LARS Information Note 121373

An Evaluation of Machine Processing Techniques of ERTS-1 Data for User Applications

by

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INTRODUCTION: A Context for the Work

For some years research has been underway to learn how to use computing machines for the processing and analysis of remotely sensed data. The motivation of this work is not to produce an automatic analysis system, but to utilize computing machinery for the repetitive and routine aspects of the total analysis and processing problem in order to minimize the costs and increase the throughput rate.

By the time of the launch of ERTS-1 this research had identified a number of machine processing algorithms useful for both preprocessing and analysis of the data. Some of these processing algorithms have been embodied into a software system known as LARSYS[1], and this system has been widely used and thoroughly tested on several different problems utilizing aircraft scanner data. Thus, an important task with the launch of ERTS-1 was to test this processing method relative to the high volume, high quality data which ERTS-1 was expected to produce.

The vantage point adopted in devising this test is based on attempting to visualize the complete spectrum of information which might be obtainable from remotely sensed data. An earth resources information tree (see Figure 1) is one way to visualize this spectrum of information. In the information tree concept, the totality of surface features is first broken down into relatively simple classes such as:

Vegetation
Soils and Geologic Features
Urban Features
Hydrological Features
Atmospheric Features

Each of these in turn may be broken down into more detail. For example, vegetation might be subdivided into natural and cultural vegetation; under cultured vegetation there would be croplands and this could be further broken down to species, variety, yield, etc. In this way one can visualize the information derivable through remote sensing of surface features as being essentially a continuum of data classification possibilities. Although it is not precisely true in every case, generally the deeper one goes down the information tree the more difficult the classification task.

From this vantage point then and realizing the importance of being able to ultimately satisfy an actual user's needs, a suitable test of a new processing approach might be devised by selecting a set of study projects which (a) are associated with specific user problems of importance and (b) which suitably sample this spectrum of information possibilities from left to right and from top to bottom. Following this approach for our study, five specific application investigations were selected.* These were:

1. General Earth Feature Identification
2. Crop Species Identification
3. Soil Association Mapping
4. Urban Land Use Analysis
5. Water Resource Identification

State and regional information users were also identified for each of these tasks and their cooperation secured so that each of these application investigations could be directed at a specific user need.

Along with these application investigations four supporting technology tasks were also proposed. These tasks were needed in order to bring the existing technology of processing and analysis into compatibility with the new data source. The four supporting technology tasks were:

- .Analysis Technique Development
- .Reformatting and Temporal Registration
- .Atmospheric Modeling
- .System and Scene Corrected Data Comparison

The purpose of this presentation is to present some new results on several of these study projects. Before doing so however, it will add to the overall perspective to briefly note results presented on these study projects in earlier ERTS-1 Symposia. At the first ERTS-1 meeting in September, 1972 a report[2] was presented which treated classes of earth surface features similar to those of application investigation number 1, above; however the real purpose of this study was to test rapid turn-around analysis possibilities and to gain an initial indication of the quality of the data which the satellite was producing. The analysis of the so-called Texoma ERTS frame, the first frame produced in computer compatible tape form by the ground station, was carried out within 48 hours after receipt of the data and within 72 hours after the data was gathered. Successful machine classifications were obtained for such

*In addition to the ERTS-Wabash Valley Study (UN 127, D. Landgrebe, Principal Investigator) two other were conceived as a part of the overall test. They are UN 103, R. Hoffer, Principal Investigator for problems involving especially terrain relief and UN 630, M. Baumgardner, Principal Investigator for other types of agricultural and range situations, e.g. dry land and irrigation farming. These are reported on elsewhere in this symposium.

classes as: forest, several categories of rangeland, cropland, and several categories of water. A quantitative evaluation of classification accuracy was not conducted.

At the March, 1973 ERTS-1 Symposium a report[3] was provided on preliminary urban land use inventory studies using these methods. Preliminary analysis of data over Milwaukee, Wisconsin; Chicago, Illinois; and Indianapolis, Indiana were reported. Urban land use categories such as older housing, newer housing, industry, commerce, wooded areas, water and grassy areas were utilized. The results were evaluated on a qualitative basis. Later in this report we shall give the results of a replication of this study together with a quantitative analysis of the accuracy.

Also in the March 1973 ERTS Symposium, the results of a relatively extensive agricultural crop classification study were reported.[4] Utilizing test areas involving 500 agricultural fields scattered over a three county area, a demonstrated accuracy in excess of 80 percent was reported; in addition, the results of extrapolating training from one county to another were reported as successful and preliminary results on the use of temporally registered data for improving classification accuracy was given. Additional work of this type has been undertaken with data from other parts of the country where cropping patterns are significantly different. Some of this work is being done in cooperation with the Statistical Reporting Service, USDA (Mr. Don VonSteen and Mr. Bill Wigton). This work is reported elsewhere in this meeting.

In the remainder of this report, we will provide results from additional studies and urban land use analysis, soil association mapping, and in reformatting and temporal registration, thus further filling in the profile of possible performance and future utility of satellite data coupled with machine processing.

URBAN LAND USE ANALYSIS

Figure 2 shows an ERTS image centered over the southern tip of Lake Michigan. This data was gathered on October 1, 1972. In order to determine the repeatability of urban land use mapping possibilities which ERTS provides a replication of an earlier urban land use mapping test was conducted using the Gary-Hammond, Indiana area.

In conducting such an experiment the first task is to display the data in a suitable fashion to the analyst. Figure 3 shows the same data displayed electronically from computer compatible tape data rather than by conventional photographic means. This image, formed on a digital image display device, utilized three channels of ERTS data in a fashion similar to standard color products available from the ERTS ground station. However, in this case rather than balancing the display of the three spectral bands in the conventional fashion the contrast of each band has been maximized in this presentation based on the actual range in this data. In theory, this results in a large quantity of information being displayed. However, of course, training in interpreting this new media would be required to realize it.

One of the advantages of electronically displaying data is in the additional flexibility it provides over conventional means. For example, in this case our interest is to be focused on the southern-most tip of Lake Michigan. The next four figures show displays of this same region at succeedingly increasing levels of detail (Figure 4, 5, 6, and 7).

The analysis proceeds by selecting small areas typical of each land use class to be used. This is done with the aid of a clustering algorithm. The set of training samples resulting is used to classify the entire study area, using the Gaussian maximum likelihood classifier of LARSYS.

