Urban Land Use Identification in the Gary-Hammond Area by Computer Analysis of Multispectral Satellite Data

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Abstract

Multispectral scanner data collected over the southern part of Lake Michigan by the first Earth Resources Technology Satellite (ERTS-1) were analyzed to assess the utility of computer-implemented classification of urban land uses. Northern Lake County, Indiana (Gary-Hammond area) was selected as the study site because of the diversity of land uses, concentrations of population, and heavy industry in this area. The resulting classification indicated that important categories of urban land use, such as commercial/industrial areas, older (higher density), and newer (low density) housing could be identified, as well as woodland areas, agricultural land, water, and smoke emissions (along the coastal areas). This study indicates that computer analysis of ERTS multispectral scanner data can be a valuable input to the urban-regional planner. Not only can ERTS data be a source of land use information, but it can be used to update and/or supplement existing land use data.

Introduction

The compilation of data of large metropolitan areas by land use planning officials is presently a very time consuming process. Inventories of such diverse areas may take several years and are often obsolete by the time they are completed.

A more rapid means of data collection is available through use of an orbiting satellite. NASA's Earth Resources Technology Satellite (ERTS), launched on 23 July 1972, offers this opportunity for land use surveys, and, because the satellite passes over any given area once every 18 days, it may also be used to monitor continuously land use changes.

The objectives of this study were to map gross land uses in the highly populated, industrialized Gary-Hammond area using multispectral data collected by ERTS, and to determine the feasibility of land use classification by this method.

Background and Study Area

Multispectral scanner data collected by ERTS may be analyzed by two methods. In the first, or pictorial approach, the analyst observes differences in gray levels in the imagery reproduced from digital tapes onto a video monitor and black and white photographs. The analyst either studies the four band images separately (band 4, 0.5-0.6μm; Band 5, 0.6-0.7μm; Band 6, 0.7-0.8μm; Band 7, 0.8-1.1μm), or uses combinations of the bands with filter systems to produce color composites.

The second approach utilizes a computer analysis of the data and is referred to as the digital, or numerical approach (4, 6). The four bands of data are spatially registered, stored on magnetic tape in computer compatible format, and then subjected to a cluster analysis procedure by which spectrally separable ground features can be discerned (8). The resulting cluster maps are used to key the various gray levels to known (pre-determined) ground features. These coded gray levels may then be used for computer pattern recognition of various surface cover types and may be studied by video monitor or computer printout. This approach has also been used successfully for accurate identification of earth surface features from multispectral scanner data collected from aircraft in earlier studies (4, 5, 11) and is also used in work reported in this paper.

Gross patterns of urban land use are detected by ERTS analyses (3, 9, 10). The resolution, *i.e.*, the instantaneous field of view, of the satellite's multispectral scanner is approximately 0.45 ha (1.1 acres). Consequently, an individual remote sensing unit (RSU) from ERTS collected over a residential area would include the integrated response measurements from rooftops, streets, grass, trees, and shrubs. Therefore each measurement results in a single response for each RSU and for each spectral band.

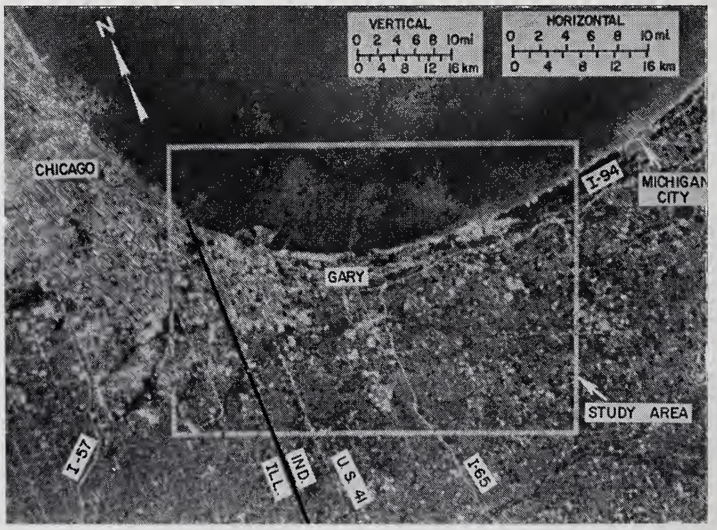

FIGURE 1. *Display image of ERTS Band 4 (0.5=0.6 um), showing location of the study area (outlined).*

