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HYDROLOGIC LAND USE CLASSIFICATION USING LANDSAT.(U)
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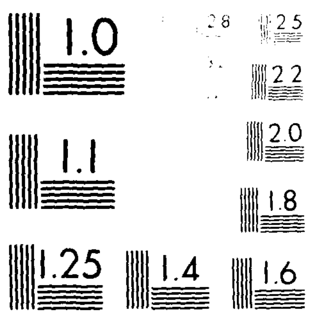
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TECHNICAL PAPER NO. 67

HYDROLOGIC LAND USE CLASSIFICATION USING LANDSAT

by

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HYDROLOGIC LAND USE CLASSIFICATION USING LANDSAT

Robert J. Cermak, Arlen Feldman, and
R. Pat Webb

U.S. Army Corps of Engineers
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609 Second Street, Davis, CA 95616

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Presented at the AWRA Fifth Annual William T. Pecora Memorial Symposium, "Satellite Hydrology," June 11-15, 1979, Sioux Falls, South Dakota

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HYDROLOGIC LAND USE CLASSIFICATION

USING LANDSAT[1]

Robert J. Cermak, Arlen Feldman, and R. Pat Webb

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Davis, California

ABSTRACT

This report will describe the Hydrologic Engineering Center's experience with land use classification from LANDSAT multispectral imagery. Land use is required for the estimation of hydrologic model parameters. The land use classification procedure used, developed at the University of California, Davis, for the Corps of Engineers, is an unsupervised, noninteractive approach requiring no special image processing equipment. Watershed land use was determined from LANDSAT digital data, entered into a geographic data bank, and compared with a conventional land use classification. Hydrologic simulation model parameters were estimated from land use and other basin characteristics. The generated discharge frequency curves, corresponding to the alternative land use classifications, permitted the hydrologic significance of accuracy in land use identification to be assessed.

(KEY TERMS: Land use; LANDSAT; hydrologic simulation; spatial data management.)

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INTRODUCTION

The hydrologic modeling of a watershed, particularly urban or urbanizing basins, requires that the distribution of land use be determined. The amount and timing of runoff is directly related to the infiltration capacity of a land area with the most important distinction being between pervious and impervious land surfaces. Water quality parameters have a similar dependence on land use data; rate of accumulation of a particular pollutant per unit area is normally expressed as a function of land use. Water resource planning studies are interested in not only an assessment of the present state of the water and related resource system, but also its possible future configuration. By expressing hydrologic parameters as a function of current land use it becomes possible to rationally predict the impact future land use changes will have on the quantity and quality of future runoff.

Manual methods for land use identification (e.g., interpretation of low altitude aerial photography and field surveys) are frequently used in watershed studies. The problem with this approach is that the resource requirements, both money and labor, for manual classification can be extensive. An attractive alternative is the utilization of available remote sensing systems and computer-assisted classification techniques. The LANDSAT satellites have been shown to have the capability of providing land use data at acceptable levels of accuracy for hydrologic modeling purposes (Ragan, 1975; Jackson, 1977). LANDSAT data is quicker and less costly to obtain and interpret than low altitude aerial photography, provides repetitive coverage of the same area at least every 18 days, and is available for the entire United States. Additionally, LANDSAT's digital format can be directly analyzed by the different classification computer programs available, and can be resampled for automatic inclusion in a geographic data bank.

This paper describes the land use classification procedure developed for the Corps of Engineers by the University of California, Davis (UCD) and presents results from applying this procedure to land use classifications of a Texas watershed. An extensive set of computer programs developed by the Hydrologic Engineering Center (HEC) for the automated analysis of hydrologic, economic, and environmental aspects of comprehensive water resource planning studies based on spatial data were used to compare the LANDSAT classification to conventionally determined land use. The calculated discharge frequency curves, corresponding to the LANDSAT and conventional land use classifications, are presented as a measure of the hydrologic significance of differences in land use identification. This study was carried out as part of NASA's Water Management and Control ASVT project.

UCD PROCEDURE

An operational procedure for land use classification from LANDSAT data has been developed at the University of California, Davis (UCD) for use by the Corps of Engineers. Referred to as the UCD Procedure, it was designed to function without the use of dedicated, interactive image processing facilities. Only output equipment normally available in Corps field offices (e.g., line printer) and batch-mode access to a general purpose computer could be expected. It was also intended that the procedure would not require specialized technical expertise in data analysis, computer programming, or remote sensing.

