A GEOREFERENCED INFORMATION SYSTEM FOR REAL TIME HYDROLOGIC MODELING

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I. ABSTRACT

Remotely sensed digital data (Landsat CCT) has proven an efficient and cost effective means of defining land cover information required in hydrologic modeling. However, an organization such as a county government finds great difficulty in collecting and integrating regional ancillary data (aerial photos, soils, etc.) with digital remote sensed data.

A computer-based information system allowing engineers to create, access, integrate, and maintain a multi-parameter geographical data base which provides information required by the Soil Conservation Service hydrologic models is described. Land cover, soils, and elevation data are stored as arrays of cells referenced to USGS quad sheets.

A typical scenario involves the analysis of the impact of proposed land cover changes on the runoff hydrograph. In the interactive mode, the user inputs the location of an outfall cell. Enhanced picture processing algorithms applied to elevations determine the watershed area and stream network. The system routes the data contained within the watershed through the model for an input rainfall. The user receives a peak discharge, statistics, and maps describing the watershed. Proposed changes are input to produce a present/proposed hydrologic comparison.

II. INTRODUCTION

One important aspect in the future planning of our world's community is the hydrologic effects of urbanization. In recent years numerous hydrologic models (SCS, EPA, HEC, etc) have been developed to predict these effects. These models have parameters dependent on the spatial distribution of land cover, soils, and topography. Research has shown that remotely sensed digital data (Landsat, Digital Terrain, etc) are an efficient and cost effective means of defining land cover and topography. However, regional jurisdictional entities such as county governments usually require ancillary modeling information derived from hard copy sources. Therefore, there is a need for a methodology to collect, merge, and manage digital remotely sensed data and hard copy data into a regional data base. Secondly, a system must be developed to provide a user-oriented interface between the regional data base and hydrologic models. These concepts must be realized within the finite technical skills and computer level of the regional government.

A computer-based georeferenced information system known as the Hydrologic Analysis Program (HAP) allowing regional engineers and planners to create, access, integrate, and maintain a multi-parameter geographic data base which provides information for hydrologic models is described. The major topics of HAP's data base management system, study area delineation, and the user-data base-hydrologic model interface will be presented.

III. LITERATURE

The concept of regional data bases is an accepted approach for applying scientists with timely and accurate information. Developments in the major problems of data collection, data management, and user-data base interfacing has produced three distinct generations of regional data base systems. Istvan1, Ragan2, Fellows3, Harding4, Corps of Engineers5, and Hardy6 conducted research which produced many foundations of the regional data bases. These systems concentrated on methods of manual encoding and computer storage of spatial data.

In the late 1970's, the promise of digital satellite (Reselling7) and terrain data (Doyle8 and Allam9) initiated additional research. Concurrently, advances in the new field of data base management systems were being made by pioneers such as Date10 and Martin11. The marriage of these
two disciplines produced what has been referred to as the georeferenced information system. Paul12 Fellow13 Adams14 Strome15 Whitley16 Campbell17 Kauth18 Keller19, and Shelton20 contributed to what has become the standards of the georeferenced information system. These systems provided a great deal of flexibility in the types of data they would accommodate and were user-oriented. The concept of developing systems which could compose raw data into useful information, be utilized by non-technical users, and provide real-time answers was becoming a reality. Users were being given navigational aides to explore the database. It was no longer necessary for the user to understand the physical computer file structure. Natural English languages were also being developed to address the database.

As the second generation of systems were developing, the science of digital image processing was making tremendous advances in picture processing. These disciplines shared the common problem of manipulating large quantities of data. Research in image processing by Rosenfeld21, Sklansky22, Dyer23, and Robinson24 and human perceptions by Pentland25 illustrated the impact picture processing principles could have on information systems. The pre-processing, enhancement, segmentation, and restoration algorithms in picture processing helped develop the image database system. These image systems researched by Shapiro26, Zobrist27, Chang28, Lien29, Tanura30, and Deek31 are sophisticated blends of data collection technology, data base management, image processing, and remote sensing. These systems have made it possible to perform tasks thought only to be accomplished by human visual perception. These tasks include edge detection, connectedness, connectedness, and surroundedness of objects; removing local and global anomalies; and matching shapes and textures. The third generation information system uses these image processing algorithms applied to the analogous land cover, soils, elevation, etc. "picture" to further automate the user-system interface.

This study intends to develop a third generation georeferenced information system for urban planning and hydrologic modeling that encompasses all the multi-disciplinary concepts of data base management and image processing. However, the principles will be adopted for the use with regional governments of finite computational and technical resources. The addition of image processing algorithms will eliminate the subjective and inefficient watershed boundary and network delineation. Data collection, storage, and retrieval will be constructed to optimize the blending of digital data and hard copy data.

