program was developed to transform the TERRAIN UNIT IDENTIFIER generated character files into numeric files represented by easily manipulated integer values. In addition, it transforms the continuous character strings into discrete components (i.e., vegetation may be variable 3, soils may be variable 4, etc.). This facilitiates the modeling process and specifically generates a multi-variable file in a format usable by POLYMODEL.

12. Add Variable (ADDVARBL) - ADD VARIABLE allows variables to be added to a file which has been expanded by the TERRAIN UNIT EXPANSION program and subsequently restructured by the SPLIT IDENTIFIER program.[1]

After the expansion and restructuring process, a polygon has a number of characteristics associated with it (i.e., a type of soil, a type of vegetation, etc.) which can be identified as variable one, variable two, etc. Sometimes, one (or more) of these variables represent variations which in turn encompass composite characteristics.

For instance, instead of polygons being represented by different soil types, polygons may be represented by different soil series. Each soil series classification may be typified by a specific ph factor, a specific erodibility factor, etc. After the SPLIT IDENTIFIER program, all that would be known per polygon would be the soil series category. For modeling purposes, the individual components of the soil series may be necessary. In such cases, the soil series

[1] It should be mentioned that the ADD VARIABLE program can be used to expand a Multi-Variable Grid File.

numeric identifier can act as a "key" to the specific characteristics associated with that particular soil series code. These associated characteristics can then be added to the SPLIT IDENTIFIER FILE, just as terrain unit components were added to the terrain unit file using the TERRAIN UNIT EXPANSION program.

While the example used a soil series code per polygon as a "key" to additional data which could be added to the SPLIT IDENTIFIER file, several variables could be used as a composite key to add additional data. This could be likened to a form of modeling (i.e., if the soil series key variable code is 0013 and the geology key variable code is 32, add an erodibility facter of "2" as a new variable).

The characteristics associated with the sub-categories of each variable which is acting as a "key" are known (i.e., soil series 0013 = ph factor Z and erodibility factor E, soil series 0014 = ph factor D and erodibility factor F, etc.). This variability was pre-determined in order to establish a coding sequence to describe polygon variation. This table of possibilities may be added to the file by the ADD VARIABLE program. The only unknown is the code(s) of the key variable(s) per polygon.

The ADD VARIABLE program examines the SPLIT IDENTIFIER file polygon by polygon. It identifies the code(s) associated with the "key" variable(s) and links this code, or specific set of codes, to the appropriate characteristic or set of characteristics input by the user. The characteristics to be associated with that code, or set of codes, are then added, as additional variables, to the variables which already define the polygon being examined. The SPLIT IDENTIFIER file is thus expanded.

A printout may be specified which lists, polygon by polygon, the old versus the new variable data.

2.13 POLYMODEL

POLYMODEL, as the name implies, allows polygon modeling. That is, the geographic variations (i.e., type of soil, type of vegetation, etc.), characteristic of a polygon within a study area can be examined and compared to the same features of other polygons within the study area. This capability can be used to develop polygon rankings which answer planning questions, such as "what areas within the study area are most capable or most suitable for a particular use". POLYMODEL is used in conjunction with a single terrain unit file which has been restructured by the SPLIT IDENTIFIER RECORD Utility program. The new structure identifies variables individually instead of as a portion of the composite terrain unit file. With POLYMODEL the user has the option to identify any of the variables associated with each terrain unit polygon and manipulate them. As mentioned, the manipulations actually represent user defined models necessary to satisfy unique analysis needs (such as identifying soil erosion potential), and may encompass a sophisticated interaction of many variables which include additive and/or multiplicative weightings, etc. When several variables are involved, the appropriate variables associated with each polygon are separately tested on a polygon by polygon basis. As these appropriate variables are tested, weighted values are determined depending on the user specified test criteria. A cumulative weighted total (a ranking) evolves for each polygon and a file is generated. The composite polygons which form the study area may then be mapped as the model, with numeric indicators (using POLYPLOT) or lighter or darker shadings (using AUTOPLOT), representing the constraints or opportunities of a landscape.

While such modeling capabilities normally require special programs to be written by computer programmers, POLYMODEL is a type of computer language which was specifically created for use by non-technical users and actually allows the users to "write" (create) these special programs. No special education, materials, etc., are necessary other than the PIOS system and this documentation of POLYMODEL.

To provide the above mentioned modeling capabilities, POLYMODEL incorporates first, a control card which describes the terrain unit file being input and, second, a number of specific purpose commands. The program is flexible and the user is able to specify variations of the POLYMODEL commands and their components. Such variations allow the user to control the analyses desired.

Regarding the POLYMODEL commands, each command and its associated data is input on a single card. All cards have the same format; while the various format fields per card allow different data inputs, for simplicity the same data input structure applies to each command card. The structure incorporates: four data identification fields; three data manipulation fields; and one text field. The inputs per card vary according to the command being input on that card in that different fields will be used for different commands.

