REMOTE SENSING/GIS INTEGRATION FOR SITE PLANNING AND RESOURCE MANAGEMENT

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ABSTRACT

In the late 1970's, the Maryland National Capital Park and Planning Commission, the county level planning offices for Montgomery County, Maryland, was faced with the problems of managing the rapid growth of their 400 square mile jurisdiction. The planning board decided digital data bases would be constructed capable of site planning and defining parameters necessary for energy, planning, hydrologic, economic and various resource forcasting models. Techniques for managing and collecting regional ancillary data (aerial photos, soils, etc.) and digital remote sensed data sets would be required to run models and produce timely graphics/statistics for present/proposed decision-making. Concurrently, the University of Maryland Civil Engineering Department (UOMCE) was developing a computer-based gridded information system (GIS) allowing engineers to create, access, integrate, and maintain a multi-parameter geographical data base for real-time hydrologic modeling.

By joining forces, the UOMCE and MNCPPC developed an interactive/batch GIS (array of cells georeferenced to USGS quad sheets) and interfacing application programs (e.g., hydrologic models). This system allows non-programmer users to request any data set(s) stored in the MNCPPC data base by inputing any random polygon's (watershed, political zone) boundary points. The data base information contained within this polygon can be used to produce maps, statistics, and define model parameters for the area. Present/proposed conditions for the area may be compared by inputing future usage (land cover, soils, slope, etc.).

This system, known as the Hydrologic Analysis Program (HAP), is currently operational on the MNCPPC's HP 3000 mini-computer and the UOMCE UNIVAC-1180 main-frame computer. HAP has been especially effective in the real-time analysis of proposed land cover changes on runoff hydrographs and graphics/statistics resource inventories of random study area/watersheds.

INTRODUCTION

In August of 1977, the Montgomery County Offices of The Maryland National Capital Park and Planning Commission incorporated an adaptation of a computer-based geographical information system known as MSDAMP. MSDAMP, an acronym for Multi-Spatial Data Analysis Mapping Program, was developed at the Iowa State University Land Analysis Laboratory in November 1972. This effort allowed cultural and physical data from existing maps and aerial photographs to be converted to a digital format and stored on the County's computer. The dominant land use or other desired parameter for each of these cells is encoded and entered into the computer. In batch mode, MSDAMP can be used to produce line printer gray-scale maps showing the distribution of various land uses, geologic features, slopes, soils, etc.

The data structure of MSDAMP is an array of five-second cells covering the entire 400 square mile Montgomery County. Each cell, encompassing an area of 4.58 acres, measures 397.75 feet east/west and 505.90 feet north/south. These dimensions were selected to give the five second increment at a latitutde of 39°00'00" and allow distortion-free symbolic maps to be produced with ten column by eight line high speed line printers. At this cell resolution, each data plane (land cover, soils, etc.) in the Montgomery County data base would contain 55895 cells. MSDAMP requires the input of each individual cell georeferenced by latitude and longitude. In the subsequent years MSDAMP proved to be generally ineffective because of this cumbersome data collection method, inability to interface with application programs (e.g., hydrologic and planning models) and inefficient sequencial data base searches.

In 1978, the University of Maryland Civil Engineering Department (UOMCE) was conducting research in geographical information systems (GIS) for hydrologic analysis. The goal of the UOMCE GIS was to improve large area geoencoding techniques, provide a data structure capable of manipulating random polygons of data within the data base, interface the data base with existing hydrologic models, and manage the data base consisting of both digital remote sensed data (Landsat, digital terrain) and ancillary hard copy information (aerial photography and soil maps).

By joining forces, the MNCPPC and UOMCE created a system called the Hydrologic Analysis Program (HAP) which satisfied both organizations goals. The MNCPPC involvement ensured that the HAP software/hardware requirements would be developed for a non-programmer county level production environment.

It was decided that the HAP data collection, data management, and model interface would be tested by expanding the MNCPPC data base to include land cover, hydrologic soil groups and slope necessary for defining parameters in the Soil Conservation Service hydrologic model, TR-55. In a typical real-time situation, the planner types the coordinates of a watershed boundary on the keyboard of an office terminal connected with a Hewlett-Packard 3000 mini-computer. The appropriate HAP compatible MSDAMP data files are automatically accessed and the planner's terminal immediately produces:

1. a series of symbolic maps showing the distribution of land use, soil type, and slope;

2. statistical tables showing the number of acres and the percentage of the watershed area devoted to each land use, soil type, or slope category;

3. a table showing the runoff curve number, hydraulic length, and time of concentration needed to enter the SCS model.

If the planner also enters a rainfall amount into the terminal, HAP will automatically list the volume of runoff and estimated peak discharge as computed with SCS-TR-55.

A major function of HAP is to give planners the capability to assess the impact of land use or other changes being considered for the watershed. Thus, after the above information has been obtained for existing conditions, the planner can type the coordinates of those subareas being considered for change into the keyboard. He lists the type of new land use or other changes being considered for each of these subareas. The program then recycles in the manner outlined above with the new subarea information to give data for the watershed under new conditions.

HAP MODEL

The guiding principle in the development of HAP was that planners must be able to obtain quantitative information in real time for any watershed/political zone in the County. This pilot HAP model consists of three major components: 1) an enhanced GIS designed for collecting and manipulating the data base; 2) the interface between the data base and SCS-TR-55 hydrologic model; and 3) graphics/statistic package.

HAP Gridded Information System

The HAP GIS was designed to simplify the user's maneuvering of data between the hierarchical levels of the data base. This task was accomplished by providing the user with a hierarchical STUDY AREA-7½^{O} UNITED STATES GEOLOGICAL SURVEY (USGS) TOPO SHEET-GRID-CELL-ATRIBUTE model. Figure 1 shows the Montgomery County, Maryland study area subdivided into its nineteen USGS topo sheets. Each topo consists of 90x90 grid of 4.58 acre cells containing various geophysical attributes. The cells are georeferenced by latitude/longitude and grid row/col.