IV. HAP DEVELOPMENTAL DATA BASE

HAP was developed by the University of Maryland Civil Engineering Department for operational usage at the water resources/planning offices of the Maryland National Capital Park and Planning Commission (MN-CPPC). The MN-CPPC is responsible for the planning of the 400 square mile Montgomery County, Maryland which borders the northwest boundary of Washington D.C.. Grid encoded hydrologic soil groups from soil maps, topography from USGS quad sheets, urban land cover from aerial photography, and suburban/rural land cover from Landsat were supported by HAP for Montgomery County.

V. HAP MODEL

Figure 1 shows that HAP consists of a database management system, boundary delineation and hydrologic analysis component. A typical scenario was developed by

Figure 1. HAP MODEL

the MN-CPPC to ensure HAP would be constructed to satisfy their needs. The MN-CPPC required a system that could store and manage their land cover, soils, and slope data such that a contractor requesting a land development permit would supply the watershed boundary and proposed hydrologic changes. The system would route all necessary data through the hydrologic model for a given rainfall. The present/proposed hydrologic conditions would then be compared. This process would be real-time so the permit is issued or denied during the contractors initial visit.

A. DATABASE MANAGEMENT SYSTEM (DBMS)

The objective of the HAP DBMS was to
provide a method for nontechnical personnel to create, load, access, and maintain spatial data differing in physical format. Information management principles of data independence and data models were incorporated.

Data independence is achieved by the DBMS provided information can be extracted from the data base without the knowledge of its physical storage. The user makes an English-like data base request and the DBMS translates the request into the appropriate physical file manipulations. This concept allows users to write programs without concern of data formats. Data independence also provides the mechanism in which data of differing format (integer, alphabetic, etc.) can be merged into one central data base.

Data independence is accomplished by providing the user with a data model and definition. Figure 2 illustrates the HAP data model/definition. These are navigational aides to assist the user in data base requests. The QUAD-GRID-CELL data model shows the user the logical view of the data structure. Montgomery County, Maryland is comprised of nineteen USGS topo sheets (Figure 3). Each quad is subdivided into a N X M grid of cells. These cells contain the hydrologic information for the area. The MN-CPCC cell size usage was 4.58 acres. However, HAP will accommodate any cell size.

The data definition is used during the initial data base load to identify the type and size of the data fields. The loading sequence is dictated by the data model and definition. A STATE-COUNTY-QUAD name is loaded into HAP according to the Fortran field data definition. Iteratively, the row/column location of each cell is input along with the cell’s spatial data until the grid is exhausted. The loading process produces a table of random access record address pointers for the topos loaded. These pointers will be used in data base queries to facilitate non-sequential searches through the data base.

The optimal HAP query is a request for all the information available within an input boundary. In the near future, HAP will compose data types to produce new information. For example, qualifying a set of land cover and soil types that constitute a sludge disposal site criteria. HAP also maintains the integrity of the data base by supplying the user with interactive/batch updating routines.

B. BOUNDARY DELINEATION (BD)

HAP provides an automatic delineation method for watershed boundaries and a manual grid/digitizer boundary input for political boundaries.

Automatic Delineation. Initially, watershed boundaries were required to be manually grid/digitized for input into HAP. However, this process was a burden to HAP’s interactive format. Therefore, the watershed area and spatial distribution are determined by a modified picture processing algorithm known as “region growing” (RG). The user inputs the location of the outfall cell on the appropriate topo. the RG algorithm finds the cells of greater elevation that are hydrologically connected to the outfall cell. RG produces a binary (0,1) picture of cells. The "1" cells

Figure 2. Data model and definition.

Figure 3. Montgomery County, Maryland.
are counted and the cell's spatial information retrieved from the data base. Adjacent topos are retrieved from the data base as necessary.

During the development of the enhanced RG algorithm, it became clear that the process was very sensitive to erroneous elevations. The RG algorithm was tested using USGS Digital Terrain Models (DEM) terrain tapes. This data proved to of questionable quality (Stow). Therefore, a noise-reducing preprocessing algorithm (Overton) was designed to eliminate elevation anomalies. Figure 4 visually illustrates the improvement in RG on preprocessed elevations.

The stream network is determined by a "thinning" image processing algorithm. The edge of the (0,1) binary picture produced in RG is delineated by a laplacian operator:

\[ V^2 f(i,j) = f(i-1,j-1) + f(i-1,j) + f(i,j+1) + f(i+1,j+1) + f(i+1,j) + f(i+1,j-1) + f(i,j-1) - 8f(i,j) \]

Where; the f(i,j)'s are the 8-cell neighborhood surrounding f(i,j) and i = j = 1

The thinning or skeletonization algorithm eliminates any edge cell provided the elimination does not "disconnect" adjacent cells and the cell is a maximum local elevation. The resultant is the stream network. Figure 5 illustrates the thinning result of the Figure 4 watershed.