The UCD Procedure consists of an organized set of computer programs and manual operations for the identification of land use from raw LANDSAT data. A detailed description is given by Algazi (1979). The primary tasks of the procedure are:

(1) Obtain LANDSAT Computer-Compatible Tapes (CCT), NASA high altitude aerial photography, and USGS topographic maps for the location and date of interest. Extract a rectangular area of data containing the watershed from the CCT. Check for radiometric errors in the LANDSAT digital data and, if necessary, correct.

(2) Determine the geometric registration of the LANDSAT image with the UTM coordinate system of the USGS topographic maps. LANDSAT control points are identified from the output of a UCD computer program which enhances roads and water bodies found in the LANDSAT image. A regression equation, calculated from the two sets of control points, provides a transformation mechanism for going from the image coordinate system to the map coordinate system.

(3) Use an unsupervised clustering algorithm to partition the LANDSAT four-dimensional data space. Groups or "clusters" are identified that contain points with spectral reflectance values that are simlar to members of the same cluster, and dissimilar to the points of other clusters. Each pixel in the watershed data file is assigned to a cluster.

(4) Select from a line printer map of the cluster assignments six sets of adjacent pixels (spatial groups), all belonging to the same cluster. Their corresponding location on the topographic maps is determined using the transformation equation of step (2). Visual translation, from the map to the aerial photographs, of the spatial group's location permits a land use to be assigned to each such spatial group. For clusters having a consistent land use assigned to all six spatial groups, a final land use has been determined. But for those clusters where conflicts exist between the land use identified with each of the six spatial groups, further partitioning of the data space is required.

(5) Clusters with conflicting land use assignments and clusters whose associated land use could not be determined from the available maps and photos are reclustered by repeating step (3), and given final land use assignments by repeating step (4).

(6) At this point the watershed data file contains a land use classification (typically 5 to 7 categories) for all pixels. The watershed file is then resampled at the grid cell centroids using a nearest-neighbor algorithm.

(7) The resampled file is then entered directly into the watershed's grid cell data bank (as explained later). Alternatively, a file containing the digitized watershed boundary can be used to mask the resampled file, leaving only the grid cells within the boundary. Total acreage of each land use class for the entire watershed is then computed.

LANDSAT-CONVENTIONAL LAND USE COMPARISON

The UCD procedure has been tested at HEC on two watersheds: Crow Creek near Davenport, Iowa and Walnut Creek near Austin, Texas. The purpose of the applications was to gain familiarity with the procedure and to evaluate the accuracy of LANDSAT-derived land use. The results of the Crow Creek classification have been reported by Algazi (1979).

Walnut Creek has a drainage area of 55 square miles. LANDSAT imagery for 3 May 1976 was analyzed using January 1974 NASA high altitude color infrared aerial photography (scale 1:121,000) and photorevised 1973 USGS 7-1/2-minute topographic maps (scale 1:24,000) as ground truth. Figure 1 shows the location of the watershed on the LANDSAT scene. Six land use classes were identified: cropland/pasture, residential, commercial/ industrial, quarry, forest/rangeland, and water.

LANDSAT land use was entered into a grid cell data bank that had previously been constructed by the Fort Worth District, Corps of Engineers for an Expanded Flood Plain Information Study (XFPI) of the Walnut Creek basin. The grid cell size of the Walnut Creek data bank is 200 feet (east-west) by 250 feet (north-south), or 1.148 acres. Using a line printer spacing of 8 lines per inch, line printer maps of this grid cell size correspond to the 1:24,000 scale of USGS 7-1/2-minute topographic maps.

Existing land use had been determined conventionally from manual interpretation of October 1977 low altitude color infrared aerial photography (scale 1:12,000). This land use classification, referred to as the conventional land use, consisted of 19 land use categories as given in Table 1. Table 1 also lists the acreage and percent distribution for the 6 LANDSAT land use categories. Figure 2 contains land use maps for both classifications.

A cell-by-cell comparison of the entire watershed required that the larger number of conventional land use categories be aggregated to the fewer LANDSAT land use categories as shown in Table 1. Because conventional and LANDSAT categories are not always compatible this created some problems. As an example, the conventional category "transportation/communication/ utilities" includes major highways, right-of-ways for railroads and power transmission lines, airport facilities (including buildings, runways, and vacant land within the airport limits), and sewage treatment facilities. LANDSAT, however, will classify the water surface of a treatment plant as "water" the open fields surrounding a runway as one of the vegetation categories, and right-of-ways as whatever land surface class if nearby. Caution should, therefore, be used in interpreting the grid cell comparison.