The study area selected for this research, the Gary-Hammond, Indiana area, just east of Chicago, Illinois (Fig. 1), contains diverse land use types including concentrations of industry, large residential areas, agricultural land, forested areas, and bodies of water. Data were collected from the 1 October 1972 ERTS pass, a cloud free day. The four ERTS bands were examined pictorially and several areas were selected from these images for land use classification by cluster analysis.

Results and Discussion

Figure 2 compares the display imagery from two bands (images A and B; D and E) with imagery from digital analysis of the data (images C; F) for the Gary-Hammond area. Images A, B, and C each show the entire study area [54 x 46 km (34 x 29 miles)]. Enlargement of the northwestern portion of each of these three images is shown in D, E, and F, respectively [areas measure 27 x 23 km (17 x 14.5 miles)]. The horizontal scale for each image in Figure 2 is approximately three-fourths that of the vertical scale and the true north-south line is rotated approximately 14° counterclockwise to vertical.

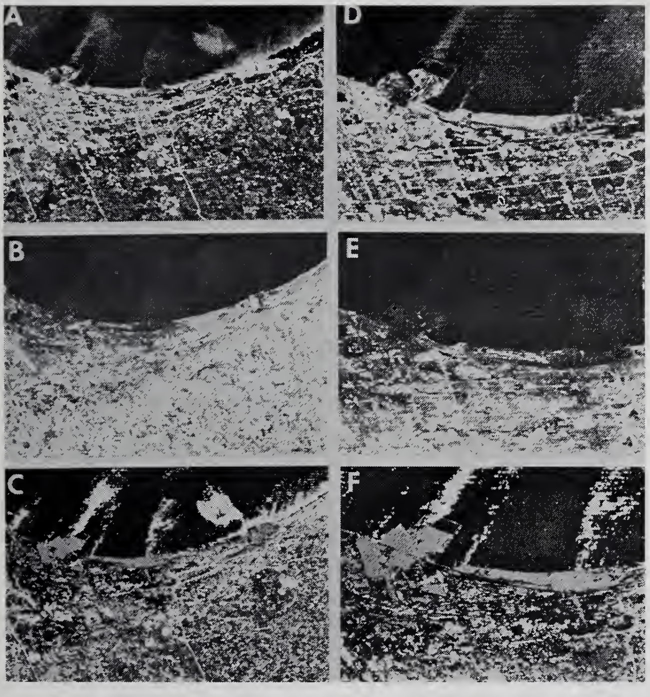

FIGURE 2. *Photos showing relationship between pictorial and digitally analyzed imagery for land use classification. Image A is Band 4, 0.5-0.6um; B is Band 6, 0.7-0.8um; C is a computer-implemented classification of the study area. Images in A, B, and C show the entire study area; enlargements of the northwestern portions of those three images are shown in D, E, and F, respectively.*

The land classification scheme was developed with imagery from digital analysis. Five gray levels used for the display of the spectral classes were as follows:

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

The resulting computer-implemented land use classes are found in Figure 3.