3 GRIPS Software

The main purpose of the GRIPS system is to convert polygon oriented data into a file form usable by the programs in the GRID System. The input layout is similar to programs in the AUTOMAP II family; however, there are several significant differences. The most significant difference is that, in GRIPS, the polygon data values are input at the same time (and normally from the same file) as the coordinates. The GRIPS system consists of three programs. The first program is used to create an unsorted Base Map Image File (BMIF). The second program is the same file sorting program used in AUTOMAP II. It reads the unsorted BMIF and outputs a sorted BMIF. The third program is a file conversion program. This program reads the sorted BMIF, changes the file structure, and outputs a single variable file for use by the GRID system. However, the last two programs require no user input and are completely controlled by system control cards.

4 GRID Software

The GRID computer graphics information system is a general purpose computerized planning tool for the collection, storage, manipulation, analysis, and presentation of geographically arranged data. It consists of several programs which produce many unique analysis and display functions useful for planners, designers, and engineers.

The programs are specifically designed for use by persons with little actual programming experience. For a given study, many separate analysis and display functions may be warranted. The programs are designed to be compatible and efficient, with preliminary encoding and file creation steps one time procedures not needing duplication each time a variable is to be used. Each variable can be retained as a single variable data file to be used along with other similar single variable data files, or several such files can be merged to form a multi-variable data file. Either way, an entire data bank of environmental information is available for the various required analyses.

While the interaction of the component programs is essential, equally important is the way information is stored for retrieval and eventual use by the programs. Since the variables to be stored, such as topography or soil type, are geographically oriented, and computer storage is sequentially (or at least numerically) oriented, a system must exist which relates the two. Thus, a locational referencing system is necessary. If a large geographic area were subdivided into many small sub-areas, each sub-area could be more definitively identified than the original area, because less variation would be likely to occur. Further reduction in size of a sub-area would further increase the possibility of unique definition. At some point, say one acre, a specific data category, such as "soil type" within the overall variable "soil", could be identified as that soil type <u>most</u> representative of the smaller areal unit regarding the variable soil. If many of these areal units were placed side by side both horizontally and vertically, each similarly representing, say, a discrete soil type, a large area could be represented regarding the variability of soils. This system of contiguous areal units to represent a variable, such as soil type, is in fact, the basis of the "GRID" information system. In fact, "GRID" takes its name from this concept.

A series of equally spaced, parallel lines, both horizontal and vertical, is overlaid on a specific area, dividing it into a grid of equal sized squares or cells, as shown in Figure 47. By identifying each grid cell (or areal unit) with a specific sub-category of a geographic data variable, the entire grid then abstractly represents the collective distribution of any data variable over an area identified for study.

The use of such a grid cell system for data identification is the significant factor linking geographic information to machine storage regarding the GRID system. Additional variables, such as slope, vegetation, etc., can be similarly identified for the same area for a composite description. This composite description can then be stored as a group of single variable data files or can be merged into a multi-variable data file.

Since the grid is a set of continuous equal sized cells, orderly and systematically structured due to horizontal and vertical lines, the cells which are horizontally side by side can be thought of as rows, and the cells which are vertically side by side can be thought of as columns. Every cell in the grid is then a part of some row and some column. Each row/column location can be matched with the data variable, such as soil type, associated with the location.

Since the grid used for identifying geographic information is actually a matrix, it can be transformed, in total, into a numeric representation as described on the preceding page. The information, once transformed, can then be sequentially fed to the computer row by row, as a ditigal matrix suitable for computer manipulations. Any number of variables for a chosen area of study can be thus stored on a computer for eventual recall for analysis and/or graphic representation of a large overall information system.

The reader should keep in mind that, as previously mentioned, associating row/column locations with geographic data may be accomplished manually or by machine, such as by using GRIPS to convert PIOS data into a grid cell format. The latter method is most efficient and is normally used by ESRI. In addition, besides being efficient, the PIOS/GRIPS/GRID sequence provides data usable with both systems.

