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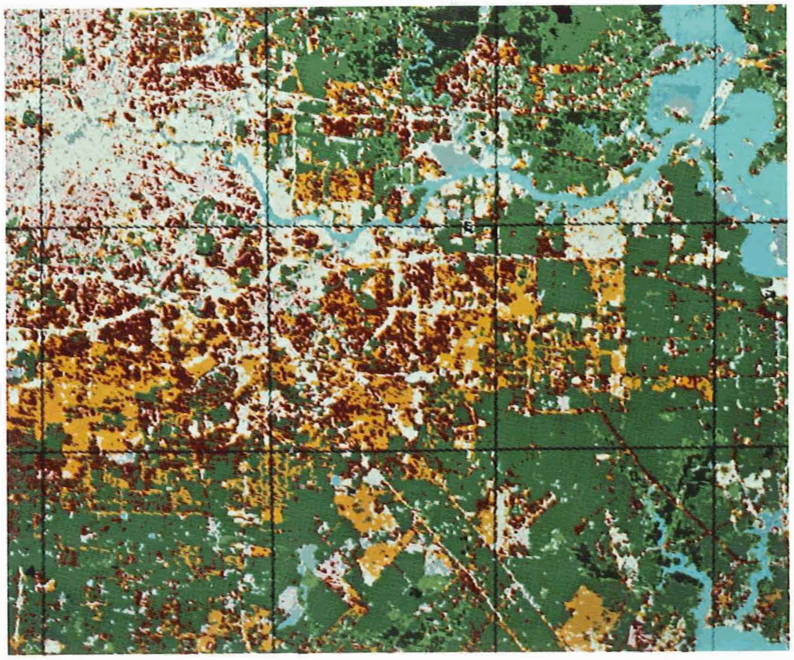
October 1974

THE ERTS-1 INVESTIGATION (ER-600)

VOLUME V — ERTS-1 URBAN LAND USE ANALYSIS

(REPORT FOR PERIOD JULY 1972 - JUNE 1973)



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LYNDON B. JOHNSON SPACE CENTER

HOUSTON, TEXAS 77058

Cover Photograph: A new technique has been developed for area measurement and feature location by overlaying a 10,000-meter square Universal Transverse Mercator (UTM) on the Data Analysis Station (DAS) output. The DAS output is a Modular Training Field Option (MTFO) where 16 training fields were aggregated into four land-use classes. The colors of pink, red and yellow are residential areas, dark and light green are woody and nonwoody vegetation areas, dark and light blue are water areas, and white, purple and gray are commercial/industrial and transportation areas. The color of black indicates a threshold area.

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16. Abstract

The Urban Land Use Team conducted a year's investigation of ERTS-1 MSS data to determine the number of Land Use categories in the Houston, Texas, area. They discovered unusually low classification accuracies occurred when a spectrally complex urban scene was classified with extensive rural areas containing spectrally homogeneous features. Separate computer processing of only data in the urbanized area increased classification accuracies of certain urban land use categories. Even so, accuracies of urban landscape were in the 40-70 percent range compared to 70-90 percent for the land use categories containing more homogeneous features (agriculture, forest, water, etc.) in the nonurban areas.

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PREFACE

This report is one of seven separate reports prepared by six discipline-oriented analysis teams of the Earth Observations Division at the Lyndon B. Johnson Space Center, Houston, Texas.

The seven reports were prepared originally for Goddard Space Flight Center in compliance with requirements for the Earth Resources Technology Satellite (ERTS-1) Investigation (ER-600). The project was approved and funded by NASA Headquarters in July 1972.

This report (Volume V) was accomplished by the Urban Analysis Team. The following is a list of the team members.

C. M. Chestnutwood, National Aeronautics and Space Administration

J. G. Garcia, National Aeronautics and Space Administration

V. L. Cook, Lockheed Electronics Company, Inc.

The total investigation is documented in the following reports:

Volume	Title	NASA Number
	A COMPENDIUM OF ANALYSIS RESULTS OF THE UTILITY OF ERTS-1 DATA FOR LAND RESOURCES MANAGEMENT	TM X-58156 JSC-08455
I	ERTS-1 AGRICULTURAL ANALYSIS	TM X-58117 JSC-08456
II	ERTS-1 COASTAL/ESTUARINE ANALYSIS	TM X-58118 JSC-08457
III	ERTS-1 FOREST ANALYSIS	TM X-58119 JSC-08458
IV	ERTS-1 RANGE ANALYSIS	TM X-58120 JSC-08459

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ABBREVIATIONS AND ACRONYMS

ADP	automated data processing
DAS	data analysis station
ERIPS	Earth Resources Interactive Processing System
ERTS-1	Earth Resources Technology Satellite
ISOCLS	interative self-organizing clustering program
JSC	Lyndon B. Johnson Space Center
LARSYS II	algorithm developed at Laboratory for Application of Remote Sensing, Purdue University
MSS	multispectral scanner
MTFO	Module Training Field Option
pixel	picture element
SAPE	Sensor Applications Performance Evaluation
USGS	United States Geological Survey

THE ERTS-1 INVESTIGATION (ER-600)

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1.0 SUMMARY

This summary describes the highlights of the investigations conducted during the past year at the Lyndon B. Johnson Space Center (JSC) to assess the utility of the ERTS-1 multispectral scanner (MSS) data in urban land use applications.

1.1 OBJECTIVE AND SCOPE

The general objective of this investigation was to evaluate how well data from the ERTS-1 MSS could be used to detect, identify, and delineate urban features within the Houston metropolitan area. Because of the complexity of the Houston urban landscape and the estimated amount of available computer time, the original scope of the investigation was restricted to four separate residential study areas and the major transportation network around Houston. During the computerized classification phase of the investigation, it was found advisable to expand the study area to include more varieties of urban land use. A larger, contiguous area embracing approximately the eastern two-thirds of the Houston metropolitan area and encompassing the four residential study areas was selected for the final investigation.

Only one set of ERTS-1 MSS data (the August 29, 1972, pass) was used in this investigation. Appropriate frames of aerial photography from April and October 1972 were used as collateral ground-truth data. The preliminary urban land use classification scheme used in this investigation was a modification of the land use scheme proposed in United States Geological Survey (USGS) Circular No. 671 (table 6.50).

1.2 ANALYSIS APPROACH

Three basic analytical approaches were used in attempting to meet the objectives of this investigation: conventional image interpretation, correlation of computer gray maps and aerial photography, and computerized classification. Several different analytical techniques were devised to evaluate the utility of these approaches.

Conventional image interpretation techniques were used to analyze ERTS-1 enlarged black-and-white imagery and false-color imagery generated from the digital data. Considerable emphasis was given to both supervised and nonsupervised computerized classification techniques.

Two data-processing procedures were used in the supervised computerized techniques. One procedure used the Earth Resources Interactive Processing System (ERIPS) developed at the JSC. This system used the LARSYS II classifier on the IBM 360 series computer. The other procedure used the Module Training Field Option (MTFO) on the Univac 1108 series computer. This procedure also used a LARSYS II classifier, but the investigation could modify the statistical inputs.

The nonsupervised computerized classification investigations involved the use of the iterative self-organizing clustering program (ISOCLS) to delineate urban land use categories. A computer-assisted classification technique was used to determine the spectral composition of picture elements (pixels) in a complex urban scene and to determine the accuracy to which the clustering program could correctly classify various urban land use categories.

The accuracy analyses of the various computer classification techniques were conducted by correlating samples of individual pixels to specific geographic areas as identified and delineated on aerial photography by a pixel correlation grid technique developed during this investigation.

A separate attempt was made to delineate the major transportation routes in the metropolitan Houston area as a major urban land use category. Conventional image interpretation techniques were used in delineating the interstate freeway system and some of the major highway routes and streets from enlarged ERTS-1 black-and-white (band 5) imagery (scale approximately 1:250,000). Both the LARSYS and ISOCLS computerized classification techniques were also used to produce maps of the major transportation routes. Two approaches were used in classifying with the ISOCLS technique: computer clustering of ERTS-1 bands 5 (red) and 7 (infrared), and clustering of bands 4 (green), 5 (red), and 6 and 7 (infrared).

1.3 RESULTS

The conventional image interpretation investigations emphasized the importance of using spatial pattern recognition for interpreting the extremely small-scale ERTS-1 imagery. The spatial resolution of the MSS was sufficient for recognizing only gross geographic patterns, rather than any detailed textures that could provide clues to the identity of certain urban features. However, the limited spatial resolution and the extremely small scale of the imagery did combine to present a gross texturelike pattern to the highly built-up areas of much of metropolitan Houston, where the wide streets and rows of bright rooftops gave a distinctive crosshatched texture to the imagery. Also, many linear patterns depicting the major highways and streets were readily recognizable, despite the fact that the widths of these features were well below the spatial resolution capability of the scanner. It was, therefore, possible to manually differentiate certain urban features from the surrounding nonurban landscapes by delineating the extensive linear and crosshatched patterns and by using these spatially as surrogates for other urban features. Difficulties were encountered in manually delineating some recognizable urban features, simply because of the extremely small physical dimensions, even when the imagery was photographically enlarged to its limit.

As the initial results from the computer classification experiments were being compared to ground-truth data, it became apparent that considerably more detailed urban land use information was surfacing than had originally been anticipated. It also became apparent that the residential land use category was actually one of the most complex and least consistent categories to be delineated by spectral classifications. It became evident that the residential category was a spectrally heterogeneous intermixture of small vegetated and nonvegetated surfaces. For this reason, the study areas were expanded to include a greater variety of urban land use categories so that a broader statistical base would be available and greater spectral contrasts would be adjacent to the residential areas.

The accuracy to which the computerized classification techniques could differentiate the original selection of residential study areas from the surrounding land use categories is shown in tables in section 7.0. From these tables it can be generally concluded that the accuracy with which the residential land use categories can be differentiated from other land use categories is not very high. This is primarily due to the special variations inherent in most of the reflective surfaces found in residential areas and also due, in some respect, to the specific geographic boundaries assigned to the study areas after examining what appeared to be contrasting patterns on aerial photographs. A considerably better accuracy for differentiating residential land use from other urban land uses was attained by extending the computer classification techniques to the larger metropolitan Houston area. Overall accuracies attained when the residential category was not limited to arbitrary geographic boundaries, and an overview of the complexities of the urban land use categories delineated by the ISOCLS classification techniques and the two LARSYS classification techniques are shown in section 7.0. A cursory comparison of the three figures indicates an impressive overall similarity of urban land use patterns. A more detailed examination reveals some errors of classification, particularly in the areal extent of some of the categories. Some of this error is due to the apparent differences in color contrast caused by selecting certain color combinations to represent particular categories on the computer displays. Some of the error could also be attributed to the manner in which specific pixel classifications were grouped into the limited number of urban land use categories.

Only a qualitative evaluation was made of the utility of ERTS-1 MSS data for delineating the major transportation routes within the metropolitan Houston area. Maps produced by both conventional image interpretation and by computer classification procedures were compared with a standard highway map of Houston. This comparison revealed that not only the major freeways and highways but also many of the major streets could be delineated from the ERTS-1 imagery and digital data. This suggests that automatic computer procedures could be used with a very high degree of confidence in delineating a substantial portion of the major highways and street patterns in a complex urban area.

The investigations involving the correlation of computer gray maps with aerial photographs revealed that relatively unsophisticated conventional image interpretation techniques could play an important role in exploiting the full capability of ERTS-1 data in urban land use analyses. The use of specially constructed reference grids demonstrated that the graphical position of a pixel could be correlated on a computer printout map to its precise geographic location on an aerial photograph. This made possible interpretation of the meaning of the classification anomalies encountered in the computer classification programs and also aided in evaluating the accuracies of the various outputs from these programs.

Although the initial guidelines for this investigation stipulated the USGS proposed land use scheme as the goal for classifying urban land use, early in the investigation such a conventional land use scheme was determined to be inappropriate when the computer classification programs had ERTS-1 spectral data as the only input. Many proposed urban land use classification schemes were considered during the course of this investigation, but each had to be discarded as more classification anomalies were discovered. Finally, a classification hierarchy was developed based on levels of spectral contrasts which appeared to correlate most consistently with the capability of the various computer classification programs developed in this investigation. Some shortcomings are recognized in trying to adapt this land use classification scheme to a user-oriented requirement, and it is offered here only as a suggested point for discussion when comparisons can be made with other land use classification schemes devised by ERTS researchers in other urban areas.

1.4 CONCLUSIONS

The ERTS-1 MSS sensor was determined to be capable of providing generalized data that could have limited application in urban land use studies. The limited spatial resolution and extremely small scale of the imagery imposed important limitations on the amount of information that could be extracted by coventional image interpretation techniques. Although the spectral resolution of the scanner was sufficient to resolve the normal range of spectral reflectivities within a complex urban scene, the spatial resolution of the scanner was not adequate to resolve the individual reflectivities from the many small three-dimensional objects in an urban scene. The spectral energies recorded by each pixel were actually integrated or averaged into one spectral response the magnitude of which was largely dependent upon the proportion of the pixel occupied by each of the objects in the field of view. Consequently, the same spectral signature could be derived from a great variety of different combinations of surface reflectivities.

In using computer classification programs to classify these heterogeneous scenes, serious difficulties were encountered in finding spectrally homogeneous urban features of sufficient size to be used as training fields. Although clustering techniques could be used to group these heterogeneous pixels into great numbers of similar clusters, the ground-truth meaning of these clusters then had to be determined and grouped manually into meaningful spatial patterns corresponding to known urban land use categories.

The greatest source of classification error was from the computer classification of urban features where vegetation was a major component of the urban scene. For this reason, greater classification accuracies could be achieved by making comparative analyses of data obtained during different vegetative seasons. This should at least be true for classification of residential areas, which are normally the most extensive of the land use categories within an urban area.

The present ERTS-1 system and the analytical procedures used in this investigation would find the most utility for urban and regional planners in providing frequent boundary revisions of the urban fringe, where the greatest spectral contrast occurs between areas of dense vegetation and new urban developments. These gross changes in landscape appear most pronounced where forested lands are being cleared for urban development.

The initial phases of the experiments for this investigation were essentially learned in experiences in coping with a new medium of remote sensing and recently developed computer analysis programs. While the planning phases of the investigation occupied a major portion of the entire allotted time, new and expanded analytical procedures could be developed for additional research along similar lines with minimum delay. These new procedures could probably supply the answers to some of the questions that had to remain unanswered in this investigation because of the lack of available analysis time. The results seem to indicate that additional time and effort would be justified in developing new research methods to investigate how well these results could be applied to complex urban scenes in other climates and in different seasons.

2.0 INTRODUCTION

This document reports in detail the investigation that was conducted during the past year by an Urban Land Use/Sensor Applications Performance Evaluation (SAPE) Team at the JSC. This team was involved only in evaluating the utility of ERTS-1 MSS data for providing usable urban land use information. This final project report discusses in detail the objectives, procedures, results, and conclusions of the team's efforts.

Because of the complexity of the Houston urban landscape and the estimated amount of available computer time, the original scope of the investigation was restricted to four separate residential study areas and the major transportation network around Houston. During the computerized classification phase of the investigation, it was found advisable to expand the study area to include more varieties of urban land use. A larger contiguous area, embracing approximately the eastern two-thirds of the Houston metropolitan area and encompassing the four residential study areas, was selected for the final investigation.

Only one set of ERTS-1 MSS data (the August 29, 1972, pass) was used in this investigation. Appropriate frames of aerial photography from April and October 1972 were used as collateral ground-truth data.

As an aid to the reader, where necessary the original units of measure have been converted to the equivalent value in the Système International d'Unités (SI). The SI units are written first, and the original units are written parenthetically thereafter.

3.0 OBJECTIVE

The objective of this investigation was to determine if the ERTS-1 MSS could provide data of sufficient quality from an orbital altitude to permit the detection, identification, and delineation of selected urban land use features of applications interest (residential and transportation routes) within a major metropolitan area.

4.0 STUDY AREAS

The general study area for this investigation embraced approximately the eastern two-thirds of the contiguous built-up area of metropolitan Houston. This area contained all the specific urban features that were used to evaluate the discrimination capability of the ERTS-1 sensors.

The complex spectral characteristics of an urban area and the limited resolution of the ERTS-1 sensors made desirable the selection of an urban area large enough to contain the following characteristics.

1. A relatively large variety of urban land use categories
2. Various types of residential areas: new, old, with many trees, with no trees
3. Residential areas clearly delineated on at least one side from adjacent areas having other land uses
4. Contiguous areas exhibiting extreme differences in ratios of paved, roof-covered surfaces to vegetation-covered surfaces
5. A major freeway system with easily defined dimensions and a variety of backgrounds

The size and complexity of metropolitan Houston and the experimental nature of this investigation required that smaller specific study areas be selected within the metropolitan area where more quantitative measurements of sensor capability could be made relative to the two urban land use categories under consideration (residential and major transportation routes).

The smaller study areas (figure 4-1) that were chosen for more detailed analysis are described in the following paragraphs.

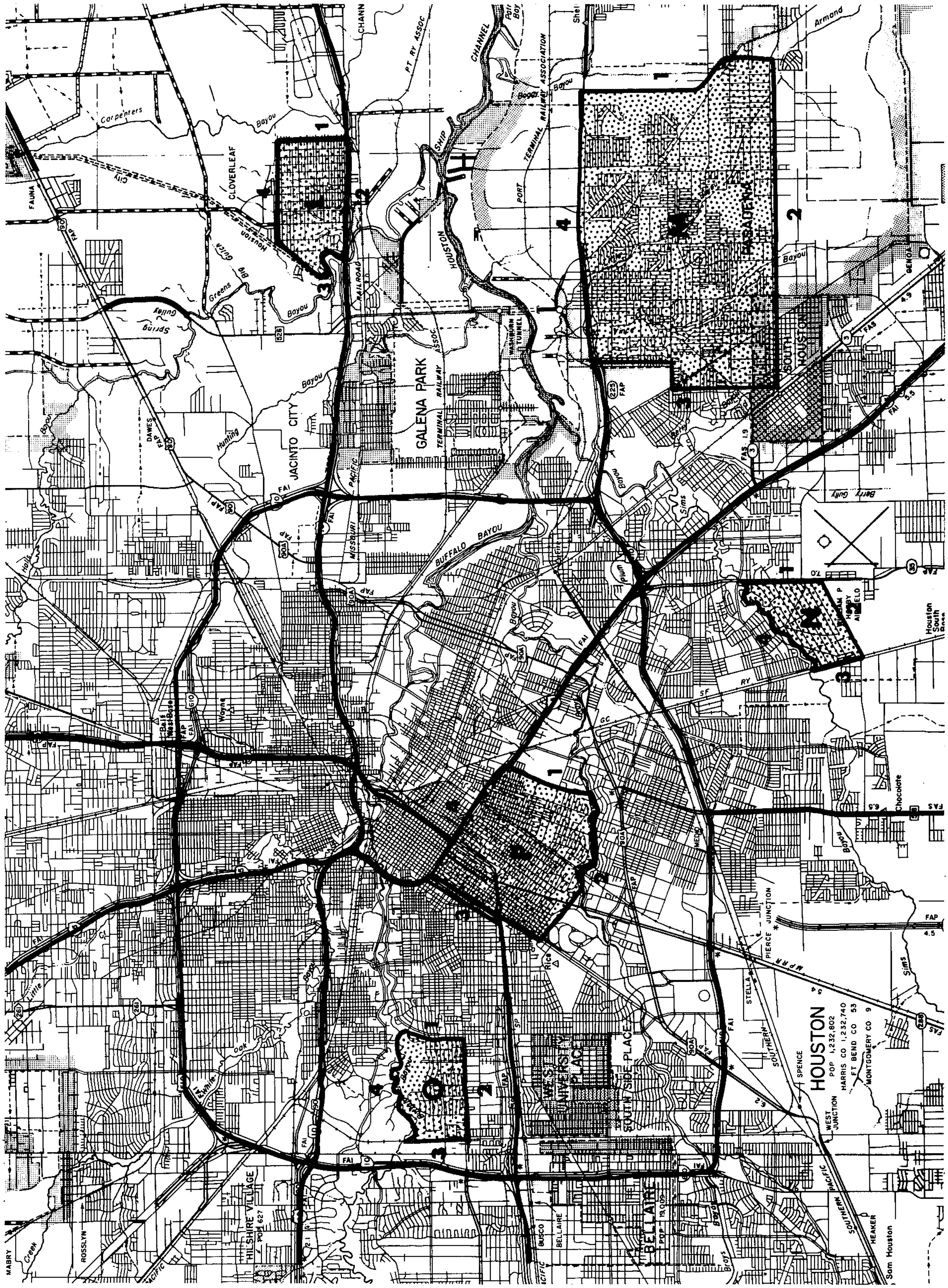


Figure 4-1.- Residential study areas.

