US Army Corps
of Engineers
Hydrologic Engineering Center

Determination of Land Use from Satellite Imagery for Input for Hydrologic Models

April 1980

TP-71

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
April 1980

2. REPORT TYPE
Technical Paper

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Determination of Land Use from Satellite Imagery for Input to Hydrologic Models

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
R. Pat Webb, Robert Cermak, Arlen D. Feldman

5d. PROJECT NUMBER

5e. TASK NUMBER

5F. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center (HEC)
609 Second Street
Davis, CA 95616-4687

8. PERFORMING ORGANIZATION REPORT NUMBER
TP-71

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/ MONITOR'S ACRONYM(S)

11. SPONSOR/ MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Presented at the Environmental Research Institute of Michigan's Fourteenth International Symposium on Remote Sensing of the Environment, San Jose, Costa Rica, 23-30 April 1980

14. ABSTRACT
A land use/Land over identification methodology using LANDSAT imagery has been applied to six watersheds across the U.S. The land use information is stored in a grid cell data bank and is the basis for calibration of hydrologic parameters for watershed models. Flood frequency studies have been completed on four of the watersheds with land use derived from both satellite data and conventional low altitude aerial photography. This paper discusses our experience using the LANDSAT land use classification procedure and compares hydrologic results obtained from the alternative determinations of land use.

15. SUBJECT TERMS
remote sensing, LANDSAT, land use, hydrologic models, grid cell database

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
U	U	U	UU	22	19b. TELEPHONE NUMBER

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39-18

Determination of Land Use from Satellite Imagery for Input to Hydrologic Models

April 1980

US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616

(530) 756-1104
(530) 756-8250 FAX
www.hec.usace.army.mil

TP-71

DETERMINATION OF LAND USE FROM SATELLITE IMAGERY

FOR INPUT TO HYDROLOGIC MODELS

R. Pat Webb, Robert Cermak and Arlen Feldman

The Hydrologic Engineering Center
U.S. Army Corps of Engineers
609 Second Street
Davis, California 95616

ABSTRACT

A land use/land cover identification methodology using LANDSAT imagery has been applied to six watersheds across the U.S. The land use information is stored in a grid cell data bank and is the basis for calibration of hydrologic parameters for watershed models. Flood frequency studies have been completed on four of the watersheds with land use derived from both satellite data and conventional low altitude aerial photography. This paper discusses our experience using the LANDSAT land use classification procedure and compares hydrologic results obtained from the alternative determinations of land use.

Land use/land cover has been found to have a significant effect on the quantity, quality, and timing of storm runoff from urban (and urbanizing) drainage basins. In an attempt to quantify this important relationship, the Hydrologic Engineering Center (HEC) has interfaced state-of-the-art spatial data management techniques with hydrologic planning models, such as HEC-1 and STORM, to simulate storm runoff as a function of land use. The grid cell data banks also contain information on the watershed's environmental, economic, and social characteristics, thus permitting a comprehensive understanding of the interaction between the water resource system and possible future urban developments.

HEC has been involved in a NASA ASVT project which tests and evaluates a procedure developed at the University of California, Davis (UCD) for determining land use/land cover from LANDSAT imagery. The UCD procedure was designed with the objective of providing Corps of Engineers District offices with an operational cost-effective alternative to conventional methods of obtaining land use data. A constraint on the procedure was that it not require the use of special image processing or computing equipment beyond that which would normally be available to the field office; i.e., line printer, card reader, remote terminal, and access to a general purpose computer. The UCD procedure consists of an integrated set of computer programs centered around an unsupervised classification routine. Data quality check, geometric registration and correction, data classification, symbol map generation, resampling and masking are all accomplished without the use of an interactive color image display.

HEC has applied the UCD classification method to Crow Creek near Davemport, Iowa, and Walnut Creek near Austin, Texas. Available ground truth data permitted the identification of seven land cover categories from the LANDSAT imagery: agricultural, residential/highways, industrial/commercial, grassland, forest, undeveloped open space, and water. Hydrologic simulations of four additional watersheds, previously classified during the development of the procedure, were made, using both conventional and LANDSAT land use data. Resulting discharge frequency curves were compared to determine the effectiveness of LANDSAT land use in estimating "true" land use for hydrologic modeling purposes.

In addition, two commercial contractors provided a land use classification of the Walnut Creek watershed based on the same LANDSAT scene to help verify the accuracy of the UCD procedure with current state-of-the-art classification methodologies. Because the LANDSAT derived land use was placed in data banks which contained conventionally classified land use, detailed cell by cell comparisons were made between the conventional and all of the LANDSAT land use classifications to get an indication of spatial accuracies associated with LANDSAT data and the classification procedures.

Based on our experience in using the UCD procedure and commercially derived LANDSAT data, recommendations are presented regarding the role of remote sensing information in the Corps of Engineers hydrologic investigations program.

LANDSAT LAND USE FOR HYDROLOGIC MODELING

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. With this approach, 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, (Jackson, 1977; Ragan, 1975). 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 all United States and many worldwide locations. Additionally, LANDSAT's digital format can be directly analyzed by several available classification computer programs, and can be resampled for automatic inclusion in a geographic data bank.

UCD PROCEDURES

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 under the following constraints:

(1) 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. This would eliminate the need for highly expensive, dedicated, interactive image processing facilities.

(2) No additional software beyond that provided as part of the procedural package would be required.

(3) No specialized technical expertise in data analysis, computer programming, or remote sensing would be required.

(4) The final classification would be a usable product; i.e., one that can conveniently be entered into a grid cell data bank and that will adequately, from a hydrologic viewpoint, represent current land use conditions.

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 of the procedure is given by Algazi (1979) and Meyer (1978). What follows is a brief outline of the primary tasks:

(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 coordinate system of the 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, estimated from the two sets of control points, provides a transformation mechanism for going between the image coordinate system and the map coordinate system, Universal Transverse Mercator (UTM).

(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 similar to members of the same cluster, and dissimilar to the points of other clusters. The clustering program is allowed to generate a maximum of 30 clusters. Each pixel in the watershed data 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 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 its pixels. The watershed file is then resampled at the grid cell centroids using a nearest-neighbor algorithm. The size of the grid cells is usually line printer compatible with the scale of USGS 7-1/2-min. topographic maps.

(7) The resampled file is entered directly into a grid cell data bank. Alternatively, a file containing the digitized (in UTM coordinates) 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.

HYDROLOGIC LAND USE COMPARISON

The primary reason for examining the land use classification ability of LANDSAT was for its potential application to hydrologic modeling. 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). The HYDPAR program (U.S. Army Corps of Engineers, 1978b) obtains the necessary information 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, HYDPAR computes subbasin average curve number.

