

URBAN LAND USE MONITORING FROM COMPUTER-IMPLEMENTED PROCESSING
OF AIRBORNE MULTISPECTRAL SENSOR DATA

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A significant portion of the budget of every city and county planning agency is allocated to the collection of land use data. A planning agency must have information pertinent to a variety of users. Often these information systems are costly, require many people, and are slow.

The purpose of this research is to investigate the alternative of using computer-implemented analysis of airborne multispectral scanner data to monitor urban land use. This monitoring should require a limited amount of human intervention. Computer-generated results from multispectral data can be ready for city and county officials to use within 24 hours after the data are acquired.

THE TEST AREA

An area of varied land use in Central Indianapolis along the West Fork of the White River was selected for this study (Fig. 1). This test area includes residential, recreational, industrial, commercial, transportation, and institutional land uses.

Multispectral scanner data were recorded at an altitude of 600 meters (2,000 ft.) on 10 August 1972 at 16:12 hours. Ground heading of the aircraft carrying the multispectral scanner was 345 degrees. The sky was cloudless, permitting the acquisition of high-quality spectral data from earth surface phenomena. Electromagnetic responses from earth surface features in the study areas were recorded in twelve spectral bands (Table 1). Eight bands are in the visible part of the spectrum, three are in the reflective infrared, and one is in the thermal (emissive) infrared.

DATA PROCESSING

A wide range of the electromagnetic spectrum is reflected and emitted continuously from the earth's surface. An airborne or earth-orbiting multispectral scanner is designed to measure the energy within several specific wavelength channels. Thus, for every area being monitored or scanned by multispectral sensors, a broad array of spectral data may be obtained. Since spectral data are recorded on magnetic tape, then digitized and arranged in lines and columns, they may be readily processed by a digital computer. The programs used in this study analyze several spectral bands and identify earth surface features by the differences in spectral responses. A surface that is spectrally separable (that is, having a unique spectral response in one or more, but not necessarily all, wavelengths) from all other features in a given study area is a good candidate to be identified accurately in a pattern-recognition classification program.

Three of the twelve wavelength bands of multispectral data (Band 6, .55-.60 μ m; 10, 1.00-1.40 μ m; 12, 9.30-11.70 μ m) are illustrated (Figure 2). Images of these three bands were photographed from an IBM digital display (an instrument which provides a television-like image of the digital data) and also displayed on alphanumeric line printer maps (Fu, Landgrebe, and Phillips, 1969). Bands 6, 10, and 12 were particularly good in providing differentiation between a large number of ground cover types on digital images of the study area. Representative areas of ground cover types which were thought to have spectrally separable characteristics were chosen. The training samples, as such representative areas are termed, were located either on the digital display or on alphanumeric line printer maps by association of

the imagery with aerial photos (Indianapolis Power and Light Company, 1972). The location or address (line and column coordinates) of a number of small, rectangular areas (training samples) in the flightline for each class of ground cover was recorded. Statistics (means, standard deviations, covariance matrices) from training samples in each class were then calculated, giving a quantitative, spectral characterization of each ground cover type. All of the data points in the flightline could be classified on the basis of the twelve band statistics, but such a job would require excessive computer time. Consequently, a separability program was used to select the best four bands to use for classification. Bands 1 (.41-.48 μ m), 6 (.55-.60 μ m), 10 (1.00-1.40 μ m), and 12 (9.30-11.70 μ m) were chosen. On the basis of the statistics from these four bands, every point in the flightline was classified into one of fourteen classes using a Gaussian maximum likelihood classifier (Wacker and Landgrebe, 1971). The classes "rooftop" (3 types), "road" (2 types), "dense grass" (2 types), "sparse grass" (2 types), "trees", "bare soil", "water" (2 types), and "shadow" were identified. The fourteen classes, along with their relative mean spectral response, are listed (Table 2).