The resulting classification is shown in conjunction with the raw data (Figure 8), and as Figure 9. Important features and land use classes are located with letters or numbers in Figure 9 and are also listed in Table 1. Gray levels used for the display of the spectral classes are as follows:

Industrial/Commercial	Medium Gray
Older Housing	Black
Newer Housing	White
Trees	Light Gray
Grassy (open, agricultural)	Dark Gray
Water	Black
Smoke	White

Older housing and water have been assigned the same gray level (black), but consideration of their areal distributions prevents confusion between the two. Water is largely restricted to Lake Michigan and to several other water bodies, such as Wolf Lake. Older housing is located between coastal industrial establishments and newer housing. Smoke and newer housing also have the same gray levels (white). Smoke, however, is found only over Lake Michigan, while newer housing is located to the south.

Agricultural areas (shown as dark gray) were identified in the southern part of the study area. This class included cropland, pasture, and idle land in rural areas, as well as parks, golf courses, and open land in urban areas. Wooded areas (shown as light gray) are commonly associated with the drainage pattern of the study area. Three principal stands of trees appeared, in conjunction with the Little Calumet River, Deep River, and the Dunes Park area along Lake Michigan. Water, displayed as black, is located in Lake Michigan and other, smaller water bodies such as Wolf Lake.

Newer housing developments, shown as white, are located on the fringes of the urbanized area, in the municipalities of Munster, Highland, Griffith, and Merriville. The majority of the structures were built since World War II. Lawns (grass) and streets are the two primary constituents of this spectral class. Therefore, four-lane highways were also classified as newer housing.

Older residential, displayed as black, consists of areas developed prior to World War II. They are found in Hammond, Whiting, East Chicago, and Gary. Closely spaced rooftops, along with mature vegetation (large trees) are the reasons for the spectral separability of this class.

Industrial/commercial areas (shown as medium gray) are usually void of vegetation. They are characterized by the occurrence of rooftops, parking lots, streets, and bare ground. Examples include Inland Steel, U.S. Steel, Standard Oil, Bethlehem Steel, the Gary Central Business District, and Broadway Plaza Shooping Center (Figure 9).

The land use classes identified in this study correspond well with the classes proposed by Anderson, Hardy, and Roach in the U.S. Geological Survey Circular 671[5] and also with those developed in previous ERTS urban analyses (2, 7, 11, 13). Further investigations were made, however, into industrial areas in this analysis because of their large areal extent in the Gary-Hammond area.

Five spectral classes of commercial/industrial land use were developed. Two of the classes are associated with closely spaced rooftops; the other three are associated with gravel or sandy areas in industrial areas, adjacent to the rooftop classes. The northern part of the classification image is shown in Figure 10. Gray levels used for the classification image are as follows:

Rooftops (dark reflectance)	Black
Rooftops (bright reflectance)	Dark Gray
Gravel/Sandy areas (3 classes)	Medium Gray
Smoke	White
All Other Classes	Light Gray

The reader will note that the same classification is shown in both Figure 9 and Figure 10; the only idfference is the assignment of gray levels to the spectral classes.

The class shown as black in Figure 10 is associated primarily with dark roofing material, but also with large coal piles. Large areas of this spectral class are associated with the three large steel firms in the study area -- Inland, U.S., and Bethlehem. The other rooftop class, displayed as dark gray, is associated with brighter reflecting rooftops. Reasons for the three spectral categories of gravel/sandy areas (all displayed as medium gray) are not entirely clear at this time but they probably relate to both the color of the material and the presence/lack of sparse vegetative cover. Two large areas of gravel/sandy material are located in the northwest part of the study area, one between the large building complexes of Inland and U.S. Steel companies and the second in the large oil refining district in the Whiting-East Chicago area. In the northeastern part of the study area, another large area of gravel/sand is located west of the buildings of Bethlehem Steel. This area was dominated by one of the three classes of gravel/sand, and had a particularly high spectral reflectance in both the visible and infrared portions of the spectrum. The ground cover in this area is the dune sand typical of this locale.

The final class used in this classification scheme, the white areas in Lake Michigan, is speculated to be smoke coming from coastal industrial establishments. Spectrally, the class is similar to water, having a very dark reflectance in the infrared (Figure 8-B). Several facts, however, when considered as a whole, lead one to conclude it is smoke. The linear, parallel arrangements of the data points, extending some 30 miles into Lake Michigan, are contrary to the circulation patterns in the lake. Moreover, the meterological records report that the wind was out of the southwest on the morning of the ERTS pass.

While smoke was probably identified in the western part of the study area, the smoke data points along the coast in the east were probably water. Moreover, the large area classified as smoke northwest of Bethlehem Steel was probably a thin cloud. Despite the spectral confusion in these areas, the partial separability does warrant further investigation of the phenomena of smoke located over water bodies.

CLASSIFICATION ACCURACY

An attempt was made to determine the classification accuracy by a sampling method. A number of rectangular test areas were determined for each land use, and the class accuracy determined (Table 2). Water, wooded areas, older housing, and newer housing were all identified with over 90 percent accuracy. Trouble was encountered in industrial/commercial areas, most of the misclassification being attributed to older housing. The poorest classification accuracy was in grassy and agricultural areas, where less than 70 percent of the data points were accurately classified. Misclassification of these areas was of two major types. One, areas in agricultural regions associated with darker colored soils proved difficult to separate from older housing. One such area was located south of Little Calumet River, in Munster and Highland. The other type of misclassification was in undeveloped marshland adjacent to industrial areas. Large areas south of U.S. Steel and along U.S. Highway 12 were misclassified as older housing.

Important tabular data can be generated from the machine processing of ERTS data. Table 3 contains an estimate of the proportion of the study area (excluding Lake Michigan) allocated to the various land uses, obtained by a simple tallying of the numbers of data points in each land use. Adjustments were made for agricultural/grassy areas, commercial/industrial, and older housing, relative to the misclassification between these three land uses. Acreages were obtained by multiplying the number of data points by 1.1, the approximate resolution of ERTS. The data in Table 3 could have been reported by smaller areal units, such as municipalities, townships, or census tracts, by storing the desired boundaries in the computer.

SOIL ASSOCIATION MAPPING

Computerized analysis of ERTS MSS data has yielded images which will prove useful in such programs as the ongoing Cooperative Soil Survey program, involving the Soil Conservation Service of USDA and other state and local agencies. In the present mode of operation, a soil survey for a county may take up to 5 years to be completed. Results reported here indicate that a great deal of soils information can be extracted from ERTS data by computer analysis. This information is expected to be very valuable in the premapping conference phase of a soil survey for a county, resulting in more efficient field operations during the actual mapping. It is expected to result in greater accuracy of mapping and decrease the time required to produce the soil survey.

Several states are presently accelerating their soil survey programs in light of the increased pressure on our soil resources for production of food and fiber. Since soils are a primary consideration in land use planning, these inventories of soils resources are desperately needed at the present time.

The task being pursued in our ERTS-1 study is concerned primarily with comparison of generalized county soil maps with multispectral maps produced by computer analysis of ERTS MSS data. A typical soil association map is given in Figure 11. Initial investigation of discriminability of individual soil types for more detailed mapping are also being conducted.