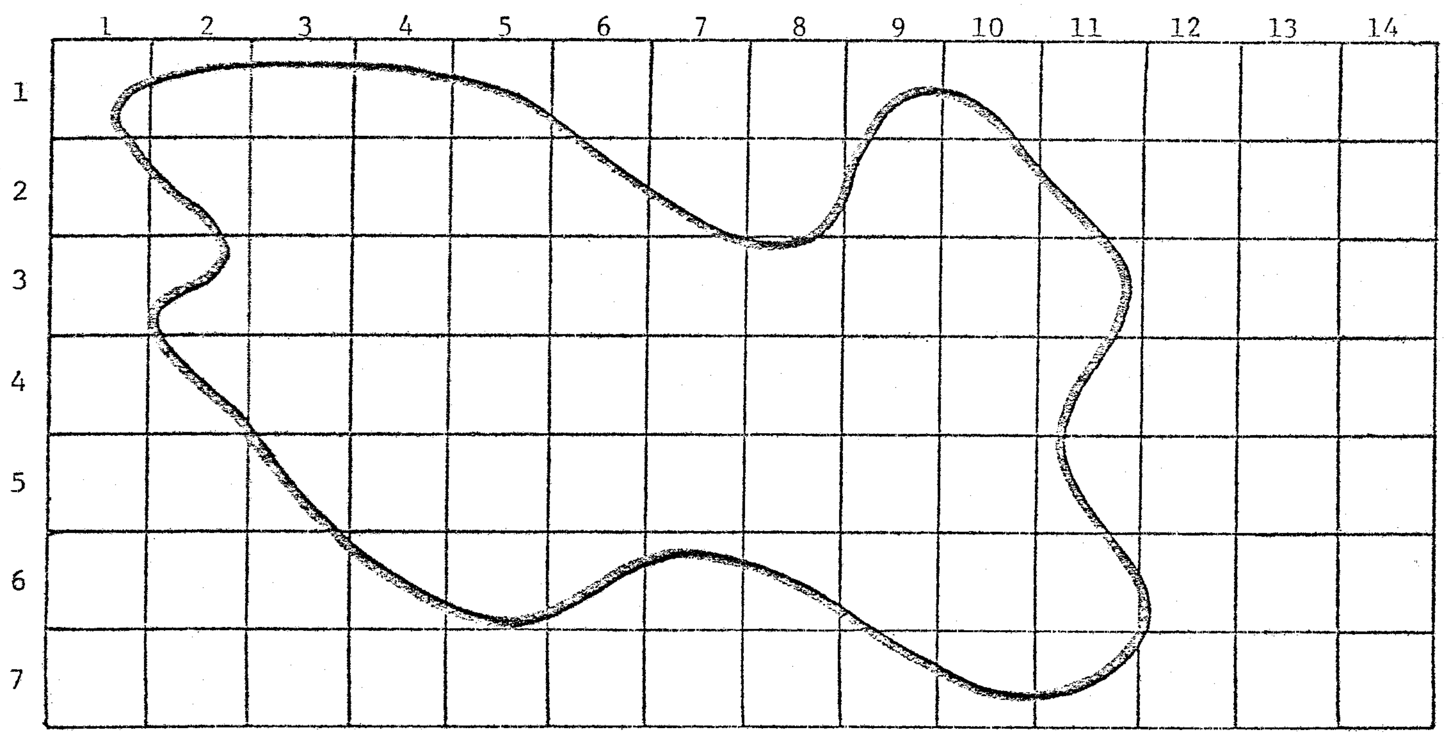


Figure 47

4.1 SINGLE VARIABLE FILE GENERATION - FILGEN PROGRAM/RECGEN PROGRAM

When geographic data variables are manually coded and keypunched, versus using PIOS and GRIPS, the next step is to generate a computerized data file. This file generation is accomplished by one of two computer programs: FILGEN or RECGEN. FILGEN is used to create a file from data encoded using a cell by cell coding convention (often used when great variation exists for the data). When a significant amount of data is homogeneous, RECGEN may be used to create (or update) a file from data encoded using coding convention which identifies beginning and ending columns for cells which contain a specific type of data, inclusive. RECGEN may also be used to create a "window" file from an existing file.

These programs are strictly storage oriented. No data manipulation (other than updating using RECGEN) can be accomplished by these programs alone; they must be used in conjunction with other programs with manipulative capabilities for specific tasks. Once one or more single variable data files have been generated with these programs, they are stored within the computer system (as a number of single variable data files, or through merging, as one or more multi-variable data files) for recall and use by any of the various manipulative programs (GRID II, SEARCH, etc.). Because of the storage aspect of such file generations, a FILGEN or RECGEN program may, or may not, be submitted simultaneously with a run whose purpose is data manipulation.

4.2 GRID II PROGRAM

"GRID II" is a grid cell oriented computer mapping program which provides map graphics of spatial information. It is an execution oriented program to be used in conjunction with stored single variable or multi-variable file data.

GRID II has been designed for speed and efficiency of map production. It normally uses the computer's standard printer because of the speed and cost advantages over plotter type maps. GRID II, with its high speed map production, allows the user instant feedback for environmental simulation modeling, a decided asset in environmental planning.

The GRID II program instructs the computer to make a map or maps, and specifies the precise form of the map or maps in terms of certain available elective treatments. One program can produce a set of maps, but each map requires its own set of instructions.

