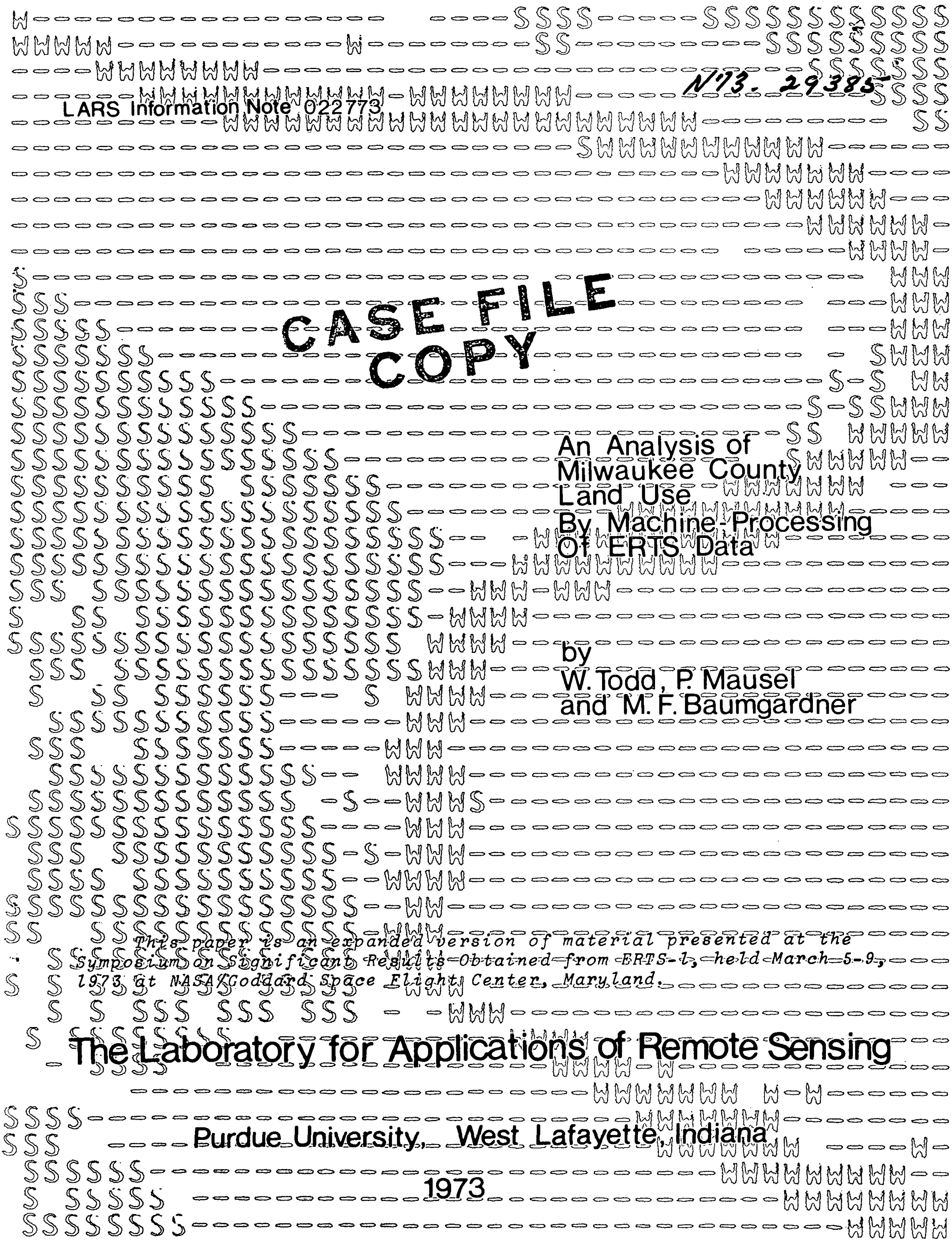

N73-29385

LARS Information Note 022773

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An Analysis of Milwaukee County Land Use By Machine-Processing Of ERTS Data

by
W. Todd, P. Mausel
and M. F. Baumgardner

This paper is an expanded version of material presented at the Symposium on Significant Results Obtained from ERTS-1, held March 5-9, 1973 at NASA/Goddard Space Flight Center, Maryland.

The Laboratory for Applications of Remote Sensing

Purdue University, West Lafayette, Indiana

1973

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An Analysis of Milwaukee County Land Use By Machine-Processing of ERTS Data

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February, 1973

Published by the
LABORATORY FOR APPLICATIONS OF REMOTE SENSING (LARS)

Purdue University
West Lafayette, Indiana 47906

ABSTRACT

The identification and classification of urban and suburban phenomena through analysis of remotely-acquired sensor data can provide information of great potential value to many regional analysts. Such classifications, particularly those using spectral data obtained from satellites such as the first Earth Resources Technology Satellite (ERTS-1) orbited by NASA, allow rapid, frequent and accurate general land use inventories that are of value in many types of spatial analyses.

In this study, Milwaukee County, Wisconsin was classified into several broad land use categories on the basis of computer analysis of four bands of ERTS spectral data (ERTS Frame Number E1017-16093). Categories identified were: 1) road-central business district, 2) grass (green vegetation), 3) suburban, 4) wooded suburb, 5) heavy industry, 6) inner city, and water. Overall, 90 percent accuracy was attained in classification of these urban land use categories.

The work described in this report was sponsored in whole or in part by the National Aeronautics and Space Administration (NASA) under Grants NGL15-005-112 and NAS 5-21773.

INTRODUCTION

The technology currently available at Purdue University's Laboratory for Applications of Remote Sensing (LARS) to classify earth surface features from multispectral data is sophisticated and esoteric. However, the availability of this technology is expanding rapidly as program packages and networks of remote computer terminals proliferate. Furthermore, an experimental laboratory such as LARS not only develops and perfects data processing techniques, but also proves their capabilities through application.

This paper describes a successful application of state-of-the-art remote sensing technology in classifying an urban area into its broad land use classes. Though such an analysis of ERTS-1 urban land use classification capabilities at this stage in the development of orbital remote sensing is very significant to the scientific community, it does not constitute an application of this technology to a specific areal problem. Nevertheless, this research is significant in that it proves that numerous urban features are amenable to classification using ERTS multispectral data automatically processed by computer. Furthermore, such automatic data processing (ADP) techniques permit areal analysis on an unprecedented scale with a minimum expenditure of time. Also, classification results obtained using ADP procedures are consistent, comparable, and replicable, hence many spatial analysis problems caused by human errors or decisions are eliminated.

Land use information systems are becoming of increasing interest to investigators who study large urban complexes. Additionally, city, county, and metropolitan officials, as well as planning agencies, find themselves in the position of needing more and better land use data to aid in their decision-making processes. The purpose of this paper therefore, is to describe classification work performed on the Milwaukee area and to assess the potential utility of ERTS data for urban land use analysis.

THE UNREFINED DATA

On July 23, 1972, the National Aeronautics and Space Administration (NASA) launched its first Earth Resources Technology Satellite (ERTS), which passes over any given point on the earth's surface every 18 days at an average altitude of approximately 915 kilometers (490 nautical miles).

August 9, seventeen days after launch, ERTS collected imagery over a large area in the Middle West, including portions of northern Illinois and southern Wisconsin. Fortunately, Milwaukee County (Figure 1) was almost cloud-free, allowing ERTS to transmit relatively clear, multispectral imagery of this large metropolitan area.