4.1 CLOVERLEAF AREA

The Cloverleaf residential study area (area L in figure 4-1; see figure 4-2 for details) is at the northeastern fringe of Houston, and includes a small residential area within the Houston city limits. Its relatively uniform rectangular street pattern covers an area of approximately 3.2 by 4.8 kilometers (2 by 3 miles). It is bordered on its western and northern edges by heavy stands of forest, and on its southern edge by a major freeway (Interstate 10) that separates it from a major industrial complex along the Houston Ship Channel. These three edges provide reasonably distinct delineations from adjacent land uses. The Cloverleaf residential study area is comprised almost entirely of one type of urban land use (residential), with only an extremely small area devoted to commercial and institutional land use.

4.2 PASADENA AREA

The Pasadena residential study area (area M in figure 4-1; see figure 4-3 for details) includes a major portion of the city of Pasadena, a moderate-size city (100 000 population) with relatively complex urban land use categories: residential, industrial, commercial, institutional, and open areas. Its residential areas are fairly sharply delineated along portions of its northern, eastern, and southern edges from the extensive open fields devoted to agricultural land uses. The western edge of Pasadena blends imperceptibly into the Houston urban complex. A major thoroughfare divides a portion of the northern residential areas from extensive industrial complexes along the Houston Ship Channel. A partially completed major freeway forms a distinct boundary along a portion of the eastern edge of Pasadena, and also divides an older, low-density residential area that has a spectral response somewhat different than most of the other residential areas of the city.

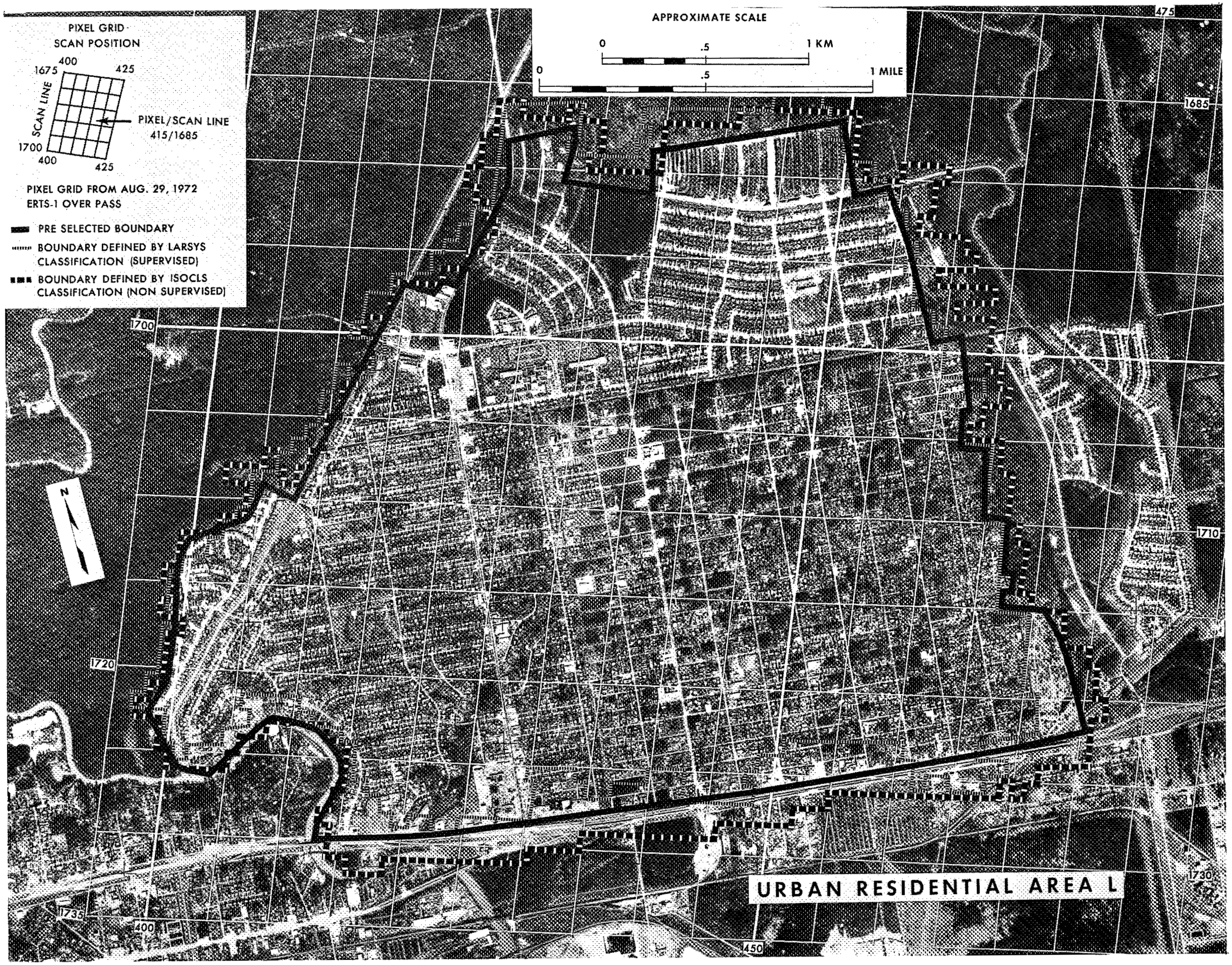


Figure 4-2.- Urban residential area L.

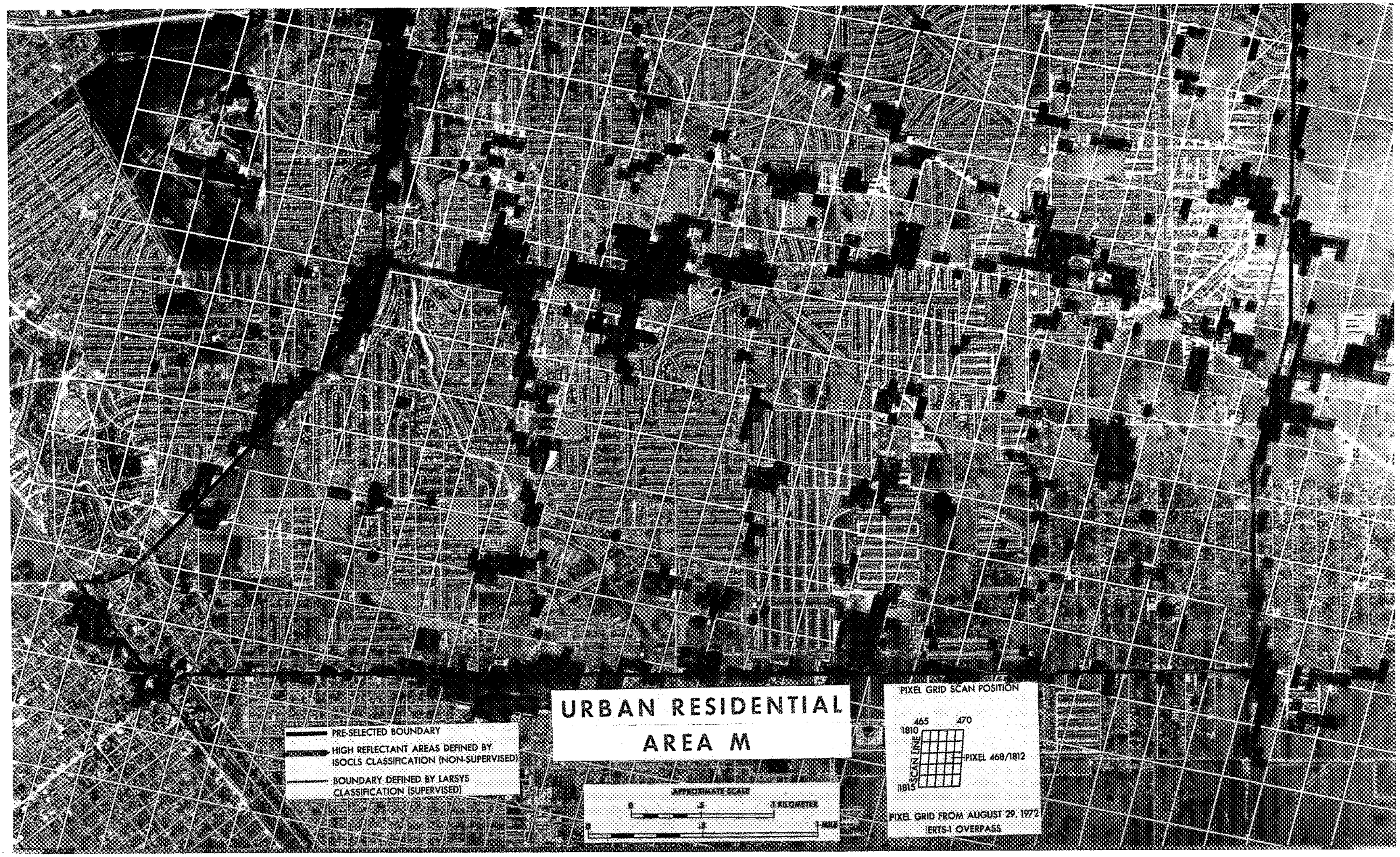


Figure 4-3.- Urban residential area M.

4.3 GARDEN VILLAS AREA

The Garden Villas residential study area (area N in figure 4-1; see figure 4-4 for details) is a low-density residential area with many tree-covered, straight parallel streets, located near the southeastern edge of Houston. It is almost trapezoidal in shape with overall dimensions of approximately 1.5 by 2.8 kilometers (0.9 by 1.75 miles). Its southern edge is distinct from an extensive open area adjacent to William P. Hobby Airport. A four-lane divided thoroughfare along this southern edge enhances this demarcation. Although the other boundaries of this residential area are not as sharply defined, the spectral response of its tree-covered streets provided some differentiation from the different types of residential areas to the north and east.

4.4 CENTER CITY AREA

The center city residential study area (area P in figure 4-1; see figure 4-5 for details) is an arbitrarily delineated area embracing a relatively high-density, single-family residential area. It is separated on the north from the central business district and adjacent commercial areas by a major freeway system. A large commercial development bounds it on the west. The channelized Brays Bayou forms a distinct boundary for most of its southern edge. Its eastern edge is well defined by the University of Houston complex. A major freeway is under construction through the western portion of the area. The overall dimensions of the area are approximately 3.2 by 4.5 kilometers (2 by 2.8 miles).

4.5 MAJOR TRANSPORTATION ROUTES

The Interstate 610 loop that encircles the central core of metropolitan Houston and the major interstate thoroughfares associated with Interstate 610 were used as the selected urban

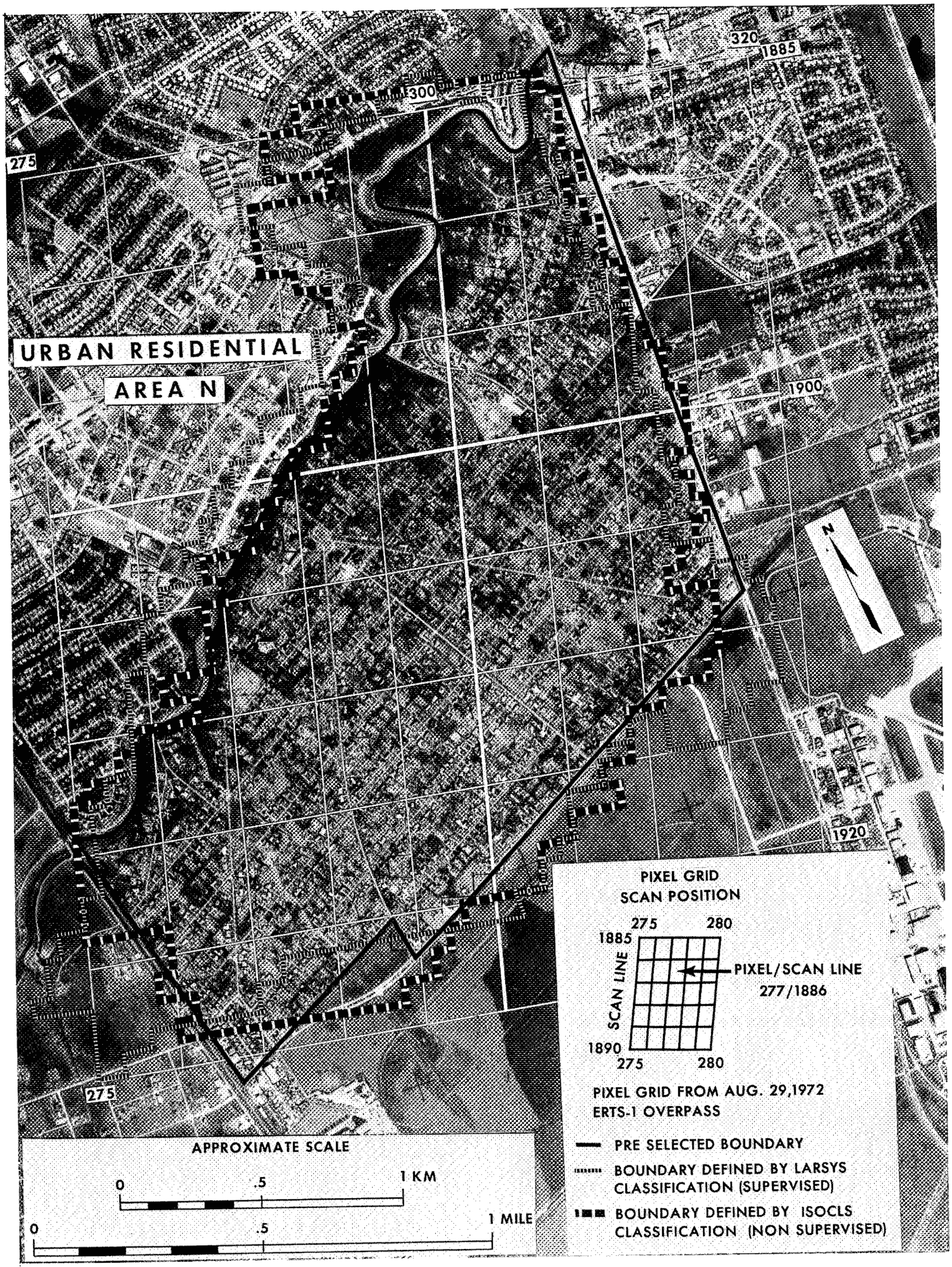


Figure 4-4.- Urban residential area N.

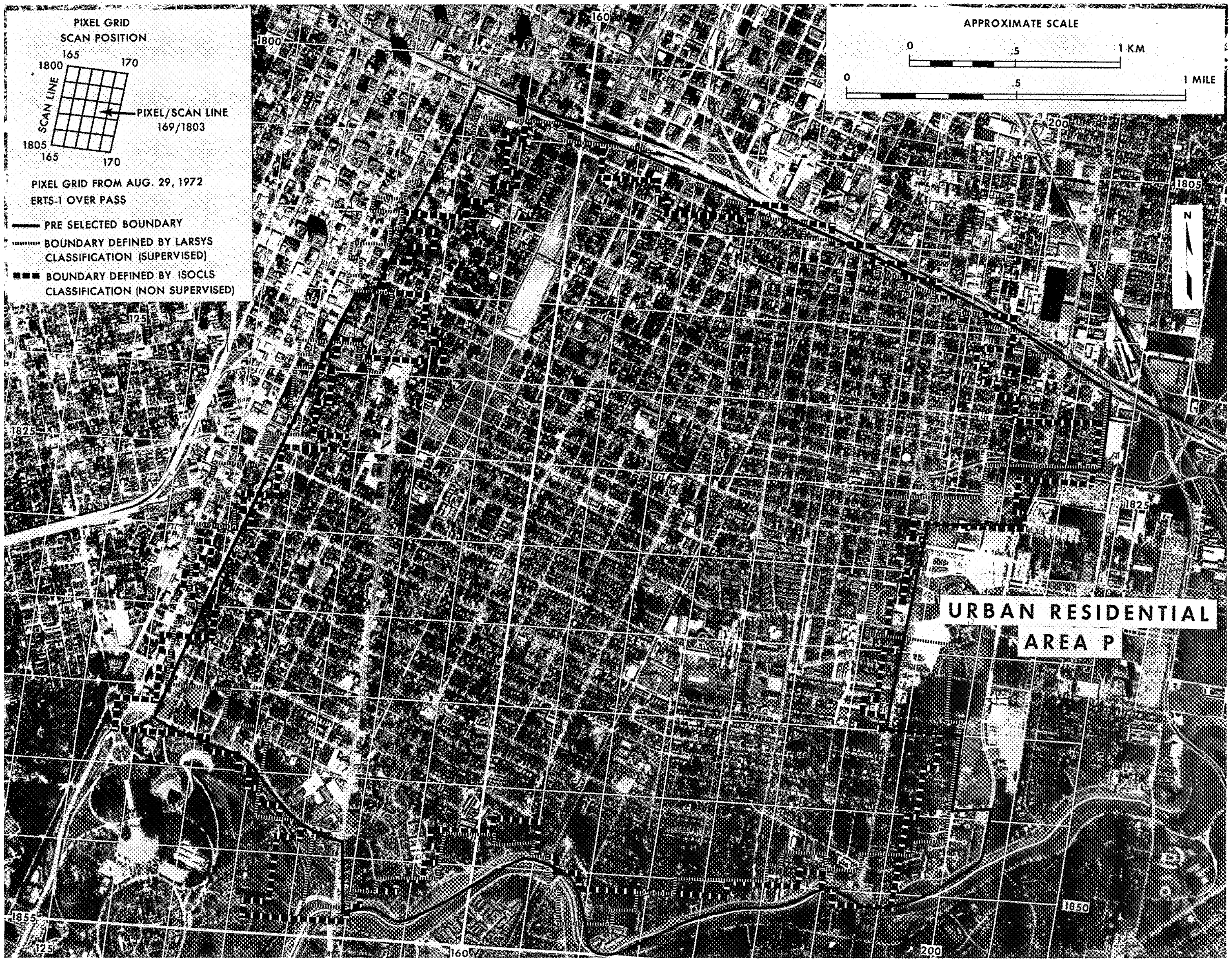


Figure 4-5.- Urban residential area P.

features for delineating the major transportation route category. A measure of how well this category could be delineated was provided by determining what proportion of each numbered section (shown in figure 4-6), could be discriminated from its background.

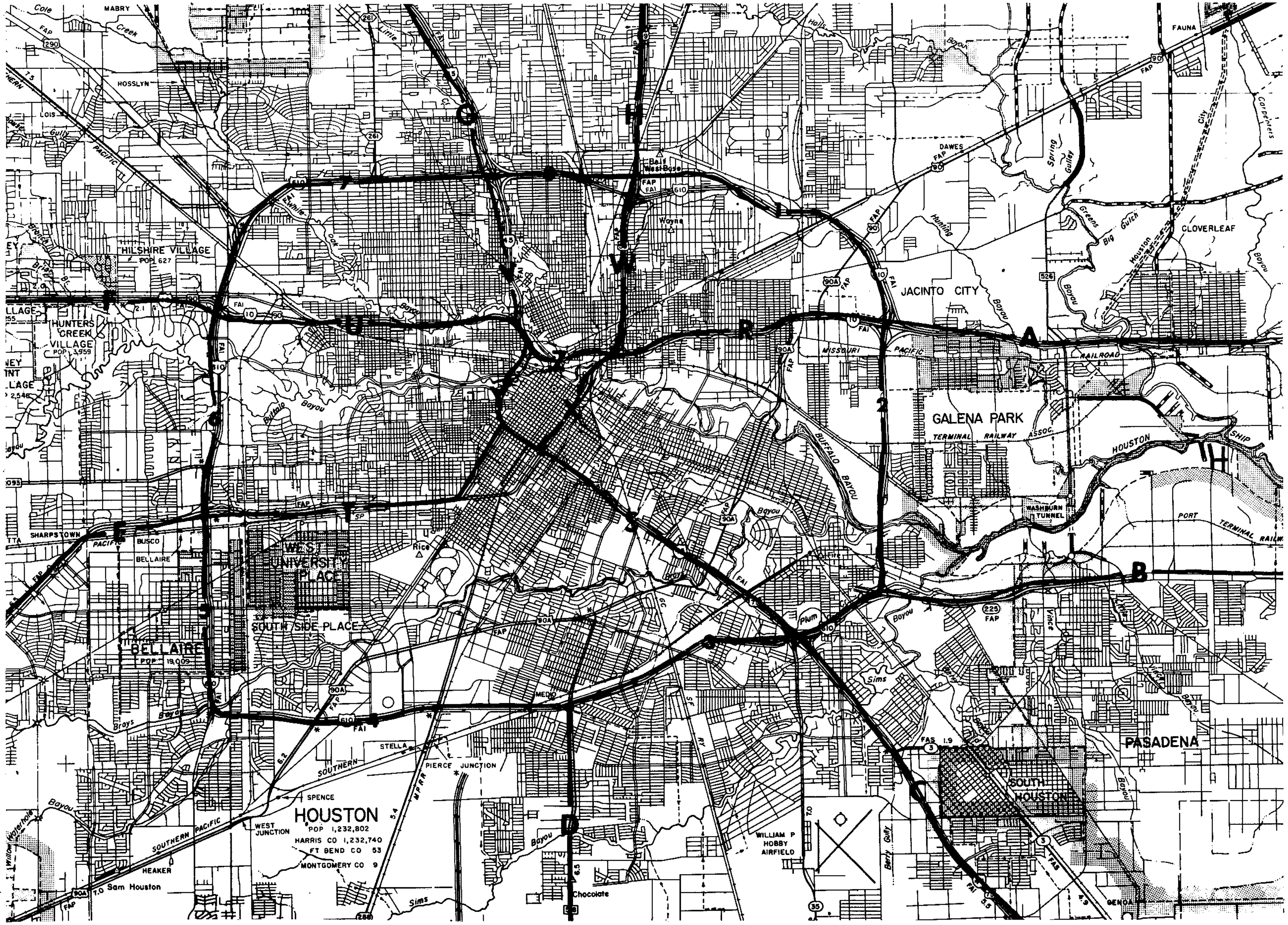


Figure 4-6.- Major transportation routes.