Table 2 summarizes the cell-by-cell comparison of LANDSAT and conventional land use classifications. Theoretically, if the land use categories were completely consistent, then the percent of grid cells that appear down the diagonal of the table, 52.7%, would represent the accuracy of the LANDSAT classification. An additional complication is the inclusion of "rangeland" in the "cropland/pasture" conventional land use category, and in the "forest" LANDSAT land use category. Being unable to differentiate between them, one should consider cropland/pasture/forest/rangeland as one category; summing the diagonal percentages would then result in 70.8% of the grid cells "correctly" classified by LANDSAT.

A comparison at the grid cell level is nearly the same as a comparison at the LANDSAT pixel level; both Walnut Creek grid cell and LANDSAT pixel are approximately 1.1 acres. At such a scale errors in the geometric correction and the resampling procedure will have significant impact on the computed accuracy. Another comparison, less sensitive to such factors, is of the major land use categories at the watershed level. Looking at the total percent classified as (a) residential, (b) commercial/industrial, and (c) cropland/pasture/ forest/rangeland by conventional and LANDSAT shows a difference of 7.6%, -4.4%, and -1.1%, respectively; the average absolute difference for the major land use categories is 4.4%.

LANDSAT land use has been determined by UCD staff for three other basins: Castro Valley, California; Pennypack Creek in Philadelphia, Pennsylvania; and Rowlett Creek near Dallas, Texas. Corps of Engineers' district offices had determined land use by conventional means for their respective basins and encoded this information into grid cell data banks. Cell-by-cell comparisons were made at HEC for the three basins. Results of these comparisons were consistent with the findings in the Walnut Creek analysis: individual grid cells were incorrectly classified by LANDSAT approximately 38% of the time, whereas aggregation of grid cells over the entire watershed showed misclassification of the major land use categories averaging 2 to 8%.

GRID CELL SPATIAL DATA MANAGEMENT SYSTEM

The grid cell spatial data management system, with which the foregoing maps and cell-by-cell analyses were made, has been an operational tool in the Hydrologic Engineering Center since 1975 (U.S. Army Corps of Engineers, 1975). The data management system consists of a set of utility programs for: (1) encoding, checking, and placing the geographic map data in the grid cell data bank; (2) displaying the data through plotting maps of one or more variables by their absolute values or by weighted combinations of relative attractiveness; and (3) extracting data from the data bank and formulating parameters for hydrologic, economic and environmental simulation programs. The principal computer programs for the LANDSAT land use identification, data bank input, hydrologic parameter identification and watershed model are shown in Figure 3.

The spatial data management system has been the focal point of the Corps of Engineers' Expanded Flood Plain Information Studies (Davis, 1978). This technology was developed to provide a comprehensive management tool for use by local governments responsible for the nation's flood plains. The pilot studies undertaken by the Corps' district offices analyzed the hydrologic, economic, and environmental aspects of existing and alternative future land use patterns. The analyses included the automatic computation of expected annual flood damages which resulted from changed hydrologic responses and/or stage-damage functions as related to each land use pattern and flood management measure.

Detailed land use identification is essential to the foregoing analyses, especially for the economic analysis of flood damages. Consequently, twenty or more separate land uses were often required to accurately represent the flood damage relationships. LANDSAT was found to be capable of identifying about six land uses and thus could not be used for the economic analyses. The LANDSAT identified land use was thought to be adequate for hydrologic purposes and the ongoing XFPI studies were used as the format to compare the hydrologic implications of LANDSAT vs. conventional land use classifications.

The HYDPAR computer program (U.S. Army Corps of Engineers, 1978), see Figure 3, automatically determines hydrologic parameters from the geographic grid cell data bank. The key element in this determination is an input relationship between the geographic features and the hydrologic parameters, e.g., Table 3. Any rainfall/snowmelt-to-runoff simulation methods which can be related to geographic features can be handled in this manner.

HYDROLOGIC COMPARISON

The primary reason for examining the land use classification ability of LANDSAT was for its potential application to hydrologic modeling. Calibration of hydrologic models typically used by the Corps of Engineers in urban areas is heavily dependent on land use data, particularly in basins where land use is changing and where future conditions are of interest.

The computer program HEC-1 (U.S. Army Corps of Engineers, 1973) has the capability of explicitly relating land use to runoff using two procedures:

Snyder's unit hydrograph with percent imperviousness, and the SCS curve number and unit hydrograph (U.S. Soil Conservation Service, 1972). As described in the previous section, the HYDPAR program accesses the necessary variables from a grid cell data bank and computes the specified hydrologic parameters, which are in turn input into an HEC-1 model of the basin.

HYDPAR contains a regression equation formulation of Snyder's lag as a function of stream length, length to centroid of subbasin, stream slope, and percent imperviousness. A table associating a percent imperviousness with each land use category in the data bank enables HYDPAR to compute subbasin percent imperviousness from subbasin land use distribution.