The Milwaukee imagery was collected by the ERTS multispectral scanner, which records reflected energy from earth surface features and converts it into electronic signals. The resolution of the scanner is approximately 80 meters. It receives data from four portions of the electromagnetic spectrum: 0.5 to 0.6 μm (Band 4), 0.6 to 0.7 μm (Band 5), 0.7 to 0.8 μm (Band 6), and 0.8 to 1.1 μm (Band 7). (The first two bands are in the visible portion of the spectrum while the second two are in the reflective infrared Thus, as the ERTS scanner "scans" an area on the earth's surface, four simultaneous signals are received and subsequently transmitted to one of NASA's three receiving stations where they are stored on magnetic tapes.

Work performed in this study was accomplished at the Laboratory for Applications of Remote Sensing, Purdue University, which is contracted to analyze portions of the ERTS data. At LARS, data received is reformatted for use by the Lab's data processing system, then stored on magnetic tape by line and column coordinates, not unlike a Cartesian coordinate system of coding.

--Procedure--

Each band was viewed areally on an IBM digital image display system (which provides a television-like image) prior to statistical manipulation (combination) of the four sets of spectral data (Ref. 1). Then, data points from each one of the four bands were displayed and photographed using sixteen brightness levels (Figure 2). Previously, the data had been "histogrammed" in each band, (i.e., the range of spectral response divided into sixteen levels having equal frequency of occurence) and successive brightness levels assigned to the different levels of spectral response. In this system, the lighter areas of the imagery have the higher responses (spectral reflectance), and the darker areas the lower responses.

It should be noted that caution must be taken in analyzing these and other images discussed in this paper because an ERTS remote sensing unit (RSU) or resolution element is rectangular, while the digital display data points are arranged in a square format. Thus, the true ratio of length to width of a data point is 4:3, while on the digital display it is 1:1. Consequently, distances on the imagery require adjustment and the data appear to have been collected from an oblique angle.

There is much similarity between the two visible bands (four and five), and between the two infrared bands (six and seven). The visible bands allow ready distinction between the highly urbanized areas, suburbia, major transportation routes and the outlying agricultural regions. The infrared bands, on the other hand, most clearly differentiate the central, older part of the metropolitan area from the suburban and agricultural areas.

DATA PROCESSING

Significant amounts of information may be deduced from studying one or more brightness level (grayscale) images from a single band;

however, it was of greater value to combine the bands of data in order to obtain a single, integrated land use classification of Milwaukee County.

System analysts at LARS have implemented the "LARSYS" package of computer programs, which allow the investigator to identify earth surface features by automatic pattern recognition techniques (Ref. 1) and individual researchers at LARS develop their own methods of utilizing the various LARSYS programs. An outline indicating the specific procedures followed in this analysis is displayed in diagram form (Figure 3).

The LARS cluster analysis program ($NSCLAS) was used to aid in the interpretation of the basic spectral data groupings. This program utilizes a clustering algorithm that dissects a given set of data points into the most spectrally separable (distinct in multi-dimensional space) classes using all four wavelength bands (Ref. 2). A priori information (ground truth) that would help identify data points (e.g. water RSU) is not required for cluster analysis. This identification of spectrally separable classes helps to facilitate the accurate recognition of classes of earth surface features. An earth surface feature that has its own distinct spectral response would be identified by a grouping or clustering of the data points spectrally characteristic of that feature in a cluster analysis.

The key step in the clustering algorithm is specification of the number of spectral classes (clusters) the researcher wishes the program to find (Ref. 3). In this study, the number of clusters was set at fourteen. The program could not, however, cluster all of the data points in the total Milwaukee urbanized area because of computer memory limitations. Therefore, a small area in the central part of Milwaukee County was chosen for cluster analysis because it was considered least likely to represent too many subclasses of vegetation and other natural features (which would seriously complicate an urban-focused analysis). Using the LARSYS statistics processor, statistics (means, standard deviation, and covariance matrices calculated from the data points in each cluster) were obtained for the fourteen spectral classes identified by the clustering program (Ref. 1). The spectral class statistical data were then automatically punched on IBM cards or recorded on tape in order to provide a statistical characterization of each class which other LARS programs could then use to complete a classification analysis. All RSU's in the study area were subsequently classified into one of the fourteen classes (the spectral characteristics of each class are known from statistical analysis of samples and possibly represent a class or subclass of a meaningful earth surface feature) using the Gaussian "maximum likelihood" classifier program ($CLASS) (Ref. 1). The results of the classification were then displayed by a line printer, with different alphanumeric symbols used for each class. The display results included computer maps which served to aid in refining classification or as an end product which indicated areal distributions of earth surface features.

The classification results of the described sequence of computer programs were generally poor when compared to samples of "ground truth" obtained from maps. Nevertheless, careful study of the line printer map and of class means and standard deviations gave important clues to the reasons for identification errors that the "non-supervised" clustering approach had made. Areas of heavy industry, for example, had been classified as a type of water. The central part of the study area consisted of data points from five classes, which had seemingly random distribution. These classes had similar means, and were subsequently considered as a single type of land use. Because of these and other errors, it was necessary to use areal samples of known phenomena to spectrally characterize each of fourteen classes of urban earth surface features (Table 1). The use of areas (samples) of known materials in training the computer to recognize similar kinds of materials is characteristic of a supervised classification.

The line and column coordinates of each sample were recorded and punched onto computer cards in order to identify, for the computer, areas that contained the spectral data used for training in a supervised classification. Only one class delimited by the clustering analysis (that representing grassy, open areas) was considered accurate enough to be retained. The field coordinate cards for that class were combined with those manually chosen for the other classes. After the samples of known phenomena were incorporated into the analysis, the statistics processor and classification programs were used to classify the study area.

The degree of spectral separability of the classes, each of which was represented by training fields, is indicated quantitatively (Figure 4). Note that some classes were not separable from all other classes in three or fewer bands; however, all classes except "trees" were reasonably separable from all other classes when all four bands of spectral data were analyzed. For example, all the water classes had very similar responses in Band 7, which made an accurate identification of each one of these classes impossible using that Band alone. Classes "water 1", "water 2", and "water 5" were spectrally separable in Band 4, but "water 3" and "water 4" were not. The latter channels were separable, however, when the data from Band 5 was also considered. Thus, the use of two bands of spectral information led to a more accurate identification of five classes of water than the use of any single band.

After the study area was classified, the $PHOTO program (Ref. 1) was used to display and photograph the results from the digital image display (Figure 5). The program allows the researcher to assign one of sixteen levels of gray to each class and the classes, along with the "brightness levels" assigned to them, are listed (Table 1). The classes, "water 3", "water 4", and "inner city", were assigned level 1 (the darkest); "road", "suburban", and cloud were assigned level 16 (the lightest); and the remaining classes had distinguishable gray levels in between. Interpretation of selected aspects of the classes delineated in the Milwaukee County study area was performed from the urban land use classification in this synthesized photographic form.

INTERPRETATION OF CLASSIFICATION

--Theoretical Considerations--

The broad land use classes used in the ERTS analysis of Milwaukee County can be divided into two types of spectral responses, herein designated as homogeneous and heterogeneous. A land use class with a relatively homogeneous spectral response is characterized by a single phenomenon or a group of spectrally similar phenomena providing the overwhelming influence in the total spectral response that is obtained from the multispectral scanner.

The resolution of multispectral data from space, for instance, tends to make the identification of subclasses of green vegetation very difficult since the spectral responses from the various botanical forms are similar. Hence, in a small-scale or highly generalized classification of land use it is initially easiest and most accurate to consider green vegetation as a mixture of phenomena with similar spectra (homogeneous) rather than attempt to analyze a large number of subclasses of vegetation, each characterized by a unique spectral signature. Higher resolution data from a low-altitude scanner or other remote sensing equipment can more easily separate green vegetation into many of its components than can be done with ERTS data. Most of the classes "water" also can be considered homogeneous, indicating the spectral response that identifies the class is similar throughout the entire area given that class designation. As a further example, grass and trees do not have an identical spectral response; however, both phenomena do occupy relatively similar positions in a spectral grouping in multi-dimensional space. Therefore, the class "grass" in the ERTS analysis can be considered relatively homogeneous spectrally, even though in reality the class contains not only grass, but also trees, and other forms of green vegetation.

