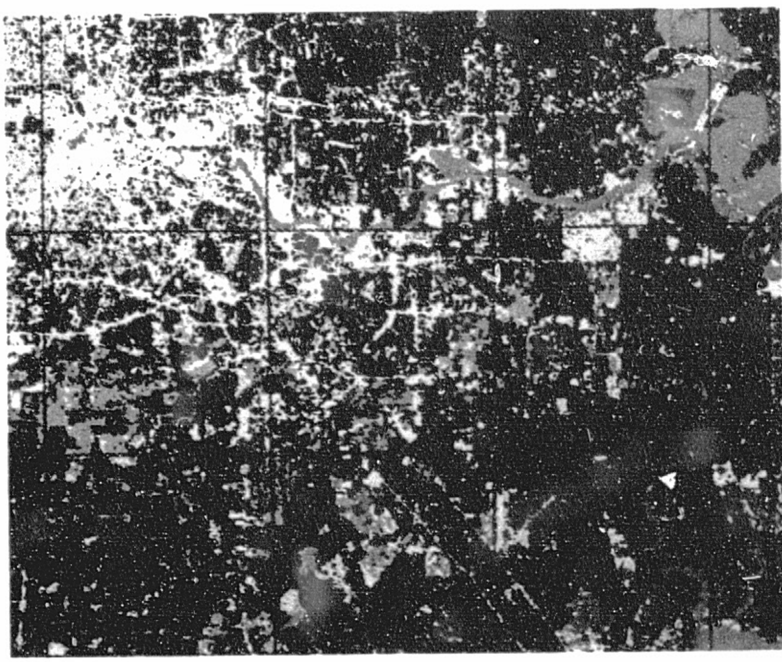
JSC-08455

NASA TECHNICAL MEMORANDUM

NASA TM X-58156
November 1974

THE ERTS-1 INVESTIGATION (ER-600): A COMPENDIUM OF ANALYSIS RESULTS OF THE UTILITY OF ERTS-1 DATA FOR LAND RESOURCES MANAGEMENT



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LYNDON B. JOHNSON SPACE CENTER

HOUSTON, TEXAS 77058

(NASA-TM-X-58156) THE ERTS-1 INVESTIGATION (ER-600): A COMPENDIUM OF ANALYSIS RESULTS OF THE UTILITY OF ERTS-1 DATA FOR LAND RESOURCES MANAGEMENT (NASA) 170 p HC $6.25 CSCL 08F G3/43

N75-21777

Unclas
20328

1. Report No. NASA TM X-58156	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle THE ERTS-1 INVESTIGATION (ER-600): A COMPENDIUM OF ANALYSIS RESULTS OF THE UTILITY OF ERTS-1 DATA FOR LAND RESOURCES MANAGEMENT		5. Report Date November 1974
		6. Performing Organization Code
7. Author(s) R. Bryan Erb		8. Performing Organization Report No. JSC-08455
9. Performing Organization Name and Address Lyndon B. Johnson Space Center Houston, Texas 77058		10. Work Unit No. 641-14-07-50-72
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		13. Type of Report and Period Covered Technical Memorandum
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The results of the ERTS-1 investigations conducted by the Earth Observations Division at the NASA Lyndon B. Johnson Space Center are summarized in this report, which is an overview of documents detailing individual investigations. Conventional image interpretation and computer-aided classification procedures were the two basic techniques used in analyzing the data for detecting, identifying, locating, and measuring surface features related to Earth resources. Data from the ERTS-1 multispectral scanner system were useful for all applications studied, which included agriculture, coastal and estuarine analysis, forestry, range, land use and urban land use, and signature extension. Percentage classification accuracies are cited for the conventional and computer-aided techniques.

17. Key Words (Suggested by Author(s))		18. Distribution Statement
· Remote Sensors · Ground Truth · Infrared Imagery · Signature Analysis · Computer Programs · Data Processing · Land Use · Image Interpretation · Classification Accuracy		STAR Subject Category: 43. (Earth Resources).

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	169	

NASA TM X-58156

THE ERTS-1 INVESTIGATION (ER-600): A COMPENDIUM OF ANALYSIS RESULTS OF THE UTILITY OF ERTS-1 DATA FOR LAND RESOURCES MANAGEMENT

R. Bryan Erb
Lyndon B. Johnson Space Center
Houston, Texas 77058

PREFACE

This compendium summarizes the results of the ERTS-1* investigations conducted by interdisciplinary teams of the Earth Observations Division, NASA Lyndon B. Johnson Space Center at Houston, Texas. It presents the important features of each investigative area, a summary of the work performed, the processing and analysis techniques applied, and the significant findings and conclusions resulting from the investigations.