The procedure being followed in determining the utility of ERTS data involves direct comparisons of ERTS images of various types to existing soil association maps. Techniques were developed during the course of the project to facilitate making such comparisons independent of the spectral characteristics of the soils. Essentially, this is accomplished by the digital geometric correction of ERTS MSS data where necessary (in the computer analysis phases) and direct overlay of conventional soil maps onto the ERTS images.

Four types of techniques are being tested:

1) B/W photographic image-single band
2) B/W electronic image-single band
3) Color electronic image-three bands
4) Computer classification image-four bands

In each case an attempt was made to draw boundaries between generalized soil associations onto the image. This was followed by comparison with a soil association map in transparent overlay form. The overlay was photographically manipulated to the same scale as the ERTS image containing the interpreted boundaries.

An inspection and test of data from various dates has verified the original assumption that data gathered at a time of maximum soil exposure provides the best results. This occurs in late Spring in the Wabash Valley. For example on June 9, 1973 it was found that 55% of Tippecanoe County, Indiana was nonvegetated.

The generation of the black and white images is straightforward with the exception that the electronically generated one has its contrast optimized relative to the scene data range. The electronically generated color image is generated in the same fashion as Figures 3 through 7.

The fourth type, the computer classification is a nonsupervised classification of the four band data. An example is shown in Figure 12 which includes the soil map overlay. It was found in this case that the data could be partitioned into 10 multispectral classes such that none were spectrally similar to one another.

In this figure the very dark colors represent vegetated areas while intermediate and light colors show nonvegetated soils. A close inspection of the image relative to the map boundaries reveals that some generalized soil boundaries are mislocated on the conventional map. An example is seen in the upper left part of the image, where a light colored area extends from soil association 81(Miami-Russell-Fincastle) across the area mapped as soil association 73 (Raub-Ragsdale) and into soil association 89 (Sidell-Parr). The Raub-Ragsdale soil association would not typically contain such large delineations of these well-drained soils.

Several soil associations can be delineated very well in Figure 12. Soil association 16 (Elston-Wea) is very distinctive in the left center of the image. Soil association 66 (Fincastle-

Ragsdale-Brookston) has a distinctive appearance in the upper right portion of the image as well as in other areas. Soil associations 73 and 89 are easily delineated from soil associations 66 and 81 in several areas.

Table 4 shows results of comparing false color electronic images and computer classification images with the soil association map. The computer classification most closely agreed with the soil map, and the discrepancies noted are associated with errors in the conventional map.

Table 5 gives results of the investigation of spectral separability of individual soil types. The overall accuracy of 89% indicates that ERTS data can be used to assist in identification and mapping of individual soil types.

Although these studies have not been completed, it seems that several positive conclusions will be forthcoming. Geometric correction of ERTS MSS data and direct overlay of existing conventional soil maps facilitated specific and precise comparisons. Used together, these two sources provide increased information on soil characteristics which should be extremely useful in the National Cooperative Soil Survey. Computer classification images contained more soils information than any other images investigated. This advantage of computer analysis, coupled with the advantages of being compatible with other data storage and retrieval systems for soils and land use data make the computer analysis approach highly desirable. Since soils are a major consideration in land use and land use planning, this type of analysis will likely become of even greater utility in the next few years.

GEOMETRIC CORRECTION AND TEMPORAL REGISTRATION OF ERTS DATA

Earlier it had been indicated that supporting technology tasks in the ERTS Wabash Valley Study involved reformatting and temporal registration, and scene corrected data comparisons. In the case of the latter it had been assumed prior to the launch of ERTS that the geometric accuracy present in scene corrected data would prove very helpful in locating specific ground points, both in the classifier training process and in the evaluation and utilization of results. This has certainly proved to be the case. A geometric correction software system which used the ERTS orbital and sensor system parameters as inputs is utilized to deskew, rotate and rescale computer compatible tape data. For example, in one test, data from Tippecanoe County was geometrically adjusted to achieve a 1:24,000 scale computer line printer printout of the area. To test the geometry the printout was then overlaid on a standard 1:24,000 quadrangle map and significant landmarks traced onto the printout. In this manner it was determined that a maximum error of 1.3 picture elements was obtained.

If greater accuracy is required ground control points can be introduced to reduce the geometric error still further. If it is desired to precisely align data from one ERTS pass onto that of another, the same system can be used, but achieving still smaller relative error between the two data sets by allowing final adjustment of the geometry to be under the control of a two dimensional correlation algorithm. Table 6 shows accuracies which appear to be typical of using these techniques to adjust the geometric qualities of ERTS-1 data. In essence, this system amounts to a digital implimentation of the scene correction capability of the ERTS ground station, but with the addition of an inter-image correlator. It has proven immensely valuable in reducing the time required for an analyst to train a classifier and to evaluate its performance by greatly simplifying the problem of locating specific ground location. It also provides a basis for developing multitemporal data sets from subsequent passes of ERTS-1 so that the value of multitemporal, multispectral classification can be tested.

CONCLUSIONS

In this presentation a broad study has been descirbed, the purpose of which is to evaluate a set of machine analysis and processing techniques applied to ERTS-1 data. The analysis phase of this study still has several months to completion. However, based on the analysis results in urban land use analysis and soil association mapping together with previously reported results in general earth surface feature identification and crop species classification, a profile of general applicability of this procedure is beginning to emerge. Put in the hands of a user who knows well the information he needs from the data and also is familiar with the region to be analyzed it appears that significantly useful information can be generated by these methods. When supported by preprocessing techniques such as the geometric correction and temporal registration capabilities, final products readily useable by user agencies appear possible. In parallel with application, through further research, there is much potential for further development of these techniques both with regard to providing higher performance and in new situations not yet studied.

ACKNOWLEDGEMENTS

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Table 1. Features of interest, land uses, and major highways indicated in Figure 9.

L[1]	Feature, land use, or highway[2]	Spectral class[3]
A	Smoke plume	smoke
B	Inland Steel	commercial/industrial
C	United States Steel	commercial/industrial
D	Bethlehem Steel	commercial/industrial
E	Oil Refineries	commercial/industrial
F	Wolf Lake	water
G	Lake Michigan	water
H	Gary-Central Business District	commercial/industrial
J	Highland-subdivision	newer housing
K	Indiana Harbor	commercial/industrial
L	Port of Indiana	commercial/industrial
M	Gary Municipal Airport	newer housing
N	Indiana Dunes State Park	wooded
O	Agricultural area	grassy/agricultural
P	Indiana-Illinois state line	-----
Q	Wicker Memorial Park	grassy/agricultural
R	Trees along Deep River	wooded
S	Hammond-residential area	older housing
T	East Chicago-residential area	older housing
U	Munster-subdivision	newer housing
V	Gary-residential area	older housing
2	Interstate Highway 80-94	newer housing
3	Interstate Highway 80-90	newer housing
4	U.S. Highway 12	newer housing
5	Interstate Highway 94	newer housing
6	Illinois Highway 394	newer housing
7	U.S. Highway 41	newer housing
8	Interstate Highway 65	newer housing
9	U.S. Highway 30	

[1] White letter or number indicated in Figure 9.

