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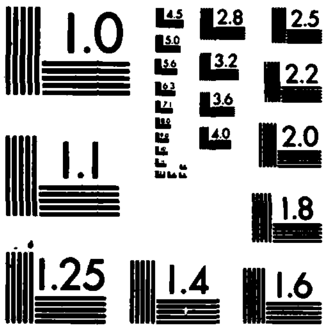

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US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Integration of Landsat land cover data into the Saginaw River Basin geographic information system for hydrologic modeling

H.L. McKim, S.G. Ungar, C.J. Merry and J.F. Gauthier

Prepared for
U.S. ARMY ENGINEER DISTRICT, DETROIT

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A May 1977 Landsat-2 scene that covered approximately 85% of the Saginaw River Basin was classified into five land cover categories (urban, agriculture, forest, freshwater wetlands and open water) using a closest centroid classifier. The Landsat digital data were geometrically corrected to conform to a UTM (Universal Transverse Mercator) grid before classification. The 1.1-acre Landsat land cover classification data base was converted to 40-acre grid cells (six-by-six blocks of Landsat pixels) using an aggregation scheme and was integrated into the Detroit District's existing grid cell data base. A regression relationship

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20. Abstract (cont'd)

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between unit hydrograph parameters and the Landsat land cover classification was developed. The results indicated that the Landsat-2 land cover data were suitable for the Corps of Engineers hydrologic model.

PREFACE

This report was prepared by Dr. Harlan L. McKim, Research Soil Scientist, Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory; Stephen G. Ungar, Physical Scientist, NASA Goddard Space Flight Center-Institute for Space Studies; Carolyn J. Merry, Geologist, Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory; and John F. Gauthier, Hydraulic Engineer, U.S. Army Engineer District, Detroit. The work was funded under U.S. Army Engineer District, Detroit, Intra-Army Reimbursable Order NCE-IA-82-0058-WE.

The authors extend their appreciation to Michael S. Miller (Sigma Data Corporation) for preparation of the land cover data files and to William J. O'Donoghue (Detroit District) for placement of the data files into the Saginaw River Basin geographic information system. Technical review was provided by Walter B. Tucker III and Lawrence W. Gatto, both of CRREL.

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CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM Metric Practice Guide (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	By	To obtain
feet	0.3048	metres
miles	1609.347	metres
acres	4046.873	square metres
square miles	2589998.0	square metres

SUMMARY

The objective of this study was to integrate remotely sensed land cover data with a hydrologic model developed for the Saginaw River Basin, Michigan. The data base developed for the Saginaw River Basin was made compatible with the HEC-SAM (Hydrologic Engineering Center-Spatial Analysis Methodology) software, which is a spatially oriented data bank retrieval system that includes a series of data management and analysis computer programs. The HEC-SAM system can place map data into a geographic information system that can be used with many of the Corps of Engineers' hydrologic, economic and environmental models.

A May 1977 Landsat-2 scene that covered approximately 85% (5200 square miles) of the Saginaw River Basin was selected for analysis. A geometric correction was performed on the entire Landsat scene so that each pixel conformed to the Universal Transverse Mercator (UTM) coordinate system. The Landsat data were classified into five land cover categories (urban, agriculture, forest, wetlands and water) using a closest centroid computer algorithm available from the GISS-ISURSL (Goddard Institute for Space Studies-Indiana State University Remote Sensing Laboratory) classification package. A refined land cover map was also prepared with the GISS MAP1 (Multispectral Image Analysis Package) algorithm. The same categories were mapped, but the urban category was separated into a low- to medium-density urban and high-density urban. Over 7 million individual pixels were analyzed using both algorithms.

Line printer maps were produced of the five land use categories using the closest centroid classifier. The Landsat land cover classification required an additional rotation of 2.02° to align with an existing grid cell data base of the Detroit District. For further verification of the geometric accuracy of the Landsat data, row-column locations of easily identifiable landmarks (road intersections, water bodies) in the Detroit District's data base were selected to match corresponding scan line-pixel locations in the Landsat data base. Maps were generated which verified that the match was successful on the first attempt. The 1.1-acre Landsat land cover classification data base was converted to 40-acre grid cells (six-by-six blocks of Landsat pixels) using an aggregation scheme. This aggregation technique used a majority decision rule coupled with an examination of neighboring grid cells and a hierarchical assignment scheme to resolve ambiguities.

The aggregated Landsat land cover data were easily integrated into the existing Detroit District 40-acre grid cell data base. A multiple regression program was used to develop a relationship between unit hydrograph parameters and the level I land use map derived from Landsat-2 digital data.

INTEGRATION OF LANDSAT LAND COVER DATA INTO THE SAGINAW RIVER BASIN GEOGRAPHIC INFORMATION SYSTEM FOR HYDROLOGIC MODELING

by

H.L. McKim, S.G. Ungar, C.J. Merry and J.F. Gauthier

INTRODUCTION

The Saginaw River Basin study was authorized by the Senate Committee on Public Works and was started on 19 May 1964. The primary objective of the Detroit District, U.S. Army Corps of Engineers, in this study was to develop an operational computer model to measure the impact of land use changes on the basin's hydrologic processes and to predict flood damages in the basin. The hydrologic model was developed to assist local and state planning agencies, to complement flood routing studies and to be used in the operation of the completed flood control projects in the basin. The computer model will be ready to use in June 1985. Achieving this goal required the input of level I land-use data into the Saginaw River Basin data base, which consists of 98,000 grid cells.

Grid cell data bases play an important role in the Corps planning methodology (Hydrologic Engineering Center 1978). Currently, conventional procedures are used to prepare soils, topography, political boundary and other maps that are then digitized into a grid cell format and stored in a data file (Fig. 1). A planning technique using Spatial Analysis Methodology (SAM) was developed by the Corps of Engineers Hydrologic Engineering Center (HEC) to systematically handle these data (Davis 1981). The HEC-SAM system uses the spatially oriented map data in a series of data management and analysis programs for input to the Corps' hydrologic and environmental models. This HEC-SAM procedure is being used in the Saginaw River Basin study.