The concept of storing geographical information in a computer can be illustrated by Figure 2. Conceptually, the spatial distribution of the geographical quantities are coded as an array of rectangular cells with the position of each cell identified by a row and column number. The dominant

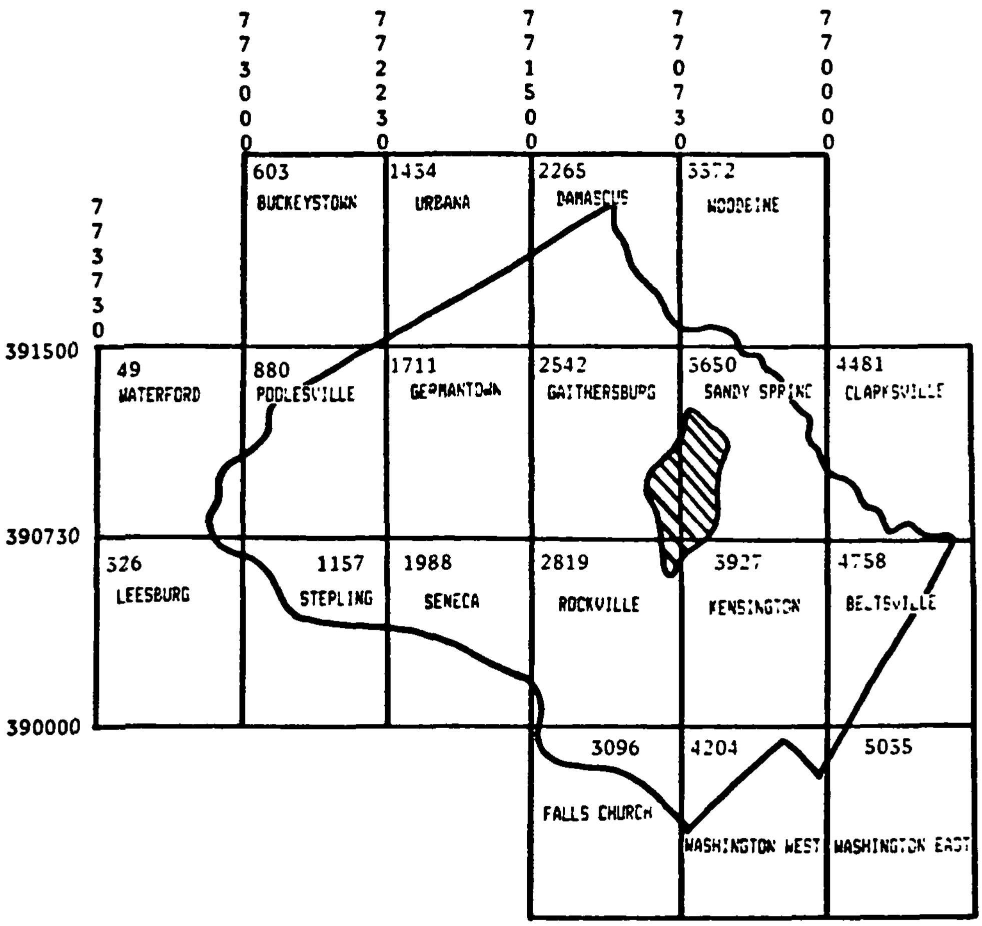

Figure 1

Quad-Sheet Storage Arrangement For
Montgomery County, Maryland

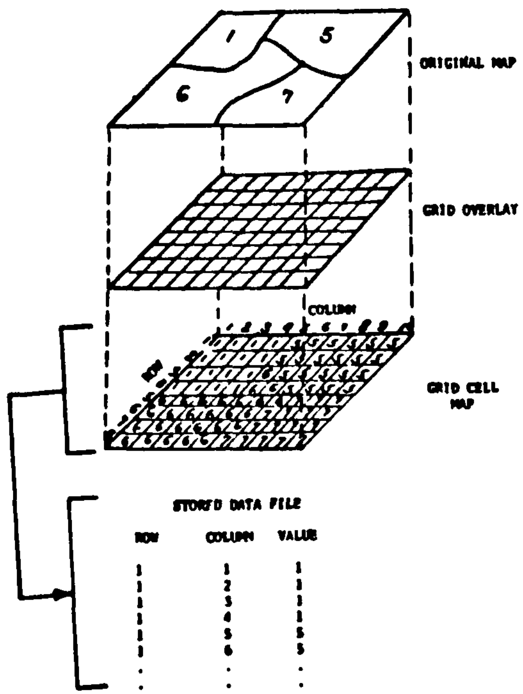

Figure 2

Concept of Single Variable Data Bank
(from the Corps of Engineers[1])

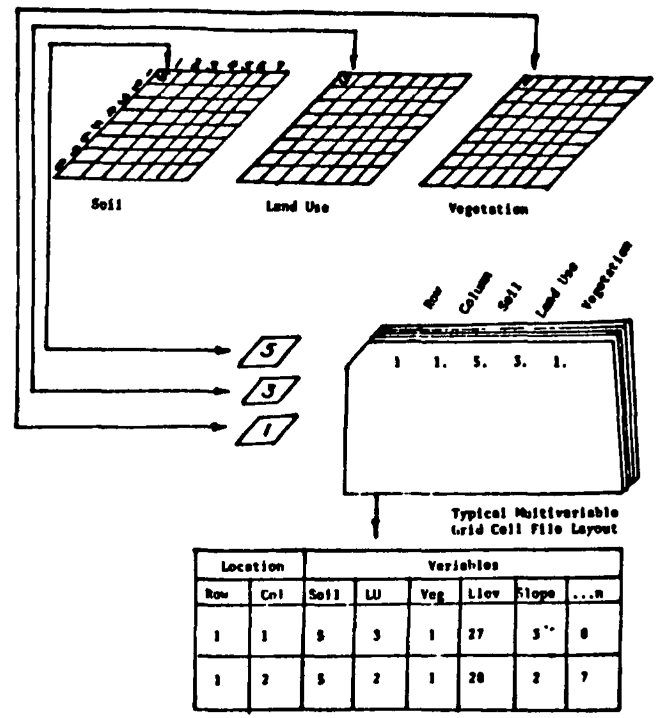

Figure 3

Storage of Multivariable Information In A Grid Cell Data Base
(from the Corps of Engineers[1])

geographical quantity within each cell is identified, generally, by a single valued alphanumeric character. This information is stored in the computer in some format similar to that listed in the lower part of Figure 2. The strategy illustrated by Figure 2 can be extended to a system in which layers of geographic information are reduced to the same format, added to the computer and interfaced with each other to produce multi-variant parameters, such as those required for hydrologic models. Figure 3 is a schematic illustrating the organization of a multi-parameter data base.