Seven final reports were prepared for submission to the NASA Goddard Space Flight Center in compliance with requirements as outlined in the task definition for the ERTS-1 Investigation (ER-600). This project was funded and approved for implementation by NASA Headquarters in July 1972.

The efforts reported in this compendium were performed by ERTS-1 analysis team members drawn from the Earth Observations Division branches and the ERTS Project Office of the support contractor, Lockheed Electronics Company, Inc. The investigations are documented in the following individual reports.

---

*Earth Resources Technology Satellite 1.

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
V	ERTS-1 Urban Land Use Analysis	TM X-58121 JSC-08460
VI	ERTS-1 Signature Extension Analysis	TM X-58122 JSC-08461
VII	ERTS-1 Land Use Analysis of the Houston Area Test Site	TM X-58124 JSC-08463

The results derived from these investigations indicate the utility and potential of ERTS-1 multispectral scanner data in terms of Earth resource applications objectives. Using conventional and computer-aided techniques, the analysis teams were able to detect, identify, locate, and measure many features of applications interest in the test areas designated for these investigations.

CONTENTS

Section		Page
1.0	THE ERTS-1 INVESTIGATION	1-1
	1.1 SUMMARY	1-1
	1.2 INTRODUCTION	1-2
	1.3 OBJECTIVES	1-4
	1.4 ANALYTICAL APPROACH	1-5
	1.4.1 Land Use Hierarchy	1-5
	1.4.2 Data Processing and Interpretation	1-7
	1.4.3 Other Specialized Analysis Activities	1-9
	1.5 ACCOMPLISHMENTS	1-12
	1.6 CONCLUSIONS	1-15
2.0	THE ERTS-1 AGRICULTURAL ANALYSIS	2-1
	2.1 OBJECTIVES	2-1
	2.2 ANALYTICAL APPROACH	2-3
	2.2.1 Data Processing	2-3
	2.2.2 Study Areas	2-3
	2.3 RESULTS	2-6
	2.3.1 Conventional Image Interpretation .	2-7
	2.3.2 Computer Classification	2-13
	2.3.3 Area Measurement	2-33
	2.3.4 Field Location	2-33
	2.4 CONCLUSIONS	2-33
3.0	THE ERTS-1 COASTAL/ESTUARINE ANALYSIS	3-1

Section		Page
	3.1 OBJECTIVES	3-1
	3.1.1 Classification Accuracy	3-1
	3.1.2 Feature Detection and Location	3-1
	3.1.3 Spectral Uniqueness and Temporal Analysis	3-1
	3.1.4 Areal Measurement	3-4
	3.2 ANALYTICAL APPROACH	3-4
	3.3 ANALYSIS RESULTS	3-5
	3.3.1 Water Features	3-5
	3.3.2 Wetland and Dryland Features	3-7
	3.3.3 Spectral Uniqueness	3-7
	3.3.4 Areal Measurement	3-14
	3.4 CONCLUSIONS	3-14
4.0	THE ERTS-1 FOREST ANALYSIS	4-1
	4.1 OBJECTIVES	4-1
	4.2 ANALYTICAL APPROACH	4-1
	4.3 RESULTS	4-8
	4.3.1 Conventional Image Interpretation	4-8
	4.3.2 Computer Classification	4-11
	4.4 CONCLUSIONS	4-20
5.0	THE ERTS-1 RANGE ANALYSIS	5-1
	5.1 OBJECTIVES	5-1
	5.2 ANALYTICAL APPROACH	5-3
	5.3 RESULTS	5-3
	5.3.1 Conventional Data Processing	5-6