Both hydrologic modeling techniques, Snyder's unit hydrograph with percent imperviousness and the SCS curve number approach, were applied to the land use classifications of two watersheds: Rowlett Creek near Dallas, Texas, and Pennypack Creek in Philadelphia, Pennsylvania. For each watershed land use was determined from LANDSAT imagery using the UCD Procedure, and conventional interpretation of low-altitude aerial photography.
The following contains summary results of the hydrologic land use comparison. Complete details of the study are reported in (U.S. Army Corps of Engineers, 1979).

ROWLETT CREEK

A calibrated HEC-1 model of a 24.6 square mile (63.7 Km^2) portion of the Rowlett Creek basin, referred to as Upper Spring Creek, was used to simulate runoff from selected recurrence interval rainfall. Initial assignments of percent imperviousness to Rowlett Creek's LANDSAT and conventional land use categories permitted HYDPAR to compute Snyder's lag for the twenty-three subbasins in Upper Spring Creek. Nearly identical values of lag were calculated from the LANDSAT and conventional land use data.

The calibrated HEC-1 model (using the two land use estimates of Snyder's lag) and synthetic rainfall produced the discharge values plotted in Figure 1 for selected stations in the Upper Spring Creek drainage. Differences between such discharge frequency curves can be interpreted as a measure of the hydrologic significance of LANDSAT's misclassification of land use. Considering the uncertainty involved in estimating a frequency curve (even from observed data), the difference between LANDSAT and conventional curves is insignificant.

PENNYPACK CREEK

The SCS curve number method was used to model the Pennypack Creek basin (55.8 mi^2, 144.5 Km^2). Curve numbers were assigned to the LANDSAT and conventional land use categories. For each of Pennypack Creek's sixty-five subbasins HYDPAR calculated subbasin average curve number and subbasin lag. Once again, nearly identical values of subbasin lag were computed from the LANDSAT and conventional land use data.

As an additional comparison, subbasin average curve number and lag were calculated for (1) all land use categories assigned the industrial category curve numbers, and (2) all land use categories assigned the natural vegetation curve numbers. Parameters estimated in these two cases, and the discharge frequency curves derived from them, demonstrate the possible extremes (in terms of runoff) that could have been generated from the model.

The calibrated HEC-1 model of Pennypack Creek simulated the basin's discharge frequency behavior for conventional, LANDSAT, all industrial, and all natural vegetation conditions. The resulting discharge frequency curves for the entire drainage area are shown in Figure 2. It is clear from this figure, especially with reference to what could have been (i.e., all industrial and all natural vegetation conditions), that the difference between LANDSAT had conventionally derived frequency curves is not significant.

ACCURACY VS. SPATIAL INTEGRITY

As previously mentioned, in order to be able to conduct the hydrologic modeling assessment, the LANDSAT land use was processed into existing geographic information system data banks. These data banks already contained an exhaustive, spatially accurate representation of the land use which was derived by conventional means. The grid cell size of these existing data banks varied in size from 0.74 acres (Pennypack Creek) to 1.148 acres (Rowlett Creek and Walnut Creek) to 1.53 acres (Trail Creek and Castro Valley). The description of the ways in which the conventional land use classification and the LANDSAT classification were derived is presented in detail in HEC's Research Note No. 7 (U.S. Army Corps of Engineers, 1979). Table 1, UCD Classification vs. Conventional Land Use, shows a summary of the cell-by-cell comparison for the Walnut Creek watershed.

For a cell-by-cell comparison of the Walnut Creek watershed it was necessary to establish an explicit aggregation of the conventional land use categories into the fewer LANDSAT land use categories, Table 2. The RIA computer program (U.S. Army Corps of Engineers, 1978a) generated the coincident matrix, Table 1. The structure of this cross tabulation table is similar to others that will be presented later in this paper. Each element of the table (row and column combination) refers to all grid cells within the watershed data bank that have the concurrent LANDSAT and conventional land use specified by the row and column headings of that particular element. For example, the 2nd row, 1st column of Table 1 refers to all grid cells in the Walnut Creek data bank that are classified both commercial/industrial by LANDSAT and residential by the conventional classification. For each element of the table, four numbers

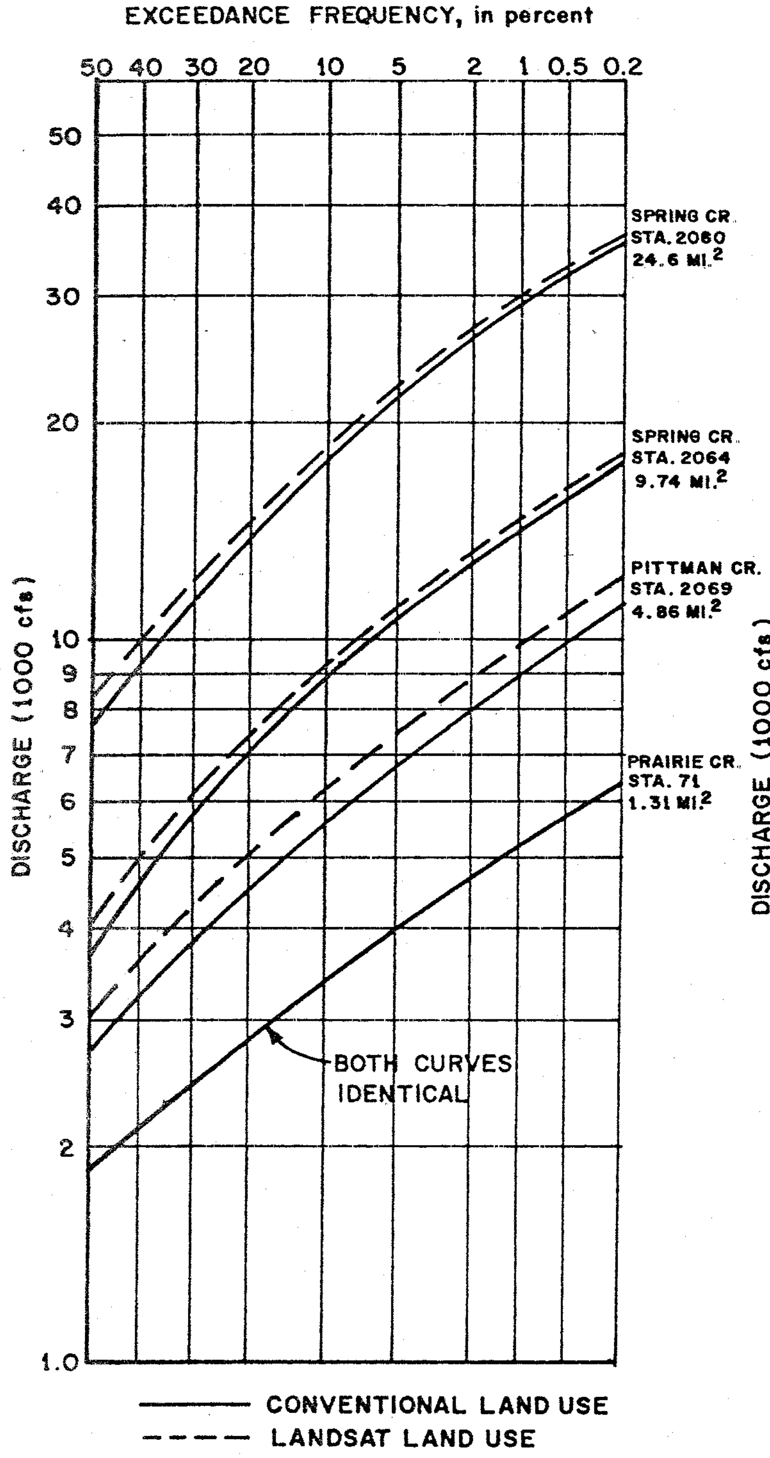


Figure 1

ROWLETT CREEK

ANNUAL PEAK DISCHARGE FREQUENCY
(SELECTED STATIONS)