Using the HAP model as a loading template, HAP will accept data by the gird-overlay featured in Figure 2, digitized polygons or previously existing gridded digital data. The electronic digitization of single-valued polygons is very efficient for homogeneous data attributes like hydrologic soil groups. The polygons are converted to grid cells within HAP. To minimize collection efforts, an entire topos grid is tagged with the dominant data class. Only the cells containing subsequent data classes are actually geo-encoded.

The model also allows an engineer or planner to use the quad sheet as a "pointer" and, thereby, manipulate only the data within the quad sheets involved in an analysis, rather than the entire MSDAMP data base. For example, if a planner was interested in the analysis of the shaded watershed shown in Figure 1, the first step would be to type in the topo access numbers 2542, 2819, 3650, and 3927. This would cause the computer to access the tape or other off line inexpensive storage and bring the 90 x 90, 5-second arrays of cells contained within the Gaithersburg, Sandy Spring, Rockville, and Kensington quadrangle sheets into temporary direct access storage. The role of the topo access will be explained in a subsequent section.

Table I lists the land use categories accessed by HAP from the MSDAMP data base. Unless specified by the planner from the terminal, the symbols listed in Table I will be used by HAP in printing any maps requested in the output. The planner has an array of options including the assignment of "blanks" to some of the categories, or all but one, in order to produce special purpose thematic maps. The Curve Numbers listed in Table I will be discussed in the following section.

Table II lists the slope categories and their map symbols stored in the HAP data base. Ranges of slopes, rather than specific slope values, are used in order to allow the slope within a cell to be represented as a single digit and, thereby, minimize the storage requirements.

HAP Hydrologic Model

The power of the system is realized when tnese arrays of stored variables are interfaced directly through the computer with simulation models. In this approach, cells within a watershed are combined to define the input parameters needed for the hydrologic model. The model then outputs desired streamflow characteristics in a format appropriate to the user's requirements.

Table I

Land Cover Symbols and Curve Numbers Used In Hydrologic Analysis Program

LAND COVER CATEGORY	SYMBOL	CURVE NUMBER FOR SOIL GROUP A	B	C	D
Grass	B	39.	61.	74.	80.
Cultivated Fields	C	72.	81.	88.	91.
Conifer Forests	E	25.	55.	70.	77.
Deciduous Forests	F	25.	55.	70.	77.
Idle Lands	G	49.	69.	79	84.
Rural Residential	J	51.	68.	79.	84.
Industrial/commercial	K	89.	92.	94.	95.
Single Family	L	61.	75.	83.	87.
Low Density	M	57.	72.	81.	86.
High Density	N	77.	85.	90	92.

Table II

Slope Category Symbols Used In Hydrologic Analysis Program

SLOPE RANGE	SYMBOL
0.0 LE* PERCENT SLOPE LT* .25	A
.25 LE PERCENT SLOPE LT .50	B
.50 LE PERCENT SLOPE LT .75	C
.75 LE PERCENT SLOPE LT 1.0	D
1.0 LE PERCENT SLOPE LT 1.5	E
1.5 LE PERCENT SLOPE LT 2.0	F
2.0 LE PERCENT SLOPE LT 2.5	G
2.5 LE PERCENT SLOPE LT 3.0	H
3.0 LE PERCENT SLOPE LT 4.0	I
4.0 LE PERCENT SLOPE LT 6.0	J
6.0 LE PERCENT SLOPE LT 8.0	K
8.0 LE PERCENT SLOPE LT 10.0	L
10.0 LE PERCENT SLOPE LT 12.5	M
12.5 LE PERCENT SLOPE LT 15.0	N
15.0 LE PERCENT SLOPE LT 20.	O
20.0 LE PERCENT SLOPE LT 25.0	P
25.0 LE PERCENT SLOPE LT 30.0	Q
30.0 LE PERCENT SLOPE LT 40.0	R
40.0 LE PERCENT SLOPE LT 50.0	S
50.0 LE PERCENT SLOPE LT 75.0	T
75.0 LE PERCENT SLOPE LT 100.	U
100. LE PERCENT SLOPE LT 200.	V
200. LE PERCENT SLOPE LT 300.	W
300. LE PERCENT SLOPE LT 500.	X
500. LE PERCENT SLOPE	Y

LE - LESS OR EQUAL TO

*LT - Less than

The model used to generate the volumes of runoff and peak discharges from the information available in the data base is a computerized version of parts of SCS-TR-55[2]. It is assumed that the HAP user has or will develop an understanding of SCS-TR-55. Thus, only the key equations needed to explain the logic flow of HAP will be presented.

The implementation of HAP starts with the user drawing a boundary around the watershed of interest on USGS 7½ minute quad sheets. Names of the quad sheets involved and a sufficient number of points to adequately define the boundary are entered into the terminal. The internal software of HAP then isolates the cells contained within the watershed boundary. The land use and hydrologic soil group are interfaced to compute a curve number for each cell in accordance with Table I. The cells are then summed and divided by the total to obtain an average Curve Number for the watershed. In a similar fashion, the average slope is obtained for the watershed. Table III lists the symbols that will be used to print HAP soil maps if desired.

After the Curve Number, CN, has been derived, the relationship

$$S = \left(\frac{1000}{CN}\right) - 10 \tag{1}$$

is then used to compute the potential maximum storage, S, of the watershed. The result of this computation is then entered into

$$Q = \frac{(P-.2S)^2}{P+.8S} \tag{2}$$

to obtain the volume of runoff, Q, from the rainfall, P.

HAP obtains the area of the watershed, A, by counting the number of cells encompassed within the boundary and multiplying by 4.58. The area is then available to estimate the hydraulic length in accordance with

$$H_L = 209(A)^{.6} \tag{3}$$

The time of concentration is then estimated from

$$T_c = \frac{1}{0.6}\left(\frac{H_L^{.8}(S+1)^{.7}}{1900\ Y^{.5}}\right) \tag{4}$$

where Y is the average slope of the watershed. Finally, the time of concentration is entered into a mathematical relationship defining the curve of Figure 4, to produce a dimensionless peak discharge which HAP converts to the peak discharge in cubic feet per second by multiplying the area in sq. miles by the volume of runoff obtained from Equation 2.