4.3 GRID MODEL

GRID MODEL allows the user to manipulate one or more variables prior to mapping. The manipulations actually represent user defined models necessary to satisfy unique analysis needs (such as identifying soil erosion potential), and may encompass a sophisticated interaction of many variables which include additive and/or multiplicative weightings, etc. When several variables are involved, the appropriate variables associated with each cell are separately tested. As these appropriate variables are tested, weighted values are determined depending on the user specified test criteria. A cumulative weighted total evolves for each cell. The composite of cells which form the study area may then be mapped as the desired model.

While such modeling capabilities normally require special programs to be written by computer programmers, GRID MODEL, like POLYMODEL, is a type of computer language which was specifically created for use by non-technical users and actually allows the users to "write" (create) these special programs. No special education, materials, etc., are necessary other than the GRID II program and its documentation.

To provide for the above mentioned mapping and modeling capabilities, GRID MODEL incorporates a number of specific purpose commands. The program is flexible and the user is able to specify variations of the GRID MODEL commands and their components. Such variations allow the user to control the mapping or analyses desired.

Each command and its associated data is input on a single card. All cards have the same format; while the various format fields <u>per card</u> allow different data inputs, for simplicity the same data input structure applies to each command card. The structure incorporates: four data identification fields; three data manipulation fields; and one text field. The inputs per card vary according to the command being input on that card in that different fields will be used for different commands.

GRID MODEL modeling capabilities vary from simple to complex and are nearly infinite. A simple model might examine a variable to identify a particular characteristic. For instance, a user might wish to examine a "soils" variable located in the 9th position on a multi-variable file, to identify the locations of one particular type of soil, such as "shallow granitic". If the variable was composed of five types of soil, identified numerically by the numbers 1-5 ("2" representing shallow granitic soil), four IF tests would be able to complete the analysis, as follows:

IF the "soils" cell being examined contains the value "0" (i.e., non-study area) input -9999 in the Add field as a "turnoff".

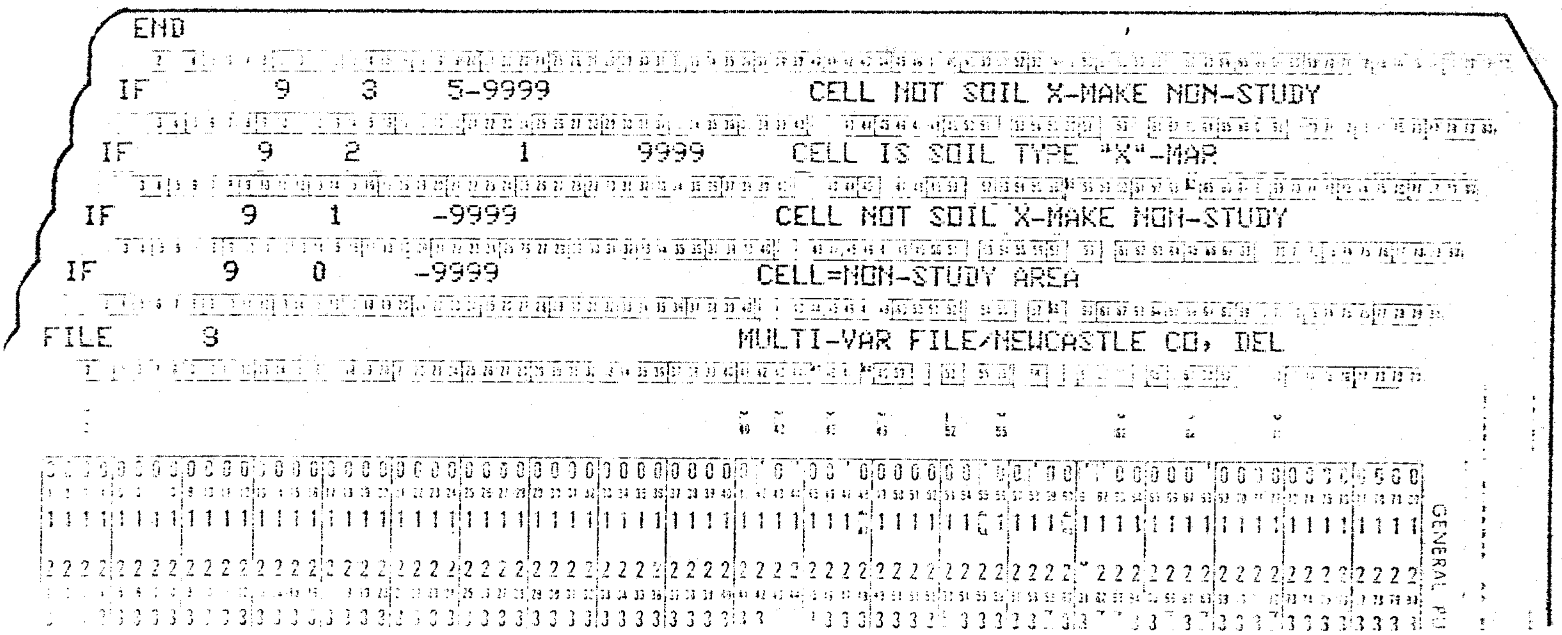
IF the "soils" cell being examined contains the value "1", input -9999 in the Add field as a "turnoff".