In a similar manner HYDPAR can determine the SCS unit hydrograph parameter from stream length, basin average land slope, and subbasin average curve number. Curve numbers represent an empirical relationship between hydrologic soil type, land use, and their resultant runoff potential. From a table identifying a curve number with each combination of land use and hydrologic soil type, Table 3, HYDPAR computes subbasin average curve number. Figure 4 illustrates HYDPAR's subbasin printout for the computation of the SCS parameters.

Both procedures, Snyder's and SCS, were used to test the "hydrologic" accuracy of LANDSAT-derived land use. Percent imperviousness was assigned to each of Rowlett Creek's LANDSAT and conventional land use categories. HYDPAR was used to compute Snyder's lag for a portion of the watershed (Upper Spring Cr., 24.6 square miles) and a calibrated HEC-1 model was used to simulate runoff from selected recurrence interval rainfall. Differences between the discharge frequency curves, based on either LANDSAT or conventional land use, can be interpreted as a measure of the hydrologic significance of LANDSAT's misclassification of land use. Considering the uncertainty involved in estimating any frequency curve, the difference between Rowlett's LANDSAT and conventional curves was judged insignificant. In the interest of conserving space, only the SCS results, described in the next paragraph, are shown graphically.

The SCS method was applied to Pennypack Creek. The SCS curve number and lag were computed by HYDPAR from both LANDSAT and conventional land use. Once again discharge frequency curves were estimated from the simulated runoff of a calibrated HEC-1 model, this time using SCS parameters to define subbasin rainfall-runoff response. The frequency curves of Figure 5, based on LANDSAT and conventional land use, are nearly identical. Also shown on Figure 5 are discharge frequency curves which would result if the basin were modeled by all industrial and all natural vegetation curve numbers. These curves demonstrate the possible extremes that could have been generated from the model and provide a set of references from which to evaluate the actual differences between LANDSAT and conventionally-based frequency curves.

CONCLUSIONS

An operational procedure for determining land use from LANDSAT imagery has been applied to five watersheds. Based on our experience the following conclusions can be made:

(1) At the grid cell level LANDSAT land use can be expected to be in error about 1/3 of the time.

(2) By aggregating the land use over the entire watershed, LANDSAT's misclassification of land use reduces to 2 to 8% for the major land use categories.

(3) Both of the above accuracy assessments must be qualified by noting that conventional land use, to which LANDSAT was compared, will sometimes have land use categories that are inconsistent with the LANDSAT land use categories (i.e., we are sometimes comparing apples and oranges). Also, errors introduced during geometric correction and resampling will be interpreted as LANDSAT misclassification errors when comparing on a cell-by-cell basis.

(4) The UCD Procedure works. It is a complete, self-contained package of computer programs and manual operations that permit a user to identify land use from LANDSAT digital data without requiring the use of expensive, interactive image processing equipment.

(5) Evaluated in terms of the difference in discharge frequency curves, the LANDSAT-derived land use was found to be completely adequate. The number and type of land use categories derived from LANDSAT data were sufficient to be able to apply two standard hydrologic modeling techniques, Snyder's unit hydrograph with percent imperviousness and the SCS curve number and lag method.

(6) LANDSAT land use can be directly incorporated into a watershed's grid cell data bank, thus providing an automated environment for applying the LANDSAT classification in routine hydrologic investigations.

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TABLE 1
WALNUT CREEK LAND USE DISTRIBUTION
CONVENTIONAL AND LANDSAT

Conventional Land Use	Acres	%	LANDSAT Land Use	Acres	%
Low density residential	1,785	4.9	Residential	9,135	25.0
Med density residential	3,671	10.0			
Hi density residential	156	0.4			
Multi-farm residential	619	1.7			
Mobile homes	126	0.3			
Strip commercial	264	0.7	Commercial/industrial	1,861	5.1
Shopping centers	85	0.2			
Institutional	536	1.5			
Industrial	488	1.3			
Ind/com complexes	742	2.0			
Public use	96	0.3			
Transpo/comun/utilities	1,261	3.4			
Barren land/quarry	1,022	2.8	Barren land/quarry	223	0.6
Cropland	3,917	10.7	Cropland/pasture	15,298	41.8
Pasture/rangeland	11,327	31.0			
Dev open space	139	0.4			
Undev open space	1,135	3.1			
Forest	9,143	25.0	Forest/rangeland	9,988	27.3
Water	62	0.2	Water	70	0.2
	36,574	99.9		36,575	100.0