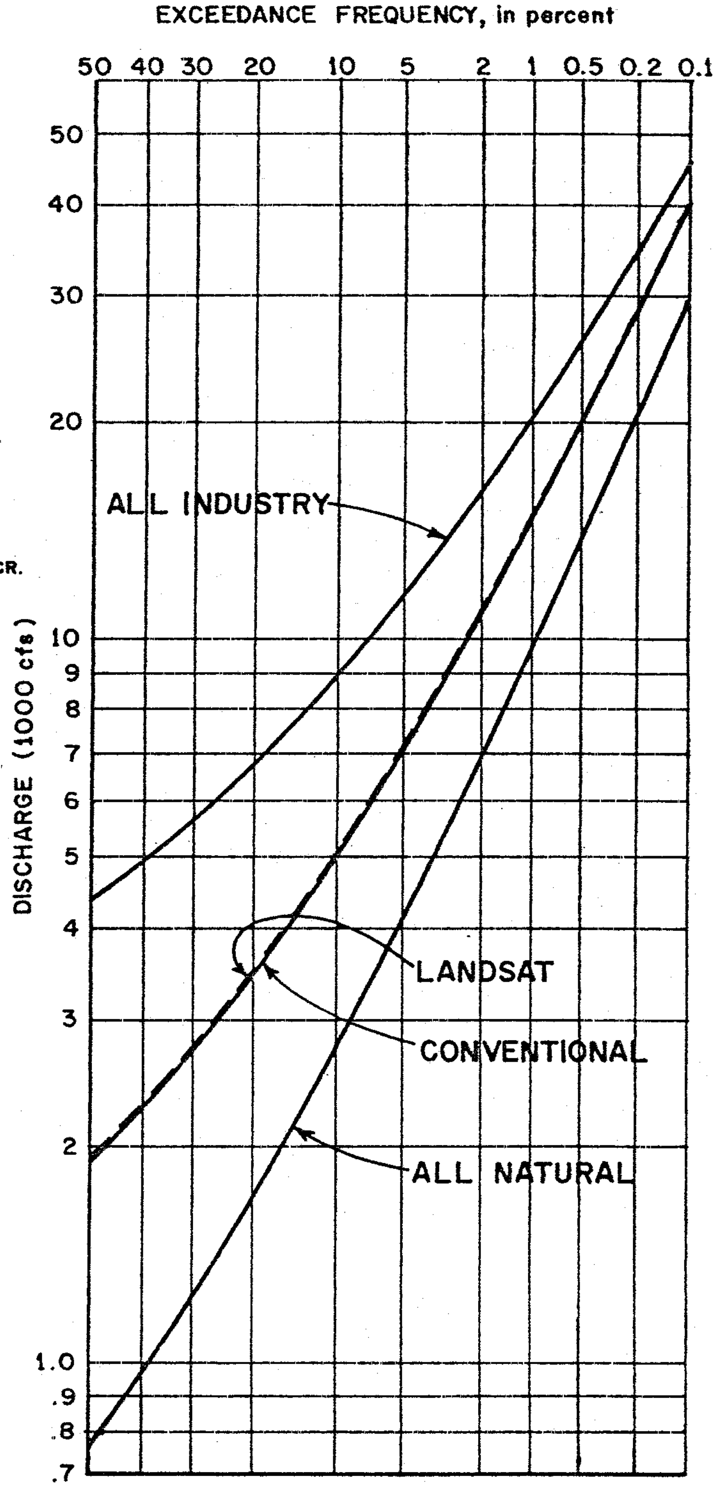


Figure 2

PENNYPACK CREEK BASIN

SUBBASINS 1-65 (55.74 sq. mi)

TABLE 1

Walnut Creek Land Use Comparison
UCD LANDSAT vs. CONVENTIONAL

	Acres* % Row % Col % Total	CONVENTIONAL						
		RES	COM/IND	QUARRY	CROP/PASTURE /RANGE	FOREST	WATER	ROW TOTAL
UCD LANDSAT	RES	3801 41.6 59.8 10.4	1098.8 12.0 31.6 3.0	225 2.5 22.0 0.6	3147 34.4 19.1 8.6	859 9.4 9.4 2.3	6 0.1 9.5 0.0	9136 100.0 25.0 25.0
	COM/IND	471 25.3 7.4 1.3	816 43.8 23.5 2.2	130 7.0 12.7 0.4	366 19.7 2.2 1.0	78 4.2 0.9 0.2	0 0.0 0.0 0.0	1861 100.0 5.1 5.1
	QUARRY	13 5.8 0.2 0.0	61 27.4 1.8 0.2	111 49.8 10.9 0.3	17 7.6 0.1 0.0	21 9.4 0.2 0.1	0 0.0 0.0 0.0	223 100.0 0.6 0.6
	CROP/ PASTURE	1581 10.3 24.9 4.3	1106 7.2 31.8 3.0	313 2.0 30.7 0.9	9324 60.9 56.4 25.5	2947 19.3 32.2 8.1	28 0.2 44.4 0.1	15229 100.0 41.8 41.8
	FOREST/ RANGE	493 4.9 7.8 1.3	361 3.6 10.4 1.0	234 2.3 22.9 0.6	3655 36.6 22.1 10.0	5233 52.4 57.2 14.3	13 0.1 20.6 0.0	9989 100.0 27.3 27.3
	WATER	0 0.0 0.0 0.0	31 44.3 0.9 0.1	8 11.4 0.8 0.8	9 12.9 0.1 0.0	6 8.6 0.1 0.0	16 22.9 25.4 0.0	70 100.0 0.2 0.2
	COLUMN TOTAL	6359 17.4 100.0 17.4	3473 9.5 100.0 9.5	1021 2.8 100.0 2.8	16518 45.2 100.0 45.2	9144 25.4 100.0 25.0	63 0.2 100.0 0.2	36578 100.0 100.0 100.0

*To obtain hectares, multiply acres by 2.471.