The HEC-SAM software provides planners with the capability to view variable futures in terms of physical, socioeconomic and environmental interrelationships when land use is changed. Several planning methods can be aided by HEC-SAM. In the plan formulation stage, hydrologic models and models that calculate flood damage can be run using the HEC-SAM gridded

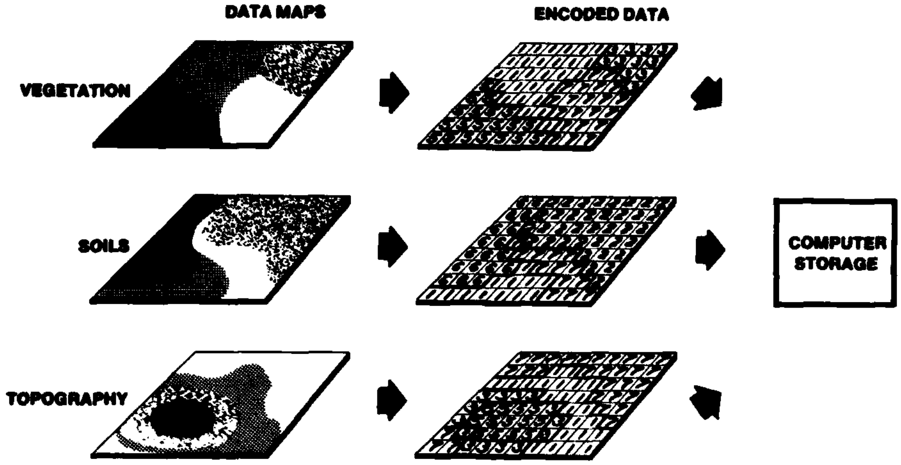


Figure 1. Creation of a grid cell data bank.

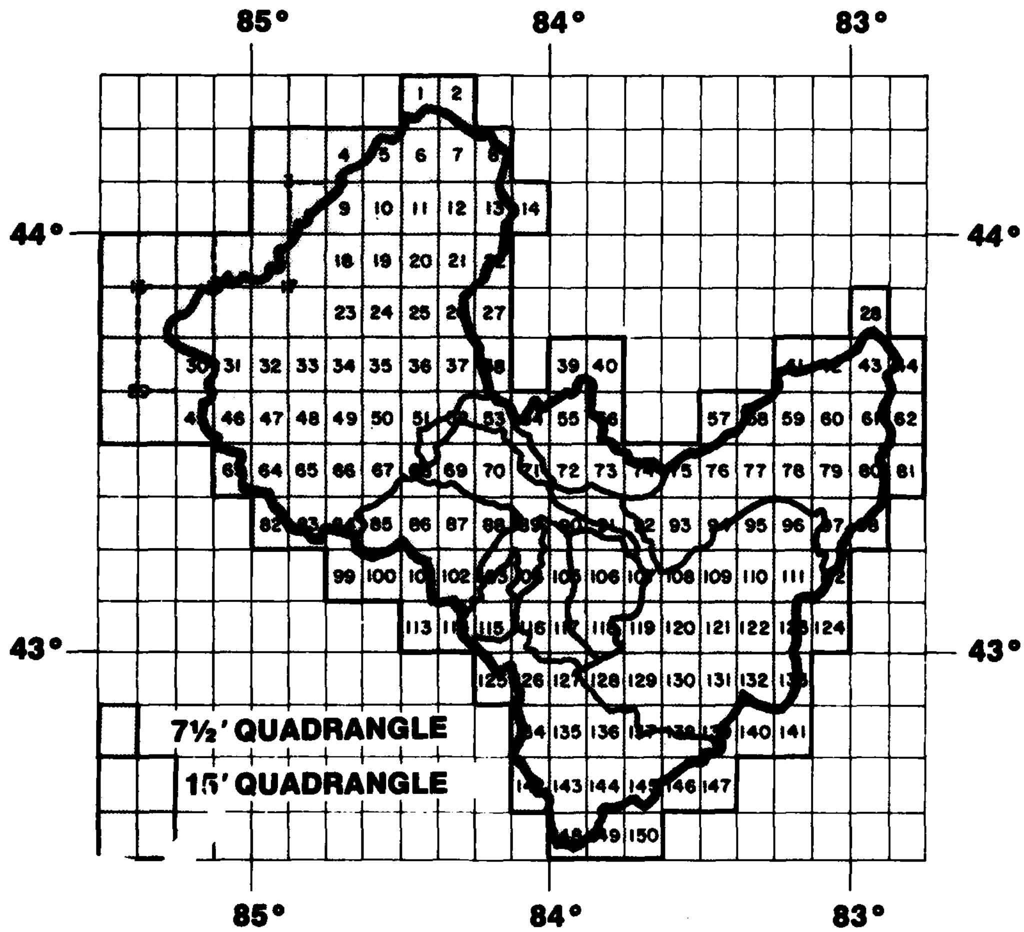


Figure 2. Quadrangle location map for the Saginaw River Basin data base system.

data base. Environmental impact can be analyzed and habitats can be evaluated using the Corps Habitat Evaluation Procedure (HEP) model. Also, land-use planners can use overlay analysis with the digitized maps in the data base.

There are two types of hydrologic models that have been used in the HEC-SAM system. One is the Soil Conservation Service (SCS) model that is based on land use and soil type and the second is the Snyder model that is based on basin geometry. We needed to develop alternatives to these two hydrologic models that would be based primarily on land use.

Previous studies (Webb et al. 1980, National Research Council 1981) have indicated that level I land use obtained from Landsat digital data is adequate for hydrologic runoff models when the watershed is larger than 10 square miles. The grid cell size used in these studies varied from 0.74 to 1.53 acres because the watersheds are small (less than 56 square miles). The Detroit District had previously used a 10-acre grid cell system for the Clinton River watershed hydrology study (760 square miles).

The Saginaw River Basin is the largest basin (6200 square miles) in which the Corps has applied HEC-SAM and remote sensing in a planning study. The basin contains approximately 150 U.S. Geological Survey 1:24,000 scale topographic quadrangles (Fig. 2). At a 10-acre grid cell size, there would be 800,000 cells in the basin. Computer storage of that amount of data is prohibitive; therefore, a 40-acre grid cell size was selected.

DATA BASE DEVELOPMENT

The data base for the Saginaw River Basin model study was originally needed to satisfy the requirements for the hydrologic runoff model. The Detroit District determined that a data base consisting of two variables, land cover and hydrologic subbasins at a 40-acre grid cell size, was best for hydrologic and hydraulic analyses. This resulted in a data base of 98,000 40-acre grid cells. The District decided to use the Landsat land cover data to obtain 85% of the land cover for the basin. The remaining land cover and subbasin data were taken from other sources.