5.0 DATA UTILIZATION

The data used in this investigation included photographic materials, computer-compatible tapes, computer output materials, ground survey measurements, and other ancillary information.

The ERTS-1 imagery used in this project consisted of 70-mm black-and-white transparencies of the Houston area (frame 1037-16244 dated August 29, 1972) from each of the spectral bands of the multispectral scanner. Each spectral band frame was enlarged to a scale of approximately 1:1,000,000 in the form of black-and-white paper prints and film transparencies. Black-and-white paper prints and film transparency enlargements of approximately 1:250,000 scale were also used in this investigation. A limited number of color composites (paper and transparencies of 1:1,000,000 scale) were acquired from the Goddard Space Flight Center later in the program.

One MSS computer-compatible tape dated August 29, 1972, containing data of one-quarter of an image frame was used as the basis for the investigation of computerized classification techniques in this project.

High- and low-altitude aircraft data over the selected study areas were used for classification verification. The relative stability of the specific urban study areas largely eliminated the need for aircraft underflights concurrent with the ERTS-1 passes during this investigation, although a slight difficulty occurred from the lack of concurrent large-scale photographic coverage when the problem of identifying individual pixels was investigated in the Pasadena study area.

6.0 ANALYSIS APPROACH

Conventional image interpretation, correlation of computer gray maps and aerial photography, and computerized classification were the three basic analytical approaches used in attempting to meet the objectives of this investigation. Several different analytical techniques were devised to evaluate the utility of these approaches. Conventional image interpretation techniques were used to analyze ERTS-1 enlarged black-and-white imagery and false-color imagery generated from the digital data. Considerable emphasis was given to both supervised and nonsupervised computerized classification techniques.

Two data-processing procedures were used in the supervised computerized investigations. One procedure used the ERIPS developed at the JSC. This system uses the LARSYS II maximum-likelihood classifier on the IBM 360 series computer. The other procedure used the MTFO on the Univac 1108 series computer. This procedure also used a LARSYS II classifier, but the investigator could modify the statistical input.

The nonsupervised computerized classification investigation involved the use of ISOCLS clustering to delineate urban land use categories. A computer-assisted classification technique was used to determine the spectral composition of picture elements (pixels) in a complex urban scene and to determine the accuracy to which the clustering program could correctly classify various urban land use categories.

The accuracy analyses of the various computer classification techniques were conducted by correlating samples of individual pixels to specific geographic areas identified and delineated on aerial photography by a pixel correlation grid technique developed during this investigation.

A separate attempt was made to delineate the major transportation routes in the metropolitan Houston area as a major urban land use category. Conventional image interpretation techniques were used in delineating the interstate freeway system and some of the major highway routes and streets from enlarged ERTS-1 black-and-white (band 5) imagery (approximately 1:250,000 scale). Both the LARSYS and ISOCLS computer classification techniques were also used to produce maps of the major transportation routes. Two approaches were used in classifying with the ISOCLS technique: one used computer clustering of only ERTS-1 bands 5 (red) and 7 (infrared), and one used the usual four bands 4 (green), 5 (red), and 6 and 7, (infrared).

6.1 CONVENTIONAL IMAGE INTERPRETATION

Several conventional image interpretation techniques were used in studying the variety of ERTS-1 imagery that was available for this investigation. High magnification stereomicroscopes and stereoscopes were used to view 70-mm and 22.86-cm (9-inch) black-and-white film transparencies and 22.86-cm (9-inch) color composite film transparencies. Photographic enlargements of this imagery were also studied.

First-generation color film transparencies obtained directly from the computer-compatible tape using the JSC data analysis station (DAS) console were interpreted by viewing with low magnification optics. These film transparencies were in the form of false-color positive transparencies in which three spectral bands were combined to produce the false-color composite at a scale of approximately 1:250,000. The three bands most often chosen for the composite were band 4 (0.5 to 0.6 nm), band 5 (0.6 to 0.7 nm), and band 7 (0.8 to 1.1 nm). The resulting color transparency was then interpreted by conventional image interpretation techniques.

Two image enhancement techniques were examined as part of the overall evaluation of conventional image interpretation procedures. Additive color imagery was prepared on the JSC additive color viewing equipment. Various combinations of three positive transparencies from the four possible spectral bands were used as input. A television color density slicing device was examined for its utility for enhancing urban features.

The results of the conventional image interpretation investigation are reported in section 7.1.

6.2 CORRELATION OF COMPUTER GRAY MAPS AND AERIAL PHOTOGRAPHS

The relatively gross resolution of the MSS at orbital altitudes was expected to impose certain limitations on the detail of urban information that could be derived from this sensor. Also, each scanner picture element (pixel) would be collecting the reflected energies coming from a very complex conglomeration of urban features, each having its own spectral signature. Thus, the inherent spatial complexity and spectral heterogeneity of urban features, together with the designed limitations of the sensor, made it desirable to examine the actual spectral composition of areas represented by individual pixels. Also, this examination would have to be somewhat more detailed than would be necessary in analyzing the more homogeneous spectral responses from forest and agricultural features.

One of the earlier investigations was concerned only with analyzing the computer printout from a clustering program that had been used to group the MSS data into a limited number of categories with similar spectral radiances. This was done by programing the computer to calculate a set of radiances for each pixel from the four scanner spectral bands. Individual pixels were then clustered according to limits arbitrarily set so that the computer printouts or electronic displays would bear the best resemblance to known geographic distributions of certain urban features. A comparison of a few computer printouts of these clusters with aerial photographs of the same area showed that the geographical distribution of some clusters did not consistently represent the actual geographical patterns of known urban features in the study areas.

To gain a better understanding of these anomalies, an attempt was made to relate certain pixels to specific urban features by using the computer printout from the clustering program as a basic tool. Each pixel can be referenced on the printout by a scan line number and an element number.

By specifying various computer parameters, small objects with the highest radiances in a scene could be clustered and printed out as one or two individual pixels. By relating pixel distribution patterns on the printout to particular patterns on an aerial photograph, specific bright pixels could be identified as particular objects on the photograph, especially if the small objects were surrounded by fairly homogeneous low-radiance backgrounds. In a few instances, small low-radiance objects surrounded by fairly homogeneous high-radiance backgrounds could also be identified as specific pixels on the aerial photographs. The major difficulty encountered in relating a particular pixel on the printout to a specific object on the aerial photograph was the differences in scale and aspect ratio of the two media. The rectangular-shaped pixel represented on the printout was depicted on an aerial photograph as a parallelogram having sides with an acute angle of approximately 85° and an aspect ratio of approximately 1:1.41.

When several widely spaced bright objects were positively identified and a relative scale for the printout was established, it was a simple matter to locate and identify other pixels on the aerial photograph by using proportional dividers between the printout and the photograph. However, the proportional dividers could be used to measure distances in either a vertical or a horizontal direction on the printout, depending upon which ratio setting was used on the dividers. This technique proved a bit cumbersome when seeking to identify numerous pixels on the photographs and, because its accuracy was not as precise as desired, a more refined technique using two pixel correlation grids was devised.

The pixel correlation grids were used throughout this project in the following manner.

1. In an investigation of the composite spectral response recorded by each pixel over an urban scene

2. In an investigation of how well selected groups of clustered pixels correlated with urban surfaces having similar spectral radiances

3. As an aid in precisely locating on an aerial photograph the sample pixels used in measuring the classification accuracies achieved by both the supervised and the nonsupervised classification procedures used in this project

The results of the first two investigations are reported in section 7.2. Details of the procedures used in constructing the pixel correlation grids are given in the appendix.

A portion of a large, complex urban area was selected for the purpose of determining the accuracy with which computer clustering techniques could be used for classifying urban land use categories. The selected area, designated residential study area M (figure 4-3), encompasses most of the city of Pasadena, Texas. The boundaries of the study area were arbitrarily delineated to coincide with selected major thoroughfares, which fortunately provided a convenient rectangular shape to the study area, and which also made the area easily recognizable on a computer printout cluster map.

Using the same preliminary techniques for identifying individual pixels on aerial photographs as reported in the preceding paragraphs and in the appendix, a five-pixel by five-pixel grid was constructed for the computer printout of the Pasadena area. A high-altitude unrectified aerial photograph enlarged to a scale of approximately 1:8700 was used for constructing the corresponding photographic grid (figure 4-3).

The 1:8700-scale photograph proved convenient for analyzing each pixel-size area on the photograph without the use of magnifying optics. Difficulty was encountered in constructing the pixel correlation grid on an unrectified photographic enlargement. Because a much larger area was involved in this phase than in the construction of the original pixel correlation grid, adjusting the convergence of the grid lines to fit the unrectified photograph was even more necessary. A smaller transparent 5- by 5-line grid was constructed to divide each 25-pixel grid square into 25 individual pixel grids. This small grid was moved over each large grid square as each pixel was located and its predominant level of brightness was determined. Because most of the pixels represented typical heterogeneous urban surfaces, an estimate was necessary of what proportion of the area of each pixel represented one or more levels of brightness. The physical dimensions of each pixel area delineated on the 1:8700-scale photograph (approximately 7 by 9 mm) made dividing the pixel in half visually most convenient, and the pixel could be classified according to the brightness level of one-half or more of the pixel area.

There were numerous instances when a highly reflective object (bright roof or pavement) could be classified several ways, depending upon its geographic position in respect to the boundaries of a pixel. When the object filled the entire field of view or even a major portion of it, the pixel would be classified as one of the highly reflective clusters. If the object fell equally between two pixels, the two pixels may have been classified as two moderately reflective clusters. Several other cluster classifications would also be possible, depending upon the percentage of the field of view that was covered by the object. This inherent inaccuracy of cluster classification precluded the delineation of boundaries between land use categories to a better accuracy than one or two pixels, even when there was a sharp contrast between the objects and their background.

There were several instances when an extremely bright object, surrounded by a dark background and much smaller than half the size of a pixel, apparently produced sufficient electronic output to cause the entire pixel to be recorded as a highly reflective pixel rather than a moderately reflective pixel, as should have been the case in a simple averaging of areas of bright and dark surfaces within a pixel.

A total of 8037 pixels were examined within the Pasadena sample study area. Selecting major highways as boundaries of the study area required that pixels touching the highways should be counted within the study area. A pixel bordering a highway boundary was included in the study area if one-half or more of its area lay inside the extreme outer edge of the highway boundary.

An attempt was made to eliminate as many cluster classification errors as possible by combining several groups of clusters into gross categories with as much spectral contrast between groups as possible. The three categories of low, medium, and high were designated for the study area, based upon an interpretation of panchromatic brightness. These three categories were derived from a subjective interpretation of the extremes in image density levels, as shown on the enlarged panchromatic aerial photograph, which had been exposed originally through a 500-nm filter. The low panchromatic brightness category corresponds to surfaces that were predominantly vegetation covered. Such surfaces included open fields of grass, weeds, or brush; forested areas, including older residential areas where trees had grown large enough to form canopies over streets and roofs; and some newer, exclusive residential areas, where most of the trees were left standing. Also included in this category were features such as grass-covered athletic fields; older golf courses where rows of houses did not border the fairways; large parking lots recently paved with asphalt; and a few very large buildings with extensive tar or asphalt roof coverings. Clear, deep bodies of water (there were none in the Pasadena study area) would be included in this category.

The high panchromatic brightness category corresponded to surfaces that in most cases had been modified by man and were predominantly paved and/or roof covered. Very little, if any, vegetation covered these surfaces. Included in this category were most commercial and industrial complexes; new residential developments where most of the native vegetation had been removed; large apartment complexes with very little landscaping; recently plowed or scraped light-colored soils; large, unvegetated industrial waste dumps; and low buildings with bright or aluminum roofs.

Between these two categories is the medium panchromatic brightness category, which corresponded to surfaces that are spectrally and spatially the most complex in the urban scene. In this category, the reflective energy recorded as a pixel was an average or integration of a great variety of combinations of small objects of low and high panchromatic brightness. This category would include the more common residential areas where one pixel would encompass several small houses with bright roofs and a few adjacent trees and lawns. The same average measure of brightness was also produced by narrow paved streets or roads surrounded by grass or trees, such as would be found in a rural or parklike setting or in some cemeteries. Portions of some industrial complexes with small irregularly spaced buildings and shadows and certain combinations of petroleum storage tanks surrounded by grass had to be placed in this category. Some conglomerations of tall commercial, apartment, and institutional buildings, with accompanying long shadows, also produced a similar average measure of brightness and had to be included in this category. The results of classifying each individual pixel within the Pasadena study area are reported in section 7.2.

6.3 COMPUTERIZED CLASSIFICATIONS

The supervised and nonsupervised data-processing techniques were used in obtaining the computer classifications in this investigation.

6.3.1 Nonsupervised Classifications

The ISOCLS program formed the basis for the nonsupervised phase of the computer classification investigations. The ISOCLS program is a computer technique designed to group objects with similar spectral characteristics. The number of classes or clusters is influenced directly by the specific mathematical functions input to the program. The number of channels of spectral data entered into the computer also influences the number of clusters that will result. This nonsupervised phase was concerned primarily with manipulating the mathematical inputs to the ISOCLS program to produce clusters of pixels that would be most representative of desired urban land use categories.

For areas as spectrally complex as an urban scene, specific land use features cannot be identified by one specific cluster, any more than a corn field can be identified by the spectral response of the leaf of one plant. The feature must be identified by a pattern of clusters and, where a change occurs, it is indicative of the boundary between two adjacent land use features. This approach was used in delineating the boundaries for each of the residential study areas and was the basis on which the delineations were made on the computer printout map. Unlike agriculture-oriented projects, such as crop acreage inventory and crop identification, where the groups of similar objects represent large plots of homogeneous clusters, the urban scene contains a set of features that are spatially complex and spectrally heterogeneous. Initially, the threshold values for the splitting and combining of clusters were those generally used for agricultural data collected by aircraft multispectral scanners with different characteristics than the ERTS-1 scanner. Consequently, the preliminary clustering results were very complex and confusing. However, by correlating the spectral separation of the clusters with the land use patterns derived from the ground-truth aerial photography and by manipulating the splitting and combining criteria of the ISOCLS program, a more satisfactory solution was eventually found. The final cluster results from which the evaluation was made separated the urban area into 32 clusters, with the gray-scale value means shown in table 6-I.

During the nonsupervised classification analysis, the four residential study areas (figure 4-1) selected for the project were treated as individual components of a larger rectangular test area that included approximately 1554 square kilometers (600 square miles) covering most of the Houston metropolitan area. This approach was taken to optimize the definition of the individual sites as residential areas based on a large sampling of cluster

TABLE 6-I.- ISOCLS CLUSTERING STATISTICS
MEAN GRAY-SCALE VALUES

Cluster	Channel -			
	1	2	3	4
1	94.08	109.77	96.80	39.05
2	33.75	25.29	46.09	24.69
3	38.68	30.76	51.47	26.72
4	32.59	24.68	40.74	21.11
5	42.57	37.40	50.36	24.71
6	33.55	24.36	51.88	28.20
7	37.78	31.09	45.35	22.96
8	26.62	17.47	40.67	22.72
9	47.67	43.87	55.92	26.79
A	39.68	36.14	34.91	14.38
B	43.14	40.38	42.54	18.56
C	29.90	21.08	45.11	24.72
D	37.36	31.61	40.15	19.00
E	24.37	14.29	33.83	20.69
F	54.65	54.10	52.03	22.04
G	48.53	46.36	46.44	19.94
H	30.60	22.39	21.24	7.94
I	28.64	20.12	36.59	10.59
J	57.36	58.27	60.69	26.62
K	33.17	26.19	34.27	16.38
L	32.30	24.68	13.33	2.57
M	26.89	18.05	29.05	14.06
N	66.54	69.74	66.80	28.18
O	28.82	18.26	58.86	34.57
P	36.30	31.12	29.05	10.87
Q	26.18	17.15	17.59	5.87
R	32.69	25.59	26.28	10.08
S	26.06	16.75	12.54	3.06
T	26.65	17.92	23.62	7.66
U	79.98	83.19	80.32	33.55
V	21.60	22.04	18.05	5.09
W	29.81	19.43	51.53	28.58

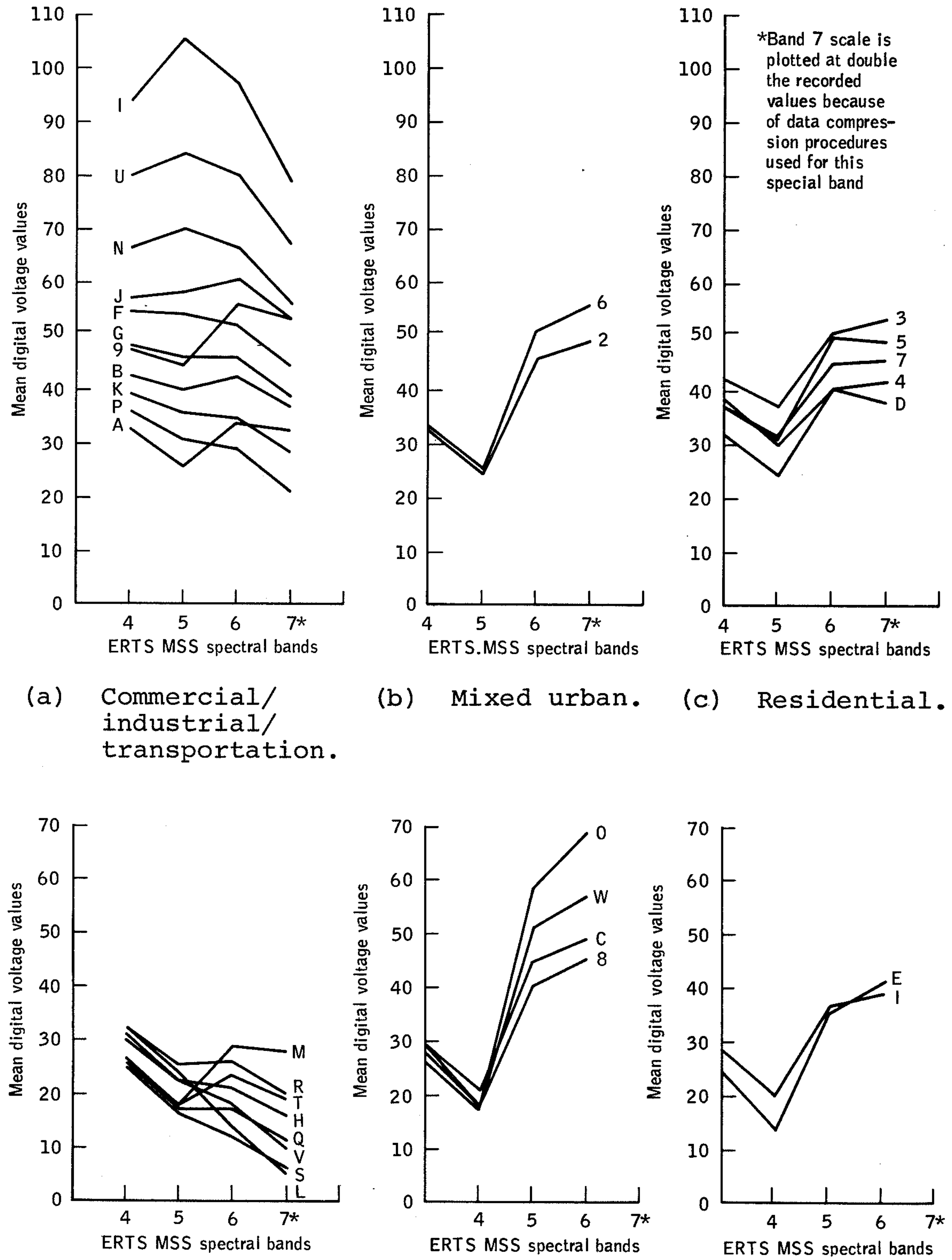
groups. Each site could have been clustered individually; however, statistically speaking, the individual approach is perhaps not as strong as the larger sample approach.