TABLE 2

WALNUT CREEK
LAND USE CATEGORY MAPPING

Conventional Land Use	UCD LANDSAT	Battelle LANDSAT	GE LANDSAT
Low density single family residential Medium density single family residential High density single family residential Multifamily residential Mobile home parks	residential	residential	residential 1 residential 2
Strip commercial Shopping centers Institutional Industrial Industrial and commercial complexes Public Use: cemetaries, public assembly areas, waste disposal areas Transportation, communication, utilities	commercial/ industrial	industrial/ commercial transportation	urban
Barren land/quarry	barren land/	barren land	highly reflective
Cropland Pasture/rangeland Developed open space Undeveloped urban land	cropland/ pasture	cropland/ pasture rangeland	vegetation/ crops dark fields open area
Forest	forest/ rangeland	forest riparian	woodland
Water	water	water	

are given: (1) total acreage of all grid cells represented by the appropriate joint land use classification; (2) row percent, or the precent of all grid cells with the given LANDSAT classification that have also the given conventional classification; (3) column percent, or the percent of all grid cells with the given conventional land use that have also the given LANDSAT land use; and (4) total percent, or the percent of the entire watershed that has the given joint land use classification. Continuing our example above, 471 acres (1186 Hectares) were found to be classified both commercial/industrial by LANDSAT and residential by conventional means. This acreage represents 25.3% of all the area (1861 acres) that was classified by LANDSAT as commercial/industrial, 7.4% of all the area (6359 acres) that belonged to the conventional residential category, and 1.3% of the total watershed area (36,578 acres).

The far right column (row total) and the bottom row (column total) of Table 1 give the marginal distributions of LANDSAT and conventional land use, respectively. These represent the acres and percent in the different land use categories without the conditional requirement described above for the body of the table.

Figures 3 and 4 show the spatial location of both the conventional and the UCD classified land use which are part of the Walnut Creek grid cell data bank.

COMMERCIAL CAPABILITY

The UCD procedure provided completely acceptable land use percentages for the subbasins and total watershed areas (the marginal values in Table 1) which were input into the hydrologic models. Spurred on by this initial success, the HEC further participated in the Water Management and Control ASVT by comparing commercially prepared LANDSAT land use classifications. The objectives of HEC's participation were: (1) to compare the results of the UCD procedure to the results from commercial vendors, (2) to provide cost data to a cost-effectiveness study of LANDSAT determined land use which was part of the ASVT and, (3) to evaluate the ability of commercial vendors to create a computer file which could be directly inserted as a data variable into an existing grid cell data bank. In order to execute this portion of the ASVT, the Walnut Creek data bank was selected as the test area because (1) the HEC was confident in the spatial integrity and accuracy of the conventional land use in the data bank, (2) the grid cell size was 1.148 acres which was comparable to a pixel size of 1.1 acres and, (3) the grid pattern for the study area was orientated to align with the UTM coordinate system. The commercial contractors which were selected to participate in this portion of the study were General Electric and Battelle's Pacific Northwest Labratories in Richland, Washington. Both commercial firms created resampled tapes which contained the land use value which corresponded to the centroid location of each of the Corps rectangular grid cells (200 feet x 250 feet). Table 2 contains the commercial LANDSAT land use classifications which correspond to the conventional classification. Tables 3 and 4 show the results of the cell-by-cell comparisons for the Battelle and General Electric classifications, respectively.

Using the diagonal percentages in Tables 1, 3 and 4, the overall cell by cell accuracies of the UCD procedure, Battelle and General Electric were 53, 44 and 44 percent, respectively. In evaluating the spatial integrity of the LANDSAT derived land use from the various classification procedures, there are three potential sources of error: (1) differences resulting from the land use, land cover conflict, (2) geometric correction and resampling error and (3) misclassification of the pixel spectral signatures.

When comparing LANDSAT and conventional land use classifications, it is important to recognize that the same land cover can be interpreted differently; i.e., conventional land use categories are not always compatible with LANDSAT land cover categories. For example, the conventional category "transportation/communication/utilities" includes major highways, right-of-way for railroads and power transmission lines, communication towers, airport facilities (including buildings, runways, and vacant land within the airport limits), and sewage treatment plants. In contrast, LANDSAT will recognize the treatment plant settling tanks as "water bodies", the open fields surrounding a runway as one of the vegetation categories, and right-of-ways as whatever land cover class is nearby. Even though this is a problem with any LANDSAT land use classification, in the Walnut Creek watershed only a very small portion of the watershed had the potential for this kind of error.