TABLE 2

WALNUT CREEK LAND USE COMPARISON

CONVENTIONAL LAND USE

LANDSAT LAND USE		RES	COM/IND	QUARRY	CROP/PASTURE /RANGE	FOREST	WATER	TOTAL
	RES	3801 acres 10.4 %	1098 3.0	225 0.6	3147 8.6	859 2.3	6 0.0	9136 acres 25.0 %
	COM/IND	471 1.3	816 2.2	130 0.4	366 1.0	78 0.2	0 0.0	1861 5.1
	QUARRY	13 0.0	61 0.2	111 0.3	17 0.0	21 0.1	0 0.0	223 0.6
	CROP/ PASTURE	1581 4.3	1106 3.0	313 0.9	9324 25.5	2947 8.1	28 0.1	15229 41.8
	FOREST/ RANGE	493 1.3	361 1.0	234 0.6	3655 10.0	5233 14.3	13 0.0	9989 27.3
	WATER	0 0.0	31 0.1	8 0.0	9 0.0	6 0.0	16 0.0	70 0.2
TOTAL		6359 acres 17.4 %	3473 9.5	1021 2.8	16518 45.2	9144 25.0	63 0.2	36578 acres 100 %

TABLE 3

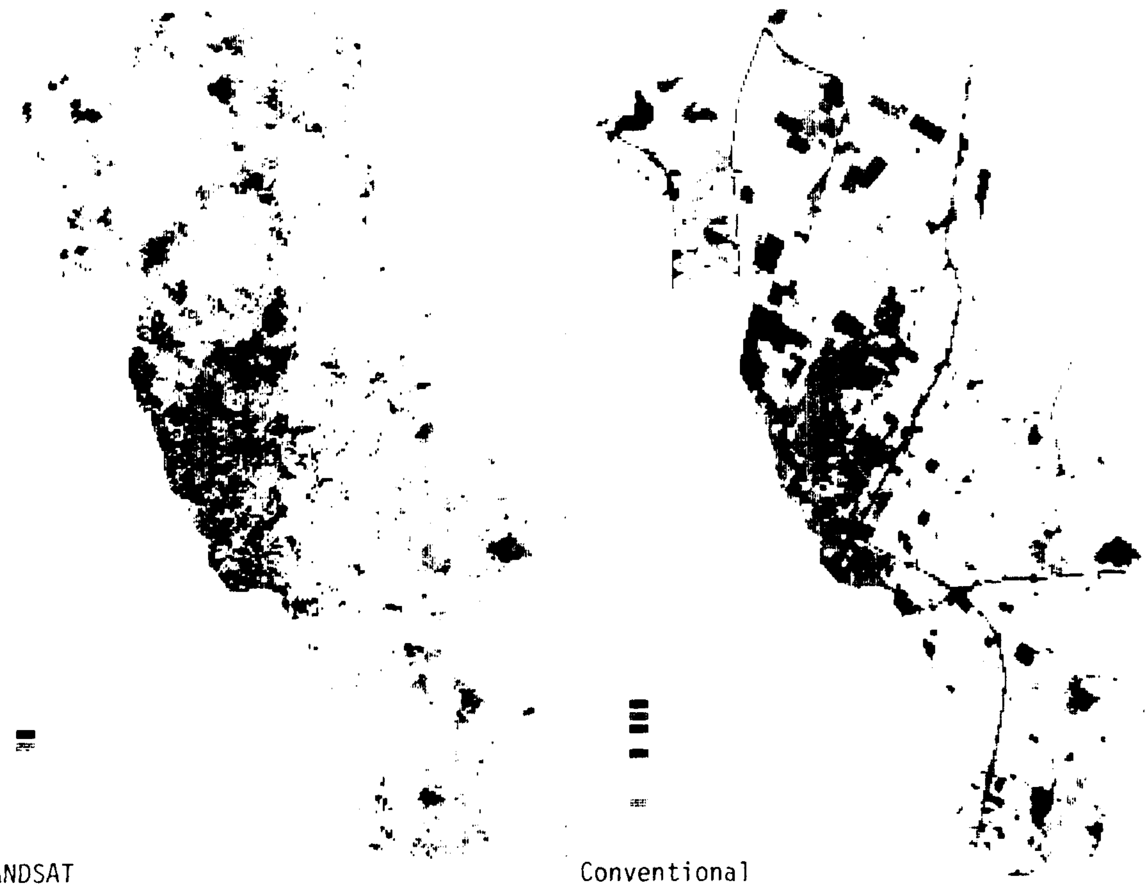
PENNYPACK CREEK LANDSAT LAND USE

CURVE NUMBER SUMMARY WITH
ASSOCIATED LAND USE CATEGORIES

LAND USE CATEGORY	TITLE	HYDROLOGIC SOIL TYPE A	B	C	D
1	Natural Vegetation	40.	63.	75.	81.
2	Pasture	62.	75.	83.	84.
3	Agricultural	62.	75.	83.	84.
4	Developed Open Space	39.	61.	74.	80.
5	Residential	65.	78.	85.	88.
6	Light Industry	81.	88.	91.	93.
7	Intermediate Industry	81.	88.	91.	93.
8	Heavy Industry	81.	88.	91.	93.
9	Water	100.	100.	100.	100.