Clustering the larger test area of the Houston metropolitan area of approximately 1554 square kilometers (600 square miles) required the processing of 560 scan lines of data by 660 pixel columns or 369 600 data points times the number of channels. Using the four ERTS-1 MSS channels in the cluster program would have required 1 478 400 words of storage space on the internal computer drum — approximately double the storage actually available. This limitation required that the data be processed in five strips of 560 scan lines by 110 sample columns in two different computer runs. All the data points were grouped into 32 clusters, and the statistics are shown in tables 6-I and 6-II.

A signature curve was developed for each of the 32 clusters (figure 6-1) from the statistics of the nonsupervised classification. These curves were plotted using the mean reflectance value of each cluster as the ordinate and the ERTS-1 bands as the abscissa. Based on these curves and ground truth (aerial photography), a preliminary identification for each cluster number was made, with the realization that a particular cluster number could be classified as more than one urban category because of the inherent spectral complexity of urban scene. Delineations of the residential study areas were made on the computer printout map on the basis of a pattern-recognition technique, in which the boundary between the residential areas and the adjacent types of land use activity was determined by detecting the change of the cluster patterns between the two types of land use. Once these boundaries were delineated on the computer printout map, they were transferred by the pixel-grid transfer technique described previously to black-and-white aerial photography for further analysis (see figures 4-2 to 4-5).

TABLE 6-II.- ISOCLS CLUSTERING STATISTICS
STANDARD DEVIATIONS

Cluster	Channel -			
	1	2	3	4
1	11.38	9.87	10.82	4.82
2	1.54	1.67	1.80	1.26
3	2.13	2.04	2.77	1.73
4	1.71	1.93	1.92	1.28
5	2.18	2.62	2.86	1.09
6	1.88	1.06	2.64	1.64
7	2.01	2.19	1.79	1.36
8	1.47	1.94	1.93	1.38
9	3.02	3.57	2.85	2.01
A	2.06	2.87	2.18	1.56
B	2.25	2.54	2.52	2.01
C	1.44	1.62	2.18	1.51
D	2.01	2.35	1.86	1.29
E	1.23	.98	1.79	1.20
F	3.15	3.04	3.12	2.07
G	2.38	2.84	2.77	2.07
H	1.83	1.82	1.65	.96
I	1.63	1.54	1.79	1.20
J	3.51	4.11	3.10	2.39
K	1.92	2.28	2.17	1.73
L	2.17	1.16	1.16	.68
M	1.77	2.34	1.85	1.87
N	4.93	5.09	4.06	3.08
O	2.35	2.28	4.52	3.20
P	2.58	2.03	1.96	1.64
Q	1.78	1.87	1.63	1.14
R	1.09	2.32	2.14	1.65
S	1.74	2.05	1.24	.81
T	1.74	2.07	1.77	1.41
U	5.56	4.06	4.29	3.19
V	3.04	2.18	1.77	.79
W	1.98	1.54	2.16	1.09



(a) Commercial/industrial/transportation.

(b) Mixed urban.

(c) Residential.

(d) Water.

(e) Nonwoody vegetation.

(f) Woody vegetation.

Figure 6-1.- Spectral signature curves for ISOCLS clusters.

The clusters were grouped preliminarily according to the shape of the signature curve. After correlating the computer cluster map with aircraft ground-truth photography, each group of clusters was assigned a land use category (figure 6-1). A set of spectral maps was then generated in a logical spectral breakdown of Levels I, II, and III, using the DAS film output and the cluster groupings.

In performing the nonsupervised classification portion of the analysis, delineating the major transportation routes and street patterns within the metropolitan Houston area as a separate land use map was considered. Unfortunately, the limited spatial resolution of the ERTS-1 sensor did not permit classifying such narrow features into a specific cluster category or group of categories. However, most large commercial and industrial complexes are dependent upon major access routes and thus are contiguous to major streets and highways. Because most commercial and industrial areas are composed of highly reflective surfaces, such as extensive roofs and paved parking areas that are spectrally similar to the paved streets and highways, the clustering procedures combine these spectrally similar features into the same cluster categories. Cartographically, this was not a serious disadvantage for, although these highly reflective features were depicted as linear features with irregular boundaries, the highway surface can be considered to occupy a very limited narrow strip near the center of these irregular linear patterns.

When a major transportation route traverses a thickly settled residential area or a fairly homogeneous vegetated area, the sensor must integrate the narrow, highly reflective surfaces with the surrounding areas of much lower reflectivity. The intensity of brightness of the highly reflective surface within the field of view of a particular pixel and the proportion of the pixel area covered by that highly reflective surface determine whether that pixel will be classified into the same category as the surrounding pixels. For this reason, the linear pattern of streets and highways through a residential or vegetated area is frequently a narrow linear series of disconnected pixels of a slightly different category than the surrounding pixels.

The major interstate thoroughfares selected to test the Houston Urban Land Use/SAPE investigation are presented in figure 4-6. Only highways in the freeway category were considered in this investigation.

During the conventional image interpretation investigation, bands 5 and 7 were ascertained to provide the best visual contrasts for delineating the linear patterns of the major transportation routes. An investigation then was conducted to input only bands 5 and 7 into the ISOCLS program for the purpose of possibly improving the boundary contrasts between the clusters representing the freeways and road patterns.

The results of the nonsupervised computerized classification investigations are reported in section 7.3.

6.3.2 Supervised Classification

The two data-processing procedures used in the supervised classification investigations (ERIPS and MTFO) were computationally identical; both are based upon the maximum-likelihood ratio concept. However, the computer manipulations required by each procedure differed sufficiently to warrant a comparison of the utility of each for classifying selected urban features.

The ERIPS procedure required that training fields be spatially defined for each class. These training fields were used to generate training statistics (means and covariance matrices) for each class and each data channel. Each picture element within the total area of interest was classified on the basis of a computed probability (maximum-likelihood ratio) for the training field.

The statistical input for the two procedures can be identical, although the operator has the option in the MTFO procedure of preprocessing the spectral data by using the ISOCLS clustering algorithm discussed in the previous section. The clustering algorithm offers the apparent advantage of basing the classifications on the statistics derived from the entire area on interest, rather than from only a sampling of a few small training fields. Subsequent computation and classification are identical for the two procedures.

Transparent color composites generated on the JSC DAS were used for selecting the training fields for the ERIPS procedure. Because of the spectral heterogeneity of an urban scene, selecting training fields that were consistently representative of each particular urban land use category was impossible. After several trial classification attempts using different numbers of training fields for each class, it became apparent that selecting more training fields than were normally required would be necessary in classifying homogeneous data sets. Also, aggregating these training fields into the desired number of classes would be necessary. Consequently, 18 training fields were chosen for the Houston urban study area. These were then aggregated into four general urban land use categories: (1) vegetation, (2) residential, (3) commercial/industrial, and (4) water.

Because the residential category constitutes the highest proportion of urban land use in the Houston study area, special emphasis had to be given to developing techniques for selecting training fields for a category that could be considered representative of general residential land use. The spectral composition and spatial patterns of the ground surfaces associated with this category are relatively complex. Many variations exist in the density of housing and in the type and amount of vegetation normally found in residential areas.

In the attempt to develop a general residential classification, this category was divided qualitatively by interpreting aerial photographs into three general subtypes: (1) high-density older housing, (2) medium-density older housing, and (3) new residential developments. Training fields were selected from each of these subtypes. No attempt was made to select training fields in another residential subtype (low-density older housing), because initial trial classifications revealed that this residential subtype was often confused with the vegetation category. This was not unexpected because the ground surface in the low-density older housing areas is usually covered with grass or with large trees that frequently form complete canopies over streets and rooftops. In general, the amount of vegetative cover can be used to determine housing density and age of development of residential areas. An important exception occurs when a new (usually exclusive) residential development is established in a forested area where many of the original trees are left standing. The Houston study area contained relatively few low-density older housing areas. Therefore, the number of pixels associated with these areas did not warrant including this as a residential subtype in this investigation.

Although subtypes of the other three general urban land use categories do exist in the Houston study area, no attempt was made to differentiate them for the purpose of selecting representative training fields. Training fields were selected to cover several varieties of surfaces in each category, but these were then considered as representative of the general category.

The clustering algorithm used as a preprocessor in the MTFO procedure permitted the grouping of individual pixels into clusters with similar spectral characteristics. The statistical input to the clustering program for this particular MTFO procedure was programed so that the pixels within the study area were clustered into a total of 28 clusters. The geographic distribution of these clusters was compared with urban land use patterns interpreted from recent aerial photography. These clusters were aggregated into four groups, the boundaries of which correlated most closely with the same four general urban land use categories previously selected in the ERIPS procedure. Difficulty was encountered in trying to assign each of the 28 clusters to one of the four categories, and a cluster distance table generated by the ISOCLS program was used to aid in grouping clusters. The mean points of four clusters that appeared to correlate most closely with the four categories were chosen as starting points for comparisons of the spectral distance of all clusters. The clusters with a distance[1] of 0.05 (Bhattaryya distance) or less from one of the four chosen clusters were grouped with one of these four clusters. When a cluster mean point was approximately equal distance to more than one of the chosen points, a selection was made on the basis of similarity to some other identified cluster. When all clusters were assigned to one of the four chosen groups, clusters consisting of only a few pixels or those with large distances were no longer considered in this analysis. This procedure resulted in 16 remaining clusters grouped into four urban land use categories: (1) vegetation, (2) residential, (3) commercial/industrial, and (4) water.

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[1]For a discussion of the distance parameter in ISOCLS, see E. P. F. Kan, W. A. Holley, and H. D. Parker, "The JSC Clustering Program ISOCLS and its Applications." Proceedings Machine Processing of Remotely Sensed Data Conference, LARS, Purdue University, W. Lafayette, Indiana, 1973.

Two correlation analyses were devised to test the validity of the ERIPS and MTFO procedures for classifying specific urban land use categories. A boundary correlation analysis was made to determine how well the two computer procedures could be used to delineate boundaries between two adjacent areas of different land use. A linear-pattern correlation analysis was made to determine how well linear land use patterns (major transportation routes) could be delineated by both computer procedures. A third correlation analysis, classification correlation analysis, was made to determine how accurately land use features could be classified into the four selected land use categories by using only the MTFO procedure.

The results of these various analyses are reported in section 7.3.

6.3.2.1 Boundary correlation analysis.- The boundaries of the four selected residential study areas were delineated from enlarged aerial photographs (scale 1:8700). These boundaries were divided into sections (figure 4-1) specifically chosen so that residential land uses would be separated from other land uses by a boundary; for example, residential from forest, residential from commercial/industrial.

Using the technique described in section 6.2, pixel correlation grids were constructed for each of the residential study areas (figures 4-2 to 4-5). The grid lines, representing every five scan lines and every five element lines and encompassing an area of 25 pixels, were drawn on overlays and fitted to the aerial photographs. The boundary determined from the aerial photograph is referred to as the base area boundary. These boundaries were then transformed pixel by pixel to a computer classification printout upon which a similar 5- by 5-pixel grid overlay had been constructed. The boundary on the printout is referred to as the classification area boundary.

The two boundary overlays were then compared pixel by pixel to determine the portions of each boundary that had been classified correctly by the ERIPS and MTFO procedures. Pixels on the classification area boundary that fell within one pixel distance of the corresponding pixel on the base area boundary were recorded as classified correctly. The number of classification area boundary pixels that were correctly classified compared to the total number of base area boundary pixels provided a measure of total boundary discrimination accuracy for both computer procedures.

6.3.2.2 Linear-pattern correlation analysis.- To obtain a more realistic number of sample land use areas for the linear-pattern correlation analysis, a major portion of metropolitan Houston was studied. This larger study area provided a greater variety of major transportation routes and adjacent urban land uses.

The final urban land use classifications from the ERIPS and MTFO computer procedures were recorded as color film transparencies on the JSC DAS facilities. These transparencies were interpreted by conventional image interpretation to delineate the major transportation routes. Color-composite transparencies from the ERTS-1 digital tapes were also used as aids in making the delineations. The actual delineations obtained from the two procedures were very similar, so that only the ERIPS film transparency was used to produce a map of major transportation routes. This final map was then compared with high-altitude aerial photography to determine how well the major transportation routes land use category had been classified by the two computer procedures.

6.3.2.3 Classification correlation analysis.- The classification correlation analysis required a more extensive sampling of the four selected land use categories than was present in the four residential study areas. For this reason, 35 sample areas were selected from an enlarged aerial photograph covering the larger Houston study area. A pixel correlation grid with a 25- by 25-pixel grid interval was constructed as an overlay for the aerial photograph. Thirty-five quadrants of 625 pixels each were randomly located throughout the photograph and used as the sample study areas. The center of each pixel in a quadrant was recorded as a dot on another grid overlay. This dot grid was then used to locate each sample point within each study area. A category of land use was determined by conventional image interpretation for each point where the dot fell on the aerial photograph. The percent occurrence of each land use class in each sample quadrant was then computed. This land use information derived from the aerial photograph was used as the ground truth for this correlation analysis.

The 35 corresponding quadrants were identified on a computer classification printout. The land use category of each pixel in each quadrant was determined and compared with the corresponding pixel on the aerial photograph. A standard least-squares linear regression technique was used to correlate the occurrences of the four land use classes on the two formats. Both the degree of linear correlation and the deviation from a perfect correlation were evaluated as a qualitative measure of computer classification accuracy.

7.0 RESULTS

7.1 CONVENTIONAL IMAGE INTERPRETATION

The conventional image interpretation investigations emphasized the importance of using spatial pattern recognition for interpreting the extremely small-scale ERTS-1 imagery. The spatial resolution of the MSS was sufficient for recognizing only gross geographic patterns, rather than any detailed textures that could provide clues to the identity of certain urban features. However, the limited spatial resolution and the extremely small scale of the imagery did combine to present a gross texturelike pattern to the highly built-up areas of much of metropolitan Houston, where the wide streets and rows of bright rooftops gave a distinctive crosshatched texture to the imagery. Also, many linear patterns depicting the major highways and streets were readily recognizable, despite the fact that the widths of these features were well below the spatial resolution capability of the scanner. It was, therefore, possible to manually differentiate certain urban features from the surrounding nonurban landscapes by delineating the extensive linear and crosshatched patterns and by using these spatially as surrogates for other urban features. Difficulties were encountered in manually delineating some recognizable urban features, simply because of the extremely small physical dimensions, even when the imagery was photographically enlarged to its limit.

Attempts were made to extract more data from the standard black-and-white ERTS-1 imagery by using additive color viewers and television density-slicing devices. The additive color viewers provided some interesting and quite spectacular color composite images. The viewers were useful for analyzing specific details of fairly homogeneous features and drew attention to subtle differences in the densities of adjacent images. However, no special advantages for detailed urban analysis were apparent. A few important disadvantages minimized the usefulness of the additive viewers as operational interpretation devices. The disadvantages were as follows.

1. An inordinate amount of time and effort (primarily trial and error) was required to aline and register the various images before a reasonably good resolution image could be obtained.

2. The scale of the viewed image was so small that only the most gross land use features could be distinguished.

3. The field of view from the original scene that could be registered was so small that much difficulty was encountered in correlating and comparing the viewed image with adjacent areas of importance.

4. The resolution of the viewed image was not sufficient to resolve the complex and heterogeneous nature of an urban scene.

5. The density contrast between adjacent urban features is normally much greater than for most vegetation or water features. Consequently, the need for detecting subtle differences in image densities is not as great for most urban features as for most features in other disciplines. Instead, in urban land use studies, it is much more desirable to be able to record and delineate mappable units that can be compared and correlated with existing collateral data or subsequent imagery of the same area.

6. There was no rapid and convenient way to map and compare the many variations in boundary positions that could be obtained by simple manipulation of the input parameters to the viewers.

The television density-slicing device proved only moderately useful for analyzing black-and-white ERTS-1 imagery. Although its greater simplicity in operation was an asset, its use for detailed urban analyses in an operational situation would have to be discounted, primarily because of its relatively poor image resolution and because there was no convenient hard-copy output from which comparative analyses could be made.

The color composites generated on the JSC DAS are normally at a scale of approximately 1:250,000. This color film output could be enlarged further either by photographic means or by changing the computer input values. For some purposes, there was no particular advantage in making these additional enlargements, because each color-coded pixel was already discernible with the unaided eye or at least with only a very low-power magnifier. This first-generation color film output had a scale comparable to the maximum effective scale that could be obtained when enlarging the Goddard-produced black-and-white imagery. However, the distorted aspect ratio of this imagery (resulting from the way the original data are formatted by the Goddard computers) caused considerable difficulty in correlating the imagery with aerial photography or with maps. Qualitative comparisons were easily accomplished; but, when actual delineations needed to be transferred to a cartographic base, the zoom transfer scope was used to anamorphically stretch the distorted images in one direction.

Several preliminary attempts were made to use this device to delineate urban land use categories from the DAS-generated imagery. The experiment was eventually abandoned and no final product was compiled for the following reasons.

1. A computer program was developed to correct the distorted aspect ratio of this imagery, which eliminated the extra step of rectifying and transferring an image with the zoom transfer scope.

2. The zoom transfer scope was somewhat cumbersome when trying to use base maps without trimming them to fit under the device. Another model with a larger base working area was not available for this project.

Despite the initial difficulties encountered in correlating delineations from the distorted DAS-generated imagery, the following advantage could be an important consideration in its use as a source of land use information. Input to the computer could be manipulated to provide interactive image enhancement by selecting any combination of a great variety of colors. In many cases, the contrast between adjacent images was greatly increased by assigning contrasting colors to each selected grouping of pixels. However, some difficulties were encountered in obtaining true or consistent film color representations of the colors that were displayed on the viewing console. A repeatability of colors from subsequent computer runs was difficult to achieve, but a proper interpretation of features could be made as long as color contrasts could be obtained between adjacent images.

7.2 CORRELATION OF COMPUTER GRAY MAPS AND AERIAL PHOTOGRAPHY

Using the pixel correlation grid technique developed during this investigation made possible locating specific pixels or clusters of pixels that represented specific urban features. In the sample urban area, the individual buildings, roads, and fields were related to the corresponding pixels, which were recorded on the computer printouts.

Once specific pixels were located, the urban features comprising the pixels that constitute each cluster could be determined. Table 7-I shows the average percentage of the area of each pixel within the sample study area that had surfaces with high, medium, or low levels of reflective brightness as recorded on panchromatic film. Several clusters, for example, 1 and 2, were almost opposite in their percentage composition of high and medium levels of brightness. Clusters 4 and 5 were composed of an even greater contrast of high- and low-brightness surfaces.

TABLE 7-I.- BRIGHTNESS COMPOSITION OF PIXELS IN AN URBAN SCENE

[Percentage of area within a pixel]

Panchromatic brightness	Cluster number					
	1	2	3	4	5	6
High	80	20	36	4	80	56
Medium	20	80	64	8	4	--
Low	--	--	--	88	16	44

For the sample study area used in this particular investigation (area near the Houston central business district), the average types of surfaces found in each cluster of pixels were as follows.

Cluster 1 - Large buildings or building complexes with highly reflective roofs

Cluster 2 - Open grass-covered fields with few trees

Cluster 3 - Predominantly grass-covered areas, but with a greater proportion of moderately bright objects (pavements, roads)

Cluster 4 - Predominantly tree-covered areas with small areas of roofs and streets intermixed

Cluster 5 - Predominantly paved and roof-covered areas with many short shadows, but no trees

Cluster 6 - Complex mixture of roofs and trees or pavements and tall buildings with long shadows

Although the descriptions of the six clusters were purposely made quite general to relate as closely as possible to typical urban land use terminology, numerous anomalies occurred, not only within the study scene, but also when the same clusters were examined in other parts of the metropolitan area. This was particularly true in the more highly built-up areas, where the intermixture of very bright objects and low brightness objects was a conglomeration of bright roofs and shadows, rather than bright roofs and trees as represented by cluster 6. Perhaps the extreme example of such an anomaly was the central business district of Houston with its skyscrapers and long shadows, which were integrated to give the same average spectral response as did areas of dense housing and trees in cluster 6. Similar examples of clustering anomalies occurred in other parts of the metropolitan area, where portions of commercial and industrial complexes and some transition zones between other land use categories apparently were comprised of similar percentages of highly reflective and low-reflective objects.