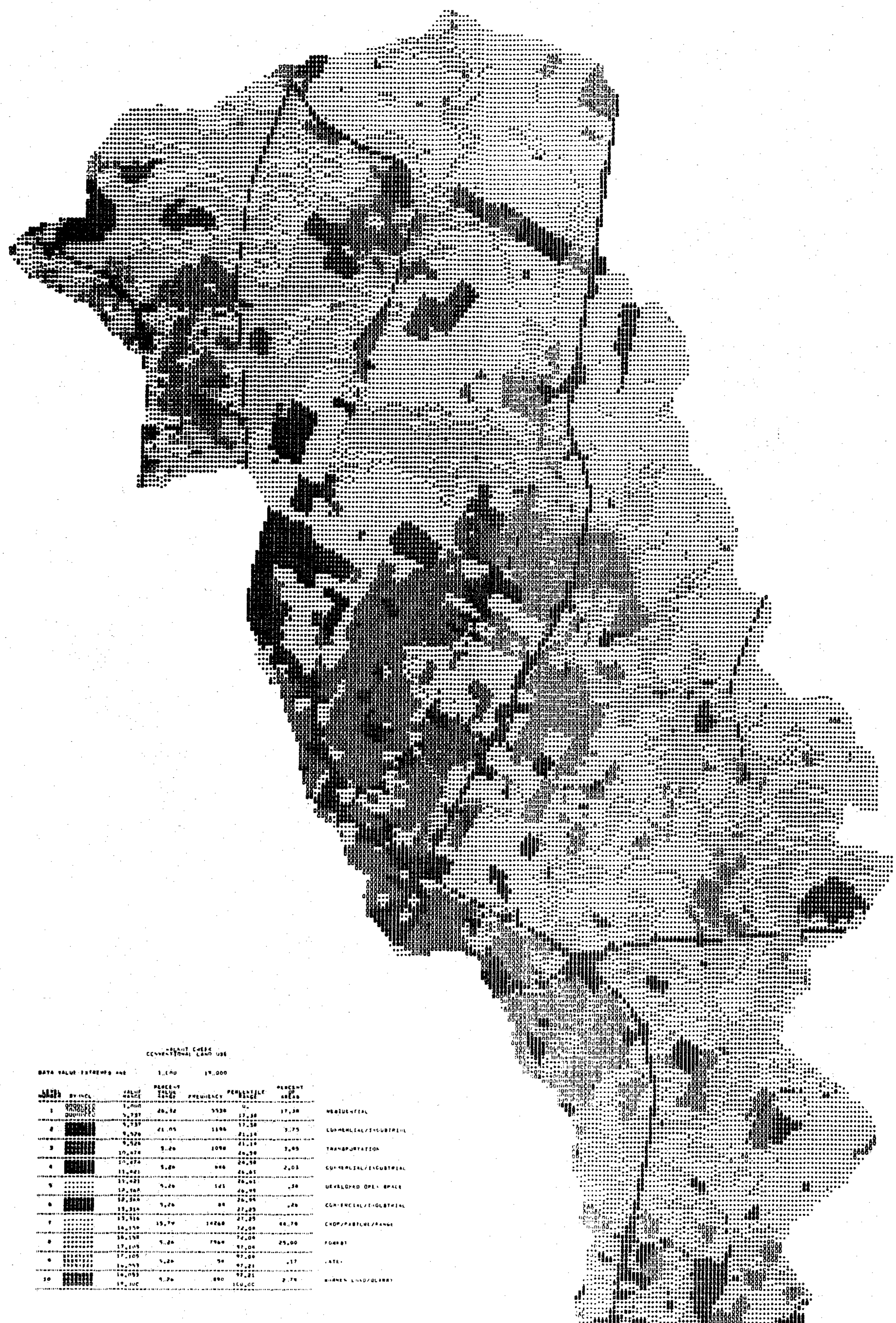


Figure 3
Walnut Creek
Conventional Land Use

TABLE 3

Walnut Creek Land Use Comparison
Battelle LANDSAT vs. Conventional

BATTELLE LANDSAT	Acres* / % Row / % Col / % Total	CONVENTIONAL: RES	COM/IND	QUARRY	CROP/PASTURE /RANGE	FOREST	WATER	ROW TOTAL
RES	Acres*	2723	976	70	1969	763	12	6513
	% Row	41.8	15.0	1.1	30.2	11.7	0.2	100.0
	% Col	45.6	31.6	7.2	12.4	8.7	19.0	18.8
	% Total	7.8	2.8	0.2	5.7	2.2	0.0	18.8
COM/IND	Acres*	661	336	79	890	319	1	2286
	% Row	28.9	14.7	3.5	38.9	14.0	0.0	100.0
	% Col	11.1	10.9	8.1	5.6	3.6	1.6	6.6
	% Total	1.9	1.0	0.2	2.6	0.9	0.0	6.6
QUARRY	Acres*	212	160	111	614	319	0	1416
	% Row	15	11.3	7.8	43.4	22.5	0.0	100.0
	% Col	3.5	5.2	11.3	3.9	3.6	0.0	4.1
	% Total	0.6	0.5	0.3	1.8	0.9	0.0	4.1
CROP/ PASTURE RANGE	Acres*	1720	1137	517	9803	4922	37	18136
	% Row	9.5	6.3	2.9	54.1	27.1	0.2	100.0
	% Col	28.8	36.8	52.9	61.8	56.3	58.7	52.3
	% Total	5.0	3.3	1.5	28.3	14.2	0.1	52.3
FOREST	Acres*	636	464	201	2572	2410	12	6295
	% Row	10.1	7.4	3.2	40.9	38.3	0.2	100.0
	% Col	10.6	15.0	20.6	16.2	27.6	19.0	18.1
	% Total	1.8	1.3	0.6	7.4	6.9	0.0	18.1
WATER	Acres*	23	13	0	8	9	1	54
	% Row	42.6	24.1	0.0	14.8	16.7	1.9	100.0
	% Col	0.4	0.4	0.0	0.1	0.1	1.6	0.2
	% Total	0.1	0.0	0.0	0.0	0.0	0.0	0.2
COLUMN TOTAL	Acres*	5975	3086	978	15856	8742	63	34700
	% Row	17.2	8.9	2.8	45.7	25.2	0.2	100.0
	% Col	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	% Total	17.2	8.9	2.8	45.7	25.2	0.2	100.0

*To obtain hectares, multiply acres by 2.471.

TABLE 4

Walnut Creek Land Use Comparison
G. E. LANDSAT vs. Conventional

	Acres* % Row % Col % Total	CONVENTIONAL						ROW TOTAL
		RES	COM/IND	QUARRY	CROP/PASTURE /RANGE	FOREST	WATER	
	RES	3573.7 45.6 57.4 10.2	1060.8 13.5 31.6 3.0	205.5 2.6 20.8 0.6	2308.6 29.5 14.8 6.6	679.6 8.7 7.6 1.9	5.7 0.1 9.2 0.0	7833.9 100.0 22.3 22.3
	COM/IND	464.90 14.7 7.5 1.3	693.4 21.8 20.6 2.0	102.2 3.2 10.4 0.3	1678.3 52.8 10.8 4.8	231.9 7.3 2.6 0.7	3.4 0.1 5.5 0.0	3174.2 100.0 9.0 9.0
G.E. LANDSAT	QUARRY	358.2 18.9 5.8 1.0	690.1 36.4 20.5 2.0	289.3 15.3 29.3 0.8	433.9 22.9 2.8 1.2	106.8 5.6 1.2 0.3	16.1 0.9 26.0 0.1	1894.2 100.0 5.4 5.4
	AGRICUL-TURE/ OPEN SPACE	1587.6 9.9 25.5 4.5	677.4 4.2 20.2 1.9	261.8 1.6 26.6 0.8	8264.6 51.6 53.1 23.5	5208.5 32.5 58.3 14.8	13.7 0.1 22.1 0.0	16013.6 100.0 45.6 45.6
	WOODLAND	242.2 3.9 3.9 0.1	238.9 3.9 7.1 0.7	127.4 2.1 12.9 0.4	2871.1 46.3 18.5 8.2	2701.2 43.5 30.3 7.7	23.0 0.0 37.1 0.1	6203.8 100.0 17.7 17.7
	WATER	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 100.0 0 0
	COLUMN TOTAL	6226.8 17.4 100.0 17.7	3360.5 9.6 100.0 9.6	986.2 2.8 100.0 2.8	15556.6 44.3 100.0 44.3	8928.0 25.4 100.0 25.4	62.0 0.2 100.0 0.2	35119.6 100.0 100.0 100.0

*To obtain hectares, multiply acres by 2.471.