[2] Features of interest of land uses are indicated by letters; highways are indicated by numbers.

[3] Five spectral categories of commercial/industrial land use were used in the classification scheme.

Table 2. Classification accuracy for test samples

Land Use	Percentage of Data Points Classified As:					
	C/I[1]	OHg[2]	NHg[3]	Wod[4]	A/G[5]	Wat[6]
Cmrc/Inds.[1]	89.8	7.3	0.3	-	0.2	2.5
Old Hsng.[2]	0.9	97.9	0.9	0.3	-	-
New Hsng[3]	0.6	4.0	94.0	-	1.4	-
Wooded	-	2.0	-	94.4	3.5	-
Agrc/Grsy[5]	0.8	27.4	3.2	3.1	65.5	-
Water	0.8	-	-	-	-	99.2

$\bar{X}$ Classification accuracy by class = 90.3%.

[1] Commerce/Industry

[2] Older Housing

[3] Newer Housing

[4] Wooded

[5] Agricultural/Grassy

[6] Water

Table 3. Land use area calculations for study area (excluding Lake Michigan).

Land Use	Number of Data Pts.	Number of Acres	Number of Hectares	% of Study Area
Cmrce/Indstry[1]	25766	28343	11479	8.2
Older Housing[1]	56528	62181	25183	.18.0
Newer Housing	28540	31394	12714	9.1
Wooded	52346	57581	23320	16.6
Agric/Grassy[1]	150982	166080	67262	48.0
Water	499	549	222	0.2
TOTAL	314661	346127	140181	100.0

[1]Adjustments made in accordance with test classification accuracy (see Table 2.)

Table 4. ERTS-Wabash Valley Study

SOIL ASSOCIATION MAPPING COMPARISON

Soil Association	Percent Difference Within Association	
	Color Electronic Image	Computer Classification Image
73 Raub-Ragsdale	35.0	8.5
89 Sidell-Parr	1.1	2.7
16 Elston-Wea	0	0
81 Miami-Russell-Fincastle	20.0	3.8
66 Fincastle-Ragsdale-Brookston	3.0	3.1
AVERAGE (Weighted)	15.0	7.3

Table 5. ERTS-Wabash Valley Study

SOIL TYPE SEPARABILITY TEST

SOIL TYPE	PERCENT CORRECT (TRAINING SAMPLES)	
Ragsdale	90.6	
Fincastle	81.8	
Genesee	100.0	
Wea	98.6	
Sidell	84.0	
Miami	77.3	
Ockley	76.9	
OVERALL	89.0	246 DATA POINTS

Table 6. GEOMETRIC CORRECTION & TEMPORAL REGISTRATION ACCURACY FOR ERTS-1 MSS CCT DATA

Task	Typical Error
Geometric correction (estimated parameters)	1-2% accumulative
Geometric correction (ground control)	Maximum 1.33 pixels RMS .65 pixels
Temporal registration (correlation control)	Maximum 1.4 pixels RMS .5 pixels