However, the land use classes of an urban study area was viewed by low resolution scanner are usually comprised of two or more distinctly different types of spectral responses which generally indicates that a mixture of diverse phenomena is present in a given class. Land use classes of this nature are termed heterogeneous. For example, the classes "road-central business district (CBD)", "inner city", "industry", "suburban", and "wooded suburb" represent the relatively heterogeneous earth surface features classified in this study.

In this analysis, it was hypothesized that there were at least three basic homogeneous groupings of earth phenomena; each with its own distinct spectral characteristics (in a multispectral application). The heterogeneous classes of land use were comprised of various proportions of a minimum of two or three spectrally diverse groups of phenomena. The class "suburban" was predominantly a mixture of rooftops (asphalt), sidewalks (concrete), roads (asphalt and concrete) and green vegetation (grass and trees).

Although an individual roof, tree, lawn, or sidewalk cannot be identified at the resolution attained by ERTS (resolution is approximately 80 meters by 60 meters) the combined spectral response from the various proportions of all phenomena present in the area may permit the differentiation of one urban phenomenon from another. The class "suburban", for instance, which is primarily a mixture of rather highly reflective materials (e.g. concrete), materials of low to very low reflectance (e.g. asphalt), and materials of variable reflectance dependent on which ERTS band is used (e.g. green vegetation), should have a combined reflectance (using all ERTS bands) different than the class "road-CBD", which is comprised solely of concrete and other rather reflective materials complimented by lower response materials such as asphalt (Table 2). The class "road-CBD" has a different overall spectral nature than that of class "suburban" because of the differences in the proportions of material that comprise each class (Table 3). Thus, it may be feasible to define broad classes of urban phenomena based on the proportions of groups of spectrally different phenomena that comprise each class (Ref. 3).

A graphic summary of the probable composition of the most important heterogeneous classes in Milwaukee County is presented (Table 3). The spectral responses of the land use classes used in Milwaukee (Figure 4) can be understood when compared with relative reflectance data (Table 2) and information on the probable composition of each class (Table 3). Further study will be required in order to better understand spectral responses from complex environments, but the basic principles of the theory as described in its less complex form worked well in developing broad land use classes for the ERTS analysis of Milwaukee County. This theoretical framework, although not complete or definitive, nevertheless provided information which aided in the selection of urban land use classes that were most likely to be classified accurately at the resolution inherent in the ERTS system.

--Areal Distribution and Characteristics of Classes--

The white zone in the central part of the study area (L - 18, 19 on Figure 5) is Milwaukee's Central Business District (CBD), and bordering modern dwelling units (luxury high rise and low rent public housing apartments). This class, initially termed "road-CBD", is almost totally a mixture of rooftops and concrete, hence it has a very high reflectance in the visible bands. Data points of this class also occur as Interstates 94, 894, and 794; U.S. highway 141; and the sandy beaches along Lake Michigan (Figure 5). All of these features have a very high spectral reflectance (bright tone areas), especially in the visible bands.

The initial ring outward from the Central Business District (in black), designated "inner city", extends from approximately Burleigh Street (I - 15,16,17) on the north to Cleveland Street (O - 17 to 21) on the south, and from 60th Street (K - 13, L - 14, M - 15) on the west, to Lake Michigan on the east. A great many of the homes in this area are the bungalow or "two-flat" type of structure. Typically, the houses were built very close together, and the majority were built prior to World War II. The "inner city" corresponds closely with the multiple-family housing area of Milwaukee County, as depicted by the Southeastern Wisconsin Regional Planning Commission land use map (Ref. 4). A "zone of transition" usually exists between the larger areas of residential land uses. For example, note the complexity of spectral response in the area where the northern part of the "inner city" meets the class "suburban" (I - 14 to 18 -- Figure 5).

The class "industry" (dark gray tone intermediate between tones given to "grass" and "wooded suburb") was identified only where the larger areas of heavy industry predominate. The principal areas identified include the Capital Drive-35th Street area (I - 14,15), Capital Drive-Richards Street area (I - 18), and the Menomonee River Valley (M - 16 to 19); additionally, the 70th Street-Greenfield Avenue area in West Allis (N - 13), southern West Milwaukee (N - 15), the Kinnickinnic River Valley on south 1st Street (M - 20,21), and Packard Avenue in Cudahay (Q - 26). The industrial areas are characterized by a large percentage of rooftops or other relatively non-reflective materials. This results in spectral characteristics that differentiate many industrial areas from other urban phenomena. Note that data points of the class "inner city" are frequently found interspersed among the industrial areas.

The second ring outward from the Central Business District is an area of complex land uses, including suburban, recreational, and institutional. This ring extends from approximately Good Hope Road (F - 7 to 10, E - 12 to 17), to College Avenue (R - 19 to 23), and westward to 124th Street (western boundary of the county). The three primary classes identified in this area are "suburban" (white), "grass" (dark gray), and "wooded suburb" (light gray). Most of the ring is classified as "suburban", the principal areas being the outer areas of the City of Milwaukee, northern Wauwatosa, West Allis, Greenfield, Greendale, Hales Corners, Cudahay, South Milwaukee, St. Francis, and Brown Deer (Figure 1). The "suburban" areas are dominated by single-family dwellings built on modest-sized lots. Roads, sidewalks, and vegetation (in addition to homes) are well-established features in this land use class. The "wooded suburb" areas include southern Wauwatosa, Fox Point, Whitefish Bay, and Shorewood. This class consists of single-family dwellings built on large wooded or grassy lots. A smaller percentage of the land is devoted to roads and sidewalks in the class "wooded suburb" when compared to that of the class "suburban".

The spectral class "grass" in the built-up area of the county is primarily found in recreational lands, parks, golf courses, and cemeteries. The primary grassy features of central Milwaukee County (Table 4), along with their locations, are identified (Figure 5) as are other spectrally separable features of interest. The class "trees" was not possible to separate or identify although this class was used initially in classification procedures to help purify other classes. The spectral response of the class "trees" overlapped (in all bands) part of the classes "grass" and "wooded suburb" (Figure 4). Thus, these two separable classes were developed from three classes that were marginally separable.

The outermost ring from the city is principally rural with the major **cover types** being "grass" and small water bodies. Two of the larger ponds identified are Big Muskego Lake (W-8) and Little Muskego Lake (V-4).

Five spectrally different types of water were identified within the study area (it is recognized that this may be more information than is presently needed or desired by the urban specialist). Four of the classes, "water 1", "water 2", "water 3", and "water 5" are located almost exclusively in Lake Michigan. In fact, there is a regular succession of water classes eastward into the Lake. Though this suggests that the water classes are indicative of water depth, examination of two U.S. Geological Survey topographic quadrangles (Ref. 5), indicates little association between the water classes and depth.

The fifth class of water ("water 4") occurs in small water bodies and in the Milwaukee River. Not unexpectedly, this class also appears in Milwaukee Harbor (K,L,M - 14) and along Lake Michigan's coast to the south. Evidently, water from Milwaukee Harbor (into which flows the Milwaukee River) slowly mixes with the lake water as it is carried south along the coast. Although only speculations can be put forth at this time, factors influencing the spectral differences of the water may be variations in color and turbidity.