The subbasin data were obtained from the Michigan Department of Natural Resources. The U.S. Geological Survey delineated the subbasin boundaries on the 150 1:24,000 topographic quadrangle maps. The maps were copied and the subbasins numbered by the Detroit District. The maps were individually digitized using a program (written by the Jacksonville District, U.S.

Army Corps of Engineers) that converts polygons directly into grid cell files (the program also allows for interactive editing of the grid cell files). After the 150 maps were digitized, the individual files were combined to form one file holding the subbasin data for the entire basin. Line printer maps were generated for correcting errors in the data file.

This data file serves as the base map for all other variables that will eventually be added. Other variables will include land cover, detailed subbasins, political subdivisions and linear features as well as updated land cover.

The District's digitized land cover data (approximately 20% of the watershed or about 1200 square miles of the basin) covered the areas within the watershed not included in the Landsat scene. The digitized land cover data used the same category classification as the Landsat data. The individual land cover data files were merged using the same method as was used for the subbasin files.

The Landsat land cover data were combined with the District's land cover file and added to the subbasin file. The final version of the data file was verified using line printer maps. The two land cover files were successfully aligned on the first attempt. Other variables of the same grid cell size can be added to the file using this procedure.

LANDSAT DIGITAL DATA

The Landsat series of satellites are in a circular, sun-synchronous, near-polar orbit at a mean altitude of 570 miles (440 miles for Landsat-4). Each orbit takes 103 minutes (99 minutes for Landsat-4), so that each satellite completes approximately 14 orbits per day, covering the Earth every 18 days (16 days for Landsat-4).

The Multispectral Scanner Subsystem (MSS) on board the Landsat satellite is a line-scanning device that continuously scans a 115-mile swath along the Earth's surface. The image data are separated into individual frames 115 miles square during processing. Each image consists of many individual picture elements (pixels) that are obtained in rapid succession by means of an oscillating mirror behind the lens of the MSS (U.S. Geological Survey and NASA 1979). The oscillating mirror scans six scan lines along the 115-mile-long swath perpendicular to the spacecraft. The MSS simultaneously records (in four spectral bands) the amount of light being reflected from each pixel, a 259-ft-square area of the Earth's surface. The four spectral bands are: MSS band 4, 0.5-0.6 μm (blue-green); MSS band 5, 0.6-0.7 μm (yellow-red); MSS band 6, 0.7-0.8 μm (red-near infrared); and MSS band 7, 0.8-1.1 μm (near infrared).

The MSS video signal is converted to digital data and telemetered to a ground receiving station, either in real time or after being recorded on board the satellite. The final data products include computer-compatible tapes (CCTs), black and white photographs of individual spectral bands (MSS bands 4-7), and color composites comprising several bands, usually MSS bands 4, 5 and 7.

The Landsat digital data can be spatially located on the ground to within one-half of a pixel (Bernstein and Ferneyhough 1975). One advantage of using the Landsat information is that the data are digital and can be directly entered into a geographic data base. One Landsat scene comprises 13,225 square miles. Also, because Landsat views the same ground point every 18 days, the accuracy of the land use map can be increased by analyzing data taken at different times of the year.

PLACEMENT OF LANDSAT DATA INTO GRID CELL DATA BASE

A major portion (approximately 85%) of the Saginaw River Basin was covered on a 27 May 1977 Landsat-2 scene (ID 2856-15212), which was selected for analysis (Fig. 3). Approximately 7.8 million pixels are contained within the Landsat scene. The Saginaw River Basin data base, with a 40-acre grid cell size, includes approximately 98,000 grid cells. We performed a geometric correction on the entire Landsat scene to make it conform to the Universal Transverse Mercator (UTM) coordinate system before we classified the Landsat digital data.

Development of the land cover classification

Closest centroid classifier. We digitally classified the 27 May 1977 Landsat-2 scene of the Saginaw River Basin into five land cover categories: open water, freshwater wetlands, forest, agriculture and urban. The classification began with an analysis using an unsupervised routine (a program where the computer classifies the pixels without human intervention). We used the BIRTHA (Boundary Identification of Ranges Through Histogram Analysis) portion of the GISS-ISURSL (Goddard Institute for Space Studies-Indiana State University Remote Sensing Laboratory) classification program. This program, which is an adaptation of the HINDU (Histogram Inspired