It became apparent early in the analysis of the clustering classifications in the Pasadena study area that many clusters were comprised of objects that normally would be associated with separate land use categories. For example, some industrial components, such as storage tanks surrounded by grass, were clustered into the same classification as single-family houses with highly reflective roofs and adjacent trees and grass. The printout and photogrid technique proved invaluable in locating and identifying objects that produced specific pixel-clustering characteristics. Some clusters appeared to be most closely associated with fairly homogeneous ground surfaces, such as grass and forest. Most urban-related clusters were associated with an almost unlimited variety of combinations of small urban features, with surfaces ranging in reflectivity from very high to very low in both the visible and near-infrared spectral bands. These various combinations resulted from the fact that an individual pixel covered an area (not considering any overlap in the scanner field of view) of approximately 57 by 81 meters (187 by 265 feet) or 0.46 hectare (1.14 acres). In an urban area of this size, very little spectral and spatial homogeneity can be found. Consequently, the spatial resolution of the MSS was insufficient to distinguish between a signal generated from a homogeneous surface of moderate reflectivity and a signal that had a similar reflectivity but was derived from an integration of various reflectivities of several small highly reflective objects surrounded by a low reflective background.

A sampling of aerial photography (scale 1:21,000) obtained near the time of the ERTS-1 pass was studied in detail to determine the range of anomalies in classifying individual pixels by clustering techniques. The printout studied with the photography was derived from a clustering program in which the Pasadena area scene had been classified into 32 clusters. The types of objects and surfaces associated with each cluster are described in table 7-II.

A review of the table reveals that several clusters contained similar types of objects. The subtle spectral differences indicated by being classified into separate clusters could not be detected by casual study of the photographs. Some of these differences could probably be detected by more sophisticated photointerpretation methods, such as image enhancement techniques and microdensitometer scanning. However, it is questionable whether the additional time and effort required in using these methods would have been justified when the spatial resolution of the MSS and the particular location of its field of view over a ground object appear to be controlling factors in determining into which cluster a particular pixel will be classified.

The variations in the configuration and composition of surface materials caused other errors to be introduced in classifying

TABLE 7-II.- PASADENA AREA CLUSTERING

Cluster	Types of Objects and Surfaces
1	Extremely high reflective surface of a chemical waste dump (brightest spots in entire scene)
2	Open fields with weeds and widely scattered houses on large lots or in open fields
3	Moderately closely spaced houses (five to six per pixel) with moderately dark roofs, surrounded with few trees and much grass
4	Moderately closely spaced houses with very dark roofs, surrounded with few trees, small grass areas, and concrete streets; widely spaced liquid storage tanks surrounded by grass; four-lane asphalt road cut through dense forest; open field with distressed low brush and weeds
5	Closely spaced houses (seven per pixel) with bright roofs and very few trees and recently plowed field
6	Scattered houses on large lots; open field with heavy growth weeds and unimproved road; and open field with heavy growth of weeds and brush
7	Closely spaced houses with bright roofs and more trees than cluster 5; closely spaced houses with dark roofs and small trees; asphalt roads; closely spaced liquid storage tanks surrounded by grass; gravel pits filled with water; and recently plowed fields
8	Solid stand of mixed pines and hardwoods; heavy brush and scattered trees; former rice-field covered with solid stand of brush; border between solid stand of trees and open fields; double-land parkway through forest; and weed-covered pipeline right-of-way through forest
9	New subdivision with bright roofs and grass and very small, if any, trees; liquid storage tanks with grass and paved roadways; and recently plowed or scraped field.
A	Large building with dark roof; newly surfaced asphalt parking lot without cars; open industrial storage yard; and edge of water
B	Large low buildings with short shadows and extensive paved surfaces and large apartment complexes
C	Open field with dense brush; fallow rice field with distressed weeds; open field with sparse grass cover; and plowed field

TABLE 7-II.- PASADENA AREA CLUSTERING - Concluded

Cluster	Types of Objects and Surfaces
D	Open field with weeds and scattered brush; fallow rice field; and four-lane highway through open area
E	Solid stand of mixed trees with distinct crowns and shadows
F	Large buildings with bright roofs; bright paved areas; and recently disturbed bright ground
G	Large building complex (schools and apartments, bright parking lot with cars)
H	Ore pile; coke pile; large building with new tar roof; and edge of water body
I	Open field with dense low brush; asphalt road through forest; unimproved road and pipeline through forest; orchard; new subdivision with street through forest but no houses; recently flooded rice field
J	Large building with bright roof and bright paved area
K	Old burned over area with scattered trees and bare soil; edge of water body
L	Large body of deep water
M	Flooded rice field; marsh; open field of damp ground; edge of water body; tar roof on large building
N	Large buildings with very bright roofs and pavements
O	Open field with dense brush and distressed weeds; cultivated field with cover crop; improved pasture
P	Industrial building complex; industrial waste dump with sparse cover of vegetation; new asphalt parking lot with cars; open storage yard
Q	Shallow body of water; tar roof on large building
R	Industrial buildings with discolored roofs; industrial waste dump with water; open storage area; edge of water body
S	Shallow body of water
T	Edge of water body; tar roof on large building
U	Large buildings with very bright roofs
V	Shallow body of water
W	Open field with dense brush and fallow rice field with distressed weeds

certain clusters in commonly recognized land use categories. For example, a housing area with wood-shingle roofs was given a different cluster classification than a similar housing area with composition-shingle roofs. Likewise, an apartment complex with an asphalt roof was classified differently than a similar apartment complex with a reflective roof. A commercial complex with tall buildings and accompanying long shadows received a different classification than a commercial complex with low buildings and virtually no shadows.

The age of a particular development also affected the cluster classification. New housing subdivisions, where the natural vegetation had been recently cleared, were classified in the same grouping of clusters as the predominantly paved and roof-covered surfaces usually associated with commercial and industrial complexes.

A few errors in classification occurred because of the difference between the time of the ERTS-1 overflight (August 1972) and the time of the aerial photography (January 1970) that provided the ground truth for this study. These errors were kept at a minimum by studying aerial photography of more recent dates (April 1972 and October 1972) when differences in classification were apparently questionable.

Table 7-III shows the comparison between the number of pixels that were classified by computer clustering and by conventional photointerpretation into three levels of panchromatic brightness. The first line of numbers refers to the number of pixels assigned to the three categories of panchromatic brightness after classification by clustering techniques. These pixels were located and identified on the enlarged aerial photography by using the grid coordinates of the computer printout grid and the aerial photograph grid.

TABLE 7-III.- ACCURACY OF CLUSTER CLASSIFICATION IN COMPLEX URBAN AREA

[Pasadena study area]

No. of Pixels classified by	Panchromatic brightness			Total no. of pixels
	Low	Medium	High	
Clustering	1852	4921	1264	8037
Photointerpretation	1656	5099	1282	8037
Difference in no. of pixels	+196	-178	-18	
No. of pixels incorrectly classified, percent	11.8 over-classified	3.8 under-classified	1.4 under-classified	

The accuracy of the clustering technique was determined by comparing the number of pixels that were classified by clustering with the number of pixels classified by photointerpretation.

The greatest error in classification occurred in the low panchromatic brightness category. Also, the polarity of error reveals a tendency for clustering to overclassify features with surfaces having low reflectivities. Because the low-brightness category is dominated by vegetation, some of the errors may have resulted because only a panchromatic photograph in the visible wavelengths was used as the basis for this analysis.

After classifying every pixel into the three categories of panchromatic brightness, the clustering input statistics were recalculated and a printout map was printed having only the three categories: high (H), medium (M) and low (L) represented (figure 7-1). The areas of "high" panchromatic brightness were

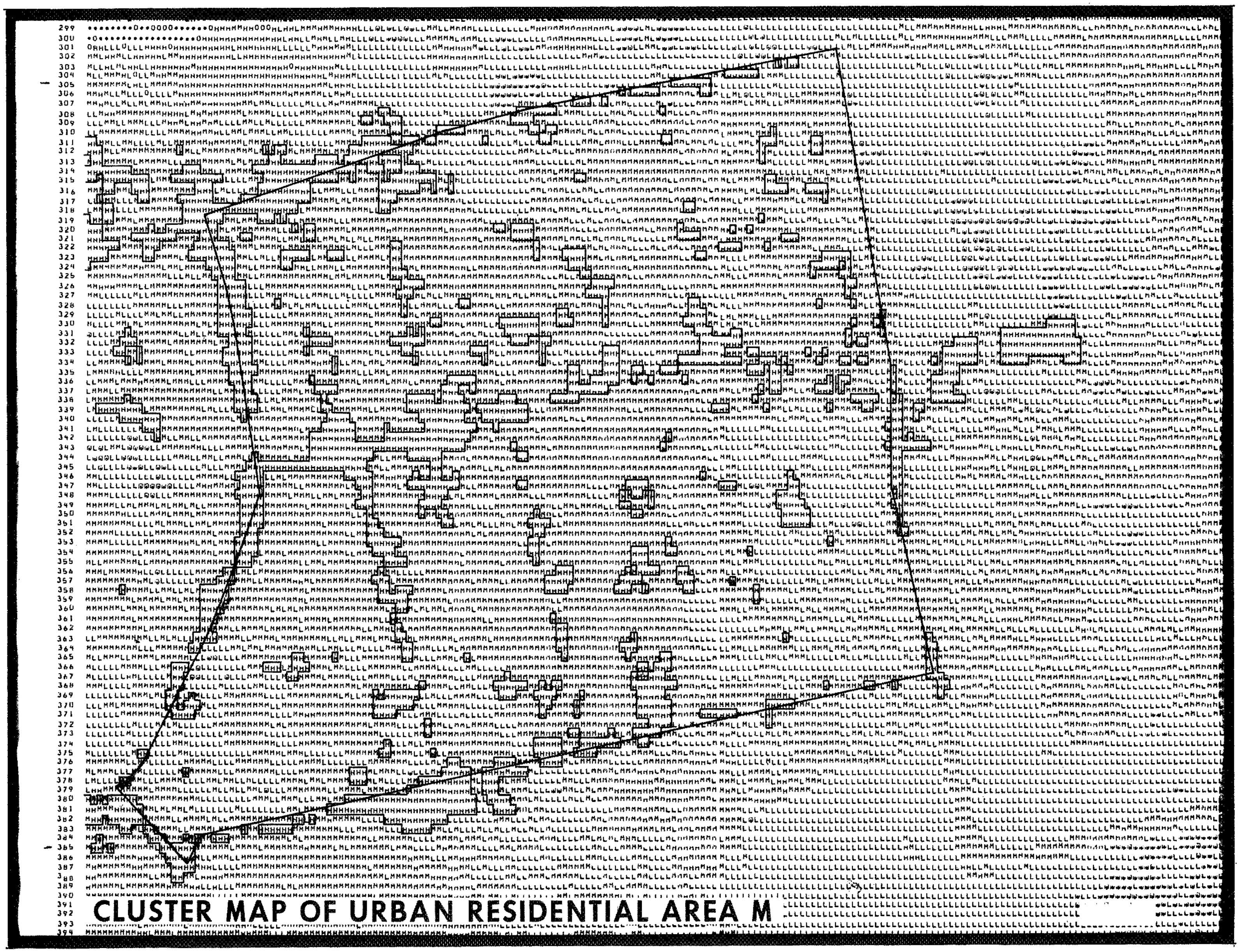

Figure 7-1.- Cluster map of urban residential area M.

delineated on the printout map. A comparison of figure 7-1 with figure 4-3 reveals an impressive spatial correlation between the "high" panchromatic brightness category and the commercial/ industrial areas within the Pasadena study area.

7.3 COMPUTERIZED CLASSIFICATIONS

Some commonality existed between the various computerized classification techniques used in this project. A few combined tables of statistics are therefore presented in this section as a convenience for making a comparative analysis of the final results where this commonality existed.

7.3.1 Nonsupervised Classifications

Table 7-IV shows the comparison of three computer classification techniques used in classifying various urban land uses associated with selected residential study areas. The ERIPS techniques and MTFO techniques were the two approaches used in the supervised classification programs. The ISOCLS technique used nonsupervised classification programs. The accuracy of these computerized techniques in differentiating the selected residential areas from adjacent land use areas was calculated by determining the proportion of the arbitrary boundary that could actually be differentiated.

Another measure of accuracy was obtained by comparing the acreage contained in each residential study area as measured on aerial photography with the acreage determined from the ISOCLS output map. Table 7-V shows the ratio of areas calculated by the ISOCLS technique. A ratio greater than 1.0 indicates that the computer classification technique overclassified the size of the area, while a ratio less than 1.0 shows that the area classified by the computer was smaller than the actual size of the area.

TABLE 7-IV.- ACCURACY OF DIFFERENTIATION OF LAND USE BOUNDARIES BY COMPUTER CLASSIFICATION TECHNIQUES

Residential study area versus land use category		Percent of boundary length correctly differentiated by technique -		
		ISOCLS	ERIPS	MTFO
Cloverleaf (area L)	Major transportation	(a)	58	28
	Water (stream)	100	(a)	(a)
	Forest	56	50	50
	Open fields	32	(a)	(a)
Pasadena (area M)	Commercial/industrial	(a)	(a)	68
Garden Villas (area N)	Major transportation	59	(a)	(a)
	Water (channel)	26	(a)	(a)
	Open fields	48	(a)	(a)
	Other residential	(a)	34	30
Center city (area P)	Commercial/industrial	34	25	27
	Major transportation	57	(a)	(a)
	Institutional	73	(a)	(a)
	Water (channel)	24	(a)	(a)
	Open fields	22	(a)	(a)
	Other residential	(a)	0	18

[a]No comparative analysis was made in this category.

TABLE 7-V.- ACCURACY OF AREAL EXTENT OF LAND USE CATEGORIES DELINEATED BY COMPUTER CLASSIFICATION TECHNIQUE ISOCLS

Residential study area	Ratio of area acreage [a] (C/B)
Cloverleaf (area L)	1.12
Pasadena (area M)	(b)
Garden Villas (area N)	1.16
Center city (area P)	0.91

[a]B = acreage of area as delineated on an aerial photograph and C = acreage of area as delineated on computer classification map.

[b]No comparative analysis was made.

Determining classification accuracies of areas encompassed by boundaries that were arbitrarily selected from panchromatic aerial photographs may possibly have imposed unreasonably stringent requirements on the classification techniques. However, for practical reasons, a compromise was necessary between the amount of digital data that could be processed within a reasonable turnaround time and the number of residential study areas having portions of boundaries that may not be entirely distinguishable, even by ground observation. Table 7-VI reveals the overall accuracies obtained when the residential land use category was not limited to arbitrary predetermined boundaries but was integrated with other land use categories over a major portion of the entire Houston metropolitan area.

The land use classification scheme originally intended to be used in this investigation was a portion of a scheme proposed in USGS Circular No. 671. The urban and built-up land portion of this land use scheme is shown in the table 7-VII.

TABLE 7-VI.- ACCURACY OF URBAN LAND-USE CLASSIFICATION

[Percent of correct classifications]

Urban land use categories	Percent
Residential	66.8
Vegetation	
Woody	95.1
Nonwoody	56.2
Commercial/industrial/transportation	94.2
Mixed urban	51.1
Water	87.7

TABLE 7-VII.- LAND USE CLASSIFICATION SYSTEM FOR USE WITH REMOTE SENSOR DATA

Level I	Level II
01 Urban and built-up land	01 Residential 02 Commercial and services 03 Industrial 04 Extractive 05 Transportation, communications, and utilities 06 Institutional 07 Strip and clustered settlement 08 Mixed 09 Open and other

Early in the investigation it became evident that differentiating the Level II categories by spectral information only would be difficult. After an extensive study of the spectral breakdown within the metropolitan area, the hierarchy was modified to one better suited to ERTS-1 type data; that is, MSS data only. The modified hierarchy as suggested in table 7-VIII is very preliminary. It was generated on the basis of only one set of ERTS-1 data (August) and only for the Houston metropolitan area. Nevertheless, the hierarchy was developed as a result of using various criteria in the computer clustering programs and making an extensive correlation with ground-truth photography of the same area.

The Level I land use categories in table 7-VIII were devised on the basis of the signature curves determined from the cluster mean gray-scale values for each band (figure 6-1). In the August 29, 1972, ERTS-1 pass that was used for this analysis, no clouds or cloud shadows were apparent, except for a faint pollution haze in the southwestern corner of the area. The haze was very faint and very difficult to delineate, but the effect of the haze on radiance levels was sufficient to shift the cluster values and to generate an uncertainty in the cluster classification. Therefore, no attempt was made to classify that specific area of the city.

A comparison of the signature curves for each cluster revealed that the curves could be grouped readily into three distinct categories. These groupings were designated as Level I land use categories; that is, (1) vegetated land areas, (2) nonvegetated land areas, and (3) water areas. The curves in each Level I category were still sufficiently differentiated to permit a further division into a Level II hierarchy. The vegetated land areas category was divided into woody vegetation, nonwoody vegetation, and mixed urban categories. The nonvegetated land areas category was divided into commercial/industrial/transportation and mixed urban categories. No attempt was made to differentiate more than one category of water, clouds, or shadows.

TABLE 7-VIII.- COMPUTERIZED CLASSIFICATION SCHEME FOR URBAN LAND USE

[Hierarchal Level]

I	II	III
Nonvegetated land areas	Commercial/industrial/ transportation	Commercial/industrial/ transportation
	Mixed urban	Mixed urban
Vegetated land areas		Single-family residential
	Nonwoody vegetation	Nonwoody vegetation
	Woody vegetation	Woody vegetation
Water	Water	Water
Clouds	Clouds	Clouds
Shadows	Shadows	Shadows

An urban area normally contains only two major types of vegetation: tall, woody vegetation (trees); and low, nonwoody vegetation (grass, weeds, brush). Spectrally, the ERTS-1 data could not separate the vegetation into more than two categories without confusing their signatures with many other urban nonvegetation features. Consequently, no attempt was made to further divide the two vegetation categories.

The commercial/industrial/transportation category also remained unchanged for Levels II and III of the hierarchy. The spectral definition of this category is dependent upon the high percentage of concrete or asphalt surfaces, bright rooftops, a minimum amount of vegetation, and the absence of minute rectilinear patterns characteristic of a residential area. An attempt was made to separate commercial land use from industrial land use but, without spatial location information, the spectral differences were not great enough to avoid considerable uncertainty, confusion, and error. The transportation category was also spectrally confusing, particularly where transportation routes crossed areas with substantial vegetative cover.

The "mixed urban" category was spectrally the most confusing in the classification scheme because of its inherent complexity. This category includes residential areas, parks, golf courses, institutions (e.g., universities), cemeteries, tank farms, excavations, smaller commercial and industrial buildings, and dumps. This spectral complexity suggested that the mixed urban and single-family residential categories should be considered as having been derived from both vegetated and nonvegetated land areas.

Considerable effort was expended in an attempt to develop distinct spectral signatures for residential areas. Through the use of ground-truth aerial photography to interpret the computerized results, residential areas were separated initially into four general categories with the following characteristics.

1. Single-family residential areas with a dense cover of trees often obscuring actual rooftops and streets

2. Single-family residential areas with a less dense cover of trees, larger lots, many open fields

3. New single-family residential areas with very small or no trees, very small lots, and an overall highly reflective, dotted pattern of bright roofs and streets

4. Multifamily apartment complexes with extensive paved or roof-covered surfaces.

Separating these categories spectrally with a reasonable degree of accuracy proved almost impossible. The apartment complexes were too similar spectrally to the commercial/industrial category. Many nonresidential land uses were classified as residential; for instance, tank farms, where large tanks were surrounded by grass, were clustered into the same category as single-family residences. Cemeteries, some golf courses, and some open fields with mottled vegetation patterns were also classified into the residential category. The residential category was also found frequently along the edges of roads or airport runways, where the resolution cells (pixels) straddled the bright paved surface and the adjacent dark vegetation.

After considerable study of the computerized results, it was decided that the best accuracies for classifying residential areas would be achieved by dividing the "mixed urban" category into only two Level II categories: (1) single-family residential and (2) mixed urban. The single-family residential category included the older residential areas, where a dense, closely spaced pattern of roofs and streets interspersed with well-established lawns and scattered large trees prevailed. These areas usually were found near the inner core of the city or near the older major thoroughfares. The mixed urban category included all other land uses not included in the commercial/industrial/transportation category and by necessity had to include some residential areas that could not be separated from adjacent nonresidential uses. Although a certain amount of error was associated with this type of separation because of the spectral "confusion" involved with ERTS-1 data, the importance of identifying the major single-family residential areas within an urban area justified underclassifying other residential areas.