CLASSIFICATION RESULTS

The classification of the study area is shown in Figure 3. The photo program can provide sixteen levels of brightness, but consecutive levels (e.g., level 3 and level 4) are difficult to distinguish visually. Thus, three different mosaics of the classification are presented to allow a clear distinction between all fourteen spectral classes. The gray levels used in each photomosaic for each class are listed (Table 3). The first photo (Fig. 3-A) shows the general classes of earth surface features identified in the study area. The three "rooftop" classes are displayed as one gray level, the two "road" classes as one level, the two "dense grass" classes as one level, and so on. "Trees", "bare soil" and shadow have distinct gray tones. The second photo (Fig. 3-B) shows variation primarily in the cultural features. The two "dense grass" classes, two "sparse grass" classes and "trees" have a single brightness level, while the three "rooftop" and two "road" classes have varying gray tones. The five cultural classes have a single brightness level, while the five natural classes listed above have varying gray tones in the third photo (Fig. 3-C).

Five classes of cultural features, three types of rooftops, and two types of roads were identified. The class "rooftop 3" appears dark in the visible and reflective infrared, while "rooftop 1" and "rooftop 2" are bright in all bands. The great majority of the residential structures were classified as "rooftop 1" or "rooftop 2" (or a mixture of the two), while data points in the larger structures (industrial, commercial, or institutional) were classified in any one of the three rooftop classes. The rooftop structures in the study area were approximately 90 per cent correctly identified by comparing known land use data to samples of the study area classified from airborne multispectral sensor data. A slight problem in classification was the confusion of either "rooftop 1" or "rooftop 2" with "bare soil", especially in the vicinity of Raymond Street.

Two types of roads were identified which strongly suggested the spectral separability of concrete and asphalt materials. "Road 1" is the brighter (more reflective) of the two classes and apparently is constructed of concrete. An example of "road 1" is Interstate 70 (under construction at the time the data were collected). Class "road 2" is composed of asphalt and occurs much more frequently than "road 1". This type of road, similar to "rooftop 1" and "rooftop 2", was confused to a degree with

areas of gravel or bare soil; however, the accuracy attained in the identification of roads was comparable to that of rooftops.

Five classes of vegetation were identified, four of which were grassy, open areas and one of trees. The class "trees" was identified with a high degree of accuracy (over 90 per cent correct). Most of the areas classified as "trees" were located along the White River. The four grassy areas were separated into the two general categories "sparse grass" and "dense grass". The two classes of "sparse grass" are a major earth surface feature of the study area, and are found in cemeteries, along parkways, and in open areas near railroad tracks. Statistical separation of sparse grass by cluster analysis into classes "SPGRS 1" and "SPGRS 2" was performed before any ground observations were made, and without any premonition that such separation was of informational value to the urban specialist. Notwithstanding, both classes of "sparse grass" phenomena are reported because of the value that some urban analyst may attribute to the separation. "SPGRS 1" is the most frequently occurring of the two types, while class SPGRS 2" is found to a minor extent in selected areas within the study area. Immediately southwest of Speedway Avenue is a "SPGRS 2" area located on a small plateau-like feature rising about 30 cm. from surrounding areas. The primary difference between that grass and the surrounding areas of "SPGRS 1" was that the latter had more patches of bare soil showing through the grass.

The general class "dense grass" occurs in more select areas than "sparse grass". 1) the small park bounded by Marion Avenue, Birch Avenue, and McCarty Street; 2) spots on the grounds of the Indiana University Medical Center; 3) the western half of Belmont Park; 4) the outfield in Bush Stadium; 5) South Grove Golf Course; and 6) Tom Taggart Park. The areas of "dense grass" seem to reflect better turf management than the areas of "sparse grass". Unusually, most of Riley Park was classified as "SPGRS 2" instead of a class of "dense grass". Similar to the separation of "sparse grass", "dense grass" was divided by cluster analysis into two classes, designated "DNGRS 1" and "DNGRS 2". The areas showing up distinctively as "DNGRS 2" were the outfield of Bush Stadium and the eastern edge of South Grove Golf Course. Otherwise, "dense grass" seems to be randomly divided between the two classes, "DNGRS 1" and "DNGRS 2".

The general class "water" was identified with very high accuracy (approaching 100 percent) and was restricted to the West Fork White River and Fall Creek. Some data points, however, influenced by building shadows were misclassified as "water". Two spectral classes of water were identified, "water 1" and "water 2". All water in the flightline was classified as "water 1", with two major exceptions. One area classified as "water 2" was a section of the White River from Morris Street to 16th Street, (including Fall Creek). However, the middle section of the stream extending from a point just south of New York Street to a point midway between Michigan Street and 10th Street was classified as "water 1". The other area classified as "water 2" extends from the northern edge of South Grove Golf Course to the northern edge of the flightline.