Figure 1

LANDSAT Scene with Walnut Creek
Watershed Boundary Outlined



LANDSAT　　Conventional

Figure 2.

WALNUT CREEK LAND USE COMPARISON MAPS

(Darker to lighter shades represent Industrial/Commercial, Residential, Natural Vegetation, and Agricultural land use categories, respectively.)

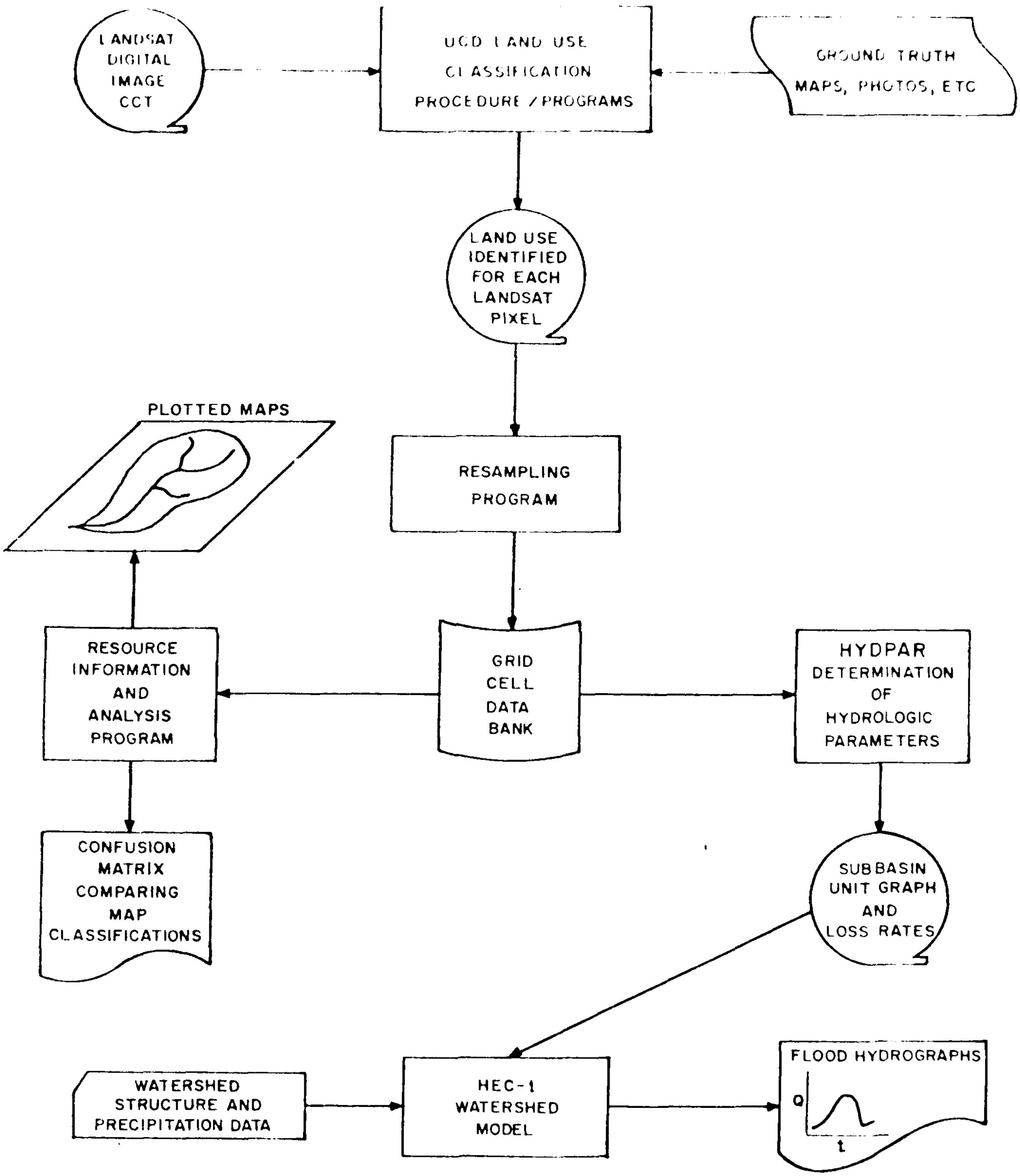


Figure 3. SCHEMATIC OF PROCESSING SYSTEM

FIGURE 4.