To demonstrate graphically the different categories of the hierarchy and how the urban scene would relate spectrally, maps showing Levels I, II, and III were generated on the DAS console and recorded on film. Figure 7-2 shows the total area separated spectrally to Level I of the hierarchy. Figure 7-3 shows the same area separated to Level II categories. This figure shows the various elements of the scene further separated, so that the vegetated areas in Level II represent woody vegetation (dark green) and nonwoody vegetation (light green). The other land areas represent commercial/industrial/transportation (black), other urban/ mixed urban areas (red), and water (blue). Figure 7-4 shows a map of the Level III categories: woody vegetation (dark green); nonwoody vegetation (light green); commercial/industrial/ transportation (black, gray, white, and very light yellow); single family residential (red and pink); mixed urban (orange and purple); and water (blue).

The accuracy evaluation of the urban residential study areas depended primarily on the ability of the nonsupervised classification technique to accurately delineate each of the residential study areas regardless of the adjacent land use feature. The evaluation is thus not only a measure of the ERTS-1 sensor performance in an urban land use inventory, but also an evaluation of

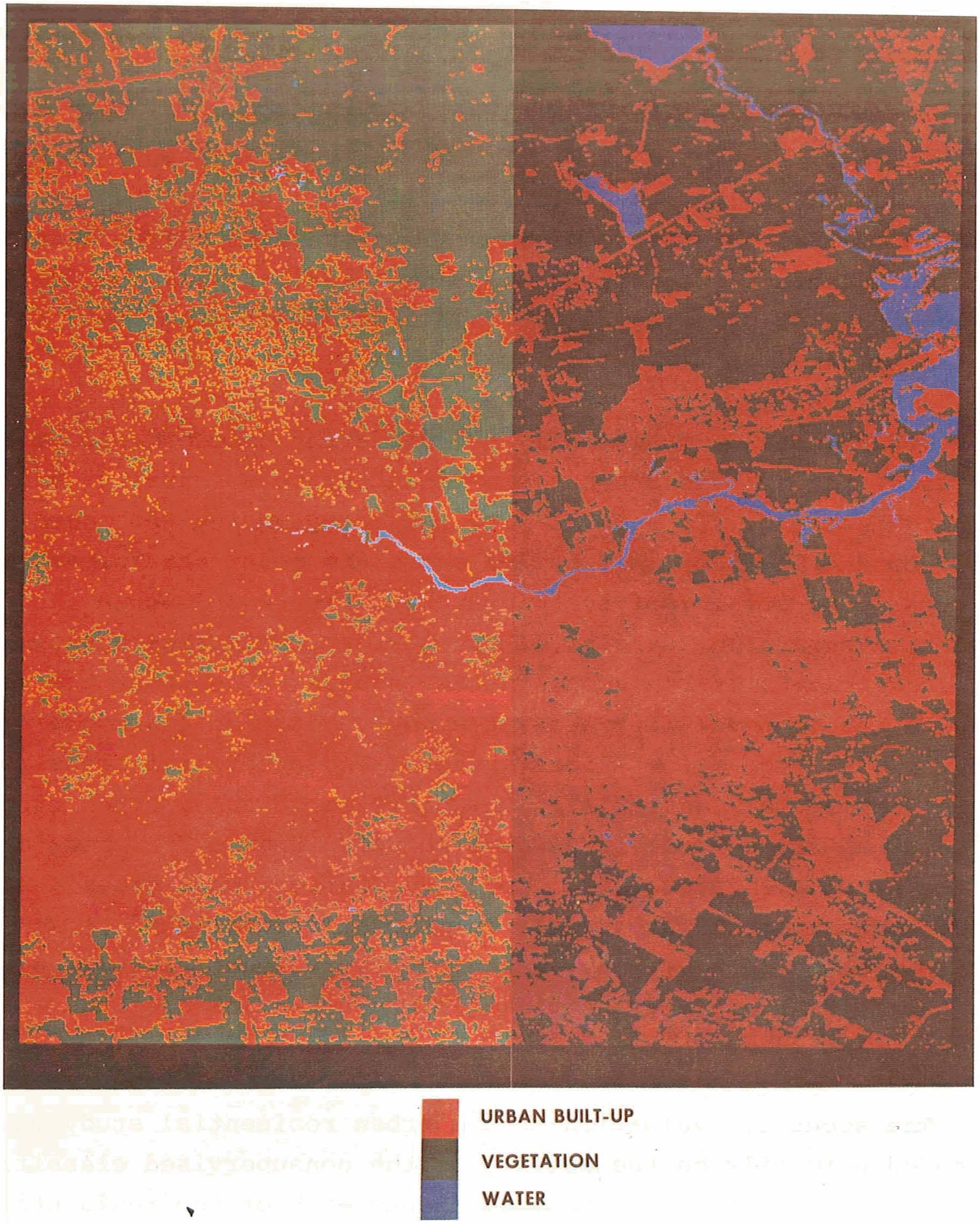

Figure 7-2.- Level I urban nonsupervised classification.

Figure 7-3.- Level II urban nonsupervised classification.

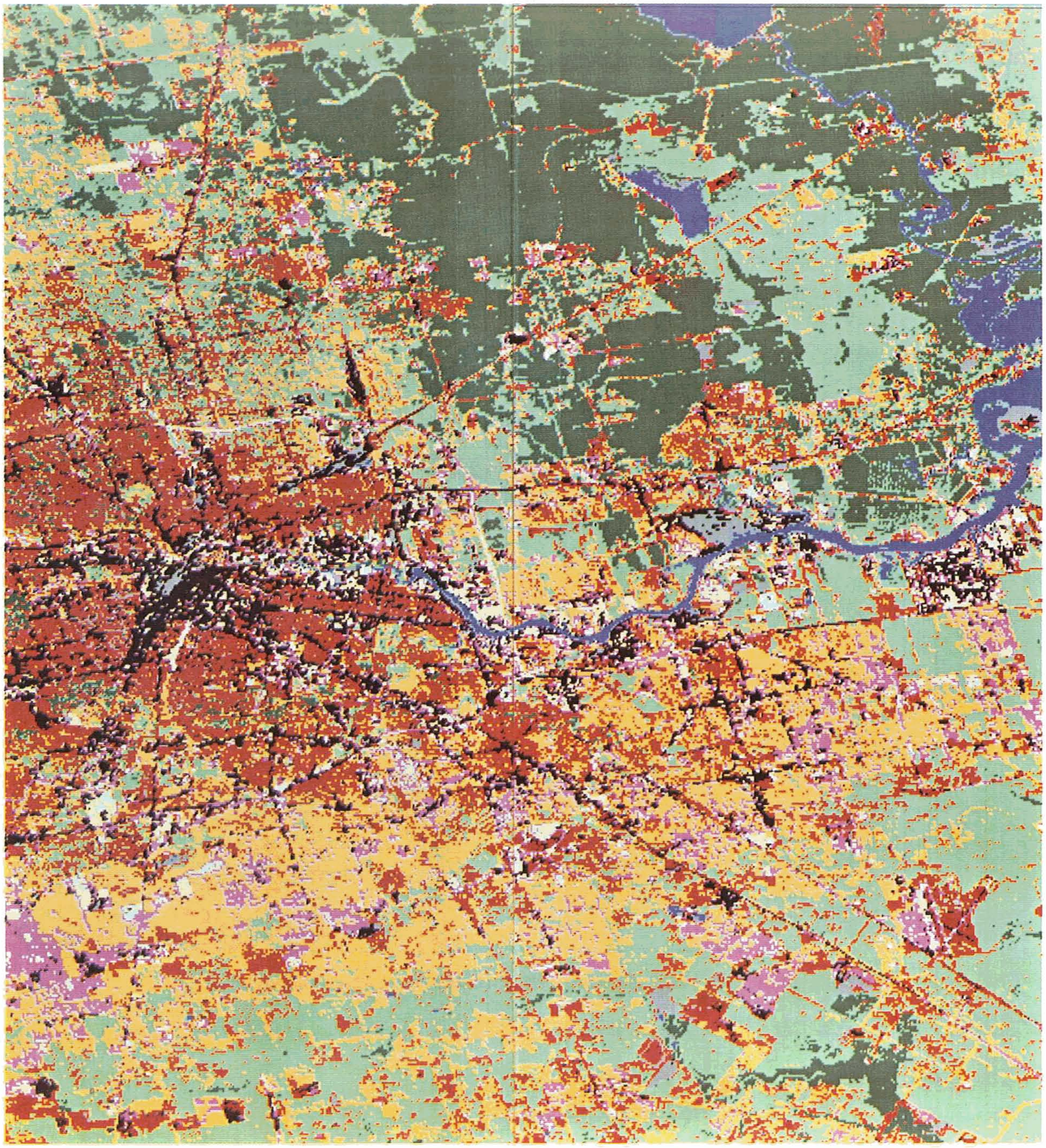

Figure 7-4.- Level III urban nonsupervised classification.

the classification techniques used. The study was limited because of time and because only one ERTS-1 data set was used in the analysis. It is assumed that better discrimination of urban land use categories could have been obtained if data from a dormant vegetative season had been available and could have been cross-correlated with the growing-season data.

The values presented in tables 7-IV and 7-V represent the performance accuracies for this portion of the investigation. With reference to table 7-IV, it appears that in the case of residential study area L (figure 4-2) the best boundary correlations occurred where the river was a boundary or where the boundary was adjacent to a homogeneous forest stand. The spectral homogeneity of the category adjacent to the area in question and the resolution of the sensor are of prime importance in discriminating between any two land use categories. For example, in the case of the major thoroughfare south of area L, distinguishing spectrally between the residential area and the freeway was not possible because of limitations in sensor resolution and lack of spectral contrast between the concrete/disturbed-Earth interface. On the other hand, the sensor was able to distinguish quite clearly the difference between the residential area and the river and also the homogeneous forested area on the west. The two forested areas within the preselected boundary on the northwest corner were actually built up at the time of the ERTS-1 pass; however, it does not appear as such in the older aircraft photography that was used as the mapping base for this study.

The delineations of the boundaries of residential study areas N and P (figures 4-4 and 4-5) were based on detecting spectral differences between similar urban features as recorded by adjacent pixels. Because the spatial resolution of a pixel is limited to a field of view of approximately 0.46 hectare (1 acre), an inherent error in boundary location of at least 1 acre could exist between two similar adjacent urban features.

The performance accuracies listed in table 7-IV appear to be low. This was not entirely unexpected, because the boundaries of the residential study areas were arbitrarily selected from aerial photographs prior to the receipt of any ERTS-1 imagery. In contrast, this apparent inaccuracy in boundary delineation is somewhat compensated by the increased accuracies obtained by measuring the areas encompassed by the delineated boundaries. Table 7-V shows the relatively high accuracies that were obtained by nonsupervised computerized classification techniques. Because a substantial portion of the correlation error is attributed to the inherent uncertainty at the boundary of two similar adjacent urban features and because this error is unpredictable (at times positive and other times negative), the area comparison is believed to be representative of the capability of ISOCLS to delineate urban land use features. The areal dimensions were obtained by making three separate measurements on a photographic data quantizer and calculating the mean. The accuracy is shown as a single ratio between the actual area measurement obtained from an aerial photograph as the base measurement and the mean area measurement obtained from the cluster classification map. A ratio greater than 1.0 indicates that the clustering technique classified a larger residential area than was determined from the aerial photography.

To determine the accuracy of the land use map generated by the nonsupervised classification, a misclassification error matrix was generated for the categories developed from the 32 clusters (table 7-IX). The misclassification error matrix was established by comparing the nonsupervised classification with the high-altitude aircraft photography (ground truth) of the same area. The statistics for each category in the misclassification error matrix were developed as described in table 7-IX.

TABLE 7-IX.- MISCLASSIFICATION ERROR MATRIX, PERCENTAGE

Category	Commercial/ industrial/ transportation	Residential	Urban	Vegetation (Woody)	Vegetation (Nonwoody)	Water
Commercial/ industrial/ transportation	94.2	5.5	--	--	--	0.3
Residential	2.6	66.8	23.0	4.5	3.2	--
Mixed urban	1.0	20.8	51.1	3.8	23.5	--
Vegetation (woody)	--	0.7	0.2	95.1	4.0	--
Vegetation (nonwoody)	1.1	12.1	25.7	4.8	56.2	--
Water	3.9	3.0	1.9	2.2	1.5	87.7

A total of five different areas containing the commercial/industrial/transportation category were randomly selected on the aerial photography. The aerial photography was considered adequate ground truth, because it provided sufficient resolution to identify the areas accurately according to this category. The occurrence of each of the 32 clusters that appeared within each of the five areas was determined. When all five areas had been analyzed in this manner, the total occurrences of all the clusters were computed and inserted in the proper locations in table 7-X. The five random sample areas used in the commercial/industrial/transportation column in table 7-IX contained a total of 1395 clusters. The distribution of those clusters appears under the ISOCLS cluster identification. For example, cluster 1 occurred only one time, cluster A occurred 146 times, and cluster K occurred 307 times. The other land use categories were analyzed in the same manner to develop the remainder of the table.

The information contained in this table includes the land use categories developed from the signature curves and preliminary analysis of the clustering results; the generic identification for each category; the number of occurrences of each cluster when identified with each of the categories; and, finally, the total number of clusters involved in all the samples used to evaluate the total area.

From the values listed in the table, each of the clusters was assigned to one of the categories based on the percentage of accuracies. This decision can be made based on factors other than the higher values, such as similarity and extreme values. In this case, the decision for assigning clusters to each of the categories was made in accordance with the highest percentage of occurrence. The results are listed in table 7-X.

TABLE 7-X.- OCCURRENCE OF LAND USE ISOCLS CLUSTERS IN THE URBAN SCENE

Category	Generic identification	1	2	3	4	5	6	7	8	9	A	B	C	D
Commercial/ industrial/ transportation	Central business district; paved roads, streets; institutional/ commercial pockets; factories/ refineries; apartments, etc.	1		4		32		18		42	146	106		22
Residential	Residential complex (dense)		1075	800	1356	231	362	1412	112	19	12	75	200	375
Mixed urban	Agriculture; low-density residential; open fields, cemeteries; parks		274	98	63	30	324	51	22	9			230	
Vegetation (nonwoody)	Open fields/ weeds; cut-back grass; vegetation		285	33	120	6	120	30	39	6		5	560	2
Vegetation (woody)	Dense forested areas		1		4				88				18	
Water	Lakes, rivers canals with/water Channels; impounded water		9	3	2	3	1	6	1				8	1

TABLE 7-X.- OCCURRENCE OF LAND USE ISOCLS CLUSTERS IN THE URBAN SCENE - Concluded

Category	Generic identification	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
Commercial/ industrial/ transportation	Central business district; paved roads, streets; institutional/ commercial pockets; factories/ refineries; apartments, etc.		117	364			57	307			22		91		61			1	4	
Residential	Residential complex (dense)	6	6	25		162	6			3	3		3		6					
Mixed urban	Agriculture; low-density residential; open fields, cemeteries; parks					22		1				13								3
Vegetation (nonwoody)	Open fields/ weeds; cut-back grass; vegetation		6			36						192								
Vegetation (woody)	Dense forested areas	416				9														
Water	Lakes, rivers canals with/water Channels; impounded water	4			11	6		3	94	11				62	17	185	38		57	

The misclassification error matrix (table 7-IX) was developed from these results. The accuracy for the classification of each category is dependent on the decision rule and the clusters identified with each category. The matrix was developed by summing the total occurrence of all clusters assigned to each category and ratioing this sum to the total occurrence of all clusters of the random samples selected as that category. As an example, the accuracy of ISOCLS classifying the commercial/industrial/transportation areas equals the total occurrence of clusters 1, 9, A, B, F, G, J, K, N, P, and R (1314) divided by 1395 (the total occurrence of all clusters in the five random sample areas (table 7-X), or 94.2 percent). Because clusters 9, A, B, F, G, J, P, and R also appear in the random samples classified as residential, this is a measure (5.5 percent) of inaccurately classifying residential areas as commercial/industrial/transportation areas and for identical reasons a measure (0.3 percent) of inaccurately classifying water areas as commercial/industrial/transportation.

The misclassification error matrix (table 7-IX) evaluates the accuracy of the ISOCLS clustering procedure in classification of urban land use within the Houston metropolitan area. Based on the sampling procedure, the percent accuracies of classifying urban land use by clustering are listed as follows.

Commercial/industrial/transportation	94.2
Residential	66.8
Mixed urban	51.1
Vegetation (woody)	95.1
Vegetation (nonwoody)	56.2
Water	87.7

By studying the matrix closely, it is obvious that the accuracy of this system of classifying is dependent on the interpretation given each cluster when compared to ground truth. For example, the mixed urban category was identified generically as areas such as low-density housing and vegetated areas. Therefore, the largest percentage of misclassifications for that particular category occurs largely for residential and vegetation (nonwoody) as the matrix indicates. If there were no interest in separating these categories, the decision rule for classifying clusters would be somewhat different and the classification performance would improve considerably.

When the same clustering program was repeated using as input only spectral bands 5 and 7, instead of the usual four bands, some very interesting classification patterns appeared. The results of this brief experiment appeared interesting enough to warrant inclusion in this report as a series of colored classification maps obtained from the DAS film output. Individual category maps, first developed for each major land use category, are shown as follows.

- Figure 7-5 Woody vegetation (dark green), nonwoody vegetation (light green and yellow)
- Figure 7-6 Water
- Figure 7-7 Single-family residential
- Figure 7-8 Commercial/industrial/transportation
- Figure 7-9 Mixed urban

These individual categories were subsequently combined to produce the final multicolor cluster map shown in figure 7-10. Unfortunately, time would not permit further experimentation with other combinations of spectral bands as clustering input.

An examination of figure 7-8 shows that the clustering techniques performed very well in delineating the major transportation routes in the Houston area, particularly when only two spectral bands (5 and 7) were used as input data to the ISOCLS program.

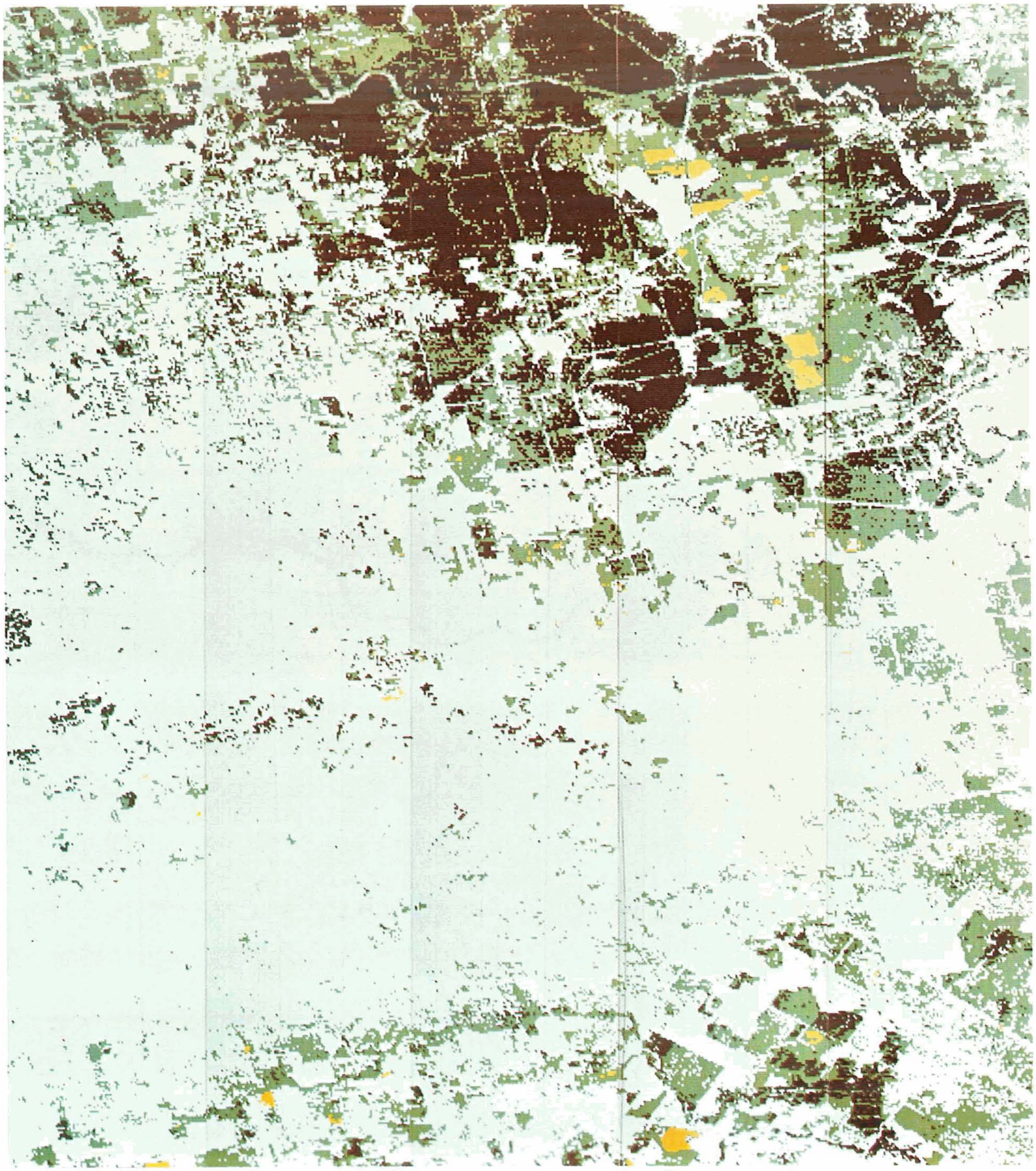

Figure 7-5.- ISOCLS urban classification (two spectral bands) delineating vegetation.