Table III

SOIL TYPE SYMBOLS USED IN HYDROLOGIC ANALYSIS PROGRAM

Group	Symbol
A	A
B	B
C	C
D	D

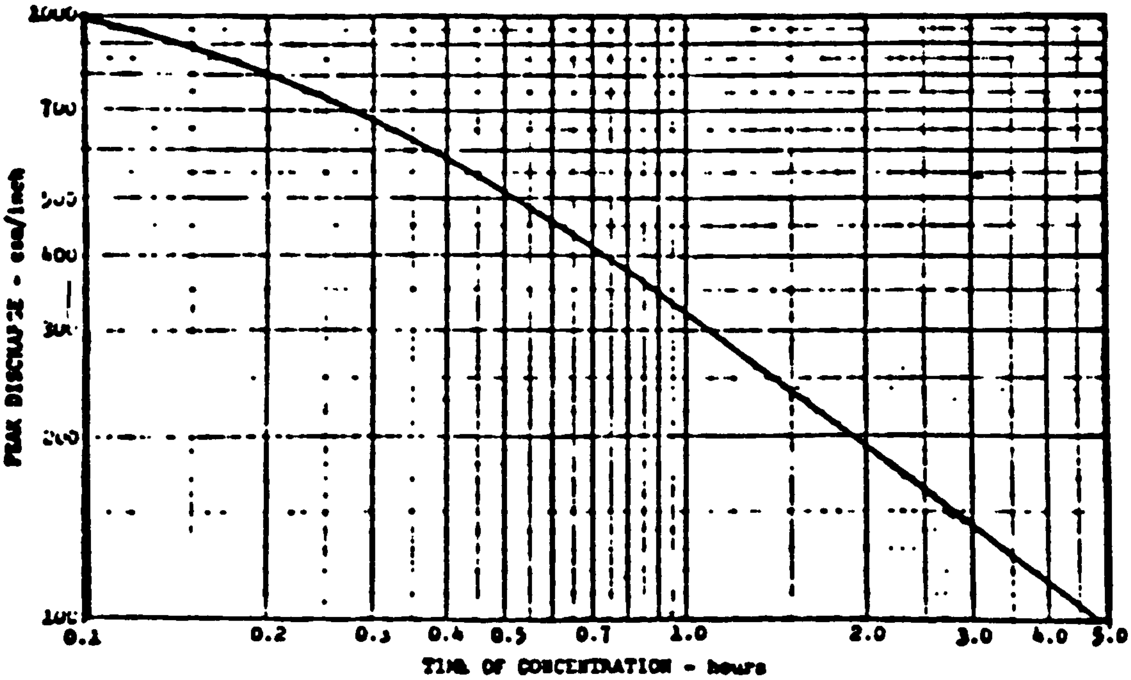

Figure 4

Peak Discharge in scm Per Inch of Runoff Versus Time of

Concentration (T_C) for 24-hour, Type-II Storm Distribution.

The use of Figure 4 imposes the requirement that the rainfall used with HAP be a 24 hour volume so it will be consistant with the intensity distribution of the SCS Type-II Storm Rainfall. The SCS Type-II Storm is excellent for use in urban and urban fringe studies. The storm structure provides a period of several hours of light rainfall during which the soils are "wetted-up" to reduce infiltration rates and fill a portion of the depression storage. There is then a period of several hours of heavy rainfall simulating thunderstorm intensities. Finally, there is a period of lightening rainfall during the last several hours.

It should be recognized that there are a number of options within SCS-TR-55. One approach within TR-55 is to use detailed maps to measure incremental hydraulic flow lengths and then develop the time of concentration through velocity computations. HAP defines the hydraulic length and the time of concentration with the empirical Equations 3 and 4 which were developed by SCS from regression analyses of watersheds throughout the United States. A constraint on Equation 4 is that it be limited to watersheds of less than 2000 acres. Table IV contains Montgomery County rainfall-frequency values required by TR-55.

Table IV

24 Hour Rainfall in Inches for Different Frequency Events for Montgomery County

Frequency	Rainfall Inches
1	2.6
2	3.2
5	4.2
10	5.1
25	5.6
50	6.3
100	7.2

USE OF THE HYDROLOGIC ANALYSIS PROGRAM FOR WATERSHED INVESTIGATIONS

The use of HAP as a tool for watershed investigations will be illustrated through the use of an example problem. The specific problem addressed is the comparison of the peak discharge for a watershed under present conditions with the peak discharge anticipated under conditions of complete development as allowed by the Montgomery County approved land use master plan. The statement of the example problem is as follows:

> There is a need to provide stormwater storage behind and existing conduit on the Rockville quad. The design of the control structure that will create the backwater requires estimates of the peak discharge for present and future land use conditions for a 100 year, 7.2 inch, 24 hour storm. Determine the current and future peak discharges, volumes of runoff and percent changes created in these quantities by developing the watershed to its ultimate land use distribution.

HAP uses four "modules" during its execution. The function of these modules are:

BOUNDARY MODULE= The BOUNDARY module is called when the user wishes to enter the coordinates of the watershed boundary. The BOUNDARY module retrieves and stores the cells contained within the boundary of the study area.

HYDROLOGIC MODEL= The HYDROLOGIC MODEL module merges the cells within the boundary and computes the slope for the study area. These parameters are then interfaced with the SCS-TR-55 and volumes of runoff and peak discharges estimated for user input rainfalls. The user is also prompted for map production and statistical summaries of the study area for present conditions (i.e., land cover, soils, and slope).

UPDATE MODULE= The UPDATE module allows the input of proposed cell changes within the study area. The cell distribution in the watershed is adjusted for the proposed conditions interfaced with TR-55 and revised runoffs compared to the present conditions. The user is prompted for production of maps and statistical summaries describing the study area under proposed conditions.

STOP MODULE= The STOP module is called when the user has completed his study and wishes to exit from the HAP program.

The solution of the example problem will assume the user is accessing the program capabilities with a 132 character terminal. The program is interactive with the terminal outputing prompts and explanations to aid the user in inputing data or requesting HAP operations. Those terminal statements within boxes are input statements entered by the user. Those statements in upper case letters are outputs from the terminal.

The following run stream describing the steps in the solution of the example problem contains explanations of key points.