The other spectral classes identified were "bare soil" and "shadow". The class "bare soil" is found primarily in the southern portion of the study area, north of Raymond Street. "Bare soil" also occurs in scattered areas throughout the flightline, and is sometimes confused with the class "road 2". The class "shadow" was largely limited to two small areas adjacent to two tall buildings on the White River Parkway West Drive, just south of Belmont Park.

LAND USE CLASSIFICATION BY COMPUTER IMPLEMENTED ANALYSIS
OF MULTISPECTRAL DATA

A reasonably accurate classification of significant earth surface features has been produced by computer-implemented analysis of multispectral data (Fig. 3). An urban land use specialist could, by hand, superimpose lines defining land uses onto such a classification. Such an effort might be questionable, since data collected at much greater altitudes (perhaps as high as 6,000-18,000 meters) by color infrared or black and white photography would yield comparable, if not superior, results.

The thrust of this article is towards rapid, computer-implemented classification of land uses, with little or, ideally, no human intervention. Consequently, the significance of this Indianapolis experiment is that a punched deck of approximately 100 computer cards provided the data by which computer analysis can identify urban surface features. The remainder of this article considers the implications of such a capability.

For purposes of speculation, consider the needs of a planning organization in Marion County, Indiana. Over thirty flightlines (scanned at 600 meters) are required to cover the county (allowing for overlap in north to south flightlines). Twelve wavelength bands of spectral data could be collected to satisfy different classification needs of a comprehensive planning organization.

If multispectral remote sensing and computer-implemented analysis techniques are to be used most effectively in urban planning and land use management, the analyst should have the facility and capability to perform the following tasks; 1) overlay all flightline spectral data into a single mosaic of the county, (or area of interest) whether it be for display purposes or for purposes of calculation (e.g., measurement of wooded area in parkland); 2) overlay sets of data collected at different times (temporal analysis) in a form that can be used either for display or calculation purposes; and 3) project all spectral data points onto a digital image display at a scale useful to the planner. The planning organization has the capability of temporal monitoring of land use changes within its area of interest, once the necessary software and hardware systems have been implemented.

Further software could readily be introduced into the total system. An important capability would be to identify automatically specific land uses. The computer could be programmed to search out and identify known areal patterns of earth surface feature combinations (i.e., grass with patches of trees characteristic of a type of recreation land use) that characterize types of land use (Fig. 4). The observed earth surface feature combinations that are characteristic of selected land uses in Indianapolis are summarized (Table 4). Changes in land use could be identified readily. For example, a change in one or more remote sensing units (RSI's defined as data points or the instantaneous field of view of the scanner or camera sensor), from "DNGRS 1" to "road 2" or vice versa would indicate a change in land use.

Assuming that ground surface features are spectrally separable, computer programs could be written to identify automatically the described land uses (Table 4). This identification is possible through analyzing the type, size, and shape of earth surface features and, most important, spatial associations and relationships between those earth surface features. Thus, the urban land use identification program should include the following tasks: 1) classify an areal agglomeration of points; 2) identify, through type, size, and shape the various earth surface features within

that areal agglomeration; and 3) identify through spatial association of earth surface features, various land uses within the agglomeration. It is important to note that automatic identification of both earth surface features and land uses is essential.

The sequence of land uses identification is best illustrated through a simple, theoretical consideration of a small area with diverse land uses (Fig. 4). The first step in the analysis (Fig. 4-A) was a simulation (by a line printer map) of a point by point classification of an area. The second step (Fig. 4-B) illustrates how size and shape characteristics, in conjunction with spectral characteristics, were used to identify specific earth surface features. Industrial rooftops and residential rooftops were in the same spectral class, but size determined the separation. The pond and stream were both classified as "water" but shape was the clue to their correct identification. In the third step (Fig. 4-C), the computer associates the spatial arrangement of the earth surface features to identify broad land use categories. The residential area is characterized by an agglomeration of residences, relatively closely spaced, and separated by trees and grass. The recreational land use (identified as a park) was typified by broad expanses of grass, with the simple association of the trees along the banks of a stream. Finally, the industrial area consisted of large buildings surrounded by bare soil and void of vegetation.