Five clouds (all classified as "clouds") were identified (white) within the study area, one just south of Franklin (Y - 17,18), one in Oak Creek (W-24), one northwest of Lawrence J. Timmerman Airport (H-8), one near Brown Deer Park (E-13), and one north of Milwaukee County (A-2). Associated with each cloud was a shadow (black), located approximately 4 blocks (1/3 mile) to the northwest. All cloud shadows were classified as "shadow", except the one near the airport. Most data points of that cloud shadow were classified as "water 4" because of similarity in spectral response.

ACCURACY OF CLASSIFICATION

The identification of land uses in Milwaukee County was least successful near the urban-rural fringe. Some small, upper income areas located in the outer areas of the county and to the west were classified as "grass" areas. Moreover, many small grassy areas in the outlying region were classified as "wooded suburb". The problem which was evidenced by these mis-classifications is that many classes (particularly "suburban", "wooded suburb", and "inner city") are mixtures of spectrally different ground cover types, including various proportions of vegetation. It was not unexpected that some portions of the rural fringe should be classified incorrectly considering the fact that no single class was determined for wooded areas.

Land use identification within the more built-up areas of the county was limited to the six general types "suburban", "inner city", "industry", "wooded suburb", "grass", and "road-CBD", though water and totally rural classes of land use are also possible to identify using classification procedures similar to those used in identifying the more urban features in the study area. Excluded from this list were important subclasses of urban land uses, such as commercial, utilities, transportation (other than road), and institutional because, at the present state-of-the-art, the resolution of the ERTS scanner is not sharp enough to detect these phenomena. It is possible that some urban land uses now excluded from accurate ERTS data-based identification will become identifiable when new techniques or sensor systems are developed.

The pragmatic value of the classes that were identified depends in large part, of course, on the degree of their accuracy. Overall, over 90 percent of the broad land use categories discussed in this analysis were identified correctly on the basis of a comparison between known land usage (obtained from various Milwaukee County maps) and samples of the study area classified from ERTS data. This high degree of accuracy indicates a good potential for spatial analysis of urbanized areas. This is particularly encouraging in view of the fact that this Milwaukee analysis was one of the first attempts made to use ERTS data in this application.

SELECTED GEOGRAPHICAL ASSOCIATIONS

In addition to the broad comparisons made between official maps and multispectral sensor (MSS) classification information, associations can be discerned between classification of the ERTS imagery gathered over Milwaukee and socio-economic data published by the U.S. Bureau of the Census (Ref. 6). The distribution of a single variable, percentage of structures built prior to 1940 is indicated (Figure 6). The area which contained 75 percent or more structures of pre-1940 construction corresponded well with the areal extent of the class "inner city". The association weakens, however, in the eastern part of the city of Shorewood, where the older neighborhoods tend to be in the class "wooded suburb". Another, more abstract, association may be made using the variable median annual family income (Ref. 6). The close association between the class "inner city" and the area with less than $9000 income is apparent (Figure 7). This association is not present in the north-western part of the "inner city". Another areal correlation exists between the upper income areas (greater than $14,000) and the distribution of the class "wooded suburb".

Though these associations were not central to the purpose of this study and have not yet been pursued, the ramifications are intriguing. It is tempting, for instance, to calculate a correlation coefficient between the percentage of data points in a census tract which have been classified as inner city and 1970 median family income; however, this concept is more easily illustrated cartographically (Figure 7).

GEOGRAPHICAL IMPLICATIONS

The most obvious users of the type information gained in this analysis are urban geographers, city planners, and urban regional planners since accurate knowledge of spatial patterns of the six broad phenomena provides a basic framework for planning and studies in the morphology and dynamics of urban systems.

--Land Use Inventory--

One of the potential functions of ERTS data classification in Standard Metropolitan Statistical Areas (SMSA) is to provide information that leads to an accurate land use inventory and those inventories, even at the scale suggested by the Milwaukee County study, are a valuable tool for many regional specialists.

Though a small-scale land use inventory map of a SMSA would appear to be a commodity easily attainable without the use of ERTS, the quality of such non-MSS maps is frequently degraded by incompatibility and gaps in the data from which they were constructed. Data that are used to construct a small-scale land use inventory map, for example, may well be derived from different years, collected by diverse methods and subject to various interpretations in compilation. A complete and accurate map of land use for a given date is difficult to obtain even in a country or area that has access to large amounts of land use data because the cost and time factors may make the development of such a map unfeasible.

Furthermore, in certain underdeveloped countries there exist urban areas where no census has ever been taken. Though the accurate broad land use inventory achieved in Milwaukee may be of modest interest to city officials there, a comparable analysis would be welcomed in a country which has only vague notions of its urban spatial arrangements and interrelationships. It has been shown from this study, for instance, that different types of residential areas may be identified within urban areas. Transposing these techniques to a foreign city, a limited amount of carefully-planned field work could sample dwellings in neighborhoods of differing socio-economic conditions, then these socio-economic data could be combined with ERTS spectral data (analyzed by automatic data processing techniques) to obtain spectral signatures of residential phenomena. Finally, population and economic characteristics could be estimated from these phenomena. The accuracy of this method would not rival the procedures currently used to evaluate socio-economic characteristics in the developed countries; however, evaluation of the information gathered from space would provide data suitable to help make urban decisions until better sources of information became available.

Theoretically (assuming cloud-free conditions), over 31 million square kilometers (12 million square miles) of the earth's surface can be scanned by ERTS every day. With these capabilities, a score or more of urban areas could be sensed remotely in a single day with classification results similar to those obtained in Milwaukee, and research does indicate that the classification procedures used for the Milwaukee study will be applicable for other urban areas that have developed under similar socio-economic conditions (e.g., Milwaukee classification data can be used to classify land use in Chicago under proper conditions). Furthermore, the data for these analyses come from one source only, (spectral reflectance data obtained from ERTS); hence, variability in and comparability of data are not problems. Additionally, the spectral data used in land use inventory analysis are subject to a variety of manipulations within the data processing system which permit the researcher to develop special purpose classifications that best fit a specific need.

--Temporal Analysis of Spectral Data--

It has been shown that an accurate small-scale land use inventory classification can be obtained through spectral and spatial analysis of ERTS data. Additionally, the use of ERTS makes possible for the first time in history, frequent and regular temporal analysis of earth surface features. Under ideal conditions, a SMSA or any other earth surface area can be spectrally analyzed and classified into land use types every 18 days. The impact of this ERTS characteristic on potential accuracy is great since the quality, accuracy, and detail of land use classification improves as the number of "scans" at different dates increases.

The possibility of viewing changes in urban land use every 18 days should excite the urban geographer and urban regional planner. These temporal data provide a dynamic inventory of urban land uses which are of inestimable value in monitoring urban systems, planning future urban growth, providing data to facilitate proper zoning and other legal land use decisions, developing and testing urban geography models, and analyzing various temporal-spatial interrelationships in contact zones between urban and rural activity.

To review, therefore, the list of real and potential advantages of using automatically data processed ERTS data for developing broad land use inventories of SMSA (and other) areas includes, in addition to the temporal capability: (a) speed and accuracy in classification of earth surface features (b) comparability of classification from one area to another (as a result of data collected in a single day, under comparable physical conditions and processed in a uniform manner); (c) versatility in the processing of spectral data (which can result in displaying land use patterns in a variety of ways); (d) economical acquisition of broad land use pattern information; (e) feasibility for obtaining accurate urban land use data in selected underdeveloped parts of the world.

Though it is too early to predict the extent to which these real and potential advantages will be applied, it is important that the urban regional specialist become aware of the possibilities inherent as this potent weapon is added to his arsenal of analytical techniques.