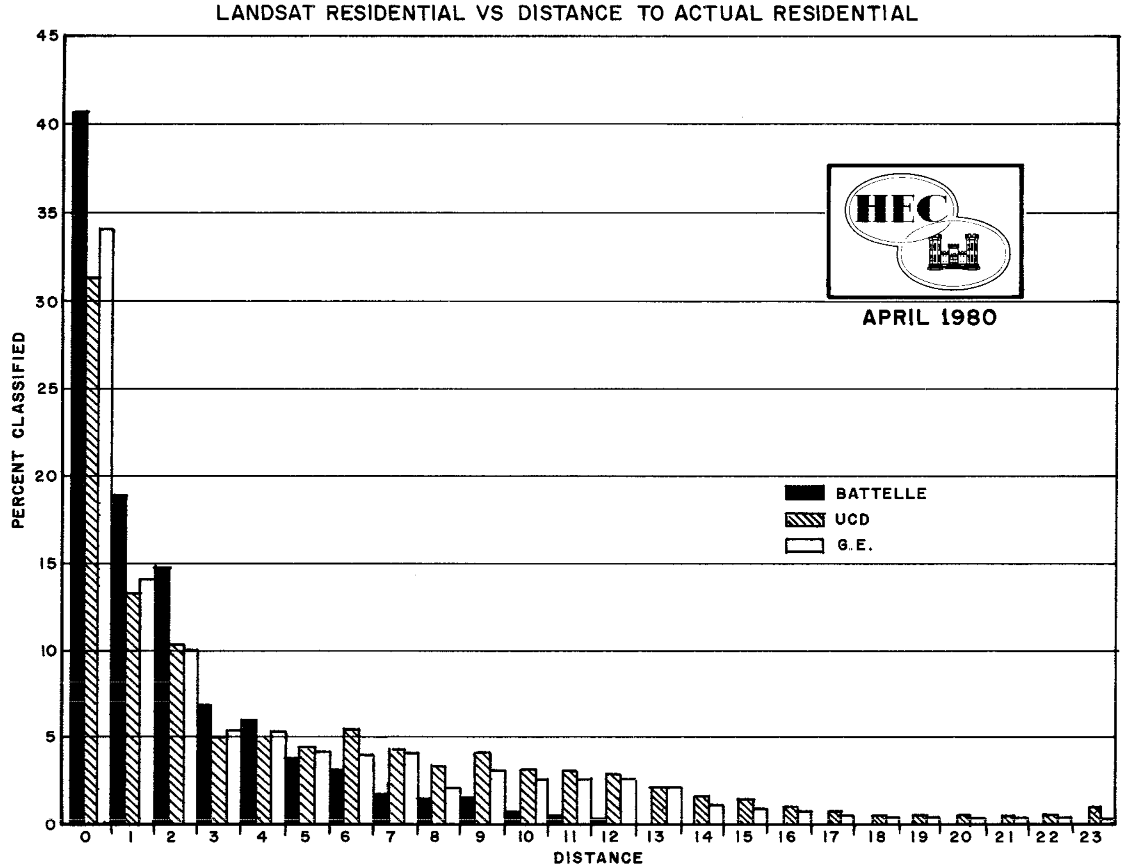
A comparison at the grid cell level can be thought of as a comparison at the pixel level; both units of area are nearly the same size. At this scale errors introduced during the geometric correction and resampling steps will be erroneously interpreted as LANDSAT misclassification errors. This will be particularly true of land use categories defined by a small number of adjacent pixels. The border areas of the larger land use categories are also susceptible to geometric problems. In order to assess the magnitude of the registration/resampling error, the RIA program was used to calculate the linear distance each grid cell was from the nearest residential category. These distances were then overlaid on the actual residential locations from the three LANDSAT classifications. The reason for this overlay was that if the major problem in the cell-by-cell comparison was in the geometric correction/resampling procedures, all of the LANDSAT residential areas should be within one or two grid cells of an actual residential area. The LANDSAT residential areas which located beyond this distance could be assumed to be errors in misclassification.

Figure 5, LANDSAT RESIDENTIAL VS DISTANCE TO ACTUAL RESIDENTIAL, is a histogram of the spatial integrity of the three classifications for residential land use and is shown as a percentage of the residential area for each classification. The figure shows that at least 60 percent of all these classifications fell within 2 grid cells of the ground truth residential areas. The Battelle classification was more accurate for the residential areas, but when compared for all land use categories it was less accurate than the UCD procedure. There were at least two reasons for Battelle's higher residential accuracy when compared to UCD and G.E.; first, they had personnel from the Corps who were very familiar with the study area to help with the classification, which was not the case in the UCD and G.E. classifications and second, they had the capability to predefine urban areas and reclassify clusters which were given a residential value but were located outside "known" residential areas.

The third source of error, misclassification, was looked at for only the UCD classification. A RIA coincidence table was generated for the conventional land use and the cluster values to see if any of the clusters were misclassified. The HEC could not identify any obvious misclassifications, therefore, it was assumed that the remaining error (40-60 percent) in the cell-by-cell comparison was due to the limitations of either the clustering techniques or the satellite sensors themselves.

Figure 5

LANDSAT RESIDENTIAL VS DISTANCE TO ACTUAL RESIDENTIAL



RESAMPLED TAPES

The resampled tapes supplied by UCD, Battelle, G.E. and Bendix (for the Castro Valley Watershed) were required to conform to the following specifications:

(1) The first record on the tape would be a header record which would give the number of rows and the number of columns in the data matrix.

(2) The data would be supplied a row (line) at a time, for however many number of rows there were in the study area.

(3) The first land use value would correspond to the grid location 1, 1 on the Walnut Creek or Castro Valley Basemap.

(4) If the contractor windowed out the watershed, cells outside the study area would be given a land use value of -1.

In addition, all contractors were warned that if they windowed the study area, to include at least some buffer area on the resampled tape to make sure that all grid cells in the existing data base would be given a value.

The HEC was able to process the UCD and Battelle tapes directly into the existing data base. The Battelle tape, however, had several problems. After the tape had been provided to HEC, it was discovered that the wrong corner grid cell was used in the resampling. All land use comparisons of the Battelle classification in this paper will be affected by this known resampling error. In addition, when the Battelle resampled file was entered into the Walnut Creek grid cell data bank only 34,697 acres (54.21 sq. mi.) were located within the geographically correct watershed boundary, the latter being defined in the data bank as containing 36,574 acres (57.15 sq. mi.). The total classified land area listed on Battelle's color-coded map was 35,869 acres (56.05 sq. mi.).

The G.E. tape was not produced to the original specifications, so that a new resampled tape had to be generated, and it also had resampling problems so that it only contained 35,120 acres (54.9 sq. mi.).

CONCLUSION

The LANDSAT derived land use classification percentages are well within an acceptable error to be used for hydrologic modeling. The LANDSAT derived land use classification may also be successfully placed into existing grid cell data banks to be used in other types of analysis, such as environmental assessments. Caution needs to be made though on the spatial integrity of the LANDSAT derived land use for grid cell data banks which have a grid cell size which is at about the same resolution as a pixel. The HEC is currently investigating the accuracies associated with a 4.6 and a 10.3 acre grid cell size with the same data.

The UCD procedure was successful in eliminating the need for expensive image processing equipment and its accuracy was as good or better than the commercial firms which supplied land use data for the same area. This paper presents problems encountered with the commercial products during the conduct of HEC's portion of the ASVT. The authors fully realize that because of continuous technology changes that these problems may have been eliminated.