Quantitative information for the area (Fig. 4) could be printed out by the computer (Table 5). One Remote Sensing Unit (RSU) is 5.25 meters (17.26 feet) long and 4.20 meters (13.80 feet) wide which represents an area of .0022 hectares (.0055 acres). Additional information may be inferred by the number of houses in the residential area. Assuming that all twelve residences are single-family dwelling units, and that the mean population of such a unit is 3.2, the population of the residential area would be estimated as 38.

MONITORING CHANGE

The largest task involved in implementing an automatic land use monitoring system is the original "storage" of data describing an area's earth surface features and land uses within a computer's data bank. Upon completion of a suitable data bank, the planning organization will have complete and instant access to land use data within its area. Moreover, if cost and technology permit, officials will be able to observe visually and study images of land use on a large digital image display. There is need for the capability to observe 1) gray-scale images of any given spectral band; and 2) different classifications of the area (for different purposes), with the capability to vary the assignment of gray levels to classes for differing emphasis. In addition, the system should also be able to highlight (perhaps through different lighting or color techniques) different types of land uses or desired areas of study.

The original spectral data storage band can be updated by the planning organization at any time interval desired. Yearly flights of the entire area probably would be adequate for overall monitoring of land use, but it may be desirable to monitor certain areas, such as the urban-rural interface, as often as every month.

Monitoring of change involves two processes for the computer. Initially, there may be a change on the classification of certain earth surface features. It is feasible that the classes of earth surface features (which were identified very accurately in classification) provide the key to identifying land use classes that are comprised of several earth surface features on varying

proportions. Secondly, the computer must update the previous land use interpretation. The change of several hectares (1 hectare = 2.47 acres) of grassy areas to houses, roads, and lawns is interpreted as single-family residential development.

There are two ways planning officials would know if a change in land use were indicated from analysis of spectral data. The computer would be able to print out the change information by a line printer. Such information would contain the type and location of the change. Also, the change could be observed and perhaps be enhanced, either through lighting or color techniques, on the digital image display. Moreover, a "before" and "after" capability should exist which permits the past and present images of an area to be displayed.

SUGGESTED APPLICATIONS

Digitized, computer-compatible land use spectral data are easily amenable to many different kinds of processing. While the computer is identifying land use changes, it can easily take the next step and perform some simple tabulations. The computer could be programmed to calculate desired "impact" statistics in consideration of the land use change it has detected. For example consider a new residential area twelve square blocks in size which has been built on the outskirts of a city. The computer initially prints out the size of the residential area in units of acres, hectares, or square blocks. It can compute how many houses have been built, and multiplies that total by a pre-determined number of inhabitants per residential unit (perhaps 3.2). The computer has data on four important parameters (location of residential area, size of residential area, number of residential units, and population of residential area) number which it can print out the "impact" statistics. Stresses that are amenable to computer analysis include:

- 1) stress placed on the district school system;
- 2) stress placed on neighborhood park and playground facilities;
- 3) stress placed on local sanitary and storm sewers, and ultimately the sewer mains;
- 4) wear which may be inflicted on local thoroughways and even regional expressways;
- 5) stress placed on local traffic densities of thoroughways;
- 6) stress which may be placed on planned emergency evacuation routes;
- 7) stress placed on utilities: water mains, gas mains, telephone lines and power lines;
- 8) imbalance of stresses caused by variation in size of local governing units;
- 9) stress placed on local commercial and service facilities;
- 10) stress placed on fire and police protection and hospital facilities; and
- 11) stress placed on mass transportation systems.

All of the above information can be generated only if information on parks, roads, utilities, and other resources has been stored in the computer before analysis begins. Thus various socio-economic capacities must be calculated beforehand for these parameters.

The computer can also calculate the statistics on various administrative units at different areal scales. From the neighborhood unit, to agglomerations of neighborhoods, to city-wide, to the multi-county, regional level, the impact of that single, new residential area (or, several new neighboring residential areas) may be ascertained.