TYPICAL HYDROLOGIC ANALYSIS PROGRAM
RUN STREAM

- -

STEP ONE GATHER NEEDED INFORMATION PRIOR TO ACCESSING HAP

Before working with the terminal, it is necessary, in the interest of efficiency, to tabulate the information necessary to define the watershed boundary and move the appropriate portion of the data base into direct access storage. The first step is to assemble the topographic sheets needed to define the watershed boundary. The watershed boundary is sketched. The 90 x 90 transparent mylar grid is overlaid on the quadsheet. Enough nodes are picked to allow the watershed boundary to be approximated as a series of straight line segments. In this example, the entire watershed is within the bounds of the Rockville quadrangle sheet. In order to get the data of this quadrangle into direct access storage, the user will have to enter the disk access number obtained from Figure 1, in this case 2819. The user will also have to enter the latitude and longitude of the upper left hand corner of the quadrangle sheet. Finally, the cells to be changed to a proposed land cover will have to be tabulated for entry from the terminal. Thus, prior to accessing the terminal, the user would write down the information below.

Latitude = 390730
Longitude = 771500
Disk Access No. = 2819

Tabulation of cell coordination of watershed boundary. Proceed clockwise. The boundary will automatically be closed between the first and last points listed.

Watershed Boundary

Boundary Point	Row	Column
1	04	50
2	04	53
3	06	55
4	08	55
5	09	56
6	11	56
7	12	55
8	14	55
9	15	56
10	17	56
11	18	55
12	19	54
13	18	52
14	17	51
15	15	51
16	15	49
17	14	48
18	12	48
19	11	47
20	07	47

Tabulation of cells to be changed to reflect proposed watershed conditions. The cell location and proposed land cover change within each cell is tabulated using the transparent mylar grid and the land cover codes of Table I . If soil type or slope were to also be changed, Tables II and III would be used to obtain the proper symbols.

LOCATION		NUMBER OF CELLS	LAND	SOILS	SLOPE
ROW	COLUMNS		COVER		
4	50-52	3	k	zero	zero
5	49-54	6	k	"	"
6	50-55	6	k	"	"
7	49-55	7	k	"	"
8	49-55	7	k	"	"
9	49-56	8	k	"	"
10	48-56	9	k	"	"
11	47-56	10	k	"	"
12	48-53	6	k	"	"
13	50-53	4	k	"	"
14	50-53	4	k	"	"
15	51-52	2	k	"	"

If more than one quadrangle is involved, this process will be repeated for each sheet.

STEP TWO SIGN ON HEWLETT PACKARD 3000 AS FOLLOWS

(a) Turn on Terminal
(b) Wait for green light
(c) Hit return key
(d) You will get a colon back
(e) Type in (HELLO USER.MPLENV,WATER)
(f) It will ask you for Password
(g) Type in ENVIRON
(h) Type in NAZ
(i) You will get # sign
(j) To execute HAP you type in HAP

THE TERMINAL INPUTS AND OUTPUTS FOR STEP 2 ARE:

```
**********************HYDROLOGIC ANALYSIS PROGRAM**********************
**ENTER: BOUNDARY,HYDROLOGIC MODEL,UPDATE,LOAD,STOP**
```

Note: At this point the terminal will stop. The output immediately above lists the modules available. HAP is ready to accept the input of the watershed boundary.

STEP THREE BOUNDARY MODULE

A. Request the BOUNDARY module by typing BOUNDARY into the terminal.
B. Specify if you need input prompts.
C. Enter name of study area.
D. Enter number of topos containing study area.
E. Enter latitude and longitude of northwest topo corner.
F. Enter DAF topo address (see Figure 1)
G. Enter whether boundary points are P=POLYGON or C=CELL format.
H. Enter whether boundary points are I=INTEGER or D=DIGITAL.
I. In this example the boundary is defined from the northeast corner row and column coordinates of a 90 x 90 (4.58 acre) cell grid. If the boundary points were entered from a digitizier the map scale would be requested. The program is set up to accept the node points from a digitizer in inches (eight sets of X, Y coordinates per card in F5.2 format).

THE TERMINAL INPUTS AND OUTPUTS FOR STEP 3 ARE:

```
BOUNDARY
================================BOUNDARY MODULE==================================

**DO YOU NEED DATA INPUT PROMPTS(Y/N)**
Y
**NAME OF STUDY AREA (MAX 30 CHAR)**
ROCKVILLE WATERSHED ANALYSIS
**ENTER: NUMBER OF TOPOS CONTAINING STUDY AREA**
1
**ENTER: TOPO LATITUDE,LONGITUDE,DISK ADDRESS,
("P"=POLYGON OR "C" CELLS DATA SET),("I"=INTEGER OR "D"=DIGITAL DATA)
390730,771500,2819,P,I
**ENTER: ROW,COL (TERMINATE WITH ENDO)**
[illegible]
[illegible]
[illegible]
8,55
8,56
11,56
12,55
14,55
15,56
17,56
18,55
18,54
18,52
17,51
15,51
15,49
14,48
12,48
11,47
7,47
ENDO
TOPO=2819 LAT=390730 LON=771500 BDYPTS=      20
===============ROCKVILLE WATERSHED ANALYSIS   BOUNDARY COMPLETE==========

****************************HYDROLOGIC ANALYSIS PROGRAM******************************
**ENTER: BOUNDARY,HYDROLOGIC MODEL,UPDATE,LOAD,STOP**
```

STEP FOUR HYDROLOGIC ANALYSIS

The Hydrologic Analysis Program heading listing the modules is on the terminal output. The cells within the watershed boundary have been assembled. HAP is ready to do the TR-55 analysis.

A. Request the HYDROLOGIC MODEL module.
B. Input rainfall (inches).
C. Specify if present condition land cover, soils, and slope maps are to be generated and to what unit they should be transmitted.