# #

TABLE 1--Relative Spectral Reflectances of Earth Phenomena in Milwaukee County

Class	Class $\overline{X}$'s				
	bd 4	bd 5	bd 6	bd 7	Level[a]
Water 1	35.20	21.41	9.94	1.49	5
Water 2	24.23	10.37	5.40	0.69	3
Water 3	19.71	9.42	5.86	1.10	1
Water 4	21.47	13.85	12.65	3.34	1
Water 5	46.83	46.50	23.83	2.83	14
Grass	27.01	19.88	53.16	31.35	6
Trees[b]	24.03	16.25	44.18	26.59	6
Road--CBD	47.42	48.26	46.84	20.16	16
Wood Sub	24.94	18.66	40.24	22.91	10
Inner City	30.16	25.97	34.59	16.53	1
Suburban	39.17	37.09	53.12	26.99	16
Industry	25.98	21.77	21.30	8.50	8
Cloud	71.55	69.50	89.08	44.38	16
Shadow	17.70	9.45	16.15	6.75	1

[a]gray levels used in $PHOTO pictures of classification; level 1 is black and level 16 is white

[b]dummy class

Source: Compiled by authors from $STAT program

TABLE 2--Selected Earth Phenomena Spectral Groupings

Class:	Green Vegetation	Highly Reflective Urban Phenomena	Low Reflective Urban Phenomena
Example:	Trees Grass	Concrete Aluminum	Asphalt Tar
Dominant Relative Spectral Reflectance (ERTS Visible Channels):	Low	High	Low
Dominant Relative Spectral Reflectance (ERTS Infrared Channels):	High	High	Low

Source: D.G. Earling and J.A. Smith, Target Signature Analysis Center--Data Compilation (Ann Arbor, Michigan, Infrared and Optical Sensor Laboratory, Willow Run Laboratories, University of Michigan, 1966).

TABLE 3.--Spectrally Significant Components of Heterogeneous Classes of Urban Land Use in Milwaukee County

Class	Primary Components	Major Secondary Components
Road-CBD	Roads Sidewalks	----
Industry	Rooftops	Roads
Suburban	Roads Sidewalks	----
Wooded Suburb	Green Vegetation	Rooftops
Inner City	Rooftops Sidewalks Roads	Roads Green Vegetation
Water 5	Water	Silt Chemicals

Source: Developed by authors

TABLE 4.--The Location and Spectral Response of Selected Earth Surface Features in Milwaukee County

Feature	Location[a]	Spectral Class
Holy Cross Cemetery	J - 11	Grass
Wanderer's Rest Cemetery	J - 12	Grass
Forest Home Cemetery	N,O - 18	Grass
Union Cemetery	J - 16	Grass
St. Albert's Cemetery	P - 20	Grass
Graceland Cemetery	F - 11	Grass
Tripoli Golf Club	E - 11	Grass
Lincoln Park	H - 16,17	Grass
Washington Park	L - 15	Grass
Koskiusko Park	N - 19	Grass
Wilson Park	P - 19,20	Grass
Humboldt Park	O - 21	Grass
Warnimont Park	Q - 27,28	Grass
Grant Park	R - 28	Grass
Lake Park	I,J - 22	Grass
General Mitchel Field	Q.R - 24	Suburb
Menomonee River Valley	L,M - 16,17,18	Industry, Inner City
Capital Dr./35th. St. area	I - 15	Industry
Timmerman Airport	H,I - 7	Suburb
Port of Milwaukee	L - 20	Road
Central Business District	K,L - 18,19	Road

[a]See Figure 5 for location

Source: Developed by authors

REFERENCES

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4. Southeastern Wisconsin Regional Planning Commission, Existing Land Use in the Southeastern Wisconsin Region (Waukesa, Wisconsin, Southeastern Regional Planning Commission, 1963).

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ERTS IMAGERY

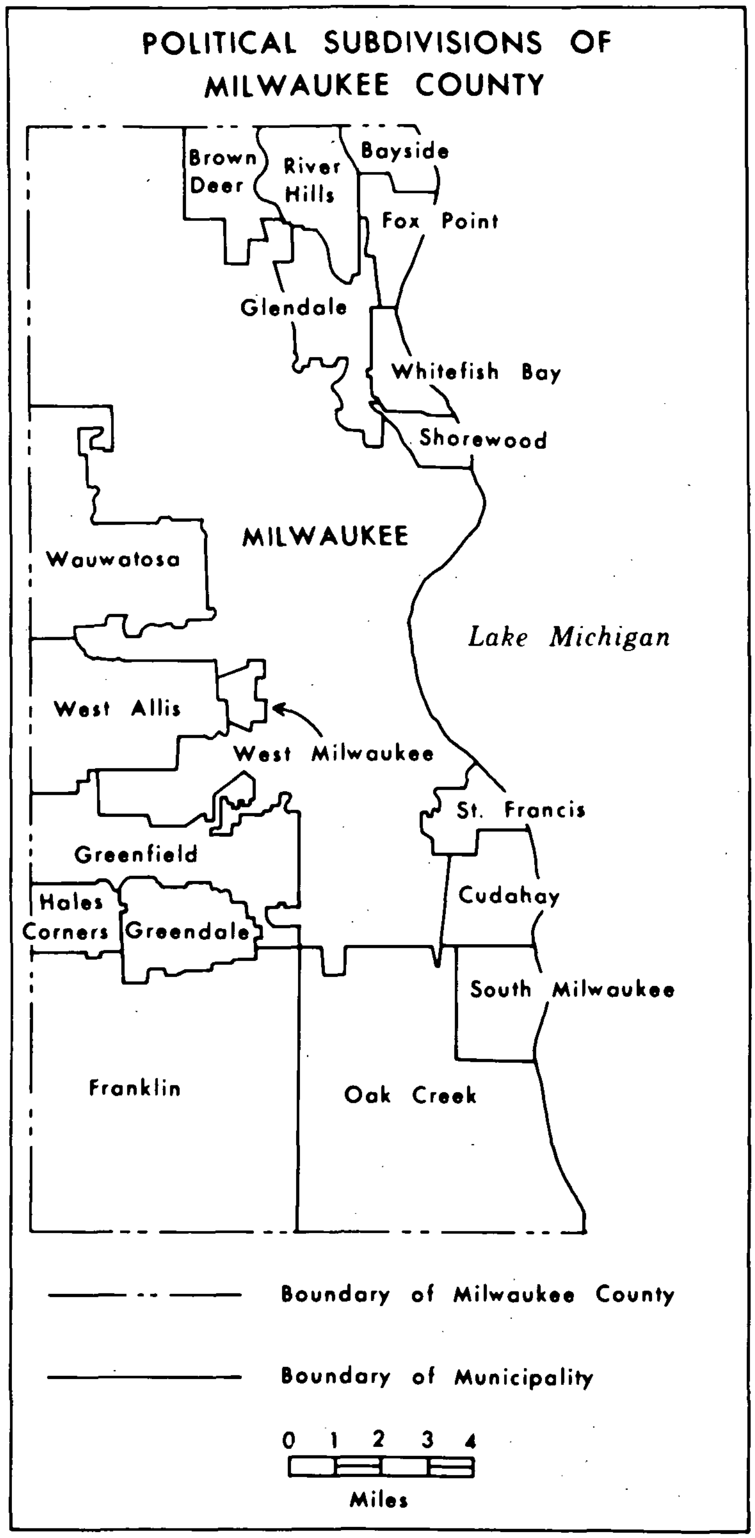
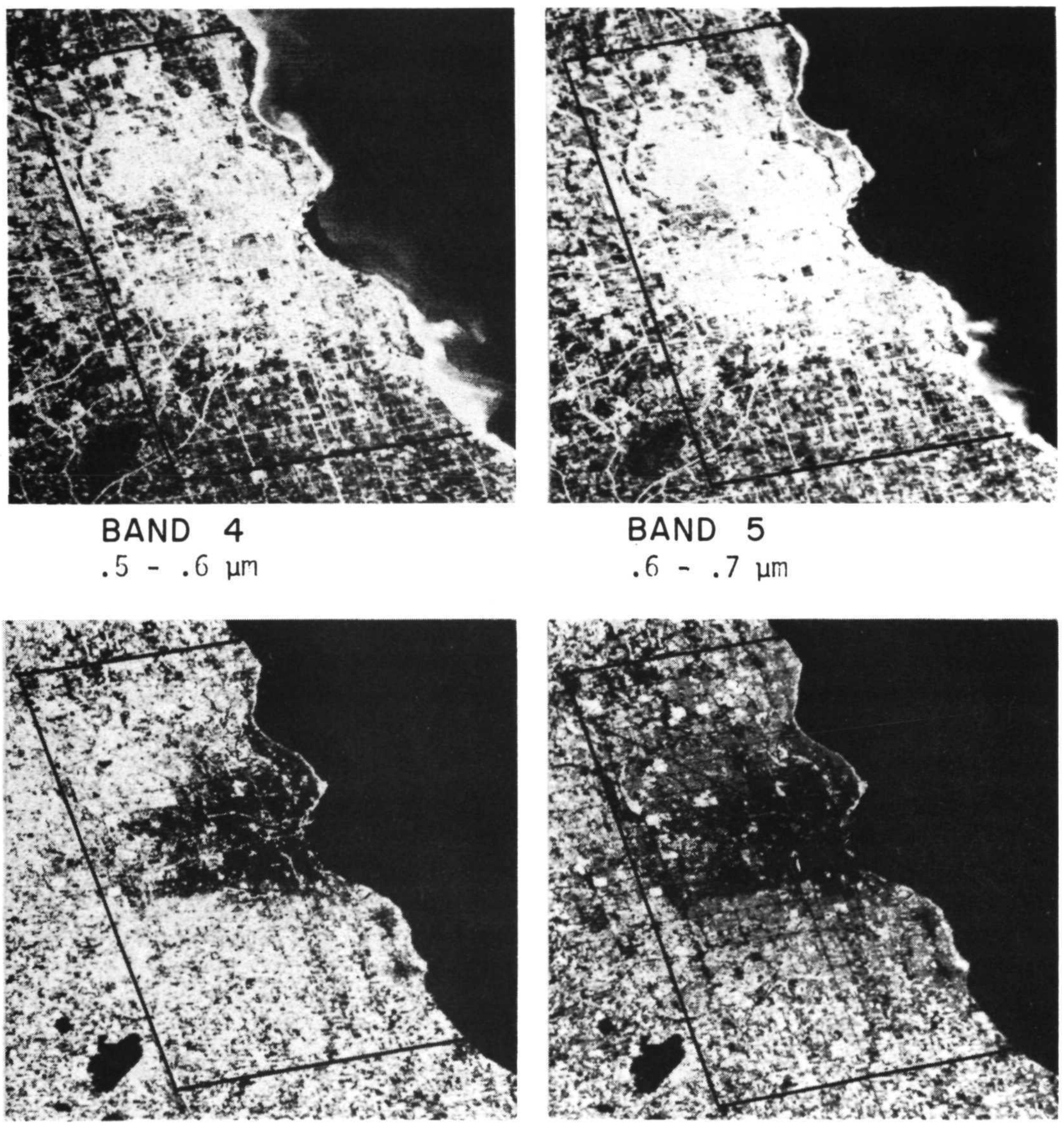