IF the "soils" cell being examined contains the value "2", add "1".

IF the "soils" cell being examined contains the integers 3 through 5, input -9999 in the Add field as a "turnoff".

The above logic would identify the shallow grantic soils and pass a "1" to the output file. Other soil types (and original non-study area cells) would all be "turned off" and passed as non-study area cells. Subsequent mapping would graphically display only the location of shallow granitic soil.

Of course, simply mapping the entire "soils" variable could graphically identify shallow granitic soil, but the other soil types being present (or being placed in all inclusive high and low level categories) would detract from the distinct separation possible if only shallow granitic soil was mapped. While the user can see the many possible ways such a need could be satisfied, if the "four IF test" approach was used, the GRID MODEL submission might look as follows:



4.4 GRID SYSTEM - MULTI-VARIABLE FILE GENERATION - GRID MERGE PROGRAM

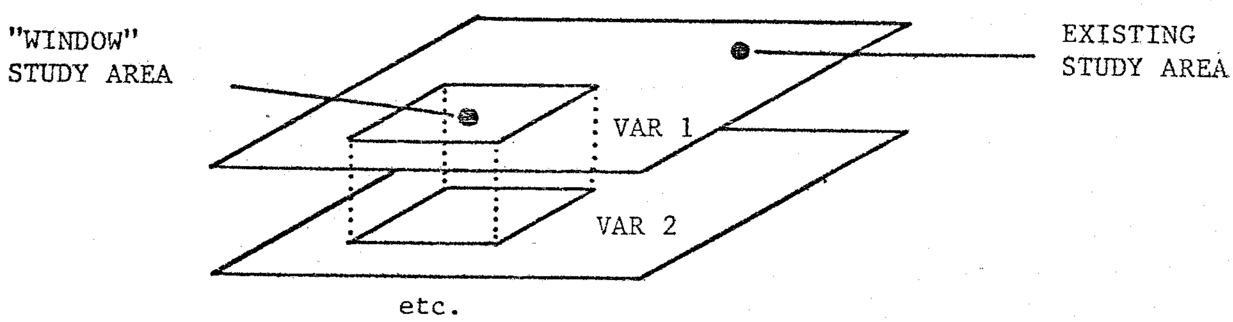
The GRIDMERGE program is used to merge several single variable data files simultaneously or separately into a new or existing multi-variable data file. Normally, additional variables are added to an existing multi-variable file called an "old" or "base" file. However, replacement of a variable may also take place. While replacement of any variable is possible, sporadic data cannot be inserted to provide update capabilities. A variable, or variables, to be added or merged must represent the same area (or data file). The user should note that a multi-variable data file is a storage concept, as opposed to simply a descriptive "name." Several variables are not necessary for a multi-variable file to function. One variable may be input, stored, and used, and other variables may then be added as desired.

The multi-variable file created by the GRIDMERGE system is an overlay concept process, similar to the manual overlay of plastic maps which can be used to describe variations in geography (i.e., soils, vegetation, etc.). The plastic overlay maps, however, are replaced by computerized digital grid (matrix) overlays. An example of this concept was shown previously as Figure 38.

Grids generated by other programs could be merged and stored here, such as by SEARCH or GRID MODEL. Since each data variable grid would represent a designated layer, each variable can be accessed by specifying the appropriate layer. Specifying the row and column, in addition to the variable layer, can locate a specific grid cell within the designated layer.

4.5 GRID SYSTEM - WINDOW PROGRAM

The WINDOW program is used to identify, for analysis, a sub-area within a larger study area for which a multi-variable file has been created and already exists. This capability is also available in RECGEN. The multi-variable file may be a product of either the GRIDMERGE or MAPMERGE program. An exmaple of a simple windowed area is shown below.



Depending on the desired analysis, there are two possible outputs associated with the WINDOW program, as follows:

1. A printout of the data values stored for the windowed area may be specified.

2. A multi-variable file of the windowed area may be specified to be created and stored.

4.6 GRID SYSTEM - CELL UPDATE PROGRAM

Cell Update is a program which allows the user to alter data in a previously created multi-variable file and output a revised multi-variable file. The alterations may involve changing a file's referencing system to coincide with an alternate system, such as the State Plane system. This is for display purposes only. The alterations may also involve changing the data file on a cell-by-cell basis, with one or more variables being changed at a time, or all the variables for a particular cell being deleted. This capability is also available in RECGEN. There are two reasons to alter the data variable(s) for any given cell. First, a user may wish to update data to reflect a current status after a change has occurred, such as in land use information. Second, a user may wish to correct an error, such as an incorrect data value for a variable due to misinterpretation, clerical error, etc.

