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# 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, region-

al jurisdictions such as county governments ususally 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 realised 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, intergrate, 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 supplying 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. Istvan<sup>1</sup>, Ragan<sup>2</sup>, Fellows<sup>3</sup>, Harding<sup>4</sup>, Corps of Engineers<sup>5</sup>, and Hardy<sup>6</sup> conducted research which produced many foundations of the regional data bases. These systems concentrated on methods of manual Geoencoding and computer storage of spatial data.

In the late 1970's, the promise of digital satellite (Hessling<sup>7</sup>) and terrain data (Doyle<sup>8</sup> and Allam<sup>9</sup>) initiated additional research. Concurrently, advances in the new field of data base management systems were being made by pioneers such as Date<sup>10</sup> and Martin<sup>11</sup>. The marriage of these

two disciplines produced what has been referred to as the georeferenced information system. Paul<sup>12</sup>, Fellows<sup>13</sup>, Adams<sup>14</sup>, Strome<sup>15</sup>, Whitley<sup>16</sup>, Campbell<sup>17</sup>, Kauth<sup>18</sup>, Keller<sup>19</sup>, and Shelton<sup>20</sup> 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 data base. It was no longer necessary for the user to understand the physical computer data file structure. Natural english languages were also being developed to address the data base.

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 problems of manipulating large quantities of data. Research in image processing by Rosenfeld<sup>21</sup>, Sklonsky<sup>22</sup>, Dyer<sup>23</sup>, and Robinson<sup>24</sup> and human perceptions by Pentland<sup>25</sup> illustrated the impact picture processing principles could have on information systems. The preprocessing, enhancement, segmentation, and restoration algorithms in picture processing helped develop the image data base system. These image systems researched by Shapiro<sup>26</sup>, Zobrist<sup>27</sup>, Chang<sup>28</sup>, Lien<sup>29</sup>, Tanura<sup>30</sup>, and Mckeown<sup>31</sup> are sophisticated blend 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; adjacentness, 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, these 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 data base management system, boundary delineation and hydrologic analysis component. A typical scenario was developed by

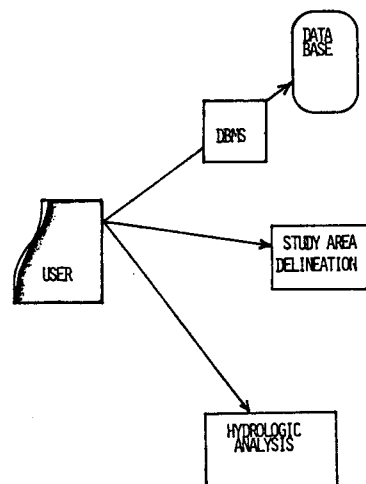


Figure 1. HAP MODEL

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 contractor's initial visit.

##### A. DATA BASE 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 navigat-

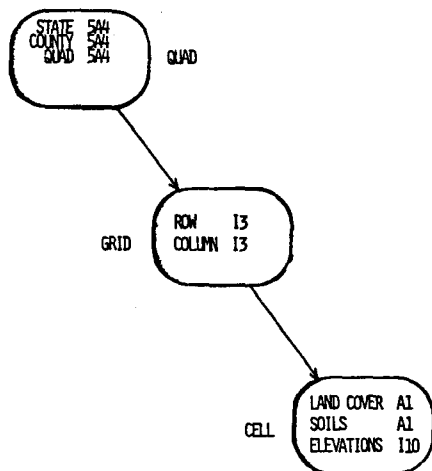


Figure 2. Data model and definition.

ional 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-CPPC cell size usage was 4.58 acres. However, HAP will accomodate 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