Figure 1. Milwaukee County Study Area



BAND 4
.5 - .6 μm

BAND 5
.6 - .7 μm

BAND 6
.7 - .8 μm

BAND 7
.8 - 1.1 μm

Figure 2. ERTS Gray Scale Imagery

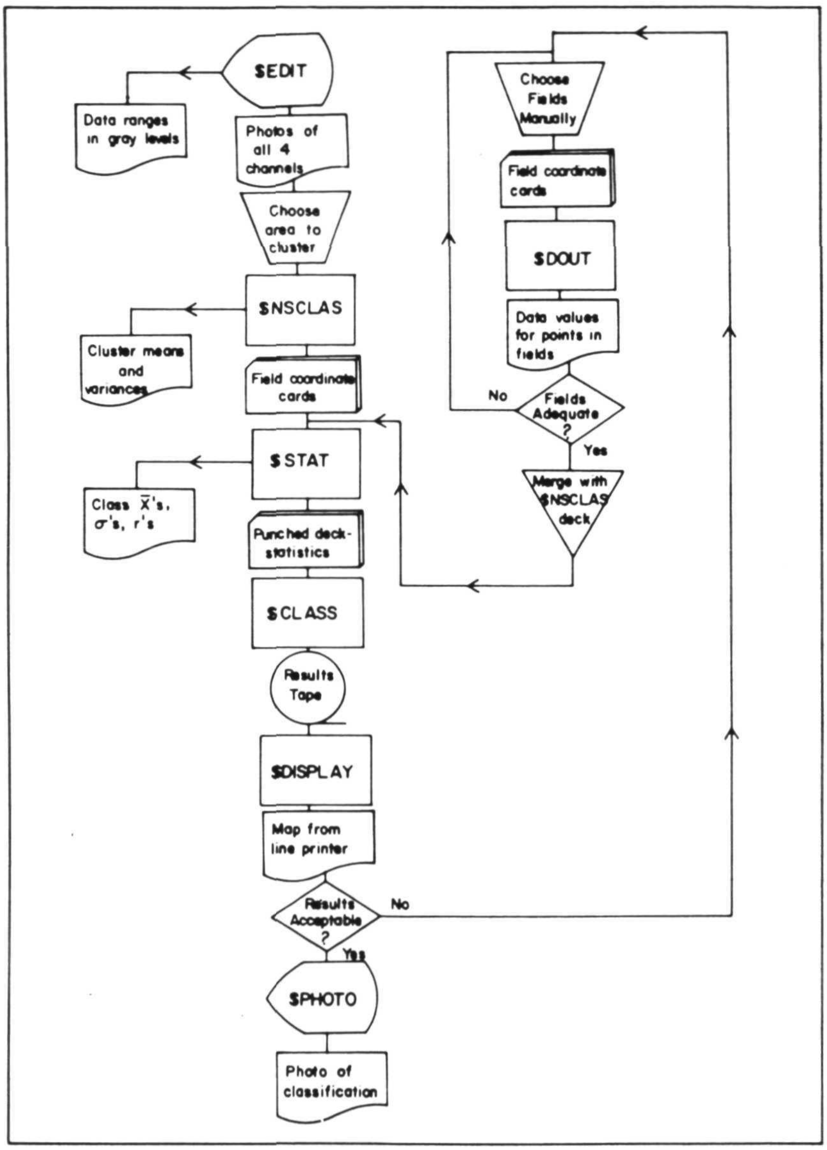


Figure 3. LARSYS Classification Procedures used in Analysis of Milwaukee County