Industrial/commercial areas are shown as medium gray and are characterized by the occurrence of rooftops, parking lots, streets, and

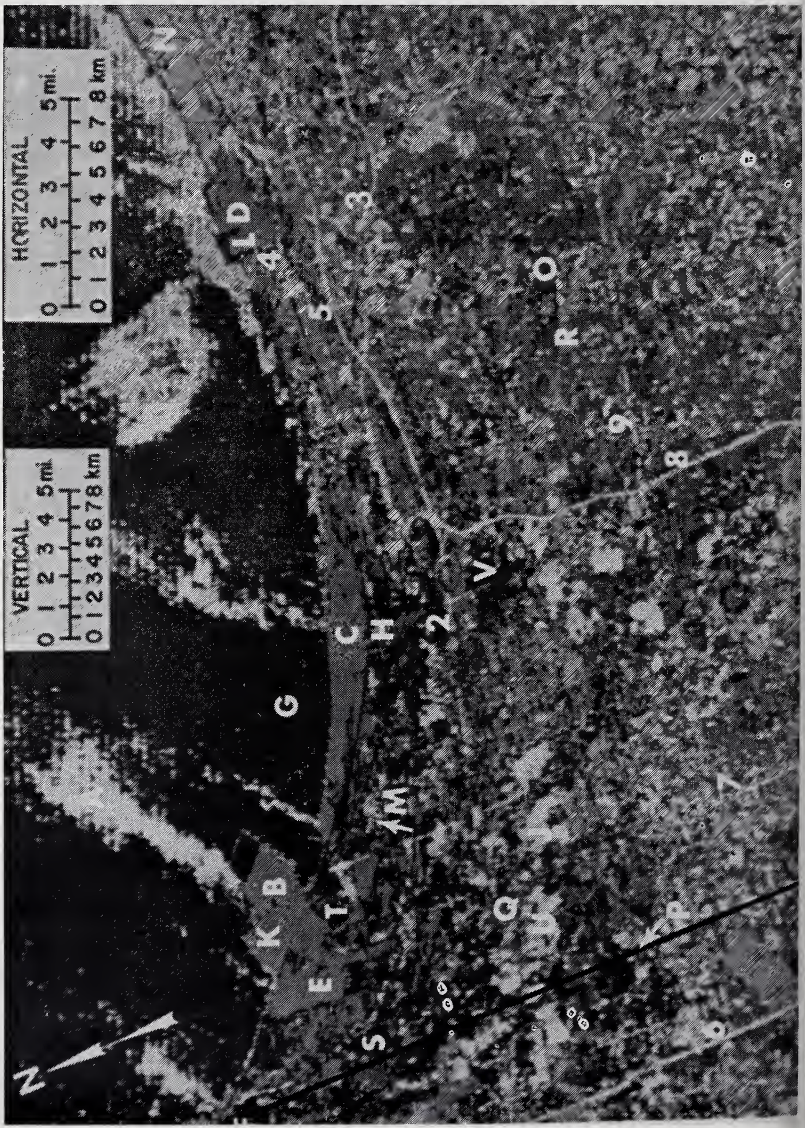

Figure 3. *Computer-implemented land use classification of Gary-Hammond area. Letters or numbers refer to the following:*

[1] White letter or number indicated in Figure 3.

[2] Features of interest and 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.

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 States 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	newer housing

bare ground. They are usually void of vegetation. Examples include Inland Steel, U.S. Steel, Bethlehem Steel, and the Gary-Central Business District.

Older Housing, displayed as black, consists of areas developed prior to World War II in Hammond, East Chicago, and Gary. Closely spaced rooftops along with mature vegetation (large trees) are the reasons for the spectral separability of this class. Water has been assigned the same gray level as older housing (black) and, considering the distribution of each, prevents confusion between the two. Water is largely restricted to Lake Michigan and other water bodies such as Wolf Lake. The older housing is located between the coastal industrial establishments and newer housing.

Newer housing developments, shown as white, are located on the fringes of the urbanized area in the municipalities of Munster and Highland. The majority of the structures were built after World War II. Since lawns and streets were also primary constituents of this spectral class, four-lane highways are placed in this category. Smoke was assigned the same gray level as newer housing (white) but is found only over Lake Michigan while newer housing is located to the south.

Wooded areas, shown as light gray, are commonly associated with the drainage pattern of the study area. Principal locations of trees appeared in conjunction with the Deep River and the dunes park area along Lake Michigan.

An agricultural class, displayed as dark gray, was 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 zones.