Section		Page

5.3.2 Computer-Aided Data Processing 5-9

5.4 CONCLUSIONS 5-10

6.0 THE ERTS-1 LAND USE ANALYSIS 6-1

6.1 OBJECTIVES 6-1

6.2 ANALYTICAL APPROACH 6-1

6.3 RESULTS 6-5

6.4 CONCLUSIONS 6-12

7.0 THE ERTS-1 URBAN LAND USE ANALYSIS 7-1

7.1 OBJECTIVE 7-1

7.2 ANALYTICAL APPROACH 7-1

7.3 RESULTS 7-3

7.4 CONCLUSIONS 7-17

8.0 THE ERTS-1 SIGNATURE EXTENSION ANALYSIS 8-1

8.1 OBJECTIVES 8-1

8.2 ANALYTICAL APPROACH 8-1

8.3 RESULTS 8-3

8.4 CONCLUSIONS 8-8

APPENDIX A — ACKNOWLEDGMENTS A-1

APPENDIX B — GLOSSARY OF TERMS, ABBREVIATIONS, AND ACRONYMS B-1

TABLES

Table		Page
1-I	LAND USE CLASSIFICATION SYSTEM FOR USE WITH REMOTE-SENSOR DATA	1-6
2-I	HILL COUNTY CONVENTIONAL IMAGE INTERPRETATION	2-8
2-II	IMPERIAL COUNTY CONVENTIONAL IMAGE INTERPRETATION	2-9
2-III	HARDIN COUNTY CONVENTIONAL IMAGE INTERPRETATION	2-11
2-IV	HILL COUNTY CLASSIFICATION PERFORMANCE SUMMARY	2-14
2-V	IMPERIAL COUNTY CLASSIFICATION PERFORMANCE SUMMARY	2-19
2-VI	HARDIN COUNTY CLASSIFICATION PERFORMANCE SUMMARY	2-23
2-VII	HOLT COUNTY CLASSIFICATION PERFORMANCE SUMMARY	2-27
2-VIII	BUTTE COUNTY CLASSIFICATION PERFORMANCE SUMMARY	2-32
2-IX	IMPERIAL COUNTY FIELD AREA MEASUREMENTS	2-34
3-I	ACCURACY OF AREAL MEASUREMENT OF SALT MARSHES	3-3
3-II	ACCURACY OF CLASSIFICATION OF BARRIER FLAT VEGETATED AREAS FOR GALVESTON ISLAND	3-3
4-I	HIERARCHY DEVELOPED FOR THE FOREST INVESTIGATION	4-5
4-II	NUMBER OF TARGETS DETECTED	4-6
4-III	MINIMUM SIZE OF FOREST FEATURES DETECTED	4-7
4-IV	SUMMARY OF CLASSIFICATION ACCURACIES	4-9
4-V	ACCURACY OF FOREST FEATURE CLASSIFICATIONS BY THE AREA-COMPUTATION METHOD IN THE PRIMARY STUDY AREA	4-18

Table		Page
5-I	RANGELAND CLASSIFICATION HIERARCHY	5-2
6-I	LEVEL I AND II LAND USE PRODUCT AGREEMENT WITH BASE DATA	6-13
6-II	LEVEL II URBAN LAND USE PRODUCT AGREEMENT WITH BASE DATA	6-14
7-I	ACCURACY OF DIFFERENTIATION OF LAND USE BOUNDARIES BY COMPUTER-AIDED CLASSIFICATION TECHNIQUES . . .	7-5
7-II	ACCURACY OF AREAL EXTENT OF LAND USE CATEGORIES DELINEATED BY COMPUTER-AIDED CLASSIFICATION TECHNIQUE ISOCLS	7-6
7-III	MISCLASSIFICATION ERROR MATRIX	7-8
7-IV	COMPUTER-AIDED CLASSIFICATION SCHEME FOR LEVEL I AND II URBAN LAND USE	7-16
8-I	STATISTICS DERIVED FOR SEVEN TYPES OF WATER FROM ISOCLS	8-5
8-II	STATISTICAL MEANS DERIVED USING ISOCLS FOR STEINHAGEN LAKE	8-7
8-III	THE MSS CHANNEL 1 (GREEN BAND) DATA LEVELS IN MSS UNITS	8-9

FIGURES

Figure		Page
1-1	The JSC ERTS MSS data-processing flow. Computer terms, abbreviations, and acronyms are defined in appendix B	1-10
2-1	Agricultural classification hierarchy	2-2
2-2	Six agricultural study areas within the United States	2-4
2-3	Imperial County conventional image interpretation ACVP false-color infrared enhancement (NASA S-73-28068)	2-10
2-4	Hardin County conventional image interpretation of JSC color composite (NASA S-73-28141)	2-12
2-5	Hill County 1972 annual ground truth (NASA S-73-23401)	2-16
2-6	Hill County computer classification (NASA S-73-28067)	2-17
2-7	Imperial County 1972 annual ground truth (NASA S-73-25512)	2-18
2-8	Imperial County computer classification, November 6, 1972, data (NASA S-73-28070)	2-20
2-9	Hardin County 1972 annual ground truth (NASA S-73-25510)	2-22
2-10	Hardin County supervised computer classification, August 13, 1972	2-24
2-11	Holt County annual ground truth	2-26
2-12	Holt County computer classification (NASA S-73-1506).	
	(a) Supervised computer classification map of six classes using July 30, 1972, data . . .	2-28
	(b) Temporal composite using July 30 and August 16, 1972, data	2-29
3-1	Feature hierarchy for coastal investigation	3-2