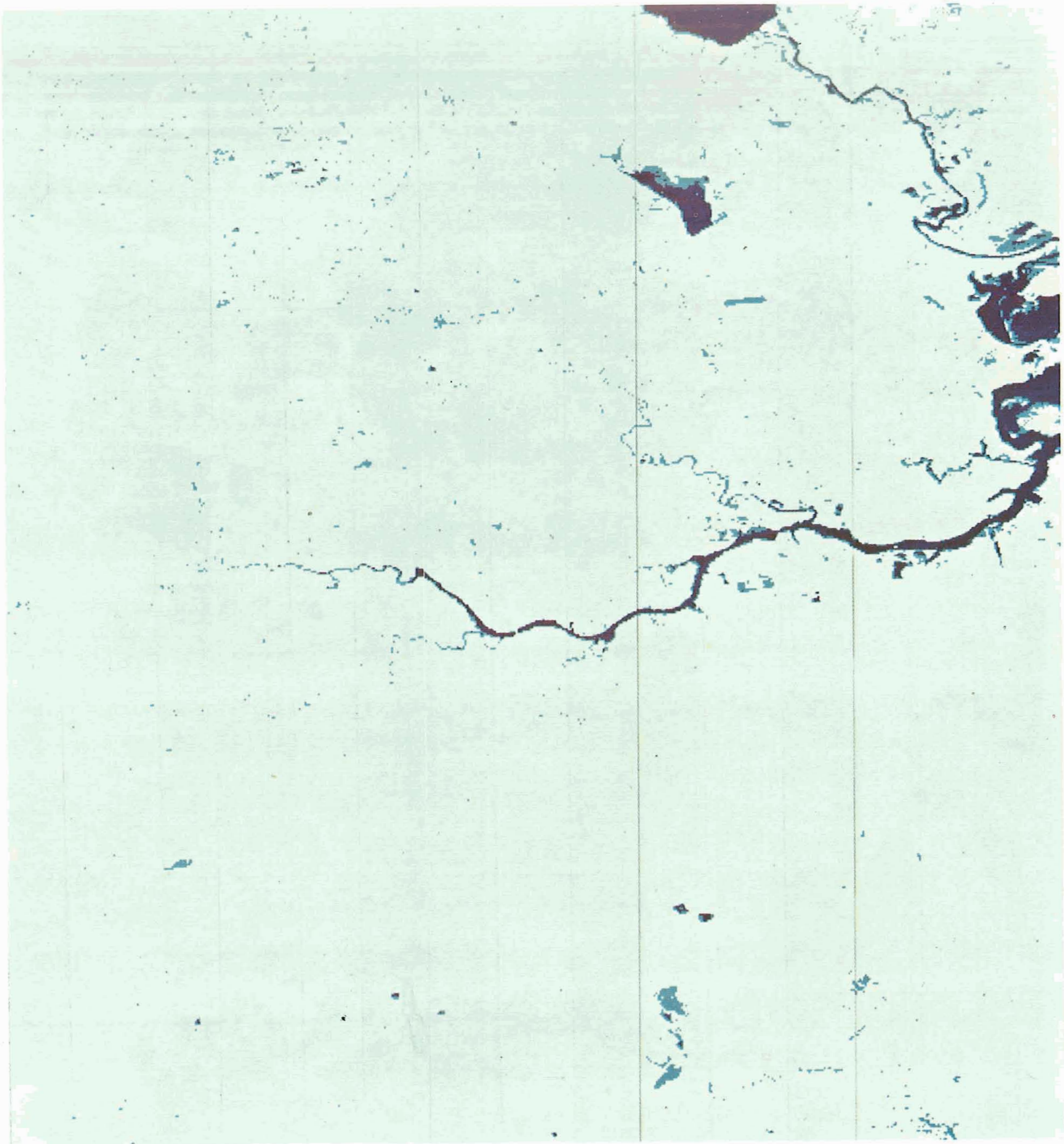

Figure 7-6.- ISOCLS urban classification (two spectral bands) delineating water.

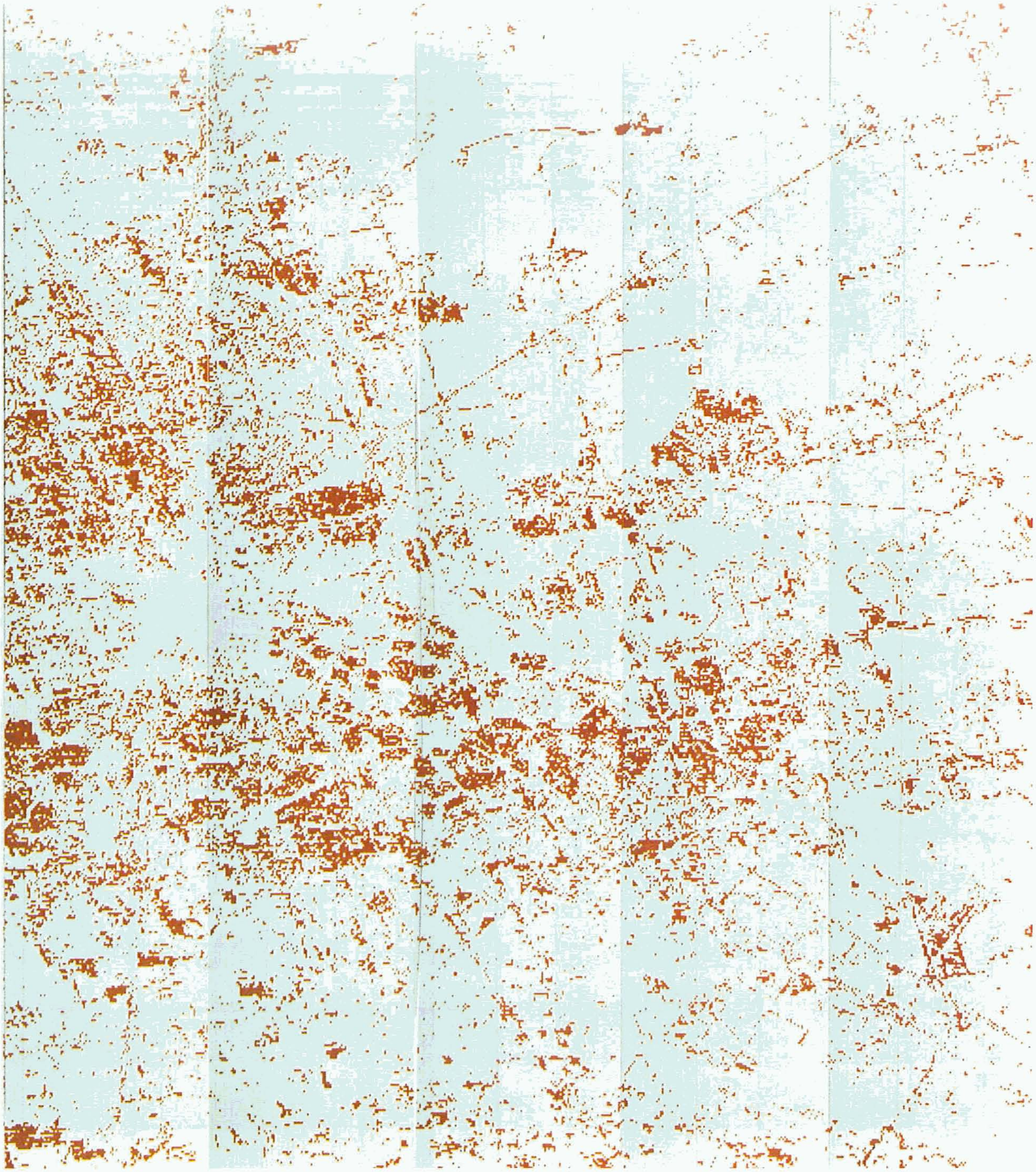

Figure 7-7.- ISOCLS urban classification (two spectral bands) delineating single-family residential.

Figure 7-8.- Urban classification (two spectral bands) delineating commercial/industrial/transportation.

Figure 7-9.- ISOCLS urban classification (two spectral bands) delineating mixed urban.

Figure 7-10.- ISOCLS urban classification (two spectral bands) delineating composite land use categories.

From the cluster map produced, the major transportation routes were manually interpreted and identified as shown in figure 7-11. The only evaluation attempted was to visually compare the interpretations from the clustering results with the base map (figure 7-12). This comparison indicates that over that portion of the metropolitan area covered by the ERTS-1 pass, all the major thoroughfares were delineated. In addition, the clustering process was able to map many more linear features that were subsequently interpreted as a substantial portion of the major road and street pattern of the Houston area.

7.3.2 Supervised Classifications

This section discusses the results of the two supervised classification procedures (ERIPS and MTFO) that were used in processing the data for the boundary correlation, linear pattern correlation, and classification correlation analyses. Computer classification displays, grouped by color coding on the DAS console to represent the four general urban land use categories (vegetation, residential, commercial/industrial, and water), are shown in figures 7-13 and 7-14.

The urban land use categories obtained by the ERIPS procedure are represented in figure 7-13 by the following colors.

1. Residential - red and magenta
2. Vegetation - yellow and light and dark greens
3. Commercial/industrial - white and lavender
4. Water - blue

The black-outlined areas represent the geographic locations of the training and test fields selected for this procedure. The small black rectangles represent individual pixels and groups of pixels that were outside the spectral range of the input statistics used in this procedure. These points are sometimes referred to as "threshold" points.

Figure 7-11.- Manual interpretation of major transportation routes (ERTS-1 August 29, 1973, pass, MSS bands 5 and 7).

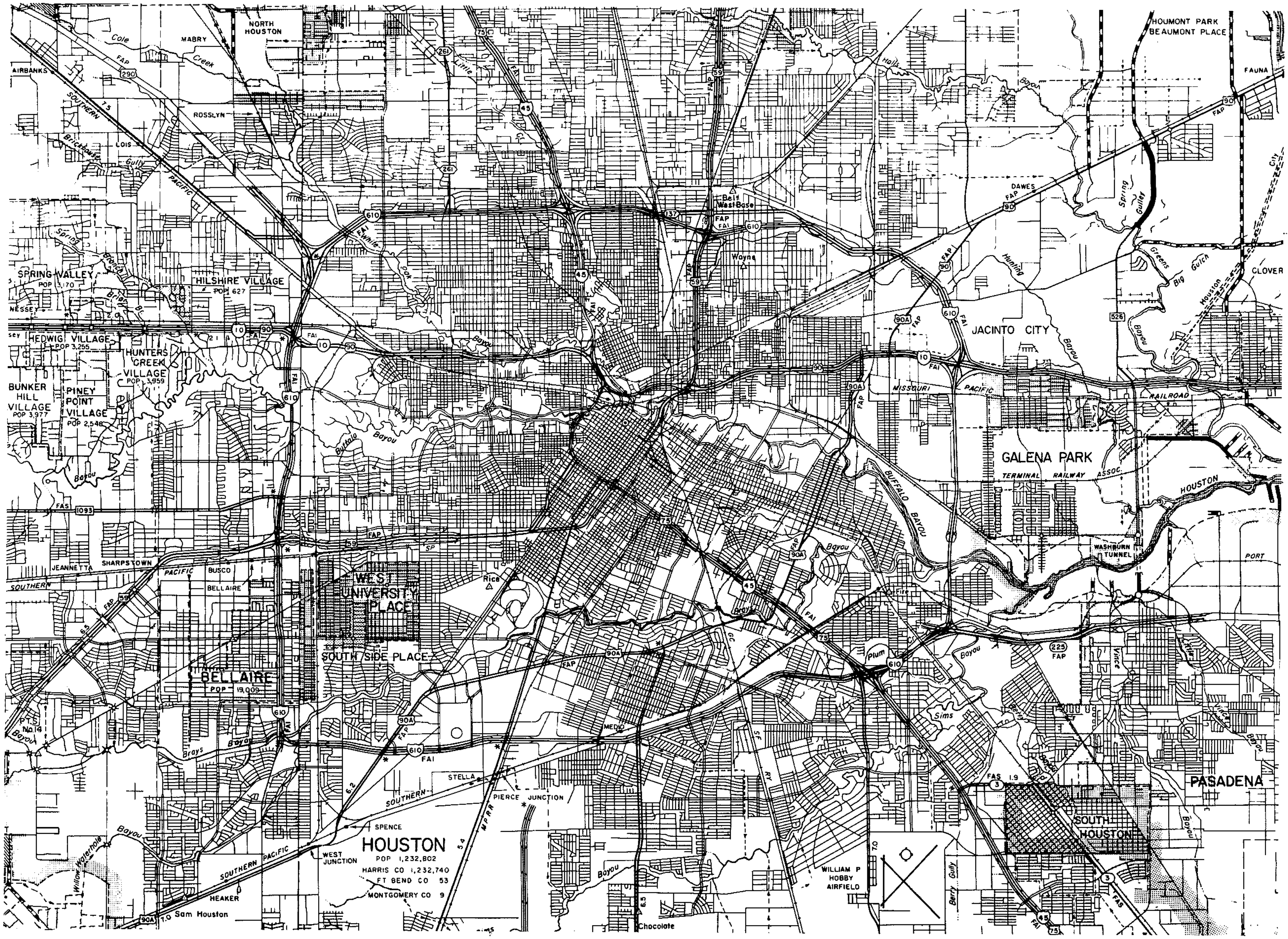

Figure 7-12.- Houston area base map.

Figure 7-13.- ERIPS supervised classifications delineating urban land use.

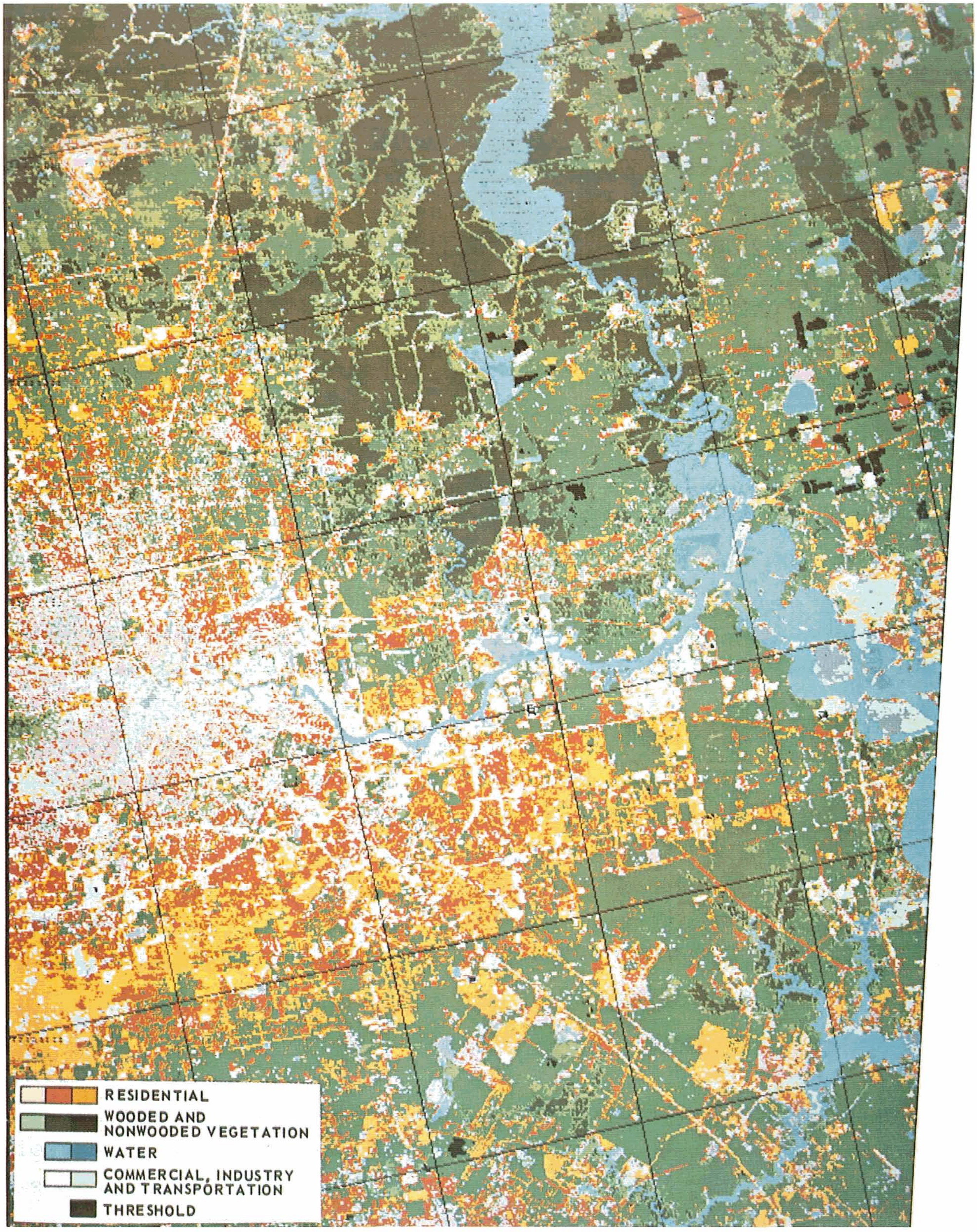

Figure 7-14.- MTFO supervised classifications delineating urban land use.

The same four general urban land use categories obtained by the MTFO procedure are represented in figure 7-14 by the following colors.

1. Residential - red, pink, and yellow
2. Vegetation - light, medium, and dark greens
3. Commercial/industrial - white and lavender
4. Water - black and light and dark blues

A cursory comparison of figures 7-13 and 7-14 reveals an impressive agreement between the two procedures for classifying urban land use. A few discrepancies are apparent, but most of these appear to be associated either with vegetation-influenced features or with the results of the deliberate detail smoothing applied to the clustering statistics in the MTFO procedure.

7.3.2.1 Boundary correlation analysis.- The accuracies with which the ERIPS and MTFO procedures were able to delineate the boundaries between residential and other urban land uses are shown in tables 7-XI and 7-XII. The overall accuracies appear to be relatively low. However, much of this inaccuracy may be due to the stringent requirements imposed upon the analytical procedures to delineate specific portions of boundaries that had been arbitrarily selected from aerial photographs before the receipt of any ERTS-1 imagery. Also, the inherent resolution of the ERTS-1 MSS was related to these low accuracies. The boundary between some contrasting land uses may be an extremely narrow demarcation; whereas, in some cases, the boundary may be a relatively broad zone of transition with only a gradual change in spectral contrast. Whether or not a particular pixel (picture element of approximately 0.46 hectare (1.1 acres)) could be classified as a part of a particular boundary depended upon whether this area was composed mostly of one predominant land use category or whether several

TABLE 7-XI.- ACCURACY ANALYSIS OF RESIDENTIAL BOUNDARY DISCRIMINATION

Residential study area	Boundary separating residential from -	Percent of specific boundary delineated by -	
		ERIPS	MTFO
Clover Leaf (area L)	Forest	50	50
	Freeway	58	28
Pasadena (area M)	Commercial/ industrial	(a)	68
Garden Villas (area N)	Other residential	34	30
Center city (area P)	Commercial/ industrial	25	27
	Other residential	0	18

[a]No comparative figures.

categories were integrated into a single spectral response and possibly bore no resemblance to any of the surrounding land use categories. A review of figures 7-13 and 7-14 reveals that the four selected residential study areas were actually fairly distinctly differentiated from their surrounding land use areas, albeit that much of area L and of area N was classified into the general vegetation category. This was to be expected because of the preponderance of vegetative surfaces in these two areas. The western edge of area L was expected to be delineated fairly accurately because of the sharp contrast between the residential features and the heavy forest cover. A comparison of figures 7-13 and 4-2 shows that a much greater overall delineation accuracy was

TABLE 7-XII.- TOTAL BOUNDARY ACCURACIES

Residential study area	Percent of total boundary delineated by -	
	ERIPS	MTFO
Clover Leaf (area L)	50	35
Pasadena (area M)	(a)	72.5
Garden Villas (area N)	61	25
Center city (area P)	13	22

[a]No comparative figures.

achieved for this boundary than would be indicated by table 7-X. Likewise, a review of figures 4-3 to 4-5 reveals that certain portions of the boundaries of these residential study areas were more accurately delineated than the specific boundary accuracies in table 7-X would indicate.