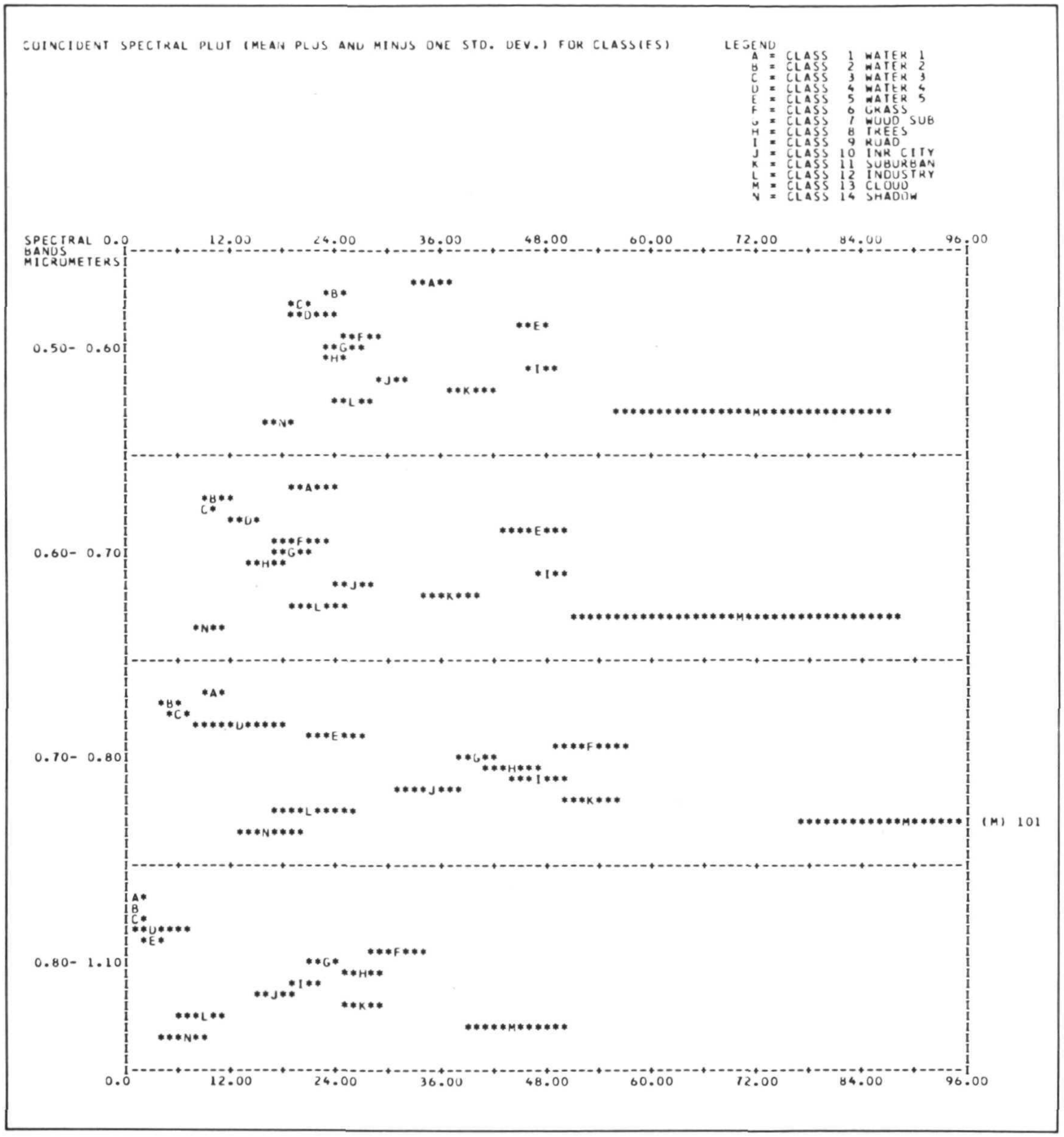


Figure 4. Relative Spectral Response Data for Land Use Classes

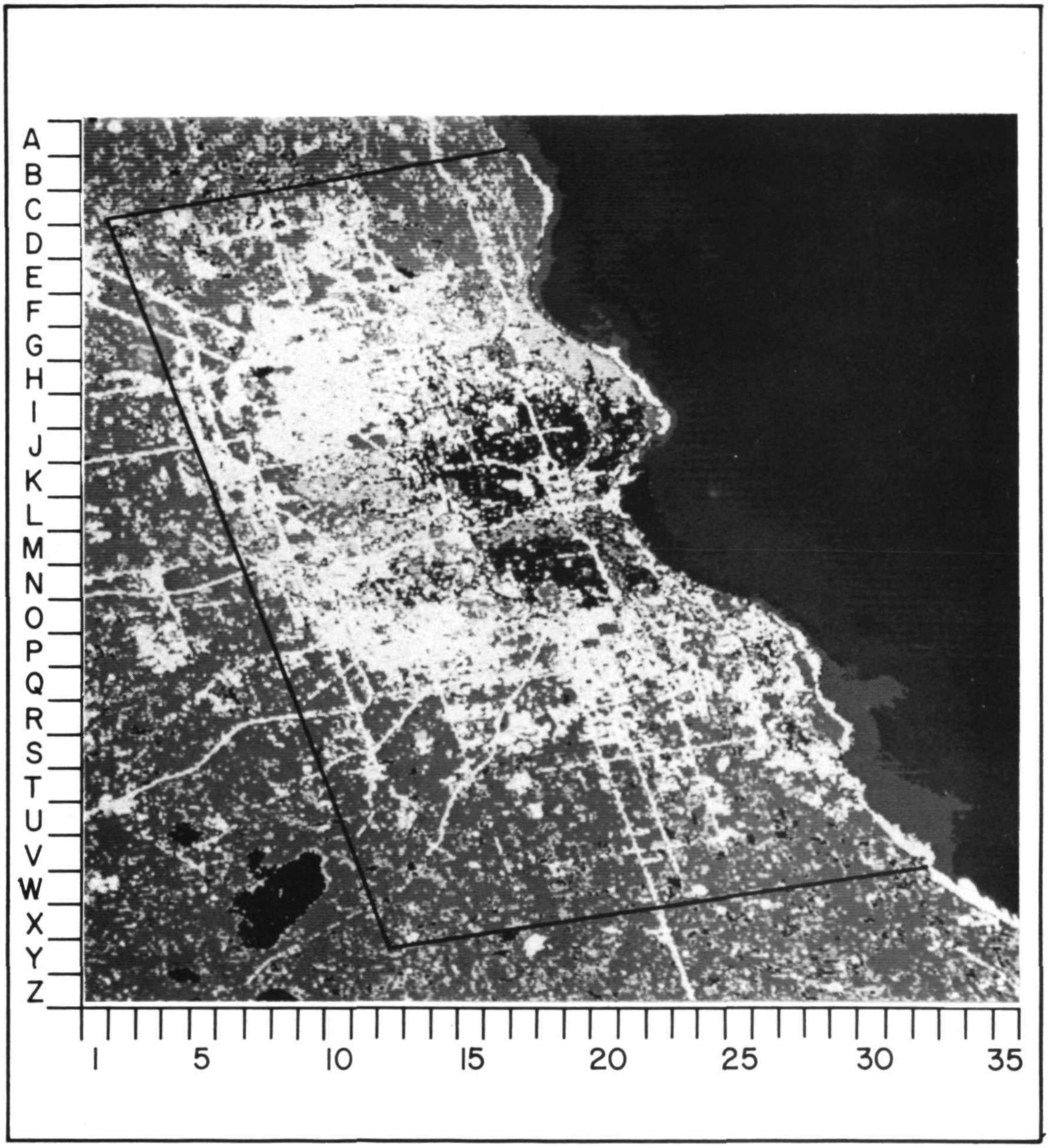


Figure 5. Digital Display Image of Land Use Classification