The land use classes identified in this study correspond well with the classes proposed by Anderson *et al.* (1), and with those developed in other ERTS urban analyses (3, 5, 7, 9, 10). Further investigations were made of industrial areas in this analysis because they constitute a large part of the Gary-Hammond complex.

For the analysis of commercial/industrial land use, the northern part of the study area was used (Fig. 1). Spectral classes were displayed using the following five gray levels:

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

The resultant classification image is shown in Figure 4. This is similar to the classification scheme used in Figure 3, the only difference being the assignment of gray levels to the spectral classes.

The class shown as black in Figure 4 is associated primarily with dark roofing material and large coal piles. Large areas of this spectral class are associated with the three large steel firms located here.

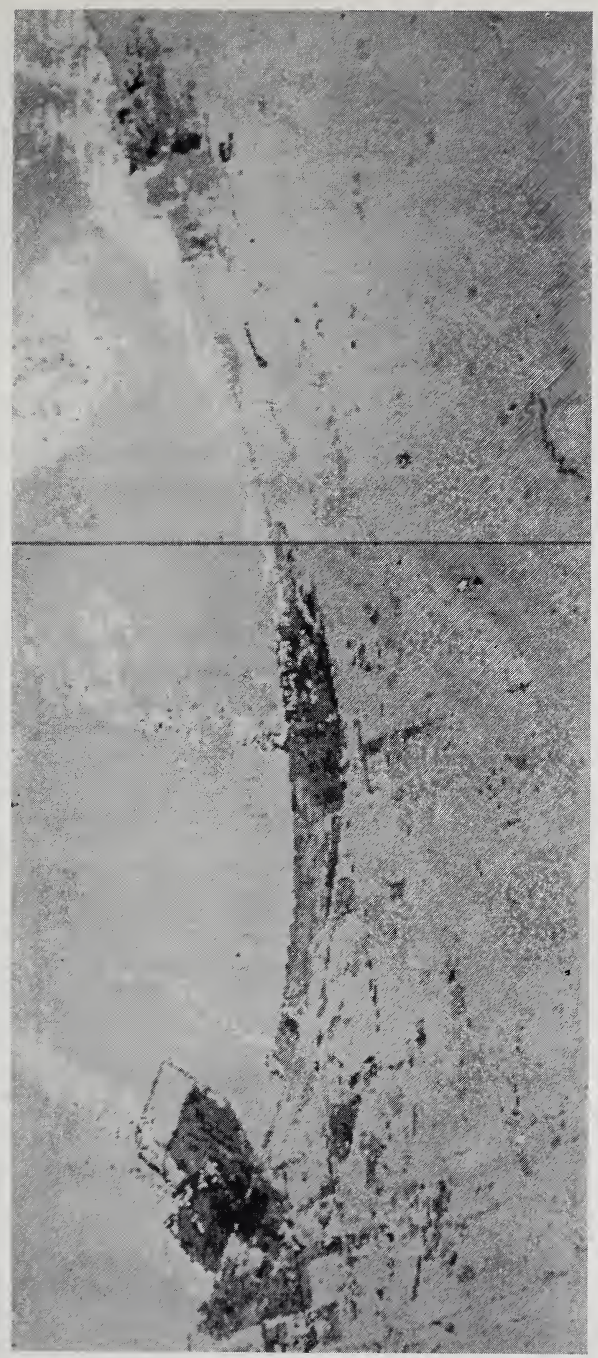

FIGURE 4. *Photo from digital display of computer-implemented land use classification of Gary-Hammond area (northern part of study area). Classes represented: dark roofing material—black; lighter-colored roofing material—dark gray; gravel/sandy areas—medium gray; smoke—white; all other spectral classes—light gray.*

The other rooftop class, displayed as dark gray, is associated with brighter reflecting rooftops. Reasons for the three spectral categories of gravel/sand (all displayed as medium gray) are not clear at this time, but they are presumably related to both the color of the material and the presence or lack of sparse vegetative cover. Two large sites of gravel/sand material are located to the northwest: 1) between the large building complexes of Inland Steel and U.S. Steel companies and 2) in the large oil refining district in East Chicago. To the northeast, another large gravel/sand deposit 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 all bands of the spectrum. The ground cover is dune sand, typical of this locale.