It is also possible to monitor industrial land uses. New industrial parks on the fringes of town place particular stresses on utilities and highways. In its area of jurisdiction, the planning organization will also be concerned with natural features including parks, golf courses, lakes and wooded areas. The extent of woodland, quality of grasslands and water can be monitored.

An important statistic which may be tabulated for the planning agency is the proportion of land use which has changed from "open" to "residential", or from "open" to "industrial". A county which has noted ten percent of its formerly open land change to residential in a relatively short period of time will be wary of the ecological imbalance which may have resulted.

Upon implementation of such an elaborate system of land use monitoring, the planning organization would certainly find it useful to "simulate" a certain change in land use. "Simulation" here refers to the input of a land use change (as might be seen by the computer through temporal overlay of new data) into the computer, to learn of the various impacts it will have on the community. A simulation capability would allow the planning official to study carefully the potential impact of a decision before it is made.

SUMMARY AND CONCLUSIONS

It has been shown that certain, important land cover types in urban areas are spectrally separable. Analysis of multispectral data collected over Indianapolis from an altitude of 600 meters indicated that "roads" (2 types), "rooftops" (3 types), "dense grass" (2 types), "sparse grass" (2 types), "trees", "bare soil", "water" (2 types), and "shadow" are spectrally distinct classes. Some confusion resulted in certain areas between "bare soil" and two of the "rooftop" classes, and between "bare soil" and the two "road" classes, but further work and computer time should result in a better separation of these classes.

The ability to separate earth surface features in urban areas is significant, because it allows identification of land uses. Land uses can be identified because: 1) certain earth surface features are spectrally separable; 2) certain earth surface features have different sizes and shapes; and 3) land uses have different combinations and spatial associations of earth surface features.

Given the capability to identify land uses, monitoring of land use changes is possible by temporal overlay of airborne multispectral scanner data. A large digital image display could be used very effectively to provide a working image of a city, county, or other area of interest. The land use changes delineated by spectral analysis would be evident on the digital display. These changes could also be quantified by the computer-implemented analysis of the spectral statistics. Further processing of these data would result in "impact" statistics, calculations of the effects of a land use change on neighborhoods or entire communities. The quality of urban land use decisions would be enhanced through the use of a monitoring system that can be used to simulate land use.

Initial cost of an effective land use monitoring system would be high, but when adequately implemented, regional centers could be established within countries, where computers and data

acquisition would be located. Each regional center could have its own remote terminals and digital display with access to the information available at all other centers ("on line" facilities). Cost sharing of the system with federal, state, county, and city governments, would make a monitoring system feasible. Most large metropolitan areas have a serious need for timely and accurate land use monitoring to facilitate effective urban and regional planning. Computerized information systems for handling of temporal land use data is absolutely essential to meet planning demands of the present and the future.

References

- Fu, K. S.; Landgrebe, D. A.; and Phillips, T. L. "Information Processing of Remotely Sensed Agricultural Data," Proceedings IEEE, Vol. 57, April, 1969, pp. 639-653.
- Indianapolis Power and Light Company. Indianapolis/Marion County Photomosaic. Indianapolis, Indiana, 1972.
- Wacker, A. G. and Landgrebe, D. A. The Minimum Distance Approach to Classification, LARS Information Note 100771. West Lafayette, Indiana: The Laboratory for Applications of Remote Sensing, Purdue University, 1971.