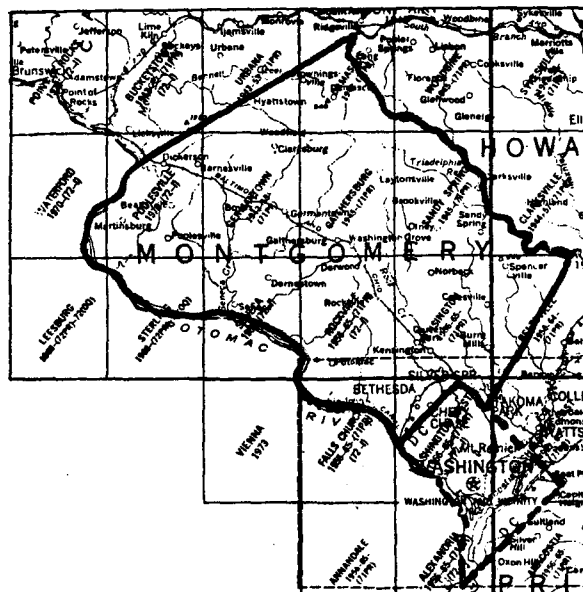


Figure 3. Montgomery County, Maryland.

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.

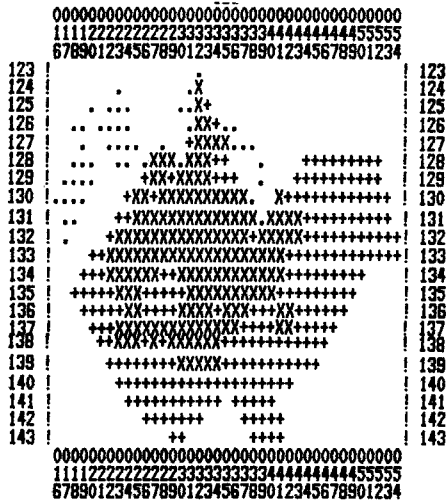
#### B. BOUNDARY DELINEATION (BD)

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

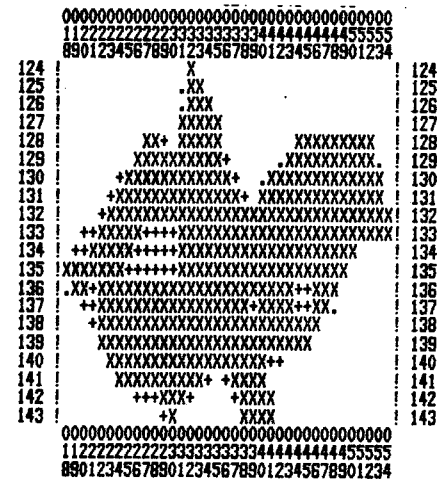
Automatic Delineation. Initially, watershed boundaries were required to be manually grid/digitized for input into HAP. However, this process was a burden to HAP's interactive format. Therefore, the watershed area and spatial distribution are determined by a modified picture processing algorithm known 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

are counted and the cell's spatial information retrieved from the data base. Adjacent topes 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 be of questionable quality (Stow<sup>32</sup>). Therefore, a noise-reducing preprocessing algorithm (Overton<sup>33</sup>) was designed to eliminate elevation anomalies. Figure 4 visually illustrates the improvement in RG on preprocessed elevations.



(a)



(b)

Figure 4. (a) original elevations. (b) preprocessed elevations. +=digital watershed, .=RG watershed, X=intersection

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:

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

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.

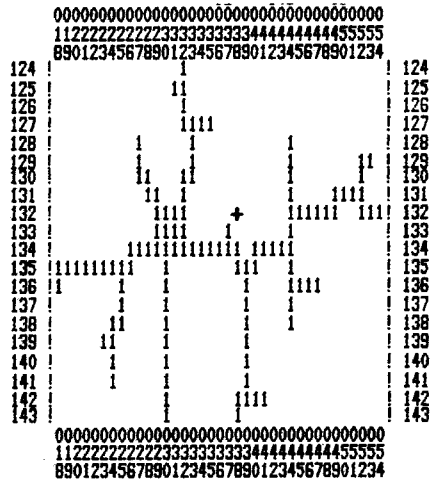


Figure 5. Thin of Figure 4. The + marks the location of the outfall cell.

**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 topes 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 users computer program workspace. All information is passed via common statements. The MN-CPPC uses the SCS-TR-55 hydrologic model (SCS<sup>34</sup>). 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 data base.