REFERENCES

Algazi, V.R., G.E. Ford and D.I. Meyer, 1979, "A Non-Interactive Approach to Land Use Determination," 1979 Machine Processing of Remotely Sensed Data Symposium, Purdue University, June 27-29.

Cermak, R.J., A. Feldman and R.P. Webb, 1979, "Hydrologic Land Use Classification Using LANDSAT," Proceedings of the AWRA Satellite Hydrology Symposium, Sioux Falls, South Dakota, June 11-15 (in press).

Jackson, T.J., R.M. Ragan and W.N. Fitch, 1977, "Test of LANDSAT-Based Urban Hydrologic Modeling," Journal of the Water Resources Planning and Management Division, ASCE, 103 (WRI), pp. 141-158.

Meyer, D. and V.R. Algazi, 1978, "Land Use Classification of LANDSAT Data Using a Clustering Algorithm," Department of Electrical Engineering, University of California, Davis, California (draft).

Ragan, R.M. and T.J. Jackson, 1975, "Use of Satellite Data in Urban Hydrologic Models," Journal of the Hydraulics Division, ASCE, 101 (HY12), pp. 1469-1475.

U.S. Soil Conservation Service, 1972, "Hydrology," SCS National Engineering Handbook, Section 4, Washington, D.D.

U.S. Army Corps of Engineers, 1973, "HEC-1 Flood Hydrograph Package, Users Manual," The Hydrologic Engineering Center, Davis, California

U.S. Army Corps of Engineers, 1978a, "Resource Information and Analysis Using Grid Cell Data Banks: Users Manual," The Hydrologic Engineering Center, Davis, California.

U.S. Army Corps of Engineers, 1978b, "HYDPAR: Hydrologic Parameters, Users Manual," The Hydrologic Engineering Center, Davis, California.

U.S. Army Corps of Engineers, 1979, "Determination of Land Use from LANDSAT Imagery: Applications to Hydrologic Modeling, "Research Note No. 7, The Hydrologic Engineering Center, Davis, California.

Technical Paper Series

TP-1 Use of Interrelated Records to Simulate Streamflow
TP-2 Optimization Techniques for Hydrologic Engineering
TP-3 Methods of Determination of Safe Yield and Compensation Water from Storage Reservoirs
TP-4 Functional Evaluation of a Water Resources System
TP-5 Streamflow Synthesis for Ungaged Rivers
TP-6 Simulation of Daily Streamflow
TP-7 Pilot Study for Storage Requirements for Low Flow Augmentation
TP-8 Worth of Streamflow Data for Project Design - A Pilot Study
TP-9 Economic Evaluation of Reservoir System Accomplishments
TP-10 Hydrologic Simulation in Water-Yield Analysis
TP-11 Survey of Programs for Water Surface Profiles
TP-12 Hypothetical Flood Computation for a Stream System
TP-13 Maximum Utilization of Scarce Data in Hydrologic Design
TP-14 Techniques for Evaluating Long-Tem Reservoir Yields
TP-15 Hydrostatistics - Principles of Application
TP-16 A Hydrologic Water Resource System Modeling Techniques
TP-17 Hydrologic Engineering Techniques for Regional Water Resources Planning
TP-18 Estimating Monthly Streamflows Within a Region
TP-19 Suspended Sediment Discharge in Streams
TP-20 Computer Determination of Flow Through Bridges
TP-21 An Approach to Reservoir Temperature Analysis
TP-22 A Finite Difference Methods of Analyzing Liquid Flow in Variably Saturated Porous Media
TP-23 Uses of Simulation in River Basin Planning
TP-24 Hydroelectric Power Analysis in Reservoir Systems
TP-25 Status of Water Resource System Analysis
TP-26 System Relationships for Panama Canal Water Supply
TP-27 System Analysis of the Panama Canal Water Supply
TP-28 Digital Simulation of an Existing Water Resources System
TP-29 Computer Application in Continuing Education
TP-30 Drought Severity and Water Supply Dependability
TP-31 Development of System Operation Rules for an Existing System by Simulation
TP-32 Alternative Approaches to Water Resources System Simulation
TP-33 System Simulation of Integrated Use of Hydroelectric and Thermal Power Generation
TP-34 Optimizing flood Control Allocation for a Multipurpose Reservoir
TP-35 Computer Models for Rainfall-Runoff and River Hydraulic Analysis
TP-36 Evaluation of Drought Effects at Lake Atitlan
TP-37 Downstream Effects of the Levee Overtopping at Wilkes-Barre, PA, During Tropical Storm Agnes
TP-38 Water Quality Evaluation of Aquatic Systems
TP-39 A Method for Analyzing Effects of Dam Failures in Design Studies
TP-40 Storm Drainage and Urban Region Flood Control Planning
TP-41 HEC-5C, A Simulation Model for System Formulation and Evaluation
TP-42 Optimal Sizing of Urban Flood Control Systems
TP-43 Hydrologic and Economic Simulation of Flood Control Aspects of Water Resources Systems
TP-44 Sizing Flood Control Reservoir Systems by System Analysis
TP-45 Techniques for Real-Time Operation of Flood Control Reservoirs in the Merrimack River Basin
TP-46 Spatial Data Analysis of Nonstructural Measures
TP-47 Comprehensive Flood Plain Studies Using Spatial Data Management Techniques
TP-48 Direct Runoff Hydrograph Parameters Versus Urbanization
TP-49 Experience of HEC in Disseminating Information on Hydrological Models
TP-50 Effects of Dam Removal: An Approach to Sedimentation
TP-51 Design of Flood Control Improvements by Systems Analysis: A Case Study
TP-52 Potential Use of Digital Computer Ground Water Models
TP-53 Development of Generalized Free Surface Flow Models Using Finite Element Techniques
TP-54 Adjustment of Peak Discharge Rates for Urbanization
TP-55 The Development and Servicing of Spatial Data Management Techniques in the Corps of Engineers
TP-56 Experiences of the Hydrologic Engineering Center in Maintaining Widely Used Hydrologic and Water Resource Computer Models
TP-57 Flood Damage Assessments Using Spatial Data Management Techniques
TP-58 A Model for Evaluating Runoff-Quality in Metropolitan Master Planning
TP-59 Testing of Several Runoff Models on an Urban Watershed
TP-60 Operational Simulation of a Reservoir System with Pumped Storage
TP-61 Technical Factors in Small Hydropower Planning
TP-62 Flood Hydrograph and Peak Flow Frequency Analysis
TP-63 HEC Contribution to Reservoir System Operation
TP-64 Determining Peak-Discharge Frequencies in an Urbanizing Watershed: A Case Study
TP-65 Feasibility Analysis in Small Hydropower Planning
TP-66 Reservoir Storage Determination by Computer Simulation of Flood Control and Conservation Systems
TP-67 Hydrologic Land Use Classification Using LANDSAT
TP-68 Interactive Nonstructural Flood-Control Planning
TP-69 Critical Water Surface by Minimum Specific Energy Using the Parabolic Method