4.7 GRID SYSTEM - SEARCH PROGRAM

SEARCH is a grid cell oriented computer program which provides data manipulation capabilities for geographically disposed information. It is a file generation program to be used in conjunction with stored single and multi-variable data files. The file generated is stored within the computer system. If manipulation and mapping of the generated file is desired, a new map package run must be initiated to allow the file to be used and mapped (printed) in conjunction with the GRID program. The SEARCH program provides three basic capabilities for the analysis of geographic data stored on a computerized GRID system:

1. Minimum Distance - The SEARCH program analyzes an area surrounding each cell (the radius around the cell is specified by the user) in the grid of geographically disposed data. It then identifies the shortest distance from the cell in question to any other cell within the specified area which represents a pre-determined value or values, called a "match" value. As mentioned, the radius of the search is specified by the user and the minimum distances to the cells searched for must be within this radius. If no searched-for values are found within the radius specified, a special "beyond scan" value is assigned to the cell being tested. The minimum distances thus calculated, or the default values, then become values associated with the respective grid cells which each search centers around. The values are then stored as a single variable file (can be merged into a multi-variable file). By defining value range parameters associated with desired levels, the minimum distance variable can be mapped for user analysis.

2. Number of Occurrences - Unweighted - The SEARCH program can also be used to compute the number of times such a pre-determined "match value" occurs within the distance specified. In this instance, the number of occurrences relating to each cell in the grid are stored as a single variable file (can be merged into a multi-variable file) for user analysis. It should be noted that cells along the outer perimeter of the study area will have a reduced search area. This is because cells outside the study area will not be searched, whether within the search radius of a given cell within the study area or not. The reduced search area also applies to cells whose distance to the outer perimeter is less than the specified search radius. This reduced search area phenomenon along the edges of particular study areas is an important concept. As an example, if an archaeology site grid were used, the number of occurrences of archaeologic sites relating to each grid cell might be used in conjunction with other geographic variables, such as slope and/or soils, for locational analysis regarding residential uses. Such location analyses might be conducted for an area whose boundary was coincidental with a political boundary, such as a county. If the respective county was conducting the analyses, archaeologic sites outside the county would probably not be pertinent to the effort, and therefore would not need to be searched. In this study, it would only be necessary to know the number of occurrences of archaeologic sites within the study area. Such may not always be the case.

3. Number of Occurrences - Weighted - In certain cases, the number of occurrences of a given searched for value may need to include occurrences outside a specific study area. An example may be water sources relative to a possible residential development. A number of occurrences search, with weighting, provides this capability. In such cases, cells outside the study area will not be searched, but occurrences outside the study area are approximated through such weighting. For the given study area, the process involves identifying for a specified search radius, a number of cells which will normally be searched. There will be a number of "match value" occurrences within this number of cells. The specified area around each cell in the grid matrix is searched in this manner. When a cell near or along the perimeter of the study area is searched, a number of cells less than normal is searched. The reduced number of searched cells is compared to the normal number of searched cells and a coefficient is produced. This coefficient is applied to the number of match values resulting from the reduced search area. This produces a number of occurrences approximation which might have occurred, had a normal search taken place, where weighting near the edge of the study area was not required.

4.8 GRID SYSTEM - GRIDPLOT

GRIDPLOT is a computer program which provides graphics output. GRIDPLOT graphics differs from GRID printer graphics in that, instead of a character printer being used to provide output display capabilities, a pen plotter is used to draw line representations of data. Grey tone drawings (shadings) represent the data, similar to the grey toning supplied by printer character overprinting. However, the plotter grey tones which represent the various levels present much sharper shading contrasts regarding area representations. Part of this definitive area separation is due to the optional capability to outline the described areas.

GRIDPLOT is an output program which is used in close conjunction with the GRID program. The computerized cross-referencing system of GRIDPLOT which controls the pen plotter was developed specifically for use with the GRID based cross referencing system.

4.9 GRID SYSTEM - ELECTROSTATIC GRIDPLOT

ELECTROSTATIC GRIDPLOT is a computer program which provides graphics output. It is used with data that has been automated according to the GRID cross-referencing system. The ELECTROSTATIC GRIDPLOT graphics differs from GRID and GRIDPLOT graphics in that, instead of a character printer and a pen plotter respectively being used to provide output display capabilities, an electrostatic plotter is used to output tonal representations of data. The tonal representations of the data are similar to the grey toning supplied by printer character overprinting and pen plotter drawings.

As previously mentioned, plotter representations present much sharper shading contrasts regarding displayed areas. Part of this definitive area separation is due to the optional capability to outline the described areas. While this is true for both plotter techniques, electrostatic plotters are much faster and more cost effective. This is because an electrostatic plotter allows plotter type visual reproductions spontaneously on a line by line basis (similar to a line printer) as opposed to the historically slow pen plotter delineations.