Figure Page

3-2 Computer classification map of area surrounding Galveston Island, Texas, showing turbidity zones (ERTS-1 data acquired November 26, 1972) (NASA S-73-28182) 3-6

3-3 Plankton bloom, February 24, 1973, MSS band 4 . . . 3-8

3-4 Plankton bloom, February 24, 1973, MSS band 6 . . . 3-9

3-5 Classification map of areas surrounding Galveston Island, Texas, showing wetland and dryland features. Nonsupervised classification of ERTS-1 data acquired November 6, 1972 (NASA S-73-28154) 3-10

3-6 Aircraft photograph of area surrounding Galveston Island, Texas. Imagery acquired November 7, 1972, from NASA WB-57F aircraft at an altitude of 18 288 meters (60 000 feet); RC-8 metric camera, 2443 estar base Aerochrome infrared film (NASA S-73-28101) 3-11

3-7 The ERTS-1 reflectance signatures of coastal features in MSS bands 5 and 7 before corrections were made. (Data taken from all cluster analyses.) 3-12

3-8 The ERTS-1 reflectance signatures of coastal features in MSS bands 5 and 7 after corrections were made. (Data taken from all cluster analyses.) 3-13

4-1 The ERTS-1 forest test site locations (NASA S-73-18483) 4-2

4-2 Ground-truth classification map of the primary area (NASA S-73-28187) 4-3

4-3 Optical multiband classification map of the primary area (NASA S-73-28195) 4-10

4-4 The MCFV multiband classification map of the primary area (NASA S-73-28188) 4-12

4-5 The DAS multiband classification map of the primary area (NASA S-73-1124) 4-13

Figure		Page
4-6	Computer printout of cluster classification of the primary area (NASA S-73-28214)	4-14
4-7	Cluster classification map of the primary area (NASA S-73-28189)	4-15
4-8	The LARSYS classification map of the primary area (NASA S-73-28190)	4-16
4-9	The DAS enhancement of light ground fire in the Sam Houston National Forest (NASA S-73-25467)	4-19
5-1	Color enhancement of the Snook site created on an MCFV. (Temporal composite of ERTS-1 August 30, November 10, and December 16, 1972, film imagery.)	5-4
5-2	Classification map of the San Bernard site made using supervised computer classification techniques (ERTS-1 October 4, 1972, digital data) (NASA S-73-28326)	5-5
5-3	Classification-like clustering map of the Snook site made using nonsupervised computer classification techniques (ERTS-1 August 30, 1972, digital data) (NASA S-73-28028)	5-7
5-4	Snook data overall classification accuracy. Snook 1 and Snook 2 ERTS-1 data were taken August 30 and November 28, 1972, respectively. The Snook 1/2 category is the temporal composition of Snook 1 and Snook 2 data	5-8
6-1	Houston Area Test Site	6-2
6-2	Level I land use classification of study area (ERTS-1 bands 5 and 7 from October 4, 1972) (NASA S-73-31699)	6-6
6-3	Level I land use manual interpretation of study area (ERTS-1 bands 5 and 7 from October 4, 1972) (NASA S-73-25517)	6-7
6-4	Level I and II classification of land use study area (ERTS-1 bands 4, 5, and 7 from August 29, 1972) (NASA S-73-28191)	6-8
6-5	Land use cluster map developed from a 3-percent data sample (NASA S-73-28073)	6-9

Figure		Page

6-6 Computer classification of Level I land use (NASA S-73-2853) 6-10

6-7 Computer classification of land use Levels I and II (urban) (NASA S-73-2866) 6-11

7-1 Urban nonsupervised computer-aided classification 7-9

7-2 The ERIPS supervised computer-aided classifications delineating urban land use (NASA S-73-25486) 7-10

7-3 The MTFO supervised computer-aided classifications delineating urban land use 7-11

7-4 Major transportation routes in the Houston area. (Conventional image interpretation from an ERIPS supervised classification of ERTS-1 MSS data, August 29, 1972.) 7-13

7-5 Cluster map of urban residential area showing high-reflectance areas from nonsupervised classification August 29, 1972 7-14

7-6 Base highway map of Houston. Heavy outline (lower right) encloses area shown in figure 7-5 7-15

8-1 Locations of water bodies 8-2

8-2 The ISOCLS output for Lake Houston and Sheldon Reservoir 8-4

8-3 The LARSYS output based on one training field and one type of water 8-6

8-4 The LARSYS output for October 4, 1972, data using ISOCLS statistics of August 29, 1972, data . . . 8-6