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 MAP module can produce 1:48,000 and 1:24,000 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 1:48,000 gray scale map of the RG 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.

```

UOM 1108 36.R2D:0
ACCOUNT NUMBER? BRUN BREWER.304621JACK,FELLOW,5.100
PASSWORD?
#####
PRINT AND BACKLOG LOST 4/10 21:37
RUNID: BREWER 04/14/81 01:14:35 LAST RUN: 04/14 01:14
DEMAND: 5, BATCH: 2, BACKLOG: 2

base.a debbie#base.
READY
#use 10..debbie#base.
READY
#xct debbie#hap.abs
#####HYDROLOGIC ANALYSIS PROGRAM#####
INPUT:
B=BOUNDARY      H=HYDROLOGIC MODEL  L=LOAD MASTER DISK
U=UPDATE        S=STOP

b
=====BOUNDARY MODULE=====
**INPUT BOUNDARY OR OUTFALL(B/O)?**
o
**INPUT X/Y OF OUTFALL**
4.00
6.25
**INPUT STUDY TITLE**
land cover impact study
**INPUT TOPO NUMBER(REAL)**
1.
=====LAND COVER IMPACT STUDY          BOUNDARY COMPLETE=====

#####HYDROLOGIC ANALYSIS PROGRAM#####
INPUT:
B=BOUNDARY      H=HYDROLOGIC MODEL  L=LOAD MASTER DISK
U=UPDATE        S=STOP

h
=====SCS MODEL MODULE=====
**INPUT RAINFALL IN INCHES(REAL NUMBER)**
7.2

===WATERSHED ANALYSIS (SCS-TR-55)===

IDENTIFICATION=LAND COVER IMPACT STUDY

WEIGHTED CURVE NUMBER= 71.17
AVE PERCENT SLOPE= 5.34
AREA= 183.38 (ACRES) .29 (SQUARE MILES)

HYDRAULIC LENGTH= 4766.08 (FEET)
TIME CONCENTRATION= 1.03 (HOURS)
RAINFALL= 7.20 (INCHES)
VOLUME OF RUNOFF= 3.91 (INCHES)
PEAK DISCHARGE= 355.84 (CFS)

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
IN ACCORDANCE WITH THE SCS METHOD OF ESTIMATING VOLUME OF
RUNOFF THE TIME OF CONCENTRATION AND HYDRAULIC LENGTH ARE
VALID FOR WATERSHEDS OF LESS THAN 2000 ACRES (SCS-TP-149)
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

**WOULD YOU LIKE A MAP OF PRESENT CONDITIONS(Y/N)**
y
.....MAP MODULE.....

**MAP REQUIRES A TERMINAL WITH MINIMUM 80 CHARACTER WIDTH**
**ENTER OUTPUT UNIT(END WITH DECIMAL)**
6.
**DO YOU WANT A MAP OF MONT. CO AER. PHOTO LAND COVER (Y/N)**
y
**DO YOU WANT DEFAULT OR NEW MAP SYMBOLS (D/N)?**
6

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## VII. REFERENCES

1. Istvan, L. and Bondy, M., 'A Digital Technique for Manual Extraction of Data from Aerial Photography', International Symposium of Remote Sensing of the Environment, Symposium 11, April 25-29th, 1977, Vol II, Ann Arbor, Mi.
2. Ragan, R. and Fellows, J., 'Development of a Regional Information System for Hydrologic Modeling', University of Maryland Technical Report 46, July 1976
3. Fellows, J. and Stewart, J., 'Use of Geo-encoded Aerial Photography as a Regional Data Base for Water Resources and Environmental Planning Studies', paper presented at the 1979 American Society of Photogrammetry and American Congress on Surveying and Mapping, Washington D.C., March, 18-24th, 1979
4. Harding, R., 'GRIDS and DNR', American Society of Photography Management and Utilization of Remote Sensing Data Symposium, Oct 29-Nov 1, 1973, Sioux Falls, S.D.
5. U.S. Army Corps of Engineers, 'Guide for the Creation of Grid Cell Data Banks', Hydrologic Engineering Center, USACE, Davis, Calif., Sept 1978
6. Hardy, E., 'The Design, Implementation and Use of a Statewide Land Use: The New York Experience', Proceedings of the NASA Earth Resource Survey Symposium, Houston, Texas, June 1975, Vol I-C, NASA TMX-58168
7. Hessling, A. and Mara, T., 'The Development of a Land Use Inventory for Regional Planning Using Satellite Imagery', dito 6.
8. Doyle, F., 'Digital Terrain Models: An Overview', Photogrammetric Engineering and Remote Sensing, Vol 44, No 12, Dec 1978
9. Allam, M., 'DTM Application in Topographic Mapping', dito 8.