Selected Bibliography

- Anderson, James R.; Hardy, Ernest E.; and Roach, John T. A Land Use Classification System for Use with Remote Sensor Data, U. S. Geological Survey Circular 671. Washington, D. C.: U. S. Geological Survey, 1972.
- Baumgardner, Marion F.; Kristof, Steven J.; and Henderson, James A., Jr. "Identification and Mapping of Soils, Vegetation and Water Resources of Lynn County, Texas, by Computer Analysis of ERTS MSS Data", Symposium on Significant Results Obtained from Earth Resources Technology Satellite-1, Goddard Space Flight Center, Greenbelt, Maryland, March 5-9, 1973, Volume II-Summary of Results, pp. 17-30.
- Chardon, Roland E. and Schwertz, Eddie L., Jr. An Annotated Bibliography of Remote Sensing Applied to Urban Areas, 1950-1971, School of Geoscience Miscellaneous Publication 72-2. Baton Rouge, Louisiana: School of Geoscience, Louisiana State University, 1972.
- Ellefson, R.; Swain, P. H.; and Wray, J. R. Urban Land Use Mapping by Machine Processing of ERTS-1 Multispectral Data: A San Francisco Bay Area Example, LARS Information Note 032973. West Lafayette, Indiana: Laboratory for Applications of Remote Sensing, Purdue University, 1973.
- Hoffer, Roger M. ADP of Multispectral Scanner Data for Land Use Mapping, LARS Information Note 080372. West Lafayette, Indiana: Laboratory for Applications of Remote Sensing, Purdue University, 1972.
- LeBlanc, P. N.; Johannsen, C. J.; and Yanner, J. E. Land Use Classification Utilizing Remote Multispectral Scanner Data and Computer Analysis Techniques, LARS Information Note 111672. West Lafayette, Indiana: Laboratory for Applications of Remote Sensing, Purdue University, 1972.
- Todd, William J.; Mausel, Paul; and Wenner, K. A. "Preparation of Urban Land Use Inventories by Machine Processing of ERTS MSS Data," Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1, Goddard Space Flight Center, Greenbelt, Maryland, March 5-9, 1973, Volume I, Section B, pp. 1031-1039.

TABLE 1

Spectral Bands Used in Computer-Implemented Processing of
Airborne Multispectral Sensor Data

<u>Band Number</u>	<u>Wavelength (micrometers)</u>	<u>Portion of Electromagnetic Spectrum</u>
1	.41 - .48	
2	.46 - .49	
3	.48 - .52	
4	.50 - .54	Visible
5	.52 - .57	
6	.55 - .60	
7	.58 - .64	
8	.62 - .70	
9	.67 - .94	
10	1.00 - 1.40	Reflective Infrared
11	2.00 - 2.60	
12	9.30 - 11.70	Thermal (emissive) Infrared

TABLE 2

Relative Mean Spectral Reflectance of Spectral Classes

Spectral Class	Relative Mean Spectral Reflectance			
	<u>Bd. 1</u>	<u>Bd. 6</u>	<u>Bd. 10</u>	<u>Bd. 12</u>
Rooftop 1	123.99	145.81	88.40	199.23
Rooftop 2	84.37	98.27	70.33	221.53
Rooftop 3	51.13	44.75	37.63	248.43
Road 1	141.18	201.79	120.61	122.80
Road 2	88.72	102.96	71.39	152.58
Dense Grass (DNGRS1)	52.30	72.20	150.58	132.11
Dense Grass (DNGRS2)	48.06	60.98	146.63	124.81
Sparse Grass (SPGRS1)	52.92	68.73	108.56	134.96
Sparse Grass (SPGRS2)	47.41	57.87	105.80	128.21
Trees	42.59	48.27	105.28	88.49
Bare Soil	84.12	106.52	80.57	153.01
Water 1	43.33	48.03	26.59	84.73
Water 2	49.50	61.13	28.04	85.03
Shadow	42.46	35.70	39.24	73.98

Source: Compiled by authors from STATISTICS Program.

TABLE 3

Gray Levels Used for Display of Spectral Classes (Figure 3)

Spectral Class	Gray levels used in Figure 3-A		Gray levels used in Figure 3-B		Gray levels used in Figure 3-C	
	No. ¹	Gray Level	No.	Gray Level	No.	Gray level
Rooftop 1	16	white	16	white	3	very dark gray
Rooftop 2	16	white	13	off white	3	very dark gray
Rooftop 3	16	white	11	very light gray	3	very dark gray
Road 1	6	dark gray	7	medium gray	3	very dark gray
Road 2	6	dark gray	9	light gray	3	very dark gray
Dense Grass (DNGRS1)	8	medium gray	5	dark gray	9	light gray
Dense Grass (DNGRS2)	8	medium gray	5	dark gray	11	very light gray
Sparse Grass (SPGRS1)	10	light gray	5	dark gray	13	off white
Sparse Grass (SPGRS2)	10	light gray	5	dark gray	16	white
Trees	12	very light gray	5	dark gray	7	medium gray
Bare Soil	4	very dark gray	5	dark gray	5	dark gray
Water 1	1	black	1	black	1	black
Water 2	1	black	3	very dark gray	1	black
Shadow	2	off black	1	black	1	black

¹Gray level designation used in PHOTO computer program (#16 is white; #1 is black; #'s 15 through 2 are intermediate gray levels).