HYDPAR Subbasin Printout and Pennypack Creek

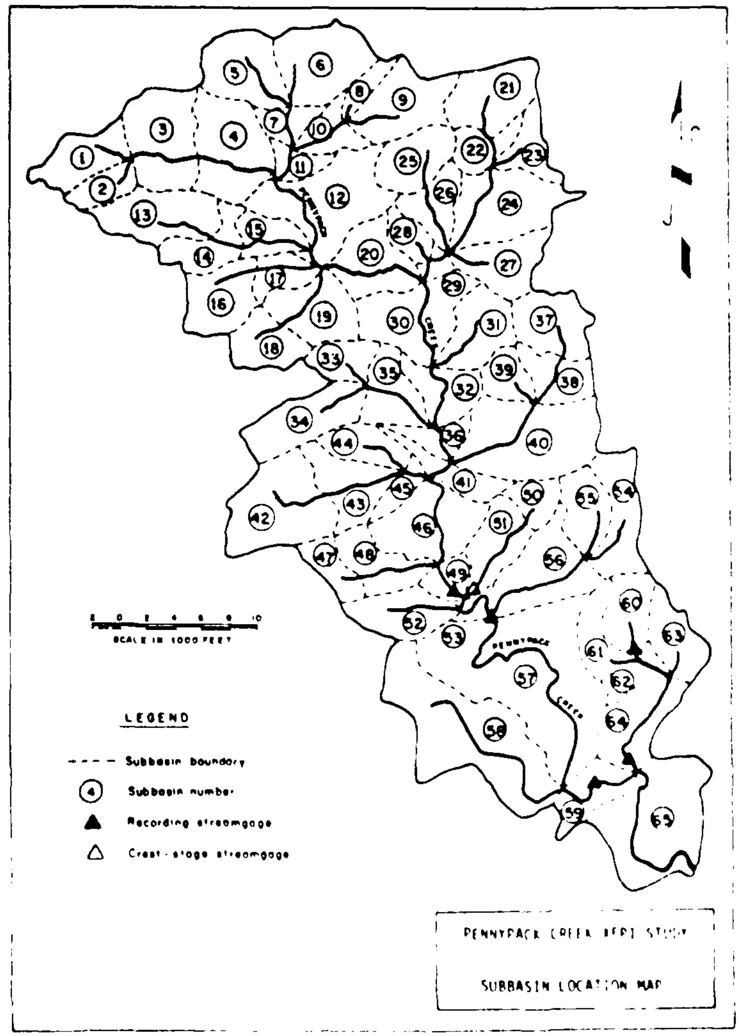
Subbasin Location Map

PENNYPACK CREEK BASIN, PA, ** HYDPAR MODEL ** (MAY 1978)
65 SUBBASINS USING PHILADELPHIA DIST, DATA BANK
PLAN 1 -- EXISTING LAND USE

SUBBASIN 65,

LAND USE CATEGORY	LAND USE	AVE CURVE NO.	SURFACE SLOPE (PERCENT)	AREA IN ACRES	PERCENT OF SUBBASIN
1	RESIDENTIAL(SINGL)HIGH VALUE	76.7	6.43	91.83	7.48
3	RESIDENTIAL(TWINS)HIGH VALUE	78.9	5.77	221.86	18.06
6	RESIDENTIAL(APTS) HIGH VALUE	88.1	7.72	91.83	7.48
8	LIGHT INDUSTRY	88.6	9.93	11.02	.90
9	HEAVY INDUSTRY	90.6	6.15	102.85	8.37
10	TRANSPORTATION	94.9	6.46	47.75	3.89
11	COMMUNICATION AND UTILITIES	86.2	8.94	12.49	1.02
12	COMMERCIAL - HIGH VALUE	92.7	6.36	[illegible]	12.80
15	COMMUNITY SERVICES LOW VALUE	79.9	5.92	[illegible]	13.34
17	RECREATION AND CULTURAL	62.6	6.97	41.14	3.35
18	AGRICULTURE	82.7	4.29	16.95	1.38
20	FOREST AND UNDEVELOPED LAND	69.8	8.89	208.63	16.99
21	WATER AREAS	100.0	11.99	[illegible]	4.96
	SUBBASIN AVERAGE	82.1	7.05	1228.28	