THE ERTS-1 INVESTIGATION (ER-600):

A COMPENDIUM OF ANALYSIS RESULTS OF THE UTILITY OF ERTS-1 DATA FOR LAND RESOURCES MANAGEMENT

By R. Bryan Erb
Lyndon B. Johnson Space Center

1.0 THE ERTS-1 INVESTIGATION

1.1 SUMMARY

This report summarizes the results of the ERTS-1 investigations conducted by Earth Observations Division personnel at the Lyndon B. Johnson Space Center. Conventional image-interpretation and computer-aided classification procedures were the two basic techniques used in analyzing the data for detecting, identifying, locating, and measuring the surface features related to Earth resources. Data from the ERTS multispectral scanner were found useful for all applications studied.

1. The Agricultural Team was able to classify crop types (i.e., small grains, truck farm crops, grasses, summer fallow) to a 95-percent accuracy on large (12 square hectometers (30 acres) or more), well-defined fields. Further breakdowns as to crop species (wheat, barley, soybeans, oats, corn) reduced the accuracy to 70 to 80 percent for single-date observations.

2. The Coastal Team was able to map salt marsh areas to an accuracy range of 89 to 99 percent and barrier island features to an accuracy range of 87 to 100 percent.

3. The Forest Team, using conventional and computer-aided techniques, was able to differentiate as many as 14 classes of forest features to accuracies ranging between 55 and 84 percent.

4. The Range Team achieved computer classification accuracies of 70 to 80 percent for separating woodland test fields from nonwoodland test fields.

5. The Land Use/Urban Team found that by processing data from only the urbanized area, it was possible to increase classification accuracies of certain urban land use categories.

6. The Signature Extension Team was able to do temporal signature extension on large, relatively homogeneous features.

7. The computer classification programs were generally more accurate than conventional image-interpretation techniques for homogeneous features that could be differentiated by spectral contrasts.

1.2 INTRODUCTION

In 1971, the Earth Observations Division (EOD) of the NASA-Lyndon B. Johnson Space Center (JSC) submitted a proposal to NASA Headquarters for using Earth Resources Technology Satellite 1 (ERTS-1) data for applications in the Houston Area Test Site (HATS). In April 1972, a detailed definition of the functional and technical aspects of the project was undertaken. The proposed investigations (ER-600) were accepted and funded by NASA Headquarters in July 1972. R. Bryan Erb, Manager of the EOD Applications Office, was named Principal Investigator.

The main effort of the project involved an assessment of the usefulness of the ERTS-1 data for detecting, identifying, locating, and measuring features of applications interest. Its scope provided the following:

1. An applications evaluation in major disciplinary areas (forestry, range and grazing management, agriculture, coastal and estuarine hydrology, and urban land use management) was initiated. It addressed features of prime applications interest because of

their geographic and economic or cultural importance. These disciplines comprised the major elements of a total information hierarchy. This investigation also involved a signature extension effort, which assessed techniques for making spatial and temporal extensions of established classification.

2. An Agricultural Stabilization and Conservation Service (ASCS) data-utilization evaluation assessed crops in parts of six counties located in different sections of the United States at three different periods during the growing season to establish the utility of temporal analysis of ERTS-1 data.

3. A HATS land use study included the analysis of a complete ERTS-1 scene by conventional image interpretation and a quarter scene by both conventional image interpretation and computer-aided analysis. The results were compared with baseline data (high-altitude aerial photography) to establish a statistical assessment of the ERTS capability for land use classification.

A report of this scope obviously required the assistance and resources of many organizations and individuals, whose help the author wishes to acknowledge gratefully. A complete list of the numerous contributors to this publication is provided in appendix A.

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

1.3 OBJECTIVES

The general objectives of the JSC ERTS-1 Investigation (ER-600) were as follows.

1. To assess the utility of the ERTS-1 remote-sensor data for Earth resources application

2. To determine the individual and combined roles of the ERTS-1 spacecraft, aircraft, and ground data-acquisition systems in an integrated Earth resources survey program

These objectives were based on the concept that, to provide resource managers with useful applications information, an entire system approach must be considered. This approach would include sensor platforms, sensors, data-acquisition subsystems, processing and analysis subsystems, and the conversion of data into usable products.