TABLE 4
Composition of Selected Urban Land Uses in Marion County

Land Use ^a	Earth Surface Features	Spectral Classes	Spatial Characteristics
Residential	Homes	Rooftop 1 Rooftop 2	3-6 RSU's ^b each separated from other houses by 1-3 RSU's
	Roads	Road 2	1-2 RSU wide
	Yards	DNGRS 1 DNGRS 2 Wood	2-4 RSU
Industrial	Buildings	Rooftop 1 Rooftop 2 Rooftop 3	40-1200 RSU's each separated by 3 or more RSU's
	Grounds	Road 1 Road 2 Bare Soil	Variable size
Recreation (Park)	Grass	DNGRS 1 DNGRS 2	4-30 RSU's of trees in patches within DNGRS 1 and DNGRS 2 dominated area
	Trees	Trees	
Institutional (Medical Center)	Buildings	Rooftop 1 Rooftop 2	4-75 RSU's
	Grounds	DNGRS 1 DNGRS 2	15-100 RSU's between buildings
	Roads	Road 1 Road 2	1-2 RSU's distributed throughout (minority features)
Watercourse	River	Water 1 Water 2 Trees	4-35 RSU's wide of extended length 2-4 RSU's bordering river water
Sanitary Landfill	Landfill Buildings	Bare Soil Rooftop 1 Rooftop 2	Bare soil is the dominant feature Scattered RSU's of rooftops are present
Parkway	Roads	Road 2	1-2 RSU's wide roads bordered by 1-2 RSU's of grass
	Grass	SPGRS 1	
Railroad Right- of-Way	Railroad Tracks	Road 2	1-2 RSU's tracks bordered by trees and grass
	Trees	Trees	
	Grass	SPGRS 1	

^aNumerous variations on spatial characteristics of each land use example is possible, thus these examples represent some but not all classes and sub-classes of land use features found in the study area.

^bEach remote sensing unit or RSU represents an average area of 5.25 meters by 4.20 meters on the alphanumeric printout of the Indianapolis classification. Every alphanumeric symbol represents one RSU.

Source: Developed by the authors from an analysis of airphotos, maps and computer-implemented multispectral ground cover classification of the study area.

TABLE 5

Quantitative Data Associated with Identification of Land Uses
and Earth Surface Features: Theoretical Example (Figure 4)

Land Use Earth Surface Feature	RSU's ¹	Hectares	Acres	Square Feet
Residential	238	.4998	1.2852	56,687
Rooftops	56	.1176	.3024	13,338
Grass	80	.1680	.4320	19,055
Trees	74	.1554	.3996	17,625
Roads	28	.0588	.1512	6,669
Transportation	190	.3990	1.0260	45,255
Major	162	.3402	.8748	38,585
Residential	28	.0588	.1512	6,669
Recreation (Park)	144	.3024	.7776	34,298
Grass	111	.2331	.5994	26,438
Trees	17	.0357	.0918	4,049
North stand	8	.0168	.0432	1,905
South stand	9	.0021	.0486	2,144
Water (Pond)	16	.0336	.0864	3,811
Waterway	112	.2352	.6048	26,676
Stream	56	.1176	.3024	13,338
Trees	56	.1176	.3024	13,338
West bank	28	.0588	.1512	6,669
East bank	28	.0588	.1512	6,669
Industrial	304	.6384	1.6416	72,407
Buildings	160	.3360	.8640	38,109
North	75	.1575	.4050	17,864
Southwest	45	.0945	.2430	10,718
Southeast	40	.0840	.2160	9,527
Bare Soil	144	.3024	.7776	34,298
TOTAL	960	2.0160	5.1840	228,655

¹Remote Sensing Units.

Source: Calculated by the authors.