SUBBASIN 65, DATA		
DRAINAGE AREA (ACRES)	=	1228.28
DRAINAGE AREA (SQ. MI.)	=	1.92
STREAM LENGTH (MILES)	=	3.30
STREAM SLOPE (FEET/MILE)	=	9.00
SUBBASIN SLOPE (PERCENT)	=	7.05
AVERAGE CURVE NUMBER	=	82.10
SUBBASIN LAG (HOURS)	=	1.10
NUMBER OF DATA CELLS	=	1672.00



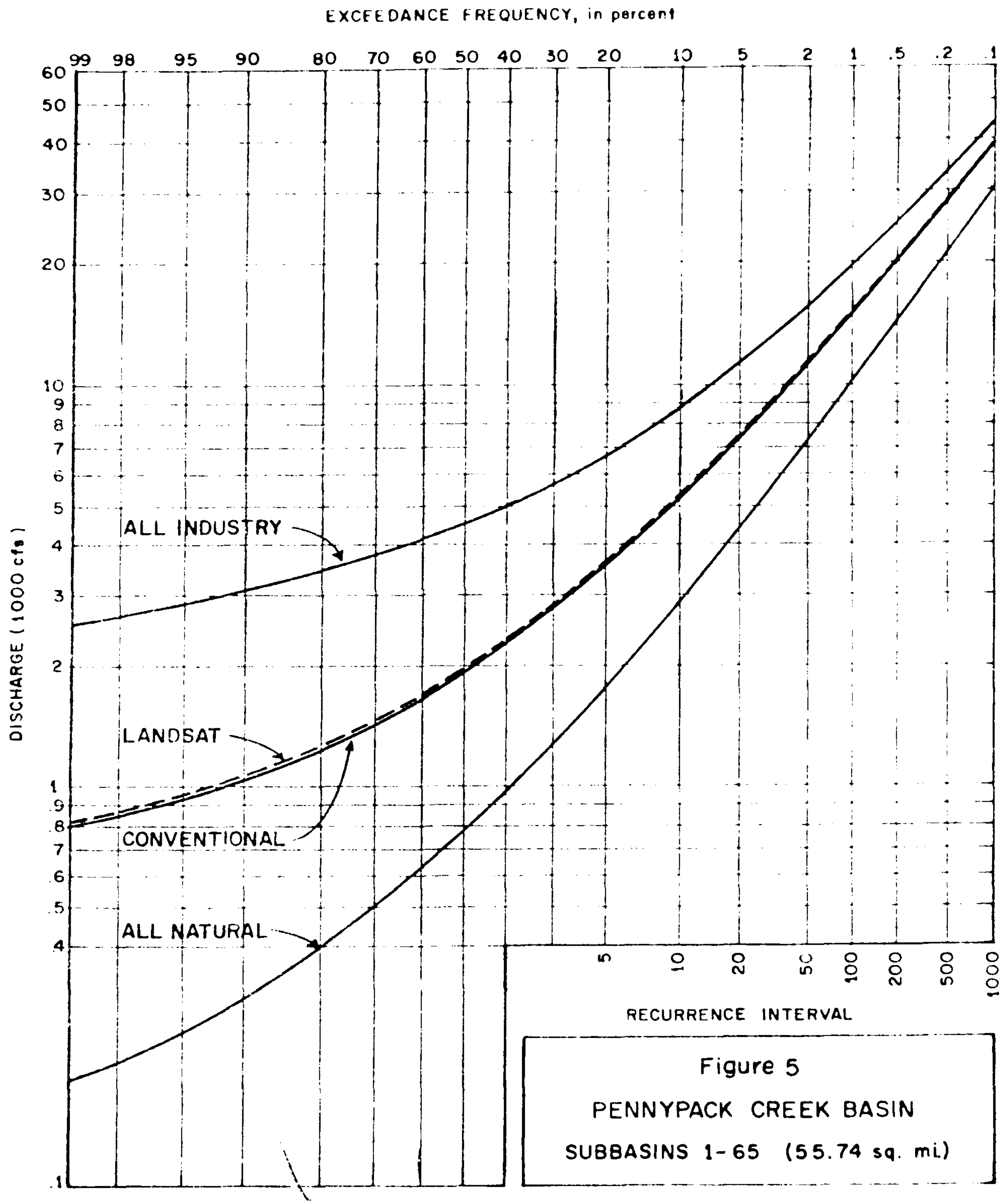


Figure 5

PENNYPACK CREEK BASIN

SUBBASINS 1-65 (55.74 sq. mi.)