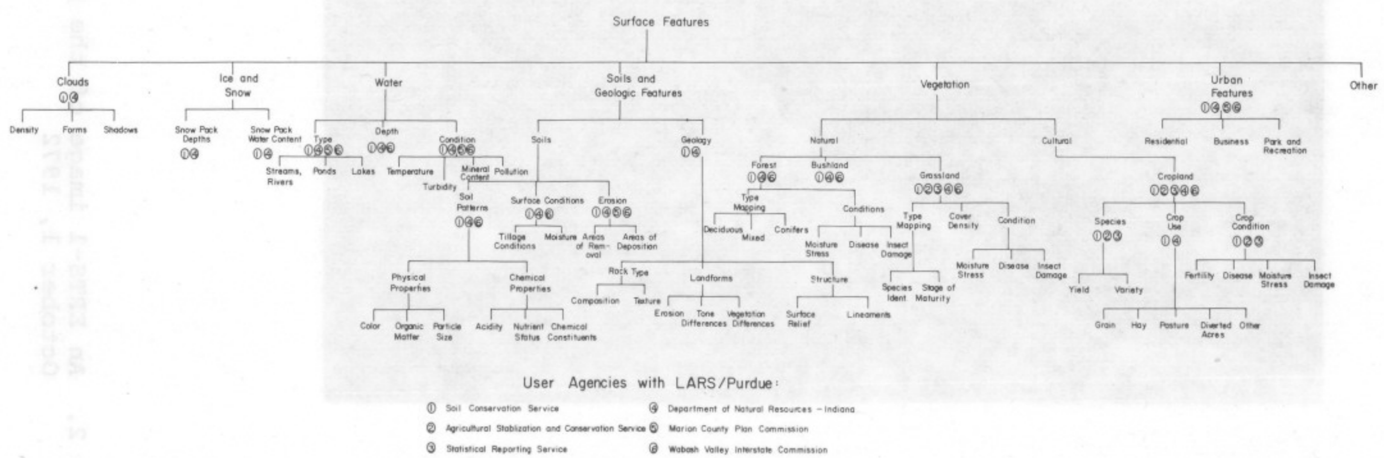

Figure 1. An Earth Resources Information Tree

Figure 2. An ERTS-1 image of the southern Lake Michigan region
October 1, 1972

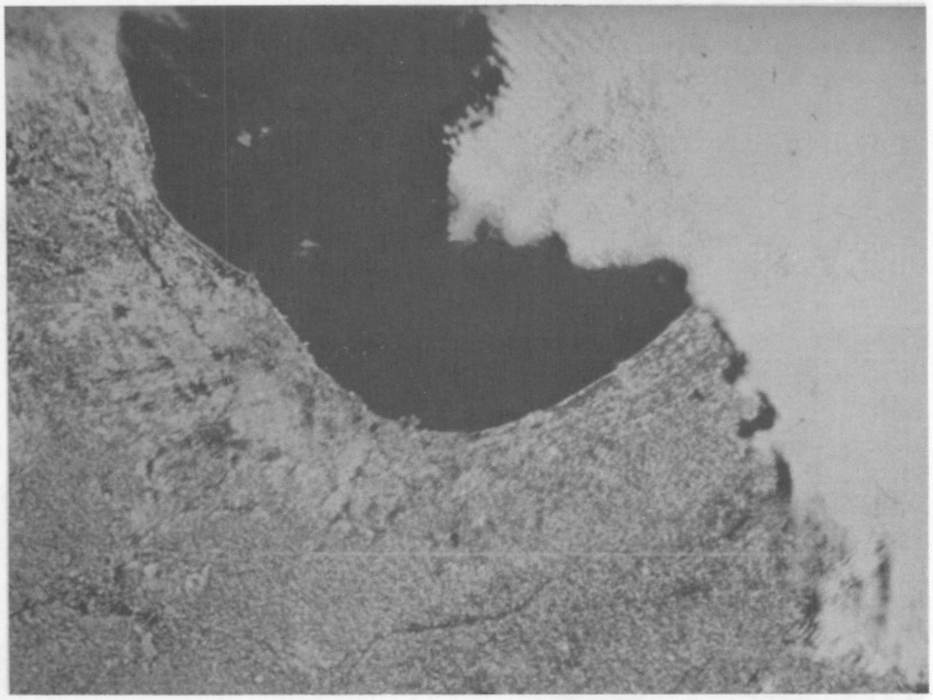

Figure 3. Electronically displayed ERTS-1 data from Computer Compatible Tape

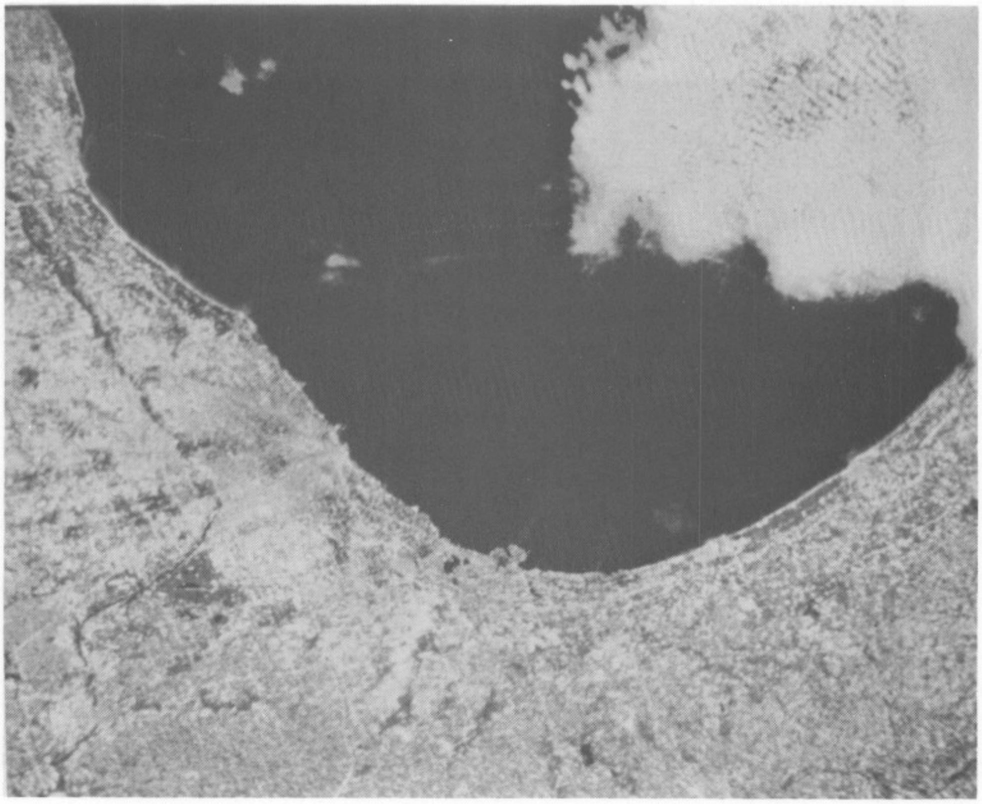

Figure 4. Electronically displayed data showing increasing detail

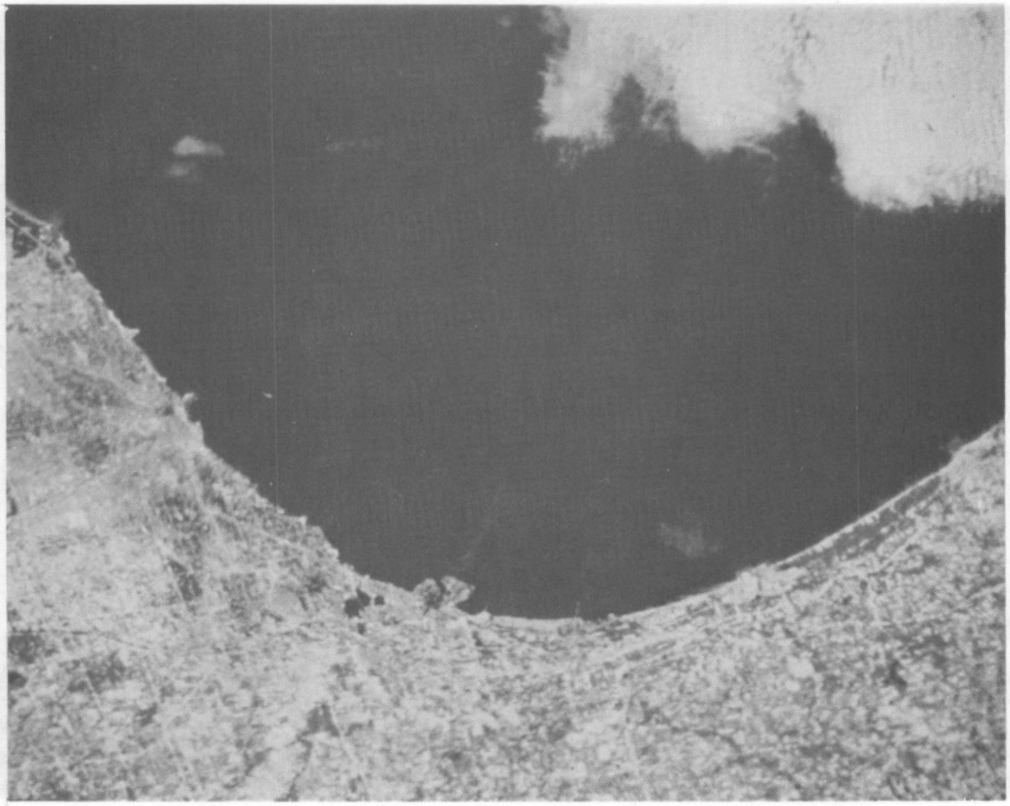

Figure 5. Electronically displayed data showing increasing detail

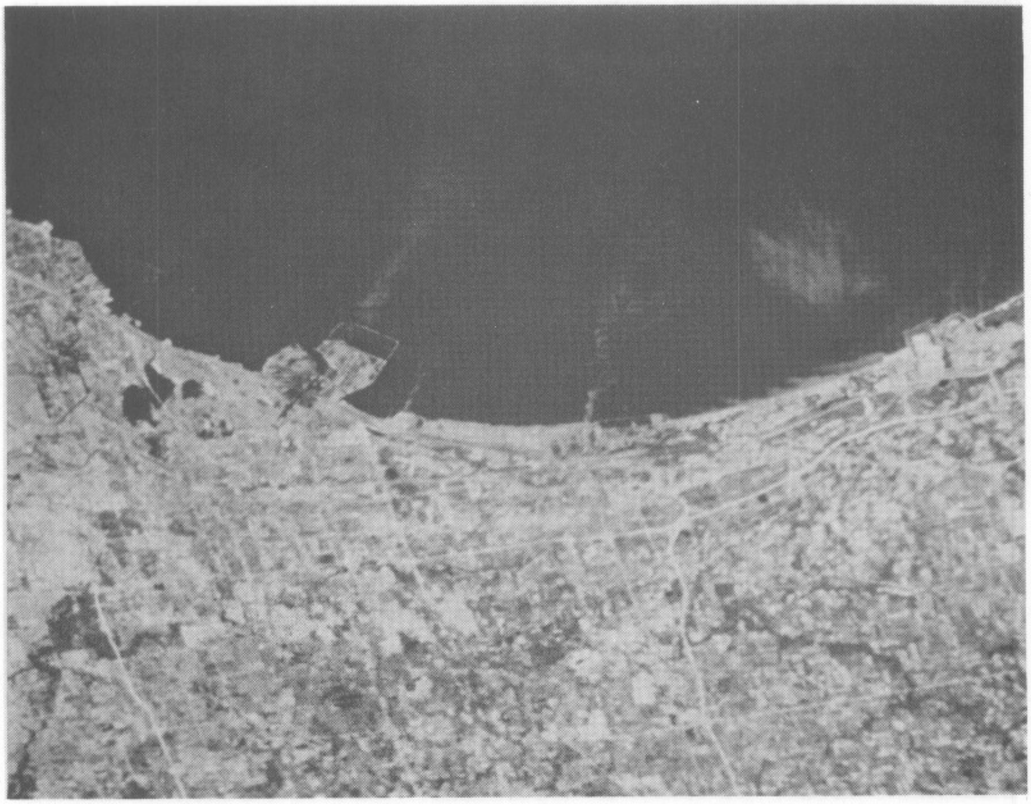

Figure 6. Electronically displayed data showing increasing detail

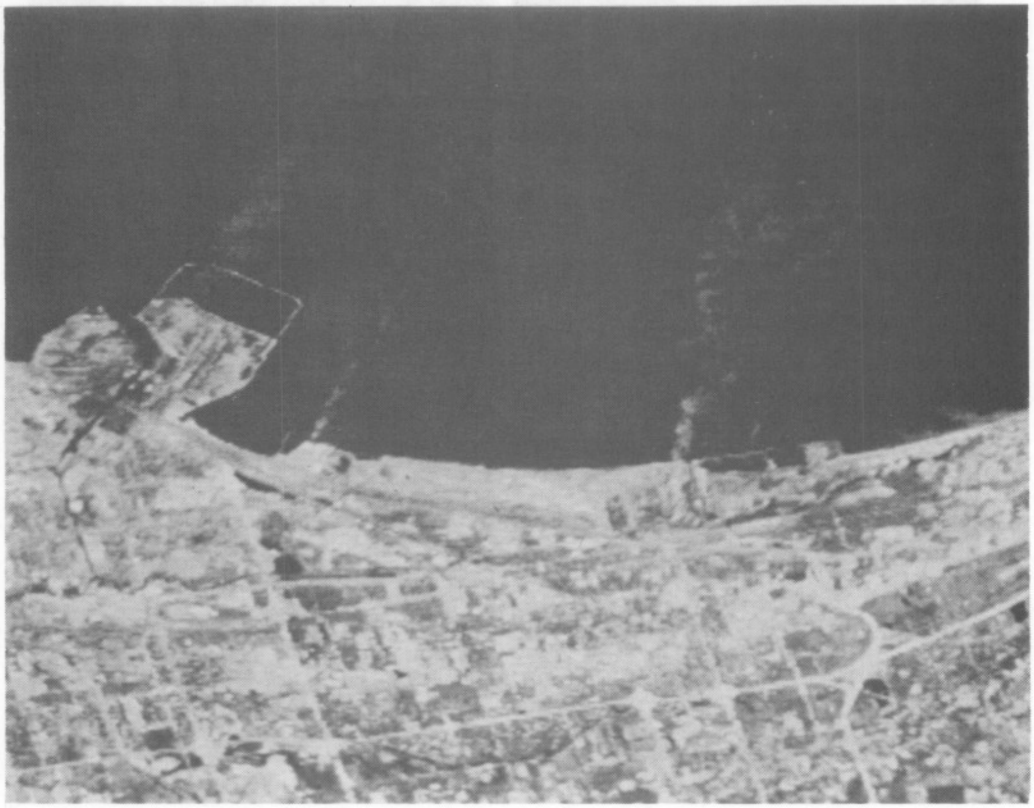

Figure 7. Electronically displayed data showing increasing detail

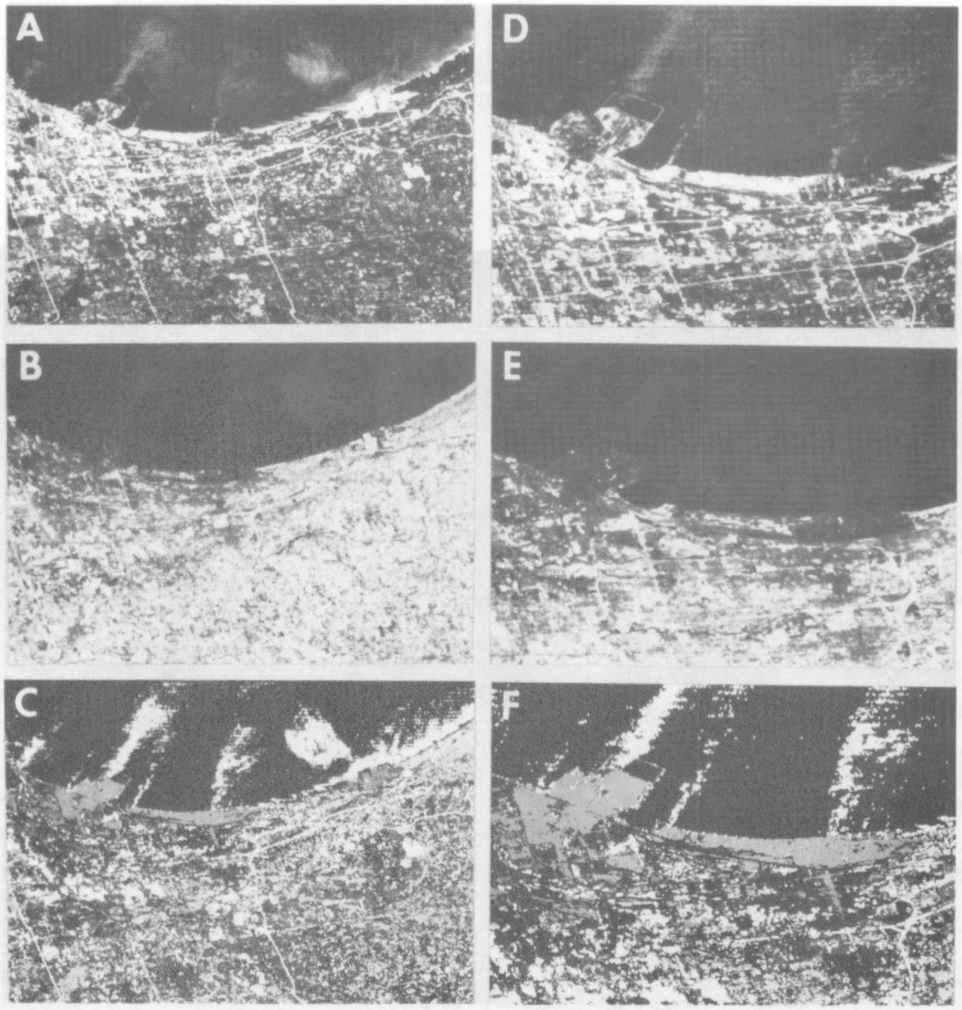