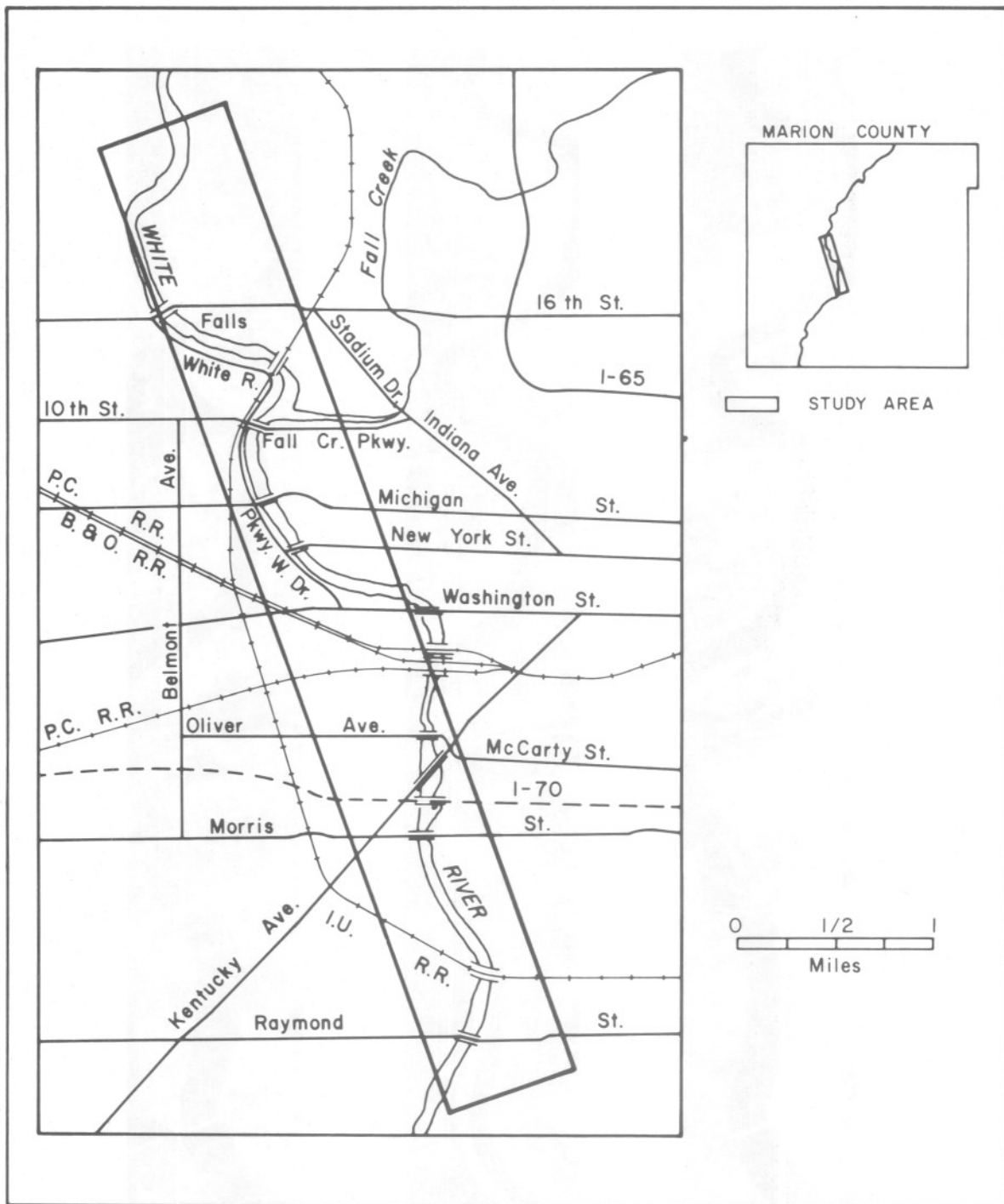


Figure 1. Indianapolis Study Area.



Figure 2. Photomosaics of Grayscale, Single-Band Imagery, Photographed from IBM Digital Display. The image in A is from the thermal infrared portion of the spectrum (Band 12, 9.8-11.7 μ m), B is from the reflective infrared (Band 10, 1.0-1.4 μ m), and C is from the visible (Band 6, .55-.60 μ m).



Figure 3. Photomosaics of the Land Use Classification, Photographed from IBM Digital Display. The image in A shows the general classes of earth surface features, B emphasizes the cultural features, and C emphasizes the natural features. For the exact brightness levels used for each feature in each photomosaic, see Table 3.