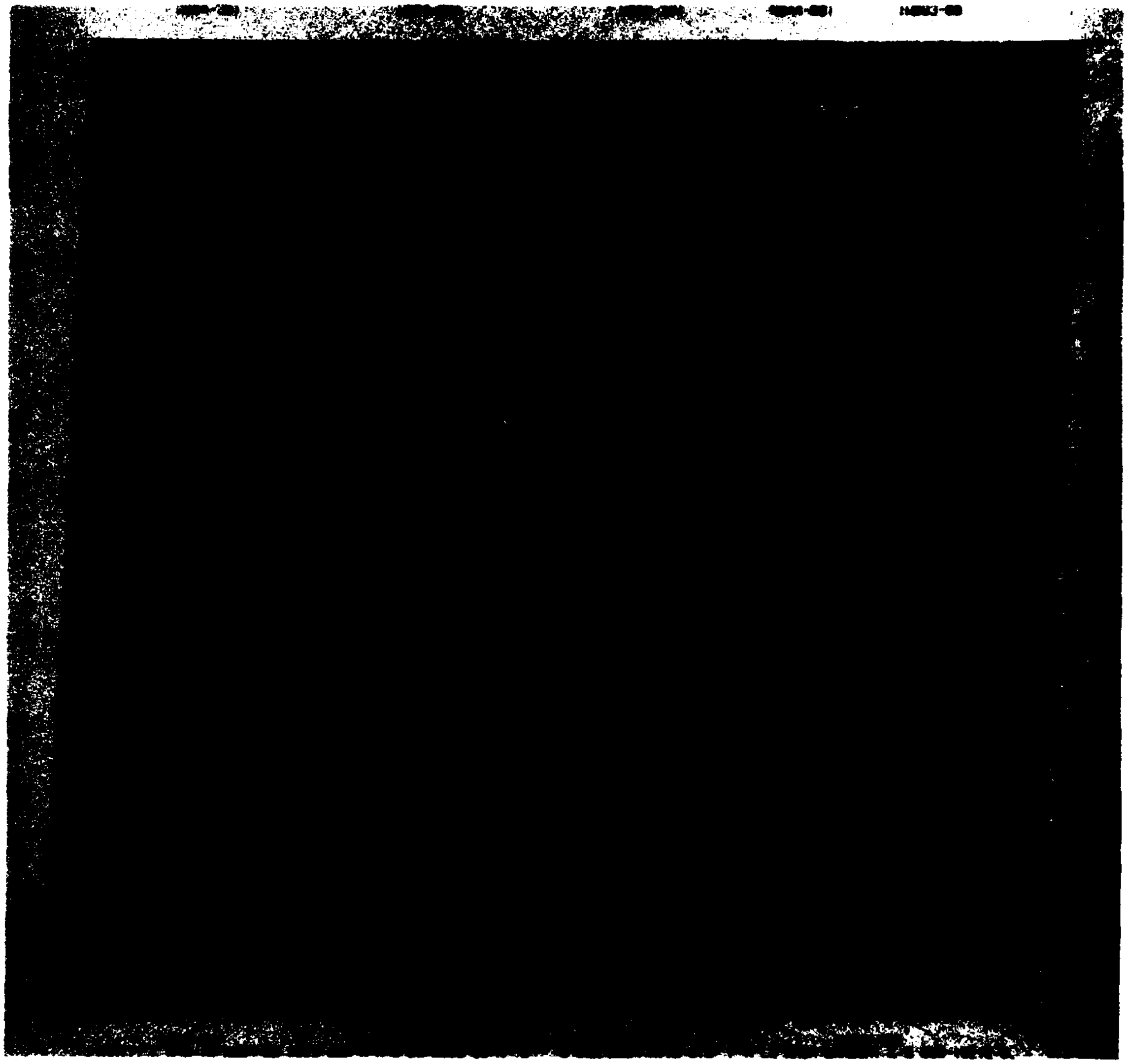


Figure 3. Landsat-2 MSS band 5 scene (ID 2856-15212) of the Saginaw River Basin.

Neighborhood Discerning Unsupervised) pattern recognition system, constructs multidimensional histograms for each pixel that show how much light in each of the four bands is reflected by that pixel. The histograms can be evaluated to determine cluster centroids from the pixel distribution.

The peaks in the histograms represent the cluster centroids. The closest centroid classifier is a minimum distance classifier in which each class is defined by a centroid in feature space. For example, the mean values of the four Landsat bands (the feature space or multidimensional space) would be used to define a centroid. All pixels in the data set would be assigned to a centroid class (corresponding to a land cover class) and thus all regions in the feature space are classified.

Table 1. The percentage of each land cover class on the 27 May 1977 Landsat-2 scene for the closest centroid classification.

	1.1-acre basis	40-acre basis
Open water	6.6	6.6
Freshwater wetlands	0.5	0.2
Forest	21.8	18.3
Agriculture	46.2	53.3
Urban	25.0	21.6

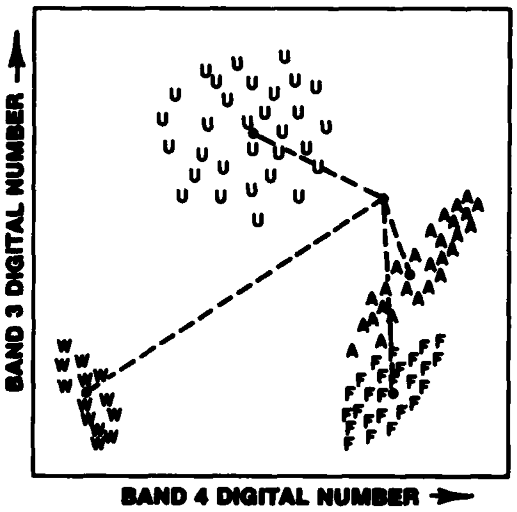


Figure 4. Schematic of the closest centroid classifier (after Lillesand and Kiefer 1979).

The BIRTHA analysis was applied to three training sites. Training sites are areas in which the land cover is known. The training sites were taken from the U.S. Geological Survey quadrangles of Bay City (55), Flint North (119), and Elba (121) (Fig. 2). The histograms were used to derive 26 spectral clusters and their centroids (hereafter called the spectral classes). We assigned the clusters to the land cover class in which they predominantly occurred by inspecting the U.S. Geological Survey topographic sheets and corresponding aerial photography flown in 1977.

The cluster centroids derived from the training sites were entered into a closest centroid classifier of the GISS-ISURSL package. For each pixel in the whole Landsat scene, the distances in four-dimensional "spectral space" to each of the 26 spectral class centroids were calculated. The pixel was assigned to the spectral class for which this distance is the least (Fig. 4). Using this technique, we placed each pixel of the entire Landsat scene into one of the 26 spectral classes and then into one of five land use classes (Table 1).

Supervised classification. We generated another land cover file using the GISS MAP1 (Multispectral Image Analysis Package) classification of the same Landsat-2 scene. We did this to separate the urban category into two classes, low- to medium-density urban and high-density urban.

A supervised classification was employed in this refinement. Training sites of known land use were used to derive spectral signatures and statistics to be applied later to the entire Landsat data base. We chose six U.S. Geological Survey 1:24,000 quadrangles for training: Bay City (55), Flint North (119), Elba (121), Mt. Pleasant (48), St. Louis (67) and Coleman (24) (Fig. 2). These quadrangles represent a wide diversity of geographic locations and predominant land cover types.

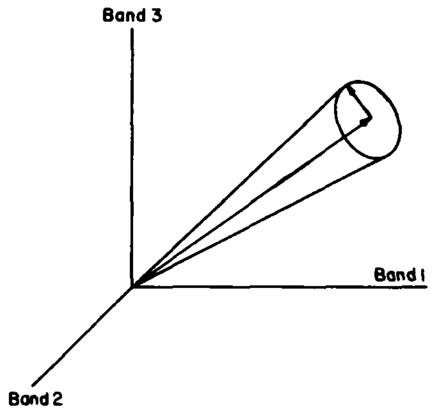


Figure 5. Schematic of the MAP1 classifier.

The classification algorithms used were part of the GISS-MAP1 program. In this package, digital count values for the four Landsat MSS bands are converted to energies (in mW cm^2 sr^{-1}) using sensor calibration data.