TP-70	Corps of Engineers Experience with Automatic Calibration of a Precipitation-Runoff Model
TP-71	Determination of Land Use from Satellite Imagery for Input to Hydrologic Models
TP-72	Application of the Finite Element Method to Vertically Stratified Hydrodynamic Flow and Water Quality
TP-73	Flood Mitigation Planning Using HEC-SAM
TP-74	Hydrographs by Single Linear Reservoir Model
TP-75	HEC Activities in Reservoir Analysis
TP-76	Institutional Support of Water Resource Models
TP-77	Investigation of Soil Conservation Service Urban Hydrology Techniques
TP-78	Potential for Increasing the Output of Existing Hydroelectric Plants
TP-79	Potential Energy and Capacity Gains from Flood Control Storage Reallocation at Existing U.S. Hydropower Reservoirs
TP-80	Use of Non-Sequential Techniques in the Analysis of Power Potential at Storage Projects
TP-81	Data Management Systems of Water Resources Planning
TP-82	The New HEC-1 Flood Hydrograph Package
TP-83	River and Reservoir Systems Water Quality Modeling Capability
TP-84	Generalized Real-Time Flood Control System Model
TP-85	Operation Policy Analysis: Sam Rayburn Reservoir
TP-86	Training the Practitioner: The Hydrologic Engineering Center Program
TP-87	Documentation Needs for Water Resources Models
TP-88	Reservoir System Regulation for Water Quality Control
TP-89	A Software System to Aid in Making Real-Time Water Control Decisions
TP-90	Calibration, Verification and Application of a Two-Dimensional Flow Model
TP-91	HEC Software Development and Support
TP-92	Hydrologic Engineering Center Planning Models
TP-93	Flood Routing Through a Flat, Complex Flood Plain Using a One-Dimensional Unsteady Flow Computer Program
TP-94	Dredged-Material Disposal Management Model
TP-95	Infiltration and Soil Moisture Redistribution in HEC-1
TP-96	The Hydrologic Engineering Center Experience in Nonstructural Planning
TP-97	Prediction of the Effects of a Flood Control Project on a Meandering Stream
TP-98	Evolution in Computer Programs Causes Evolution in Training Needs: The Hydrologic Engineering Center Experience
TP-99	Reservoir System Analysis for Water Quality
TP-100	Probable Maximum Flood Estimation - Eastern United States
TP-101	Use of Computer Program HEC-5 for Water Supply Analysis
TP-102	Role of Calibration in the Application of HEC-6
TP-103	Engineering and Economic Considerations in Formulating
TP-104	Modeling Water Resources Systems for Water Quality
TP-105	Use of a Two-Dimensional Flow Model to Quantify Aquatic Habitat
TP-106	Flood-Runoff Forecasting with HEC-1F
TP-107	Dredged-Material Disposal System Capacity Expansion
TP-108	Role of Small Computers in Two-Dimensional Flow Modeling
TP-109	One-Dimensional Model for Mud Flows
TP-110	Subdivision Froude Number
TP-111	HEC-5Q: System Water Quality Modeling
TP-112	New Developments in HEC Programs for Flood Control
TP-113	Modeling and Managing Water Resource Systems for Water Quality
TP-114	Accuracy of Computer Water Surface Profiles - Executive Summary
TP-115	Application of Spatial-Data Management Techniques in Corps Planning
TP-116	The HEC's Activities in Watershed Modeling
TP-117	HEC-1 and HEC-2 Applications on the Microcomputer
TP-118	Real-Time Snow Simulation Model for the Monongahela River Basin
TP-119	Multi-Purpose, Multi-Reservoir Simulation on a PC
TP-120	Technology Transfer of Corps' Hydrologic Models
TP-121	Development, Calibration and Application of Runoff Forecasting Models for the Allegheny River Basin
TP-122	The Estimation of Rainfall for Flood Forecasting Using Radar and Rain Gage Data
TP-123	Developing and Managing a Comprehensive Reservoir Analysis Model
TP-124	Review of U.S. Army corps of Engineering Involvement With Alluvial Fan Flooding Problems
TP-125	An Integrated Software Package for Flood Damage Analysis
TP-126	The Value and Depreciation of Existing Facilities: The Case of Reservoirs
TP-127	Floodplain-Management Plan Enumeration
TP-128	Two-Dimensional Floodplain Modeling
TP-129	Status and New Capabilities of Computer Program HEC-6: "Scour and Deposition in Rivers and Reservoirs"
TP-130	Estimating Sediment Delivery and Yield on Alluvial Fans
TP-131	Hydrologic Aspects of Flood Warning - Preparedness Programs
TP-132	Twenty-five Years of Developing, Distributing, and Supporting Hydrologic Engineering Computer Programs
TP-133	Predicting Deposition Patterns in Small Basins
TP-134	Annual Extreme Lake Elevations by Total Probability Theorem
TP-135	A Muskingum-Cunge Channel Flow Routing Method for Drainage Networks
TP-136	Prescriptive Reservoir System Analysis Model - Missouri River System Application
TP-137	A Generalized Simulation Model for Reservoir System Analysis
TP-138	The HEC NexGen Software Development Project
TP-139	Issues for Applications Developers
TP-140	HEC-2 Water Surface Profiles Program
TP-141	HEC Models for Urban Hydrologic Analysis

TP-142 Systems Analysis Applications at the Hydrologic Engineering Center
TP-143 Runoff Prediction Uncertainty for Ungauged Agricultural Watersheds
TP-144 Review of GIS Applications in Hydrologic Modeling
TP-145 Application of Rainfall-Runoff Simulation for Flood Forecasting
TP-146 Application of the HEC Prescriptive Reservoir Model in the Columbia River Systems
TP-147 HEC River Analysis System (HEC-RAS)
TP-148 HEC-6: Reservoir Sediment Control Applications
TP-149 The Hydrologic Modeling System (HEC-HMS): Design and Development Issues
TP-150 The HEC Hydrologic Modeling System
TP-151 Bridge Hydraulic Analysis with HEC-RAS
TP-152 Use of Land Surface Erosion Techniques with Stream Channel Sediment Models
TP-153 Risk-Based Analysis for Corps Flood Project Studies - A Status Report
TP-154 Modeling Water-Resource Systems for Water Quality Management
TP-155 Runoff simulation Using Radar Rainfall Data
TP-156 Status of HEC Next Generation Software Development
TP-157 Unsteady Flow Model for Forecasting Missouri and Mississippi Rivers
TP-158 Corps Water Management System (CWMS)
TP-159 Some History and Hydrology of the Panama Canal
TP-160 Application of Risk-Based Analysis to Planning Reservoir and Levee Flood Damage Reduction Systems
TP-161 Corps Water Management System - Capabilities and Implementation Status