The detailed objectives of the investigations were to determine

1. The accuracy and precision to which processed ERTS-1 data could be used to identify study features, locate their boundaries, and measure their areal size

2. The nature and uniqueness of the spectral characteristics of the study features using the four spectral bands of the ERTS-1 multispectral scanner (MSS) sensing system with and without atmospheric corrections

3. The degree to which temporally composed ERTS-1 data derived from registering data sets of the same scene at different times could be used to aid in the detection, identification, and location of study features

1.4 ANALYTICAL APPROACH

1.4.1 Land Use Hierarchy

The land use classification system proposed in U.S. Geological Survey (USGS) Circular 671[1] provided the initial hierarchy of study features addressed by each of the ERTS-1 analysis teams (table 1-I). The USGS hierarchy is a system designed to be compatible with other classification systems as well as with remote-sensor data. The system constitutes first and second levels of generalized land use categories that are compatible with remote-sensor data acquired from both satellites and high-altitude aircraft.

The USGS land use hierarchy was based on the following assumptions.

1. That Level I categories could be differentiated using "satellite imagery with very little supplemental information"

2. That Level II categories could be derived from "high-altitude-aircraft and satellite imagery combined with topographic maps"

The Level I categories would be compatible with imagery scales of 1:1,000,000 to 1:250,000, and the Level II categories would require imagery scales of approximately 1:100,000 to 1:24,000. The authors of USGS Circular 671 also noted that supplementary information might be required to resolve certain Level II categories in "especially difficult areas."

---

[1] Although USGS Circular 671 is in the process of revision, slight changes in the categories or definitions will not alter the significant conclusions of this investigation.

TABLE 1-I.- LAND USE CLASSIFICATION SYSTEM FOR USE WITH REMOTE-SENSOR DATA

Level I	Level II
Urban and built-up land	Residential Commercial and services Industrial Extractive Transportation, communications, and utilities Institutional Strip and clustered settlement Mixed Open and other
Agricultural land	Cropland and pasture Orchards, groves, bush fruits, vineyards, and horticultural area Feeding operations Other
Rangeland	Grass Savannas (palmetto prairies) Chaparral Desert shrub
Forest land	Deciduous Evergreen (coniferous and other) Mixed
Nonforested wetland	Vegetated Bare
Water	Streams and waterways Lakes Reservoirs Bays and estuaries Other
Barren land	Salt flats Beaches Land other than beaches Bare exposed rock Other
Tundra	Tundra
Permanent snow and icefields	Permanent snow and icefields

The USGS proposed land use hierarchy was designed for remote sensors in general, not for a specific sensor, and was structured for visual imagery interpretation. Therefore, it was anticipated that the system would have to be modified to accomplish best utilization of automatic data analysis.

For each of the ERTS-1 investigations, conventional image interpretation and computer-aided data analysis were used. As a result, some modifications were made to the USGS hierarchy to facilitate a specific classification approach. In addition, some changes were desirable because of ERTS-1 data characteristics or local ground-cover conditions in the areas being classified. However, most of the analysis teams addressed study features in greater detail than Level II of the USGS hierarchy. As a result, some hierarchies at Level III and a few at Level IV were established to accommodate the detailed information retrievable from the ERTS-1 MSS data. The modifications or extensions of the USGS hierarchy are discussed in the individual sections that follow.

1.4.2 Data Processing and Interpretation

Each EOD ERTS-1 analysis team used data derived from the ERTS-1 MSS in its investigation. Several options in conventional image interpretation, data enhancement, and computer-aided data processing were used, modified, or developed at JSC. The following paragraphs describe the form of the MSS data, the instrumentation available for conventional analysis, the computer programs and data flow used for data reformatting and analysis, the temporal analysis of data sets, and the atmospheric correction of data.

Standard products.- The ERTS-1 MSS data are available as standard products from the NASA Goddard Space Flight Center (GSFC) in film imagery and digital data tape formats. A typical ERTS-1 scene covers an area of 185 by 185 kilometers (100 nautical miles square). Film is in either 240- or 70-millimeter format, black-and-white or color composites, in the form of transparencies or prints. Digital data are stored on computer-compatible tapes (CCT's). Four standard 1.3-centimeter (0.5-inch) magnetic tapes cover one ERTS-1 scene, with 2340 scan lines and 810 elements per line on each computer-compatible tape (CCT). Both data forms were used and analyzed by the ERTS-1 analysis teams using conventional image-interpretation techniques and computer-aided processing techniques.

Conventional image-interpretation film data processing.- In the conventional image-interpretation film data processing, multiband ERTS-1 film imagery was displayed on optical and electro-optical color-film viewers to produce color enhancements, which accentuate features of interest in contrast to the background scene. Photointerpreters delineated, interpreted, and planimetered the enhanced features. Ground-truth information derived from low-altitude-aircraft photographs was used to evaluate the interpretations and areal measurements obtained.