THE TERMINAL INPUTS AND OUTPUTS FOR STEP 4 ARE:

```
HYDROLOGIC MODEL
******************************SCS MODEL MODULE******************************

**INPUT RAINFALL IN INCHES(REAL NUMBER)**
7.2
        ***WATERSHED ANALYSIS (SCS-TR-55)***

IDENTIFICATION=ROCKVILLE WATERSHED ANALYSIS

WEIGHTED CURVE NUMBER=     71.75
AVE PERCENT SLOPE=      3.87
AREA=    531.81 (ACRES)          .83 (SQUARE MILES)

HYDRAULIC LENGTH=   8028.18 (FEET)
TIME CONCENTRATION=       2.65 (HOURS)
RAINFALL=      7.20 (INCHES)
VOLUME OF RUNOFF=      3.87 (INCHES)
PEAK DISCHARGE=    838.83 (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**
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)?**
D
              777777777777777777777777777777777777777777777777777777777
              777777777777777777777777777777777777777777777777777777777
              111111111111111000000000000000000000000000000000000000000
              111000000000000999999999999888888888888777777777777666666
              100554433221100554433221100554433221100554433221100554433
              050505050505050505050505050505050505050505050505050505050

              000000000000000000000000000000000000000000000000000001111
              444555555555566666666667777777777888888888899999999990000
              789012345678901234567890123456789012345678901234567890123
390715   4 !   BBFX                                                    !  4 390715
390710   5 !  BFFFCC                                                   !  5 390710
390705   6 ! KKFFBBBC                                                  !  6 390705
390700   7 !KKGFBBBC                                                   !  7 390700
390655   8 !KKGCBBBCC                                                  !  8 390655
390650   9 !KKCCBBCCCB                                                 !  9 390650
390645  10 !KCCCCBBBBB                                                 ! 10 390645
390640  11 !CCBBCBBBBB                                                 ! 11 390640
390635  12 ! CCFFBBBB                                                  ! 12 390635
390630  13 ! KKCFFFFF                                                  ! 13 390630
390625  14 ! BBBFFFFF                                                  ! 14 390625
390620  15 !  BKBFFFFF                                                 ! 15 390620
390615  16 !    BKFFFL                                                 ! 16 390615
390610  17 !    BBBFLL                                                 ! 17 390610
390605  18 !     BBLL                                                  ! 18 390605
390600  19 !      LL                                                   ! 19 390600
390555  20 !*******************************************************    ! 20 390555
390550  21 !*             ROCKVILLE WATERSHED ANALYSIS             *    ! 21 390550
390545  22 !*             MONT. CO AER. PHOTO LAND COVER           *    ! 22 390545
390540  23 !*                                                      *    ! 23 390540
390535  24 !* SYM CLASS                               ACRES     %   *    ! 24 390535
390530  25 !* ===================================================  *    ! 25 390530
390525  26 !*  B   GRASS                              197.14  37.07 *    ! 26 390525
390520  27 !*  C   CULTIVATED FIELDS                  100.86  18.97 *    ! 27 390520
390515  28 !*  F   DECIDUOUS FORESTS                  128.37  24.14 *    ! 28 390515
390510  29 !*  G   IDLE LANDS                           9.17   1.72 *    ! 29 390510
390505  30 !*  K   INDUSTRIAL/COMMERCIAL               64.18  12.07 *    ! 30 390505
390500  31 !*  L   SINGLE FAMILY                       32.09   6.03 *    ! 31 390500
390455  32 !*     TOTAL                               531.81 100.00 *    ! 32 390455
390450  33 !*                                                      *    ! 33 390450
390445  34 !*******************************************************    ! 34 390445
              000000000000000000000000000000000000000000000000000001111
              444555555555566666666667777777777888888888899999999990000
              789012345678901234567890123456789012345678901234567890123

              777777777777777777777777777777777777777777777777777777777
              777777777777777777777777777777777777777777777777777777777
              111111111111111000000000000000000000000000000000000000000
              111000000000000999999999999888888888888777777777777666666
              100554433221100554433221100554433221100554433221100554433
              050505050505050505050505050505050505050505050505050505050
```

```
**DO YOU WANT A MAP OF MONTGOMERY COUNTY HYDRO SOIL   (Y/N)**
[Y]
**DO YOU WANT DEFAULT OR NEW MAP SYMBOLS (D/N)?**
[D]
                777777777777777777777777777777777777777777777777777777777
                777777777777777777777777777777777777777777777777777777777
                111111111111110000000000000000000000000000000000000000000
                111000000000000999999999999888888888888777777777777666666
                100554433221100554433221100554433221100554433221100554433
                050505050505050505050505050505050505050505050505050505050

                000000000000000000000000000000000000000000000000000001111
                444555555555566666666667777777777888888888899999999990000
                789012345678901234567890123456789012345678901234567890123
390715  4 !   BBBB                                                      !  4 390715
390710  5 !  BBBBBB                                                     !  5 390710
390705  6 ! BBBBBCBB                                                    !  6 390705
390700  7 !BBBDBBDBB                                                    !  7 390700
390655  8 !BBBDBBBBB                                                    !  8 390655
390650  9 !BBBDBBBDBB                                                   !  9 390650
390645 10 !BBBCDBBCBB                                                   ! 10 390645
390640 11 !BDBBBDDDCB                                                   ! 11 390640
390635 12 ! BDBBBDDB                                                    ! 12 390635
390630 13 ! BBBBCBDB                                                    ! 13 390630
390625 14 ! BBBBBBDB                                                    ! 14 390625
390620 15 !  BBBBBDDB                                                   ! 15 390620
390615 16 !    DBBBDB                                                   ! 16 390615