Each pixel is considered a vector defined by the four bands (Ungar, unpublished). Pixels are compared against one another using the two indices of color and brightness (Fig. 5). Color differences are based on the direction of the pixel vectors relative to the four-band axes. Brightness differences are based on the summation of the four bands.

The topographic sheets, the corresponding aerial photographs and the line printer gray scales generated from the Landsat CCT data were used to identify training sites of homogeneous land cover within the six quadrangles. Twenty-nine training sites representing the six land use classes accounted for the variability in spectral properties. At the time of the Landsat-2 scene (May), agricultural landscapes could range from bare soil fields to heavily vegetated pastureland. Similarly, forested sites could be at various stages of leaf growth or could be a mixture of deciduous and coniferous species. Urbanized landscapes are always composed of a wide diversity of surface types.

An algorithm was applied to each of the training sites to group pixels of similar spectral characteristics into individual clusters. From the 29 training sites, 42 spectral clusters were generated, with each cluster defined by a unique reflectance. For each cluster, a mean four-band spectral signature was calculated by the classifier.

Table 2. The percentage of each land cover class on the 27 May 1977 Landsat-2 scene for the MAP1 classification.

	1.1-acre basis	40-acre basis
Open water	7.4	7.2
Freshwater wetlands	0.4	0.1
Forest	26.2	26.6
Agriculture	42.7	51.1
Low- to medium-density urban	21.4	14.8
High-density urban	1.9	0.3

The signatures and their corresponding maximum distances were applied to the entire data set. The 42 spectral clusters were aggregated into the six land-use classes (Table 2). We found a larger-than-expected percentage for low- to medium-density urban areas because numerous agricultural areas in which portions of pixels contain either structures or roads were included. Such pixels display reflective properties similar to low-density residential areas in which one finds a mix of man-made surfaces and vegetation.

The MAP1 supervised classification is deterministic rather than probabilistic. Thus, unclassified pixels will not be included within the maximum distances specified from any of the derived cluster signatures. In this classification, less than 2% of the area was left unclassified.

Registering the Landsat land cover data with the District's data base

During the initial land cover classification where we used the closest centroid classifier, line printer maps of the 26 spectral classes for the Bay City and Flint North quadrangles were produced. We compared these maps to corresponding U.S. Geological Survey quadrangle maps. The Landsat land cover classification required an additional rotation of 2.02° to align with the Detroit District's grid cell data base, which was aligned with the U.S. Geological Survey quadrangle maps. The quadrangles are located to a Lambert conformal coordinate system.

For further verification of the geometric accuracy of the Landsat data, row-column locations of easily identifiable landmarks (road intersections, water bodies) in the Detroit District's data base were selected to match with corresponding scan line-pixel locations in the Landsat data base. We again generated line printer maps to verify the match with the U.S. Geological survey quadrangle maps; the match was successful. Since the Landsat image covered more than the Saginaw River Basin, the Detroit District deleted the Landsat land cover data outside the basin boundary. In addition, the Detroit District merged the remaining 15% of the land cover data that was derived in-house with the Landsat land cover file.

Aggregation of land use data into 40-acre grid cells

The original Landsat land cover information was retained at the 1.1-acre resolution. This allowed for future aggregation of the data into different grid cell sizes for other models. The 1.1-acre Landsat land cover classification data base was converted to 40-acre grid cells (six-by-six blocks of Landsat pixels) using an aggregation scheme. The technique allows for the remapping of a Landsat pixel classification onto a grid cell data base whose grid cell size is an integer multiple of Landsat pixels (i.e., 1 grid cell = n × m pixels, where n is the number of pixels in the x-direction and m is the number of pixels in the y-direction). The technique employs a majority decision rule coupled with an examination of neighboring grid cells and a hierarchical assignment scheme to resolve ambiguities.

The user must specify the position of the pixel that will be the upper left-hand corner for the first grid element. The technique then remaps blocks of six-by-six pixels into aggregated cells by reading six scan lines at a time into the computer and categorizing in the along-scan direction. The grid cell that corresponds to each block of 36 pixels is assigned to the land use category that occurs most frequently within the block (Fig. 6). If more than one category appears at the same high frequency, then two

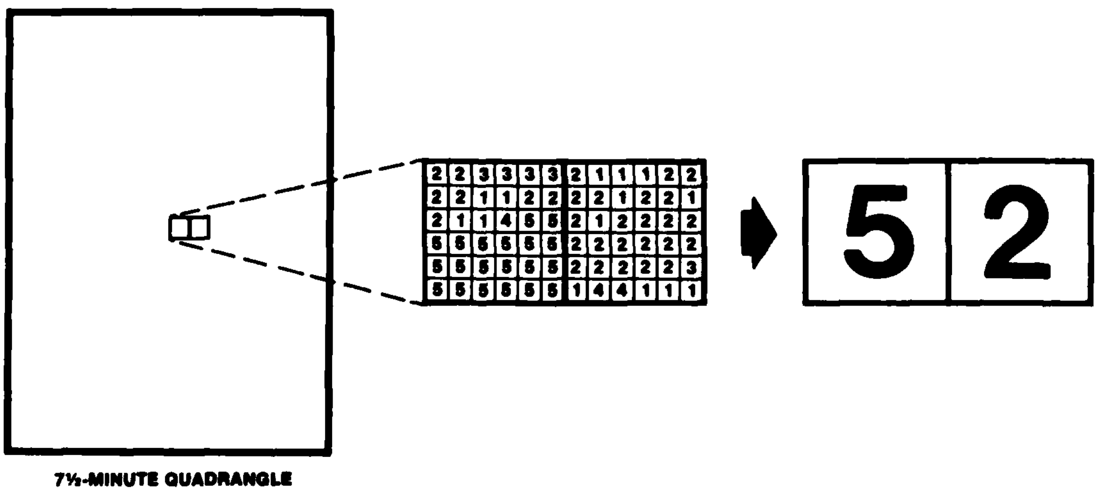


Figure 6. Schematic of the aggregation scheme.

previously classified nearest neighbors, the grid cell (corresponding to a block of 36 pixels) directly above and the grid cell directly to the left, are examined. If the classes assigned to these adjacent grid cells unambiguously match a single entry in the list of candidate categories (the ones that were most frequent), then the matching category is selected for the grid cell being classified. However, an ambiguous situation exists if neither of these two adjacent grid cells matches any of the candidate categories or if each of these adjacent grid cells matches a different candidate category. In this instance, a third adjacent grid cell, the one diagonally up and to the left, is considered in the analysis. If an ambiguous situation persists, the hierarchical classification scheme (presented later) selects the lowest category number appearing in the candidate list.