The greater accuracies that appear to be evident when the classification maps (figures 7-13 and 7-14) are viewed in a general "big picture" context are confirmed by table 7-XI, where the length of the total boundary around a study area is considered, instead of only a specific boundary as represented in table 7-X. The exception to this general observation appears to be in area P, where greater accuracy was achieved in discriminating between specific residential and commercial/industrial boundaries than when delineating the total boundary. A study of figure 4-5 shows that a substantial portion of the total boundary was between residential areas with similar spectral characteristics.

In summary, this boundary correlation analysis showed that the best accuracies in discriminating residential boundaries could be achieved when the adjacent land use was either forest or commercial/industrial, particularly when the boundary coincided with a major freeway. The degree of accuracy in delineating residential land use boundaries appeared to be directly proportional to the size of the residential study area, but the lack of sufficient statistical evidence makes this observation only tentative and inconclusive without further analysis.

7.3.2.2 Linear pattern correlation analysis.- Linear patterns were one of the more distinguishable features found on the classification film transparencies from the DAS console. Manual delineations of these linear patterns were readily accomplished, but the actual identification of these patterns was much more difficult and in some cases impossible (figure 7-15). However, commercial activities, with their extensive paved and roof-covered surfaces, being often associated with major thoroughfares, made it possible to delineate some major transportation routes that otherwise would not have been distinguishable.

Roads and streets with fewer than four lanes usually were not distinguishable, except in the few instances where a highly contrasting background, such as dense trees or lush vegetation, made the narrcw, linear patterns visible. Even major highways of more than four lanes could not be distinguished as a separate category where the background had similar spectral characteristics, such as the extensive paved areas in the central business district, or in other large commercial areas. Consequently, major transportation training fields were grouped with the commercial/industrial training fields during the ERIPS procedures for supervised classification of these land use categories.

Figure 7-15.- Major transportation routes in the Houston area. (Source: manual interpretation from an ERIPS supervised classification of ERTS-1 MSS data, August 29, 1972).

East-west oriented streets appeared to be slightly more distinguishable than north-south oriented streets. This slight difference is suspected to be due to the shadows of buildings that would exhibit a linear pattern along the south side of the east-west streets at the time of the ERTS-1 overpass.

The residential land use category was sometimes classified in the form of a linear pattern. This misclassification may result when contrasting reflectivities form narrow, linear boundaries between vegetation and paved surfaces were integrated by a pixel into a single spectral response.

Several instances of major freeway construction were identified as linear patterns. Although these were linear, they did not have the added radiance effects of surrounding commercial activity. The training samples taken on one of these construction areas did aid in identification of other construction areas around the city.

A comparison of figures 7-11 and 7-15 reveals an overall similarity in the capability of supervised and nonsupervised computer procedures for classifying major transportation routes. The slightly greater detail of roads evident in figure 7-11 should not be construed as a superior procedure, because the clustering of only two spectral bands was a very limited investigation in which insufficient time precluded adequate testing for verification.

7.3.2.3 Classification correlation analysis.- The results of using a least-squares linear regression statistical approach for measuring the accuracy with which urban land use can be classified by supervised automated data processing (ADP) are shown in the form of four graphs in figure 7-16. The graphs show the degree of correlation that resulted when the occurrences of four selected urban land use categories in 35 randomly located sample areas were determined by supervised classification and by conventional image interpretation of aerial photographs.

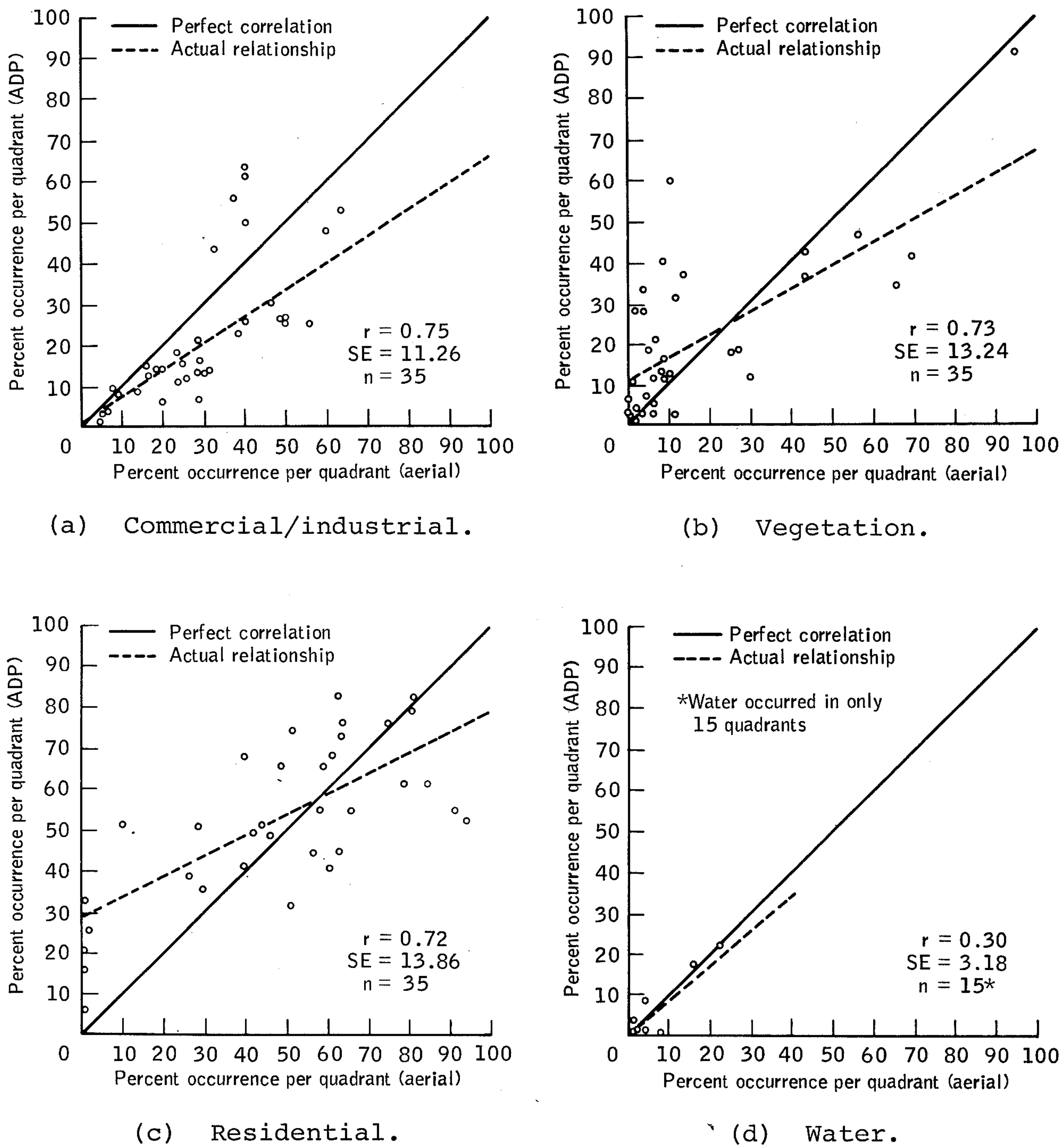

Figure 7-16.- Correlation land use occurrences in sample quadrants (aerial photography versus ADP classifications).

Residential, vegetation, and commercial/industrial correlation coefficients are close, ranging between 0.72 and 0.75. All resulted in a significant F ratio, suggesting that the correlations did not occur by chance. Additionally, the standard error of the estimate is high in these three cases, indicating that the point spread about the regression line was large and that the accuracy of prediction was poor, if the regression were to be used as a predictor. Of the three classes, commercial/industrial yielded the highest correlation coefficient and smallest standard error.

If perfect correlation had occurred, each point would have fallen on the solid line. In each case, the deviation of the regression line (i.e., the dashed line) from the perfect correlation line indicates the deviation of the nominal predicted value over the whole range of occurrences. For example, the commercial/industrial graph shows that the origin of the regression nearly coincides with that of the perfect correlation, but the percent occurrence is consistently underestimated and tends to get worse as the actual occurrence per quadrant increases. Relating this trend to the study site and the spectral characteristics, when vegetation occurred in the scene with commercial/industrial, computer classifications tended to misclassify those pixels as residential. Thus, the error of omission increased in the residential class and in the commercial/industrial class. In interpreting the correlation, however, it should be emphasized the most quadrants contained between 15 and 50 percent commercial/industrial; that is, the full range of percent occurrence was not equally sampled.

Vegetational and residential classes were overclassified when low percentages per quadrant occurred and underclassified when high percentages per quadrant occurred. This is related in part to the similarity in spectral signatures between the two classes. Overestimation of residential usually was the result of vegetation.

and some commercial/industrial being misclassified. Underestimation of residential usually resulted in residential being classified as vegetation. In contrast, vegetation was seldom confused with commercial/industrial; but, when overestimated, the analysis indicated that residential was misclassified as vegetation.

The water classification only occurred in 15 of the 35 quadrants and shows a high correlation between computer classified and actual, a relatively low standard error, and a close approximation of perfect correlation for the range considered. Typically, when there was zero actual occurrence, no water was classified (i.e., two waters predicted in 22 zero occurrences). Thus, when water occurred, it was usually easily discriminated, and other classes seldom were incorrectly classified as water.

8.0 CONCLUSIONS

From this investigation, the ERTS-1 multispectral scanner sensor was determined to be capable of providing generalized data that could have limited application in urban land use studies. The limited spatial resolution and extremely small scale of the imagery imposed important limitations on the amount of information that could be extracted by conventional image interpretation techniques. Although the spectral resolution of the scanner was sufficient to resolve the normal range of spectral reflectivities within a complex urban scene, the spatial resolution of the scanner was not adequate to resolve the individual reflectivities from the many small, three-dimensional objects found in an urban scene. The spectral energies recorded by each resolution cell (pixel) were actually integrated or averaged into one spectral response, the magnitude of which was largely dependent upon the proportion of the pixel occupied by each of the objects in the field of view. Consequently, the same spectral signature could be derived from a great variety of different combinations of surface reflectivities.

In using computer classification programs to classify these heterogeneous scenes, serious difficulties were encountered in finding spectrally homogeneous urban features of sufficient size to be used as training fields. Although clustering techniques could be used to group these heterogeneous pixels into great numbers of similar clusters, it was then necessary to determine the ground-truth meaning of these clusters and group them manually into meaningful spatial patterns corresponding to known urban land use categories.

The techniques used in locating and identifying individual pixels aided greatly in delineating areas that had the most homogeneity, and made it possible to readjust the input parameters to the clustering program where this was deemed desirable.

Determining the precise geographical location of each pixel made possible grouping similar clusters into meaningful land use patterns with greater accuracy than the more conventional visual aerial photography method permitted. The clustering program was capable of grouping pixels into more than the 32 clusters used in this investigation but, after the analysis of the spectral characteristics of individual pixels and the trial-and-error grouping of clusters into various land use categories, 32 clusters appeared to be a reasonable compromise. Better classification results were usually achieved by manually grouping certain clusters to correlate with known spatial patterns, rather than reducing the number of computer interactions, where the resultant grouping would be based on spectral analyses. This technique may not be valid in an unknown area where the lack of ground truth would preclude grouping clusters into desired land use patterns.

From clustering with only two bands of ERTS-1 data rather than the usual four spectral bands, the amount of computer time required for clustering analyses could possibly be reduced by approximately one-half and still provide comparable classification results for certain types of land use categories. It is emphasized that this limited investigation involved only bands 5 and 7 of the ERTS-1 data and was concerned at the time with only one urban land use category (major transportation routes).

The greatest number of classification anomalies came from the computer classification of urban features having low spectral (visible) reflectivities, such as vegetation and asphalt. For this reason, greater classification accuracies could be achieved by making comparative analyses of data obtained during different vegetative seasons. This should at least be true for classification of residential areas, which normally are the most extensive of the land use categories within an urban area.

The present ERTS-1 system and the analytical procedures used in this investigation would find the most utility for urban and regional planners in providing frequent boundary revisions of the urban fringe, where the greatest spectral contrast occurs between areas of dense vegetation and new urban developments. These gross changes in landscape appear most pronounced where forested lands are being cleared for urban development.

Classification using spectral or spatial characteristics has a definite bearing on classification accuracies and potential applications for which the data might be considered. This investigation indicated that boundaries between land uses could be discriminated with low accuracy and that the areas of the various classes were not accurately estimated although highly correlated. This might be of special interest in the development of area predictive models for regional resource planning or mapping. The predictability of accuracy is, however, dependent on using a variable and complex error factor.

Many factors influence the classification of residential land uses. Some of these factors are age of the building, the presence and amount of vegetation, roof composition, and the amount of street, sidewalk, or other pavement in each pixel. The signatures developed for residential land uses were composed of many elements (vegetation, structure, concrete). Many nonresidential items were therefore often misclassified.

Different types of residential and commercial/industrial training fields were selected using manual interpretation procedures. The subtle spatial and spectral differences used in field selection were not detected through automatic processing of ERTS-1 data. The highest boundary delineation correlations occurred in separating residential from commercial/industrial, and residential from freeway within the largest study area. The lowest boundary delineations were observed in delineating the boundary between two different residential areas. Geographic accuracy of these delineations for small areas within the city is questionable; however, the larger the urban subarea under analysis, the smaller the relative error for geographic and classification correlations.

Gross urban features can be distinguished by manually interpreting computer classification results. This process involves a spatial as well as spectral evaluation, which compares favorably to conventional low-altitude photographic interpretation. Classification accuracy of small subsets within the urban complex has very low correlation with base data. The resolution of the ERTS-1 sensor provides limited spatial and spectral information necessary for discrimination of the functionally defined urban land use categories of the USGS Circular 671 hierarchy. A rather weak relationship was found between functional land uses and gross spectral classes.

The initial phases of this investigation were essentially learning experiences in coping with a new medium of remote sensing and recently developed computer analysis programs. Although the planning phases of the investigation occupied a major portion of the entire allotted time, new and expanded analytical procedures could be developed for additional research along similar lines with a minimum of delay. These new procedures could probably supply the answers to some of the questions that had to remain unanswered in this investigation because of the lack of analysis time. The results seem to indicate that additional time and effort would be justified in developing new research methods to investigate how well these results could be applied to complex urban scenes in other climates and in different seasons.

9.0 RECOMMENDATIONS

The experimental aspect of this investigation suggests several recommendations for consideration in possible future investigations of similar nature. It is recommended that additional time and effort be allotted to a low-key program of adapting, revising, and testing some of this investigation's more promising experimental procedures to ERTS data from other seasons and from other geographic areas. The preliminary results of this investigation show promise in classifying complex urban features by computerized classification and conventional image interpretation procedures. However, additional research toward a more complete integration of conventional image interpretation and computerized classification procedures appears necessary before an operational satellite data analysis system for acquiring necessary urban information can be recommended. The relatively recent upsurge in national interest in urban problems would seem to justify additional research in this dynamic discipline.

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APPENDIX

PROCEDURES FOR CONSTRUCTING PIXEL CORRELATION GRIDS

The following materials were used in constructing the pixel correlation grids for this project.

1. A computer gray-map printout provided by an ISOCLS clustering program

2. An aerial photograph (enlarged paper print) of the same area covered by the gray-map printout

3. Conventional drafting and photointerpretation equipment and materials (polyester drafting film, straightedge, dividers, engineer's scale, proportional dividers, magnifiers)

The following paragraphs provide a brief description of the procedures used in constructing the grids.

A grid was drawn on the printout to coincide with every five scan lines and every five pixel columns. This produced a grid encompassing 25 pixels within each grid rectangle. A transparent overlay grid for an aerial photograph of the same area was then constructed to correspond to the printout grid. The initial step in constructing this photogrid was to identify three or more bright objects on the photograph, which could be related to specific pixels on the printout. It was advantageous to find bright objects that were directly on one of the printout grid lines. When this was not possible, the distance to the nearest line was measured and this distance was proportioned on the photograph. The photo distances between these points (vertical and horizontal distances) were then divided into the number of equal distances represented by the number of pixels on the printout. The photogrid was constructed by extending these horizontal and vertical distances to cover as much of the photograph as was represented by the printout grid. The initial photogrid was drawn by scribing a few fine lines on a transparent overlay to fit a 1:120,000 scale aerial photograph. When these few lines appeared to intersect at the proper points on this small-scale photograph, a complete grid was constructed to fit a 1:60,000 photograph. After evaluating this complete grid for accuracy, a small transparent grid was constructed to divide 1 of the 25-pixel squares into 25 individual squares. This smaller grid was also constructed by scribing fine lines on a transparent film with a high magnification viewer, which could then be used under a tube magnifier. By shifting the tube magnifier and small grid over the larger grid, individual pixels were located and identified on the 1:60,000-scale photography.

It soon became evident that a much larger scale aerial photograph would be necessary to determine the spectral composition of a specific pixel. A portion of a low-altitude aerial photograph of an area adjacent to downtown Houston, enlarged to a scale of 1:1980, was selected for the construction of a one-pixel-square grid. Because of the very limited number of highly reflective individual objects that could be identified as specific pixels and used for determining the grid spacing on the enlarged photograph, the approximate size of an individual pixel was calculated from the 1;60,000 photography. The ground size of a pixel (not considering any overlap in the scanner field of view) as represented by the grid spacing on the printout was calculated to be approximately 57 by 81 meters (187 by 265 feet) or 0.46 hectare (1.14 acres). Using these dimensions for the size of an individual pixel, a transparent grid was constructed to cover the entire 1:1980-scale photograph. Although the 1:1980 photogrid was constructed without first identifying specific pixels, when the grid was placed over the photograph and each pixel square given the same identifying cluster symbol as on the printout, a surprising degree of correlation accuracy was evident between the gridded photograph and the gridded printout. Objects other than those most highly reflective (specific fields and buildings) could now be readily identified, because they occupied the same grid positions on the two media. A few misalinements were noted as the extreme distances between grids were compared. Greater accuracies could be obtained if more refined photogrammetric procedures were used. A rectified enlargement of this aerial photograph was not available, so an unrectified enlargement was used in developing the experimental procedures. Consequently, the minor inaccuracies in pixel location were not unexpected. A subsequent grid was constructed in which the lines converged slightly to correspond to the unrectified photograph. The accuracies of pixel location improved impressively with this corrected grid.

With the completion of the corrected photogrid, a more detailed examination was begun of individual pixels as outlined by the grid. The enlarged photograph contained only six different clusters of pixels as determined by the particular computer clustering program for the printout used in this experiment. In an urban scene as heterogeneous as the one depicted on the enlarged photograph, each pixel encompassed a wide variety of roofs, pavements, trees, grass, and shadows, each with its own range of spectral reflectivities. No single pixel in this scene encompassed only one homogeneous feature. Consequently, it became necessary to determine what percentage of a pixel was composed of several different reflective surfaces. To keep this initial analysis as simple as possible, no attempt was made to make quantitative densitometric measurements of actual photographic densities representing the various features in the scene. Neither was any attempt made to quantify the reflectivities of specific features as might be recorded in various portions of the electromagnetic spectrum, except for a cursory, visual comparison that was made of three bands (green, red, and infrared) of extremely small-scale multiband aerial photography obtained over the area during a different season. Instead, three general levels of brightness, as seen on the enlarged panchromatic photograph, were used as the criteria for determining the spectral composition of each pixel. The selected levels of brightness were (1) highly reflective objects, such as white or aluminum roofs, pavements, some parking lots and roadways, and new excavations; (2) low-reflective objects, such as trees, shadows, and certain roofs; and (3) moderately reflective objects, such as open fields of grass and some pavements.

Another transparent grid was constructed to make a gross approximation of the areal extent of the three levels of brightness that appeared within the boundaries of each pixel. This grid divided the parallelogram of each pixel on the enlarged photograph into 25 equal parts. A quick, visual count of the number of these smaller parallelograms that were covered by a particular level of brightness (multiplied by 4) gave an approximate percentage of each level that had been integrated into the composite spectral response of each pixel.

The spectral compostion of a sampling of pixels in each of the six clusters within this particular urban scene was determined. The averaged results of this sampling are presented in section 7.2 of the text.

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