390610 17 !    BBBBBB                                                   ! 17 390610
390605 18 !     BBBB                                                    ! 18 390605
390600 19 !      BB                                                     ! 19 390600
390555 20 !#######################################################      ! 20 390555
390550 21 !#                 ROCKVILLE WATERSHED ANALYSIS             #  ! 21 390550
390545 22 !#                 MONTGOMERY COUNTY HYDRO SOIL             #  ! 22 390545
390540 23 !# SYM CLASS                                  ACRES      %   #  ! 23 390540
390535 24 !# ======================================================  #  ! 24 390535
390530 25 !#  B    HYDROLOGIC SOIL GROUP B              408.03  76.72  #  ! 25 390530
390525 26 !#  C    HYDROLOGIC SOIL GROUP C               22.92   4.31  #  ! 26 390525
390520 27 !#  D    HYDROLOGIC SOIL GROUP D              100.86  18.97  #  ! 27 390520
390515 28 !#      TOTAL                                 531.81 100.00  #  ! 28 390515
390510 29 !#######################################################      ! 29 390510
                000000000000000000000000000000000000000000000000000001111
                444555555555566666666667777777777888888888899999999990000
                789012345678901234567890123456789012345678901234567890123

                777777777777777777777777777777777777777777777777777777777
                777777777777777777777777777777777777777777777777777777777
                111111111111110000000000000000000000000000000000000000000
                111000000000000999999999999888888888888777777777777666666
                100554433221100554433   110055443322110055443322110055443 3
                050505050505050505050 050505050505050505050505050505050505
```

```
**DO YOU WANT A MAP OF MONTGOMERY COUNTY % SLOPE        (Y/N)**
[Y]
**DO YOU WANT DEFAULT OR NEW MAP SYMBOLS (D/N)?**
[D]
              77777777777777777777777777777777777777777777777
              77777777777777777777777777777777777777777777777
              11111111111111100000000000000000000000000000000
              11100000000000009999999999999888888888888777777777777666666
              100554433221100554433221100554433221100554433221100554433
              05050505050505050505050505050505050505050505050

              00000000000000000000000000000000000000000001111
              44455555555555666666666677777777777888888888889999999999990000
              78901234567890123456789012345678901234567890123
390715  4 !   JJII                                          !  4 390715
390710  5 !  KJKKJH                                         !  5 390710
390705  6 ! IKKJJAGJ                                        !  6 390705
390700  7 !FGJJIJHFI                                        !  7 390700
390655  8 !GIKKJJJJJ                                        !  8 390655
390650  9 !FGEJJIIIHJ                                       !  9 390650
390645 10 !HIJJJFIIII                                       ! 10 390645
390640 11 !GJJEHGIIIH                                       ! 11 390640
390635 12 ! JJFGFDFI                                        ! 12 390635
390630 13 ! IKKIFGFF                                        ! 13 390630
390625 14 ! HJIHGFHH                                        ! 14 390625
390620 15 !   GHIIHHJH                                      ! 15 390620
390615 16 !     FIIIFD                                      ! 16 390615
390610 17 !     IIIJJJ                                      ! 17 390610
390605 18 !       FJHI                                      ! 18 390605
390600 19 !        JJ                                       ! 19 390600
390555 20 !                                                 ! 20 390555
390550 21 !                                                 ! 21 390550
390545 22 !                                                 ! 22 390545
390540 23 ! ############################################### ! 23 390540
390535 24 ! #                                             # ! 24 390535
390530 25 ! #          ROCKVILLE WATERSHED ANALYSIS         # ! 25 390530
390525 26 ! #          MONTGOMERY COUNTY % SLOPE            # ! 26 390525
390520 27 ! #                                             # ! 27 390520
390515 28 ! # SYM CLASS                         ACRES    % # ! 28 390515
390510 29 ! # ========================================== # ! 29 390510
390505 30 ! #  A    S GE  0.00 AND S LT  0.25     4.58   .86 # ! 30 390505
390500 31 ! #  D    S GE  0.76 AND S LT  1.00     9.17  1.72 # ! 31 390500
390455 32 ! #  E    S GE  1.01 AND S LT  1.50     9.17  1.72 # ! 32 390455
390450 33 ! #  F    S GE  1.51 AND S LT  2.00    64.18 12.07 # ! 33 390450
390445 34 ! #  G    S GE  2.01 AND S LT  2.50    45.85  8.62 # ! 34 390445
390440 35 ! #  H    S GE  2.51 AND S LT  3.00    68.77 12.93 # ! 35 390440
390435 36 ! #  I    S GE  3.01 AND S LT  4.00   137.54 25.86 # ! 36 390435
390430 37 ! #  J    S GE  4.01 AND S LT  6.00   151.29 28.45 # ! 37 390430
390425 38 ! #  K    S GE  6. 1 AND S LT  8.00    41.26  7.76 # ! 38 390425
390420 39 ! #      TOTAL                         531.81 100.00 # ! 39 390420
390415 40 ! #                                             # ! 40 390415
390410 41 ! ############################################### ! 41 390410
390405 42 !                                                 ! 42 390405
390400 43 !                                                 ! 43 390400
390355 44 !                                                 ! 44 390355
390350 45 !                                                 ! 45 390350
              00000000000000000000000000000000000000000001111
              44455555555555666666666677777777777888888888889999999999990000
              78901234567890123456789012345678901234567890123

              77777777777777777777777777777777777777777777777
              77777777777777777777777777777777777777777777777
              11111111111111100000000000000000000000000000000
              11100000000000009999999999999888888888888777777777777666666
              100554433221100554433221100554433221100554433221100554433
              05050505050505050505050505050505050505050505050
.......................END MAP MODULE.........................

===========================ANALYSIS COMPLETE===========================

#######################HYDROLOGIC ANALYSIS PROGRAM#######################
**ENTER: BOUNDARY,HYDROLOGIC MODEL,UPDATE,LOAD,STOP**
```