The two systems used to create color enhancements were the 2000 multichannel film viewer (MCFV) and an additive color viewer printer (ACVP). Film density slicing and additive color viewing were performed on this equipment. Photograph printing devices were available on both systems.

Computer-aided digital data processing.- The two methods of computer-aided data processing used to analyze the digital tape data were supervised maximum-likelihood classification and nonsupervised classification using clustering techniques. The first method of processing requires information from training fields that are defined by the analyst. Then, unknown data are classified into the various classes (i.e., into the classes that have been fed into the computer). When the classification results are displayed, a threshold is specified so that data points that are far from the mean of the class are left unclassified. In the second method of processing, the unknown data are organized into spectrally homogeneous groups (clusters) and classification-type clustering maps are produced in which the clusters require identification and interpretation in a postprocessing analysis.

Three main computer systems were available at JSC for digital data processing: the Univac 1108 computers; the Earth Resources Interactive Processing System (ERIPS), which uses IBM 360/75 computers; and the Purdue terminal, a remote terminal connected to the IBM 360/67 computing facility at Purdue University. Supervised pattern recognition software packages existed on these three facilities. Two clustering algorithms were used for nonsupervised classification, the ISOCLS program of JSC and the NSCLAS program of Purdue University. (Appendix B contains amplifying information about these programs.) Figure 1-1 is a schematic drawing of the data flow.

1.4.3 Other Specialized Analysis Activities

Additional activities of the analysis teams are described in the following paragraphs.

Conventional image interpretation of first-generation color composites from digital data.- Two data analysis stations (DAS's) at JSC were used to screen and edit digital data. Instead of using film imagery to create color enhancements on film viewers, the film recorder on the DAS was used to create first-generation color composites that were interpreted and analyzed. The positive transparency color composites obtained directly from the digital data at JSC were of higher quality than those obtained from the NASA data-processing facility at GSFC. However, a skewing distortion inherent in the digital data display required special treatment to restore geometric fidelity.