4.10 COLORMAP

COLORMAP is a computer program which provides color graphics output of GRID and GRIPS generated data files. COLORMAP graphics differs from GRID printer and plotter graphics in that, instead of a character printer or plotter being used to provide output display capabilities, a DICOMED digital image recorder is used to generate color graphic representations of grid cell oriented data. Color hues and tones represent areas of homogenous data, similar to the grey toning supplied by printer character overprinting or plotter drawings. However, because of color, the image recorder representation presents much sharper contrasts regarding area representations. This definitive area separation can be enhanced by the optional capability to outline the described areas.

4.11 AREA CALCULATIONS

The AREA CALCULATION program is an output oriented program of the GRID system. The main purpose of the program is to quantify, in areal units (i.e., acres, square feet, square meters, square miles, etc.) the sub-categories of one variable which, when another variable is superimposed on it, fall within the sub-category boundary definitions of the other variable.

For instance, the AREA CALCULATION program would allow a user to summarize the various land uses by acres, square miles, etc., which occur within census tract boundaries, planning district boundaries, etc., or different soil types as they occur within floodplains, agricultural preserves, planning districts, etc. If land uses were to be summarized relative to census tract boundaries, all census tracts in the variable (or specific census tracts selected by the user) would be examined, one at a time, and the land uses within its boundary would be identified. The identified land uses for each census tract would then be aggregated by land use category and summarized in the appropriate user specified areal units.

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DISCUSSION

Q. As a side issue, can you relate how the terrain unit analysis approach your organization uses in many of its studies compares to the triangle approach of W.E. Gates and Associates?

A. In both the triangle approach as well as the integrated terrain unit approach there is an attempt to classify variation of geography according to its lowest common denominator within some generalized classification system (i.e., soils breakdown, slope classes, etc.). The similarity essentially stops at this conceptual level. It's important to discuss within this context the differences. First, the integrated terrain unit approach envisions the integration of natural factors separating for another type of display, cultural features, including infrastructure and coverages such as land use. The philosophical basis for terrain unit mapping is that landscape can be classified into relatively homogeneous morphological units which have varying degrees of predictability. This is not necessarily influenced although quite by chance it often occurs that cultural factors fall into some of these patternings (i.e., ownership, linear cultural developments, land use, etc.). Second, terrain unit attempt to integrate the various classified factors along common boundaries which are highly irregular in shape. This is markedly different from the triangle unit which is at best a gross abstraction of morphological boundaries.

It's important to focus on the uses of triangles vs. the uses of polygonal terrain units. In the case of the triangle structure the basic unit application developed by W.E. Gates and Associates was for manipulating information in an aggregated format such that area data originating from aerial unit definitions could be handled at a watershed or sub-watershed unit scale. The terrain unit analysis is primarily structured for mapping as well as overlay and area summaries within units of larger size. Graphics are a very important component therefore, of the terrain unit analysis and this stress on accuracy of the boundary definitions is important. It is particularly relevant when one considers that these maps are often used in terms of defining lines for environmental management which actually are used in the field. My understanding of the triangles are that although maps are made from them these maps are not meant for management of the environment on the ground but rather the presentation of abstractions to be used in general analysis or communication of such patternings of geography. Finally, the terrain unit analysis focuses on the classification of qualitative information and does not attempt to consider the third dimension (i.e., topographic elevation).

Q. Can you compare or rank the grid cell, triangles, and terrain unit approach as to their desirability for the types of analysis the HEC does in its studies?

A. It is almost impossible to rank grid cell vs. triangles vs. terrain units as being approaches which could be weighted according to desirability by HEC. They are clearly different approaches and in one sense are designed to handle different things. Triangles are a form of abstraction. They work very well for handling topographic data and are much more generalized for handling polygonal data such as vegetation, soil, geologic structures, etc. The grid cell, like triangles, can handle both elevation as well as polygonal information, however, it defines a three-dimensional surface less accurately and perhaps what one might call differently than the triangular approach. It is not as useful when considering a variable sized grid or unit of aggregation. On the other hand it is regular and if we're considering certain types of polygonal data it has many advantages. The terrain unit is qualitatively a different type of unit for representation of geographic data. It does not handle three-dimensional information yet handles the qualitative information, soils, geology, vegetation, etc., in a way which is better than parametric mapping because it resolves many of the boundary variations resulting from inaccuracies in original map data. For the polygonal maps, information is represented more accurately (i.e., less abstract) than a triangle or grid cell. For graphics it is superior. Triangles on the other hand, because of their multiple use capabilities, offer some unique possibilities particularly in the terrain areas.

Q. Your organization has worked with both multivariable grid file and polygon overlay systems. Since none of the seminar participants has suggested a total polygon overlay system, can you explain why ESRI did not make it a recommendation?