Figure 8. Photos from digital display, showing relationship between gray scale imagery and land use classification. Image in A is from the visible portion of the spectrum (Band 4, 0.5-0.6μm): B is from the reflective infrared (Band 6, 0.7-0.8μm); C is a computer-implemented classification of the study area (see text for explanation of gray levels). Images in A, B, and C show the entire study area; enlargements of the northwestern portions of those three images are shown in D, E, and F, respectively. Horizontal length of A, B, and C is 54 kilometers (34 miles); vertical length is 46 kilometers (29 miles). Horizontal length of D, E, and F is 27 kilometers (17 miles); vertical length is 23 kilometers (14.5 miles). The true north-south line is rotated about 18 degrees counterclockwise to vertical. Horizontal scale is approximately three-fourths that of the vertical scale.

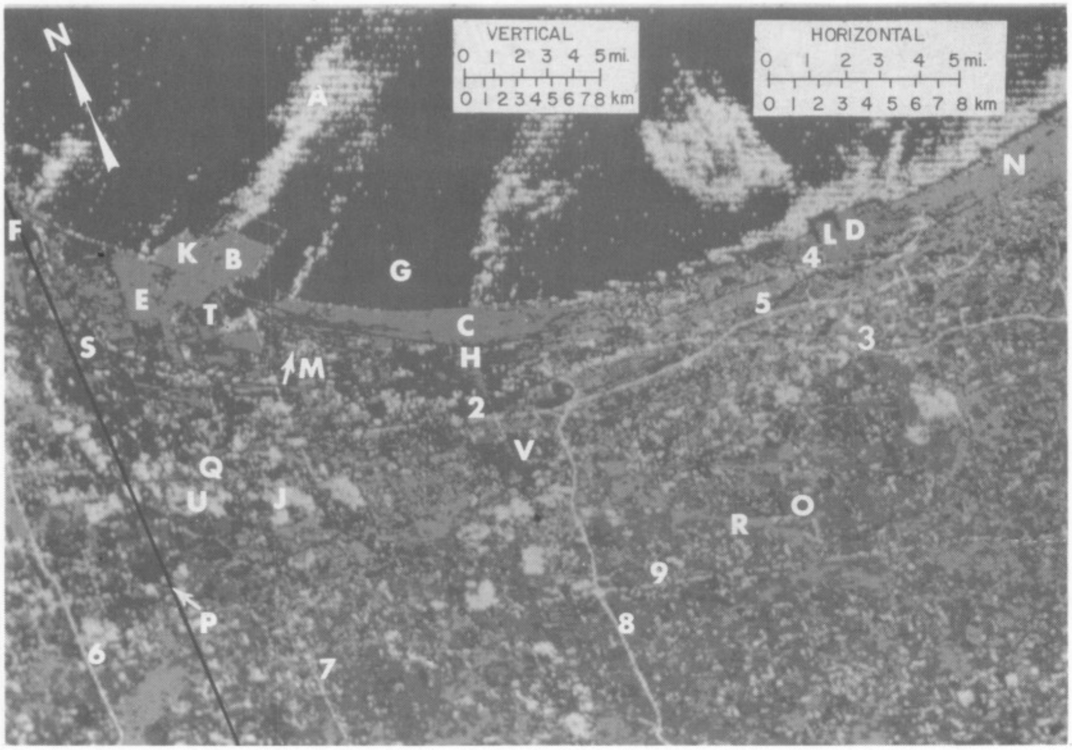

Figure 9. Photo from digital display of computer-implemented land use classification of Gary-Hammond area (see text for explanation of gray levels). Letters/numbers refer to features of interest, a listing of which is found in Table 1.

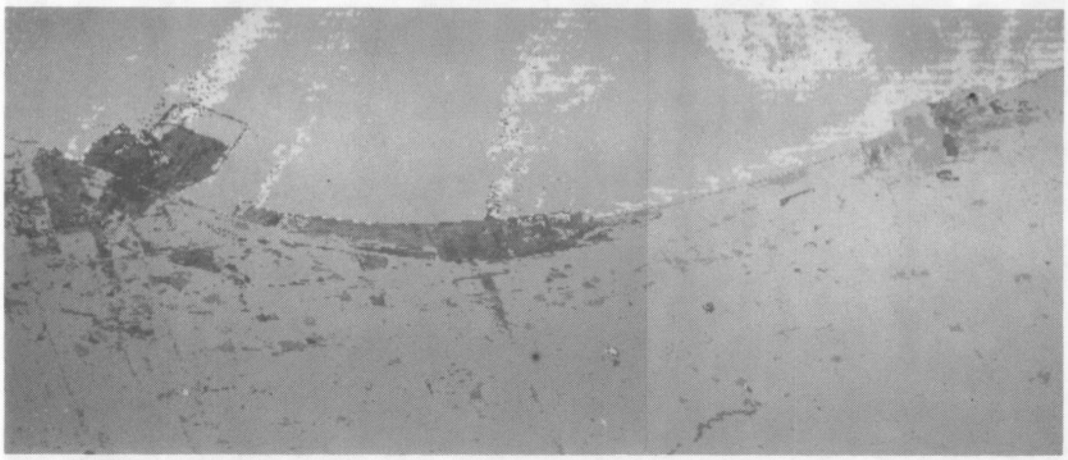

Figure 10. Photo from digital display of computer-implemented land use classification of Gary-Hammond area (northern part of study area) using gray levels which emphasize the industrial land uses. Class shown as black is dark roofing material; dark gray is lighter colored roofing material; medium gray is gravel/sandy areas; smoke is white. All other spectral classes are shown as light gray.