Grid cells below the row corresponding to the six scan lines currently being processed, as well as the grid cell directly to the right of the block of six-by-six pixels currently being aggregated, are not used to resolve ambiguity since classes have not been assigned to these grid cells. Furthermore, the procedure for resolving ambiguities must be restricted to a single adjacent cell when the technique is considering the first row and the first grid cell in each row. When a grid cell in the first row is being considered, only the adjacent cell directly to the left has been assigned to a class. Similarly, only the cell directly above is available when the technique considers the first grid cell in each row. Finally, the first grid cell to be aggregated must be treated as a special case since no previously classified adjacent cells exist. If in this instance an ambiguity arises, the algorithm would immediately revert to the hierarchical classification scheme to select a category. The unlikely situation of finding an ambiguity in the aggregation of the initial grid cell did not arise during this study.

The hierarchical order of classes used for the closest centroid land cover classification was as follows: 1) urban, 2) agriculture, 3) forest, 4) freshwater wetlands and 5) open water (Table 1). For the MAP1 land cover classification the hierarchical order of classes was: 1) high-density urban, 2) low- to medium-density urban, 3) agriculture, 4) forest, 5) freshwater wetlands and 6) open water (Table 2).

Table 3 shows the percentage of each land cover category in the entire Saginaw River Basin at the 40-acre grid cell size. Of the land cover, 85% was derived using the closest centroid classifier and the remaining 15% was derived by the Detroit District.

Table 3. The percentage of each land cover class at a 40-acre grid cell size for the entire Saginaw River Basin. Of the land cover classification 85% was derived using the closest centroid classifier with the remaining 15% derived by the Detroit District.

	40-acre basis
Open water	0.8
Freshwater wetlands	1.7
Forest	22.5
Agriculture	52.2
Urban	22.8

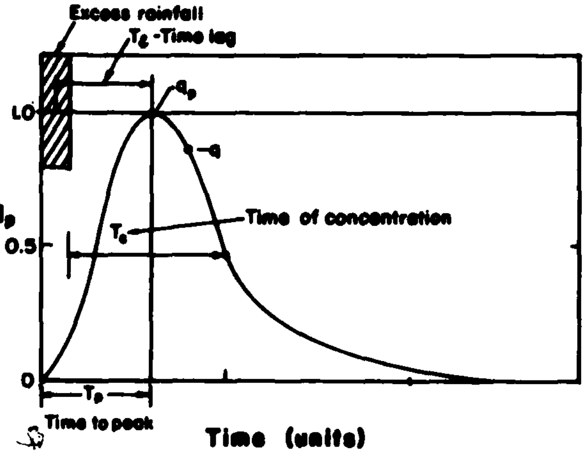


Figure 7. Dimensionless unit hydrograph (after Viessman et al. 1977).

RESULTS

The need for analyzing the sensitivity of the hydrologic response of a watershed to a range of possible future land use developments motivated the development of the entire HEC-SAM process. The existing software for the HEC-SAM hydrology process can utilize land use in determining unit hydrograph coefficients and percent imperviousness.

A unit hydrograph is a plot of runoff on the y-axis versus time on the x-axis. The concept of the unit hydrograph was first developed by Sherman (1932). The unit hydrograph for a given watershed results from 1 in. of rainfall that is applied uniformly over the watershed at a constant rate during a specified time. To develop the hydrograph for any other similar storm of the same duration, the ordinates of the unit hydrograph would be multiplied by the storm runoff. Other methods used to derive the unit hydrograph have been developed by Clark and Snyder. They developed the coefficients of time to peak (T_p) and time to concentration (T_c) to define the unit hydrograph (Fig. 7). Storage coefficients to account for watershed slopes were also developed by Clark and Snyder.

Prior to the Detroit District's Clinton River Basin study, two methods had been used in SAM hydrology studies (Hydrologic Engineering Center 1981) and included the Soil Conservation Service method and a Snyder method based primarily on subbasin geometry (Brater and Sherrill 1975, Brater and Sangal 1968). HEC modified the hydrology utility software for the Clinton River study so that a regional regression method based on the work of Brater could be used in the modeling process. Brater's data were further analyzed by regression to develop equations for directly determining Snyder unit hydrograph parameters using the variables of drainage area and population density. Hydrologic methods that relate unit hydrograph characteristics to land use can represent potential future hydrologic conditions resulting from altered land use patterns, whereas methods based primarily on basin geometry could not do that since basin geometry will not change.

Based on the success of using the Brater hydrograph data in the Clinton River Basin SAM study, we decided that a similar hydrologic method would be suitable for the Saginaw River Basin SAM study. The principal shortcoming of the Clinton regression analysis was the inclusion of a subjective variable -- population density -- in the regression relationship. At the beginning of the regression analysis for this study, we decided that the regression relationship would be based on directly observable parameters.

Alternatives to the two existing hydrology methods previously used in the HEC-SAM system were developed for this study. One was the Brater-based hydrologic method, which is related to population density, which is indicative of land use. We called the other alternative the Saginaw method, in which level I land use is the principal factor.

In the Brater-based hydrologic method, 13 subbasins were analyzed in southeast Michigan. Brater developed regional regression equations relating population density to unit hydrograph characteristics, based on the analysis of a diverse group of streams and precipitation events in southeast Michigan (Brater and Sherrill 1975, Brater and Sangal 1968). The results of this study indicate a strong relationship between population density and runoff characteristics. The relationship is only considered valid for southeast Michigan, but we wanted to expand on his method by using observable parameters rather than subjective parameters.