The final class shown in the classification scheme (the white areas in Lake Michigan) is speculated to be smoke coming from coastal industrial establishments. Several facts support a conclusion of presence of smoke. The linear, parallel arrangements of the data points, extending some 50 km into Lake Michigan, are contrary to the circulation patterns in the Lake. Moreover, meteorological records report that the wind was out of the southwest on the morning of the ERTS pass.

While smoke was identified in the western part of the study area, the smoke data points along the eastern lake shore were probably water. Spectrally, this class is similar to water, having a very dark reflectance in Band 6 (Fig. 2-B). The large area classified as smoke northwest of Bethlehem Steel is assumed to be a thin cloud cover. Despite the spectral confusion, the partial separability does warrant further investigation of the phenomenon of smoke located over water bodies.

Classification Accuracy

An attempt was made to determine the classification accuracy of this study by selecting a number of test sites for each land use and determining the class accuracy (Table 1). Water, woods, older housing, and newer housing were all identified with over 90% accuracy. Difficulty was encountered in identifying properly industrial/commercial areas, most of the misclassification being attributed to older housing. The poorest classification accuracy was in grassy agricultural areas, where less than 70% of the data points were accurately classified. Misclassification of these areas was of two major types: 1) agricultural regions associated with darker colored soils which proved difficult to separate from older housing (one such area was located in Munster and Highland), and 2) undeveloped marshland adjacent to industrial areas (large areas south of U.S. Steel and along U.S. Highway 12). A better separation of grassy/agricultural areas from older housing might be expected by collecting data during the summer months, when there is a greater contrast between vegetation and urban classes (9).

Area Calculations

Important tabular data can be generated from machine processing of ERTS data. Table 2 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 class. Adjustments were made for agricultural/grassy areas, commercial/industrial, and older housing, relative to the misclassification between these three land uses (see Table 1). Various land use areas were obtained by multiplying the number of data points by 0.45 for hectares and also 1.1 for acres, the approximate resolution of ERTS. The data in Table 2 could have been reported by small areal units, such as municipalities, townships, or census tracts, by simply storing the desired boundaries in the computer.

TABLE 1. *Classification accuracy for various land uses.*

Land Use	Percentage of Data Points Classified As:					
	C/I[1]	OHg[2]	NHg[3]	Wod[4]	A/G[5]	Wat[6]
Commercial/Industry	89.8	7.3	0.3	--	0.2	2.5
Older Housing	0.9	97.9	0.9	0.3	--	--
Newer Housing	0.6	4.0	94.0	--	1.4	--
Wooded	—	2.0	--	94.4	3.5	--
Agriculture/Grassy	0.8	27.4	3.2	3.1	65.5	--
Water	0.8	--	--	--	--	99.2

X Classification accuracy by class = 90.3%

[1] Commerce/Industry; [2] Older Housing; [3] Newer Housing; [4] Wooded; [5] Agricultural/Grassy; [6] Water.

TABLE 2. *Land use area calculations for study area (excluding Lake Michigan).*

Land Use	No. of Data Pts.	No. of Hectares	No. of Acres	% of Study Area
Commerce/Industry[1]	25766	11479	28343	8.2
Older Housing[1]	56528	25183	62181	18.0
Newer Housing	28540	12714	31394	9.1
Wooded	52346	23320	57581	16.6
Agriculture/Grassy[1]	150982	67262	166080	48.0
Water	499	222	549	0.2
Total	314661	140181	346127	100.0

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

Conclusions

Computer processing of ERTS data in the Gary-Hammond area resulted in the mapping of gross land uses with a reasonable degree of accuracy.

Digital, multispectral ERTS data can be readily overlayed and used to monitor land use changes (2). If ERTS data are interfaced with other land use and areal information schemes, planners would have a computer-compatible land use data bank, with ERTS data as an important, temporal supplement.

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