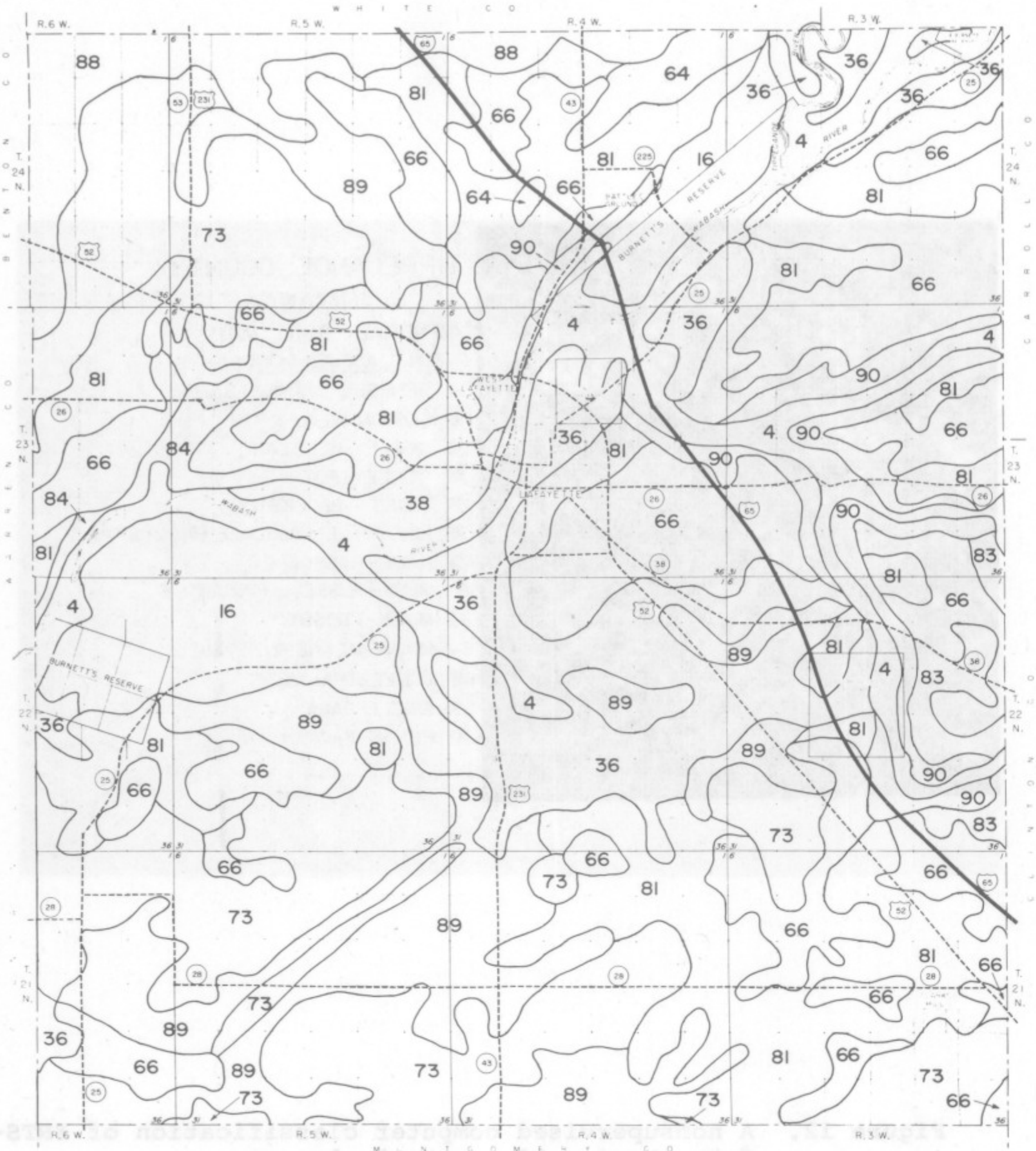

Figure 11. A typical conventional soil association map.

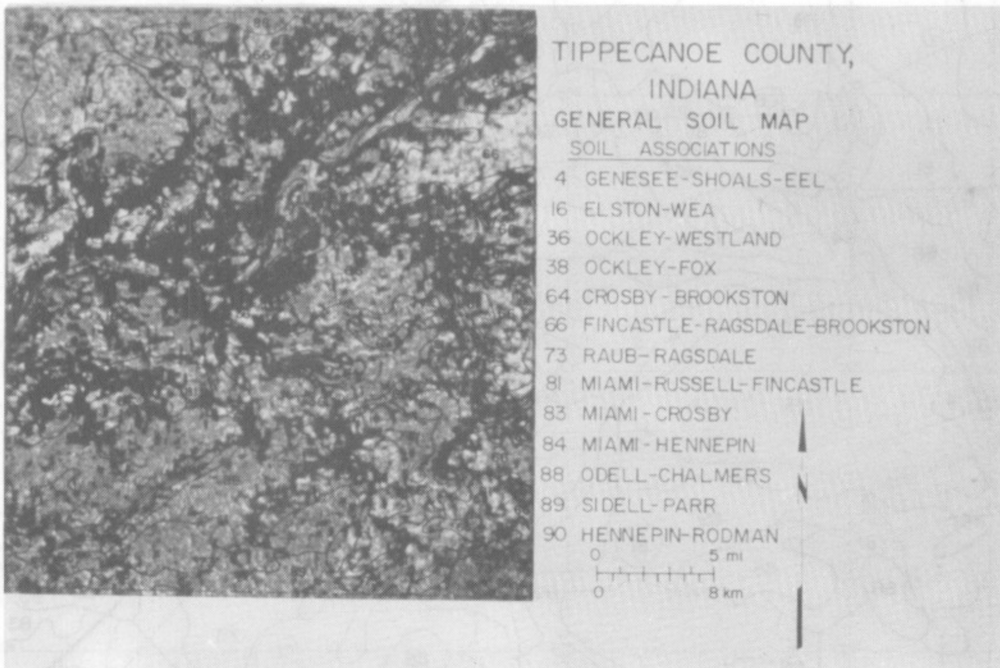

Figure 12. A nonsupervised computer classification of ERTS-1 data showing 10 spectral classes.