For developing unit hydrograph parameters, we divided the Saginaw River Basin into eight subbasins for the Saginaw River Basin model. The basin boundaries were defined by the location of the major long-term flow gauges (Fig. 8); seven of these subbasins were analyzed for the study. The complete daily average flow records for each gauge were obtained from the HEC GETUSGS program (Hydrologic Engineering Center 1979) and reviewed for runoff events suitable for optimization of runoff. Eight runoff events were encoded into the HEC-1 program for optimization. In most cases, we

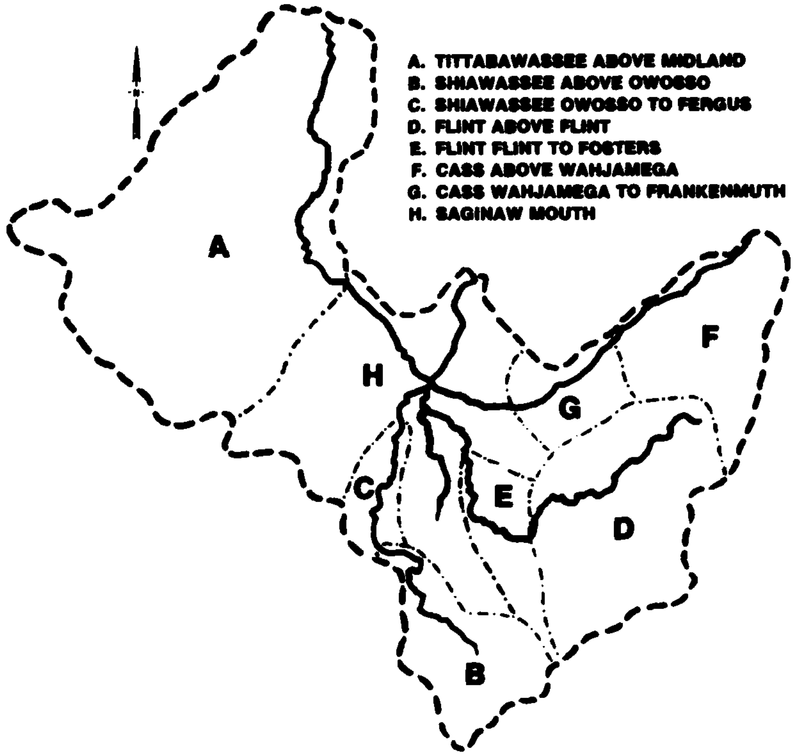


Figure 8. The eight subbasins within the Saginaw River Basin, Michigan.

found two or three of these events to be unsuitable because of antecedent conditions, widely scattered precipitation, or gaps in precipitation records. We considered the optimization complete when we identified the pair of Clark unit hydrograph parameters having the lowest average error function for each of the selected events for a given subbasin.

The HEC MLRP (Multiple Linear Regression Program) (Hydrologic Engineering Center 1970) was used for developing a relationship between the unit hydrograph parameters and the level I land use classification developed from the analysis of the 1977 Landsat scene. The initial results of the Saginaw River Basin regression analysis are shown in Table 4. The highest correlation was found between the subbasin area and the log of Snyder's time to peak coefficient T_p. A strong correlation was also observed between percent forest and T_p, probably because the forest category can be mapped fairly accurately with the Landsat MSS data. There is no correlation between the Snyder storage coefficient C_p and any of the independent variables. In the closest centroid classification there was

Table 4. Initial correlation coefficients developed from the regression analysis.

Independent variables	Dependent variables			
	log T_p^*	$\sqrt{C_p^+}$	T_c^{**}	$\frac{1}{R}^{++}$
log area	0.7824	0	0.5595	0
%urban	0.1842	0	-0.3927	0
%forest	0.7593	0	0.7080	0
log %wetland	0.0654	0	0.0493	0
area	0.8533	0	0.5747	0
%water	0	0	0	0.1902

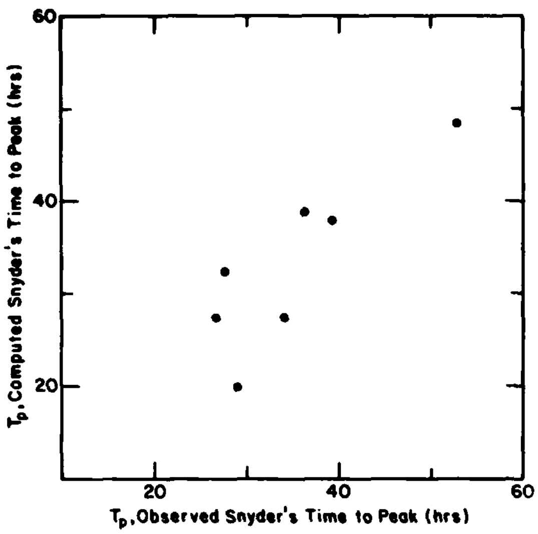
* Snyder's time to peak.
\+ Snyder storage coefficient.
** Clark's time of concentration.
\++ Clark's storage factor.

some misclassification between the urban and agriculture areas. With an improvement in the land cover mapping, there should be a stronger correlation between the percent urban and the storage coefficient.

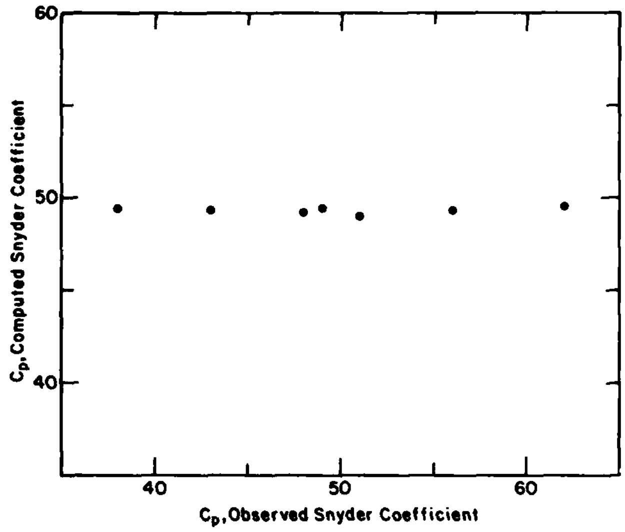
The relationships developed for the Clinton River Basin study based on Brater's research could have been based on land use, rather than population density. Land use and population density are, from a hydrologic standpoint, merely alternate expressions of the level of imperviousness within a locale. If a given land use can be considered to have a fixed level of population density throughout a river basin, then the Brater-based equations for population would have an equivalent expression based on land use by varying only the constants.