STEP FIVE ENTER PROPOSED CHANGES OF STUDY AREA AND COMPARE SCS TR-55 RESPONSE FOR PRESENT/PROPOSED CONDITIONS

The heading listing the modules has output on the terminal. The SCS-TR-55 analysis for current conditions is complete. HAP is ready to accept changes within the watershed and repeat the SCS-TR-55 analysis. If there are no watershed changes to be investigated, proceed to Step Six to exit program.

A. Request the UPDATE module.
B. As prompted, select the quads requiring changes.
C. Enter the location and proposed land cover, soil, or slope value for each update cell from Tables I, II, and III. In this case, only land covers are being changed.

D. For the given rainfall in STEP FOUR, the updated conditions will be routed through TR-55 and the response compared with the present conditions.
E. The user will be prompted for proposed condition maps to verify the update input.

THE TERMINAL INPUTS AND OUTPUTS FOR STEP 5 ARE:

```
UPDATE
*******************************UPDATE MODULE*******************************

**ARE THERE ANY CHANGES IN THE 390730 771500 TOPO(Y/N)**
Y
**ENTER: ROW,COL,OCCUR,LAND COVER,SOIL,SLOPE (EX: 10,50,4,A,B,C)
**IF NO CHANGE INPUT A ZERO (TERMINATE WITH ENDO)**
4,50,3,K,0,0
5,49,6,K,0,0
6,50,6,K,0,0
7,49,7,K,0,0
8,49,8,K,0,0
9,49,8,K,0,0
10,48,9,K,0,0
11,47,10,K,0,0
12,48,6,K,0,0
13,50,4,K,0,0
14,50,4,K,0,0
15,51,2,K,0,0
ENDO
          ***WATERSHED ANALYSIS (SCS-TR-55)***

IDENTIFICATION=ROCKVILLE WATERSHED ANALYSIS
RAINFALL(INCHES)=          7.20
DRAINAGE AREA(ACRES)=    531.81        .83 (SQUARE MILES)
HYDRAULIC LENGTH(FEET)=   9028.18

QUANTITY                               PRESENT    PROPOSED
CURVE NUMBER                             71.75       86.23
AVERAGE PERCENT SLOPE                     3.67        3.67
TIME OF CONCENTRATION(HOURS)              2.05        1.30
VOLUME OF RUNOFF                          3.97        5.58
PEAK DISCHARGE(CFS)                     439.63     1244.69

    ***CHANGE IN RUNOFF              1.61 (INCHES)       40.57 %***
    ***CHANGE IN PEAK DISCHARGE    805.06  (CFS)         84.60 %***

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
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 PROPOSED CONDITIONS(Y/N)**
[Y]
.........................MAP MODULE.........................

**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)?**
[D]
                  777777777777777777777777777777777777777777777777777777777
                  777777777777777777777777777777777777777777777777777777777
                  111111111111111000000000000000000000000000000000000000000
                  111000000000000999999999999888888888888777777777777666666
                  100554433221100554433221100554433221100554433221100554433
                  050505050505050505050505050505050505050505050505050505050

                  000000000000000000000000000000000000000000000000000001111
                  444555555555566666666667777777777888888888899999999990000
                  789012345678901234567890123456789012345678901234567890123
390715  4 ! KKAK                                                     ! 4 390715
390710  5 !  KKKKKK                                                  ! 5 390710
390705  6 !  KKKKKKKK                                                ! 6 390705
390700  7 !KKKKKKKKK                                                 ! 7 390700
390655  8 !KKKKKKKKK                                                 ! 8 390655
390650  9 !KKKKKKKKKK                                                ! 9 390650
390645 10 !KKKKKKKKKK                                                ! 10 390645
390640 11 !KKKKKKKKKK                                                ! 11 390640
390635 12 ! KKKKKKBB                                                 ! 12 390635
390630 13 ! KKKKKKFF                                                 ! 13 390630
390625 14 ! BBKKKKFF                                                 ! 14 390625
390620 15 !  BKKKFFFF                                                ! 15 390620
390615 16 !    BKFFFL                                                ! 16 390615
390610 17 !    BBBFLL                                                ! 17 390610
390605 18 !     BBLL                                                 ! 18 390605
390600 19 !      LL                                                  ! 19 390600
390555 20 !                                                          ! 20 390555
390550 21 !                                                          ! 21 390550
390545 22 !********************************************************  ! 22 390545
390540 23 !*                                                      *  ! 23 390540
390535 24 !*              ROCKVILLE WATERSHED ANALYSIS            *  ! 24 390535
390530 25 !*              MONT. CO AER. PHOTO LAND COVER          *  ! 25 390530
390525 26 !*                                                      *  ! 26 390525
390520 27 !* SYM CLASS                             ACRES       %   *  ! 27 390520
390515 28 !* ================================================     *  ! 28 390515
390510 29 !*  B   GRASS                              50.43    9.48 *  ! 29 390510
390505 30 !*  F   DECIDUOUS FORESTS                  55.01   10.34 *  ! 30 390505
390500 31 !*  K   INDUSTRIAL/COMMERCIAL             394.27   74.14 *  ! 31 390500
390455 32 !*  L   SINGLE FAMILY                      32.09    6.03 *  ! 32 390455
390450 33 !*     TOTAL                              531.81  100.00 *  ! 33 390450
390445 34 !*                                                      *  ! 34 390445
390440 35 !********************************************************  ! 35 390440
390435 36 !                                                          ! 36 390435
                  000000000000000000000000000000000000000000000000000001111
                  444555555555566666666667777777777888888888899999999990000
                  789012345678901234567890123456789012345678901234567890123

                  777777777777777777777777777777777777777777777777777777777
                  777777777777777777777777777777777777777777777777777777777
                  111111111111111000000000000000000000000000000000000000000
                  111000000000000999999999999888888888888777777777777666666
                  100554433221100554433221100554433221100554433221100554433
                  050505050505050505050505050505050505050505050505050505050
**DO YOU WANT A MAP OF MONTGOMERY COUNTY HYDRO SOIL    (Y/N)**
[N]
**DO YOU WANT A MAP OF MONTGOMERY COUNTY % SLOPE       (Y/N)**
[N]
.......................END MAP MODULE.........................

===========================UPDATE COMPLETE===========================
```

STEP SIX EXIT HAP

The heading listing the modules has output on the terminal. The analyses are complete and you are ready to exit from the program by calling the 'STOP' module.

THE TERMINAL INPUTS AND OUTPUTS FOR STEP 6 ARE:

```
**********************HYDROLOGIC ANALYSIS PROGRAM**********************
**ENTER: BOUNDARY,HYDROLOGIC MODEL,UPDATE,LOAD,STOP**
STOP

STOP    NORMAL HAP EXIT
```

These interactive inputs may be placed in a data file prior to HAP execution. HAP can be instructed to receive inputs from this file creating a quasi-interactive terminal session. This mode is especially advantageous when testing the same watershed for many different rainfall rates.

CONCLUSION

Because of its interactive, real-time capabilities, the Hydrologic Analysis Program (HAP) is very valuable as a tool to assist in decision making processes. Although it is optimized for water resource analyses, HAP's ability to access any area or cell within the MSDAMP data base and then produce statistical tabulations or symbolic maps should make it an extremely attractive tool for an array of problems encountered by county officials. HAP is currently operational on the MNCPPC's HP3000 mini-computer and the UOMCE UNIVAC 1180 main frame computer.

REFERENCES

1. U.S. Army Corps of Engineers,'Guide for the Creation of Grid Cell Data Banks', Hydrologic Engineering Center, USACE, Davis, Calif. Sept. 1978.

2. U.S. Department of Agriculture, Soil Conservation Service, SCS-TR-55

3. U.S. Department of Commerce, Technical paper 40