A. Polygon overlay systems are not a feasible alternative at this time due to the cost associated with these systems. However, new programs are under development which may result in more efficient solutions to the polygon overlay problem. A second aspect to polygon overlay which does not deal with cost is the complexity of resulting maps that occur when polygons are overlaid. A resolution of problems which result from the overlay of lines which in fact are the same line represented in two separate variables is a major technical problem. The essence of this problem is that when these polygons are overlaid the results may be the creation of many very small polygon structures which are not meaningful.

Q. The run-length storage of multivariable files seems to be desirable as far as reducing required storage device size and the costs associated with large disc files. However, there currently is no communication module available to have existing programs access or create this new file structure.

A. It is true that considerable savings would occur both in processing and also storage if the multivariable run length files could be created. If uses are to be made of this new file structure, existing programs will have to have adjustments made to utilize the data. The extent of these adjustments is not known at this time, however, it is expected that rather than restructuring all the programs an interface module would be developed which would convert files from one format to the other. The implication of this is that there is a strong theoretical process for this type of system and cost savings particularly in large amounts of processing would no doubt result in a major benefit many times greater than the initial investment in conversion of the program. More specifically, much of the cost associated with existing programs is in reading each cell. Savings should be made in reading only where there is a change in the data variables when you're analyzing and then looping through the calculations for how many cells are the same.

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AUTHOR'S ADDITIONAL COMMENTS

1. In order to attain a perspective on digitizing techniques it is proper to review two definitions related to the subject: a) map and geographic features placed on them, and b) computer methods for recording them.

There are four primary categories of map elements that are used to represent geographic variation (i.e., points, lines, polygons and surfaces).

In their map form these elements are represented relative to other elements on the map and in space through a system of measurements commonly known as coordinates. These coordinates are of varying types and possess variable accuracies (i.e., from roughly sketched maps to highly accurate cartographic displays and from graphically defined visual relationship coordinates to world based projection systems such as latitude, longitude, UTM, etc.).

Most of the experiences with geographic information systems suggests that handling data in a "least common denominator" form is "the way to go". This is justified because you can always aggregate smaller units into larger units but you cannot disaggregate the minimum size unit. Also this concept of data is conceptually most beneficial to the maximum number of applications, because, of course, you can build a structure which is most useful for a given application.

Cells, triangles and x,y coordinates expressed as polygons represent alternative ways that geographic data can be abstracted for the computer. All of these techniques are ways to spatially identify geographic variations.

Grid and triangle data structures build in certain inflexibilities and inaccuracies that may not be acceptable for certain applications.

From my point of view, x,y coordinates continue to offer the greatest flexibility for conversion to all other data "cells". This is a very important factor because the investment in data files by the Corps is and will be great. The files should be in a form that can be used by other agencies for other applications. To do this the data can later be converted to triangles, grids, or any other form.

Specifically, one can build from x,y coordinates of points, lines and polygons which represent surfaces (e.g., contours), any aerial unit or "cell"* which would be useful for a given application (i.e., grids, triangles or any other polygon shape).**

The ultimate recording of data in the lowest common denominator is a useful concept which should ultimately become the focus of HEC, USACOE and institutions involved in this avenue of application. However, in the short term this may not be practical for many reasons (i.e., existing software and procedures, administrative and institutional arrangements, hardware availability, manpower problems, etc.).

The system for encoding at HEC must remain one which is simple, consistent, and workable in a field office unless there is a dramatic reorganization of who does the data preparation later.

Several short term recommendations should be considered. These are outlined below:

(a) Compressed data structures using multiple compressed run-encoding file structures should be incorporated.

(b) Investigation (in pilot studies) of the feasibility of using triangles for both conversion of topo to grid as well as a complete conversion from grid to a triangular format for data processing.

In longer terms there is considerable justification for examination of one or more centralized centers for data preparation in a format which is consistent and in the lowest common denominator. This has implications for hardware acquisition staff organization and institutional arrangements. As part of long-range expansion considerations federal agencies (i.e., USGS, Census, SCS) should be stressed regardless of the ultimate manner in which the files are created.

2. Additional computations indicate that there is considerable savings in file storage if the compressing scheme is employed. They are outlined as follows:

   The Northern Venezuela data vase of 31 variables including topographic elevation and aspect showed a storage savings of

*Cell is defined here to mean any spatial data unit and is not limited to a "grid" cell.

**I am assuming that the unique ability of triangles to represent terrain can be generated by computer from x,y coordinate file of terrain and ridge and course lines.

72% if compressed multivariable files were used. If slope and aspect had not been included in the multivariable data file but stored as separate files the storage savings would have been 80% on the multivariable file, but the storage of separate files for these variables would cut the actual savings to only 76% for a 4% relative reduction. If all data items varied greatly then these compression approaches would not be worthwhile. The processing time for compression and expansion is not significant and should be easily offset by the reduced time accessing data from the file.

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