Two forms of equations were developed through the regression procedure: a Snyder method set of equations similar to the expressions used in the Clinton River Basin SAM study, and a set of equations based on the Clark method of unit hydrographs (Clark 1945). The four equations having the minimum average error are shown in Table 5. The results of applying the equations from Table 5 to the available data are illustrated as scatter diagrams in Figure 9.

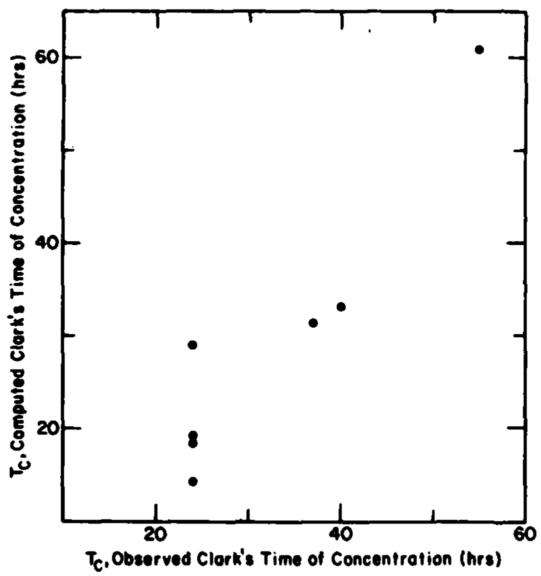
The Clark equations were more satisfactory than the Snyder equations. The equations for peak timing were more accurate than the equations expressing hydrograph shape. It is not clear why the Clark method yielded more accurate regression results than the Snyder method, although the Snyder expression for basin timing is not so inaccurate that it could not be used. The Snyder shape equation is so static that it has the effect of a constant



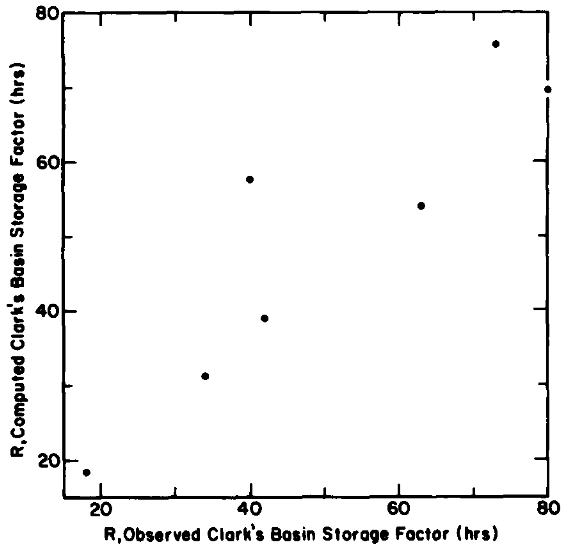
a. Snyder's time to peak, T_p.



b. Snyder coefficient, C_p.



c. Clark's time of concentration, T_C.



d. Clark's basin storage factor, R.

Figure 9. Scatter diagrams showing the regression analysis for the Saginaw River Basin, Michigan.

Table 5. The four equations developed from the regression procedure. Area is expressed in square miles; the remaining variables are in percent.

Equation	R^2	$\bar{R}^2$	%E
$T_p^* = \text{Antilog}(0.8242 + 0.2417 \log \text{area} + 0.0033\ \%\text{urban})$	0.7352	0.6027	9.5
$C_p^+ = (0.7043 - 0.00001\ \%\text{urban})^2$	0.0004	0	12.0
$T_c^{**} = (0.5476 + 0.3153 \sqrt{\%\text{forest}} + 0.1767 \log \%\text{wetland} - 0.0003\ \text{area})$	0.8083	0.6166	15.7
$R^{++} = 1/(-0.2470 + 0.0045\ \%\text{urban} + 0.0422 \sqrt{\%\text{forest}} + 0.0510\ \%\text{water} - 0.00004\ \text{area})$	0.9680	0.9041	9.5

* Snyder's time to peak.
\+ Snyder storage coefficient.
** Clark's time of concentration.
++ Clark's basin storage factor.

throughout the entire range of observations, but its average error is within an acceptable range.

These equations were based on a preliminary land use classification, which had only five land cover categories and a partial overlap between the urban and agriculture land uses. Furthermore, only seven subbasins were used in the optimization process. The subbasins were not significantly diverse in size and land use mix, and this limited the opportunity to develop relationships based on these characteristics.

CONCLUSIONS

The Landsat-2 MSS scene covering 85% of the Saginaw River Basin was geometrically corrected to a UTM coordinate system. The five land cover categories mapped using the closest centroid classifier were urban, agriculture, forest, freshwater wetlands, and open water. The MAP1 algorithm was used to differentiate the urban category into low- to medium-density urban and high-density urban for a total of six land cover classes. Both classification schemes resulted in a Landsat land cover file at a 1.1-acre resolution. A software program was developed to rotate the land cover classification into the Detroit District's data base and an aggregation scheme was written to remap the Landsat land cover classification file into a 40-acre grid cell size.

We found a regression relationship between unit hydrograph parameters and the Landsat land cover classification, and we developed two forms of equations from the regression relationship using the Snyder and the Clark methods. The set of equations from the Clark method yielded more accurate regression results.

Landsat digital data can now be placed into a geographic information system easily and at low cost. We kept the Landsat land cover data at the smallest possible resolution size (1.1 acres) so that aggregation schemes could be used to remap the data into any desired grid cell size. For this study a 40-acre grid cell size was selected for the operational hydrologic model being developed for the Saginaw River Basin; however, in the future the aggregation scheme can be easily modified to remap the Landsat 1.1-acre data into 10-acre or any other size grid cells for use in various Corps modeling activities. Also, the geographic information system for the Saginaw River Basin can be used interactively for editing and updating.

RECOMMENDATIONS

From our experience in this study, we recommend the use of improved Landsat classifications. A refined Landsat MSS level I land use classification has been completed and will be analyzed with the hydrologic parameters. In the future, Landsat Thematic Mapper data with 30-m resolution would also result in a more detailed land cover classification.

An expanded hydrologic subbasin analysis, in which 20 to 30 additional gauged subbasins would be added to the analysis, would improve the accuracy of the results. This would allow for more diversity and more accurate mapping of land cover categories. In this way improved unit hydrographs would be developed for the Saginaw River Basin.

Our methods developed in this study may be applicable to other regions. Once that is established, this method would be useful for developing hydrologic models for basins with inadequate flow records.

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