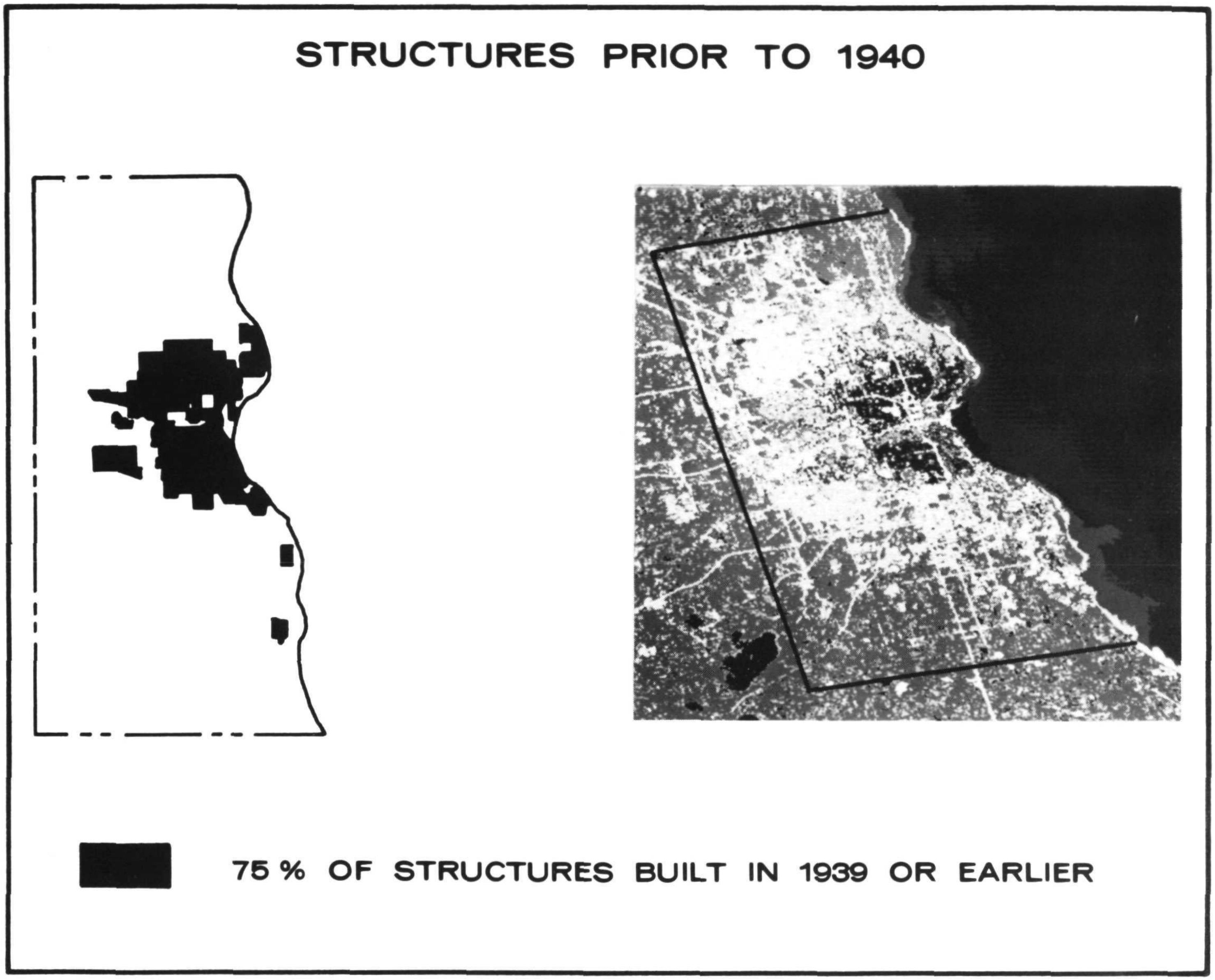


Figure 6. Association between pre-1940 Construction Areas and class "Inner City"

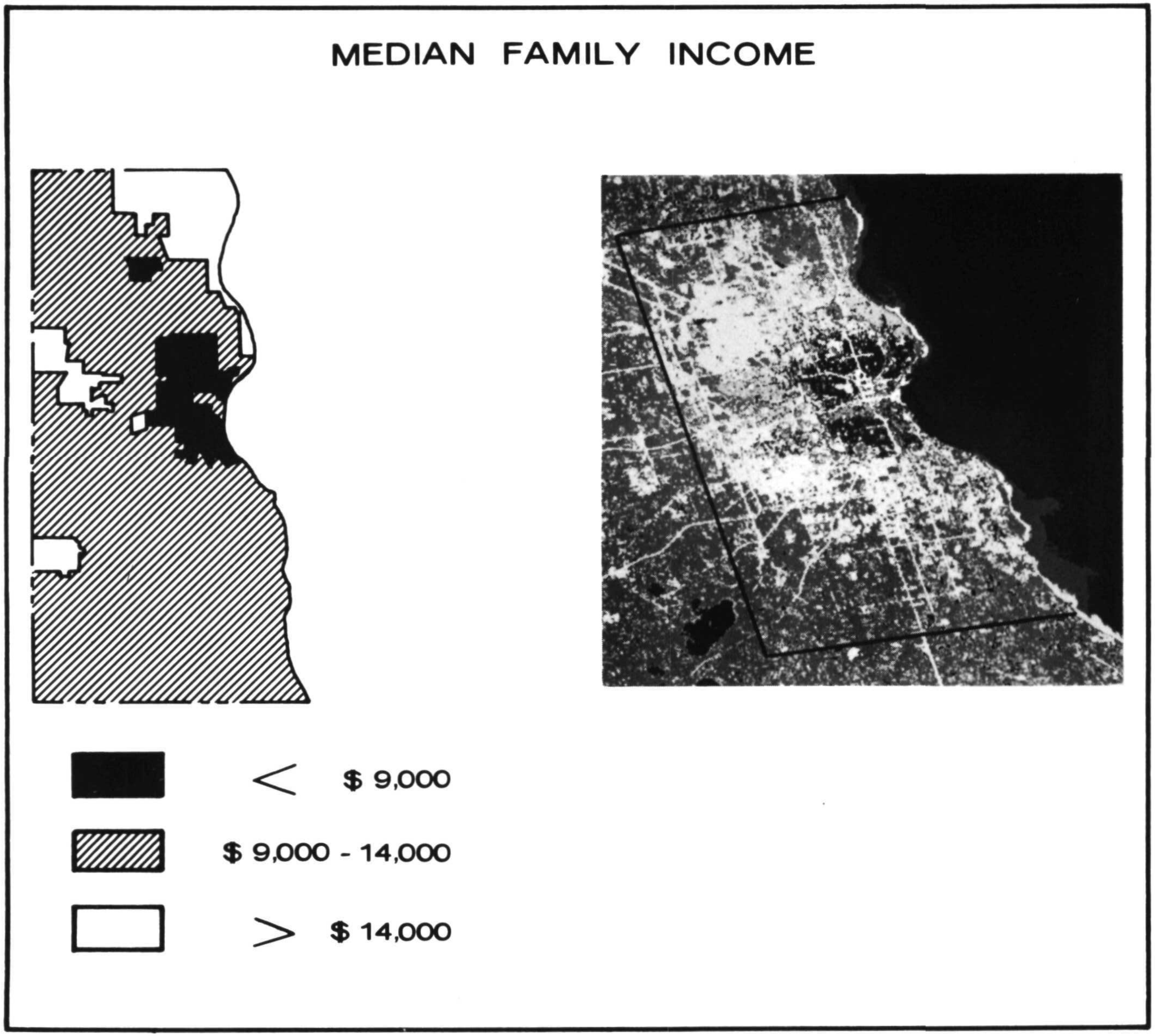


Figure 7. Association between Median Family Income Distribution and Land Use Classes