10. Date, C., Introduction to Data Bases, Addison-Wesley, 1975
11. Martin, J., Principles of Data Base Management, 1st ed, Prentice-Hall, Englewood Cliffs, 1976
12. Paul, C., 'LUMIS- A Land Use Management Information System for Urban Planning', dito 6.
13. Ragan, R. and Fellows, J., 'A Data Base System for Real Time Hydrologic Modeling', American Society of Civil Engineering Remote Sensing Aeronautics Division Specialty Conference, Madison, Wis., Aug 13-15, 1980
14. Adams, J. and Istvan, L., 'Development of an Integrated Data Base for Land Use and Water Quality Planning', International Symposium of Remote Sensing of the Environment, Symposium 11, April 25-29, 1977, Vol III
15. Strome, W., et al, 'Integrated Information for Resource Management', International Symposium of Remote Sensing of the Environment, Symposium 14, April 23-30, 1980, Vol I
16. Whitley, S., 'A System for Processing Landsat and Other Georeferenced Data for Resource Management Applications', 1979 Machine Processing of Remotely Sensed Data Symposium, June 27-29, 1979, Purdue, Ind.
17. Campbell, R. et al, 'Design of a Nationwide Natural Resource Inventory and Information System for Costa Rica', International Symposium of Remote Sensing of the Environment, Vol 1, Symposium 14, San Juan, Costa Rica, April 23-30 1980
18. Kauth, R., et al, 'Design Consideration for Resource Inventory Systems', dito 17.
19. Keller, D. and Frippel, G., 'AIDS: An Advanced Integrated Data System Concept', International Symposium of Remote Sensing of the Environment, Symposium 13, Vol 1, April 23-27, 1979
20. Shelton, R. and Estes, J., 'Integration of Remote Sensing and Geographic Information Systems', dito 19.
21. Rosenfeld, A., Digital Picture Processing, Academic Press, New York, 1976
22. Sklansky, J., 'Onfilling Cellular Cavities', Computer Graphics and Image Processing, 4, 1975
23. Dyer, C., 'Thinning Algorithms for Gray Scale Pictures', University of Maryland Technical Report 610, Nov 1977
24. Robinson, G. and Reis, J., 'A Real-Time Edge Processing Unit', IEEE Computer Society Proceedings of the Workshop on Picture Data Description and Management, Apr 21-22, 1977, Chicago
25. Pentland, A., 'The Application of Human Visual System Processing Techniques to Remote Sensed Data', International Symposium of Remote Sensing of the Environment Vol III, Symposium 14, San Juan, Costa Rica, Apr 23-30, 1980
26. Shapiro, L., 'A General Spatial Data Structure', IEEE Computer Society Conference on Pattern Recognition and Image Processing, May 31-June 2, 1978



27. Zobrist,A., 'Elements of an Image Based Information System', IEEE Computer Society Proceedings of the Workshop on Picture Data Description and Management, Apr 21-23, 1977, Chicago
28. Chang,S., et al, 'A Relational Data Base System for Picture', dito 27.
29. Lien,Y. and Utler,D., 'Design of an Image Data Base', dito 27
30. Tamura,H. and Mori,S., 'A Data Management System for Manipulating Large Images', dito 27.
31. Mckeown,D. and Reddy,D., 'A Hierarchical Symbolic Representation for an Image Data Base', dito 27.
32. Stow,D. and Estes,J., 'Analyzing Accuracy Attributes of Landsat and Digital Terrain Tape Data in the Context of a Digital Geobase Information System', dito 16.
33. Overton,K. and Weymouth,T., 'A Noise Reducing Proprocessing Algorithm', IEEE Computer Society Conference of Pattern Recognition and Image Processing, Aug 6-8, 1979, Chicago.
34. SCS, 'Urban Hydrology for Small Watersheds', Technical Release 55, Soil Conservation Service-USDA, Beltsville, Maryland

#### 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.