Figure 5. Thin of Figure 4. The + marks the location of the outfall cell.

Manual Delineation. Manual delineation may still be desirable in cases of bad data or political boundaries. HAP has both grid and electronic digitizer delineation. The watershed/political boundary is subdivided into polygons on the appropriate topos containing the study area. Once the sub-boundaries and appropriate topo pointers are input, the study area is masked together and the spatial information contained within the boundary retrieved from the data base.

C. HYDROLOGIC ANALYSIS

The hydrologic analysis module is the directive subroutine for HAP. The HAP DBMS and BD modules were designed to be called upon by the hydrologic analysis module.
The BD provides a method to identify a requested spatial area within the data base. The DBMS accepts this request and delivers the necessary information to the user computer program workspace. All information is passed via common statements. The MN-CPPC uses the SCS-TR-55 hydrologic model (SCS74). This model requires a cell-by-cell interface of land cover and soil to define a storage term (curve number), the watershed area, and slope to determine the peak discharge for a given rainfall intensity. A Fortran subroutine was written to inventory the spatial information delivered to the program workspace by the HAP DBMS request. HAP will accept any hydrologic model provided the model parameters can be defined by the information within the database.

HAP has an UPDATE and MAP module. The UPDATE subroutine allows the user to input the location and proposed land cover, soil, or slope change for any cell(s) in the study area. The proposed conditions are routed through the model and a new peak discharge is produced. The HAP module can produce 148,000 and 124,000 gray scale maps of present/proposed study area conditions.

VI. TYPICAL HAP SESSION

The following computer output demonstrates a typical HAP interactive computer session. A private consulting firm in Maryland was requested to design storm water storage behind an existing conduit. HAP was used to determine the peak discharge for the present and proposed conditions for a 100 year 7.2 inch storm. The city's master plan was available to project the proposed land cover conditions. The location of the outfall cell on USGS topo was measured. The resulting HAP run produced a 148,000 gray scale map of the RC watershed and a present SCS-TR-55 hydrologic analysis. The proposed land cover changes were input. A proposed map and present/proposed hydrologic comparison were output. The users inputs are in lower case letters and the computer prompts/responses are in upper case letters.

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****CHANGE IN RUNOFF .32 (INCHES) 8.24 x-****  
****CHANGE IN PEAK DISCHARGE 53.08 (CFS) 14.82 x-****  

IMPROPERLY

***********

In accordance with the HS method of estimating volume of runoff, the time of concentration and hydraulic length are valid for watersheds of less than 2000 acres (SC-TP-14B).  

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**DO YOU WANT A MAP OF MONTGOMERY COUNTY HYDRO SOIL (Y/N)>>

**DO YOU WANT A MAP OF MONTGOMERY COUNTY I SLOPE (Y/N)>>

End MAP module.

***********

HYDROLOGIC ANALYSIS PROGRAM***********

INPUT:
BOUNDARY H=HYDROLOGIC MODEL L=LOAD MASTER DISK U=UPDATE S=STOP

***********

UPDATE MODULE***********

**ARE THERE ANY CHANGES IN THE 09720 771500 TOP(Y/N)>>

1-LAND COVER 2=SOILS 3=SLOPE
End module (REMEMBER WITH "END")

41 32k
42 32k
43 32k

WATERSHED ANALYSIS (SC-TP-55)>>

IDENTIFICATION=LAND COVER IMPACT STUDY
RAINFALL (INCHES)= 7.20
DRAINAGE AREA (ACRES)= 103.28
 .29 (SQUARE MILES)
HYDRAULIC LENGTH (FEET)= 4765.86

QOAUANTITY PRESENT PROPOSED
CURVE NUMBER 71.17 74.15
AVERAGE PERCENT SLOPE 5.34 5.34
TIME OF CONCENTRATION (HOURS) 1.02 1.02
VOLUME OF RUNOFF 3.91 4.22
PEAK DISCHARGE (CFS) 355.84 408.92

NORMAL EXIT. EXECUTION TIME: 4323 MILLISECONDS.

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VII. REFERENCES


10. Dre, C., 'Introduction to Data Bases', Addison-Wesley, 1975


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AUTHOR BIOGRAPHICAL DATA

Jack D. Fellows is a Faculty Research Associate in the Department of Civil Engineering at the University of Maryland, College Park. His NASA sponsored Ph.D. dissertation involves the merging of data base management, digital image processing, and remote sensing for applications in hydrologic modeling.