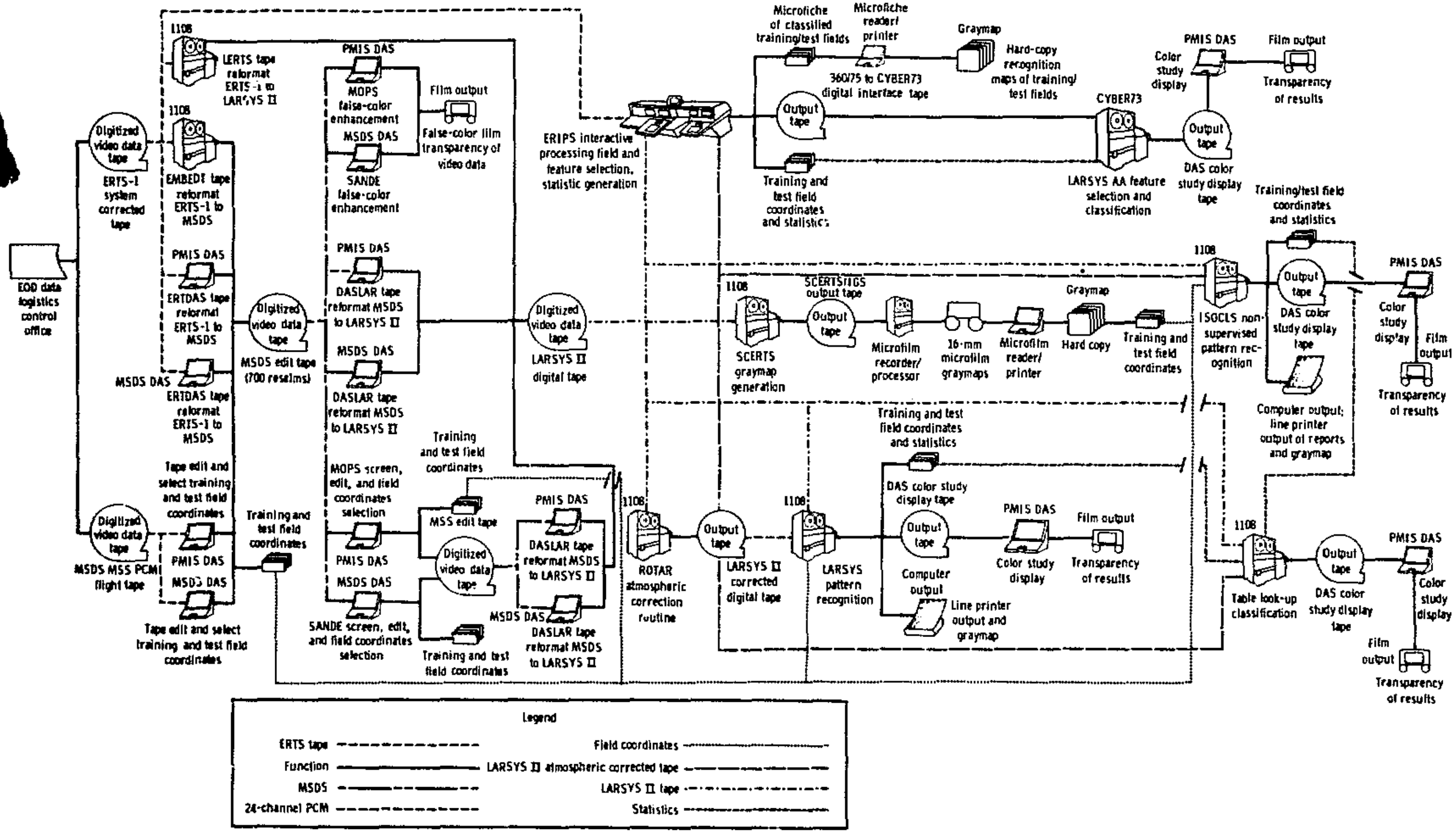


Figure 1-1.- The JSC ERTS MSS data-processing flow. Computer terms, abbreviations, and acronyms are defined in appendix B.

Temporal analysis.- The cyclic coverage of ERTS-1 made possible a temporal analysis of the data. This analysis was performed to investigate the possible advantages in data classification and the analysis gained by a knowledge of the changes that occurred, for example, between different vegetative phenological stages. The term temporal analysis in this report connotes the analysis of a composed data set, which is a unique set of data derived from considering a feature described by a temporal signature. The phrase temporal signature is generally construed as the characteristic of a feature over time. To give an extremely simplified example, one might say that a deciduous tree has the temporal characteristic of being light green in spring, richly deep green in summer, yellow in fall, and brown in winter.

Temporal studies of film imagery were performed by creating color enhancements on film viewers using scenes of different dates on different channels. Temporal studies of digital tape data were performed by analyzing combined data sets of the same scenes at different dates (e.g., a composed data set of eight channels derived from registering two data sets of the same scene on two different dates). The capability existed on the Univac 1108 computers and on the ERIPS to register digital data sets; thus, composite temporal data sets were compiled.

Atmospheric corrections and study of absolute reflectance.- The effects of the varying Sun angle and atmospheric conditions were expected to be significant and were known to change the detected radiance levels of various features. The removal or correction of these effects was attempted to investigate the uniqueness of the spectral characteristics of the various features.

1.5 ACCOMPLISHMENTS

Significant improvements were made in existing data-processing and analysis techniques. Furthermore, the analysis techniques that were applied to the ERTS-1 data and to corollary information provided an appropriate framework for the systematic evaluation of important elements of a prototype multispectral data-processing and analysis system.

Most of the techniques used in processing and interpreting ERTS-1 data were refined or developed in the context of resource application or use. Because most of these techniques must be closely tailored to operational requirements, participation by user organizations would have permitted them to become more knowledgeable in the development and use of techniques appropriate for their application.

An outstanding example of this operational philosophy was the development of a computer-aided procedure to successfully detect and locate surface water using ERTS-1 data. The work was initiated at JSC in support of the State of Texas in its cooperative effort with the U.S. Army Corps of Engineers for an inventory of water impoundments pursuant to Federal legislation. This development of an accurate and efficient method for locating surface water using the ERTS-1 data evolved from the investigations performed by the analysis teams.

The procedure was evaluated for a test site area in east-central Texas and resulted in 100-percent identification of all lakes with a surface area of at least 4 square hectometers and location of those lakes within an accuracy range of 300 meters (1000 feet). This computer-aided procedure produces line printer output at any desired scale with symbols depicting the surface water. The printout is precisely registered to the base maps.

The procedures, with the data products, were provided to the Texas Water Rights Commission and Texas Water Development Board and will be evaluated with other techniques in Howard, Montgomery, and Washington Counties in Texas. This example is a specific instance of the transfer of remote-sensing technology to the user community.

Using conventional interpretation and computer-aided processing, the feasibility of extracting useful resource information from satellite data was demonstrated as a result of this project. However, further refinements in the use of temporal data and radiometrically calibrated data, together with improved precision in compensating for atmospheric effects within the data, will increase the degree of accuracy to which selected surface features of applications interest can be detected and identified.

The following is a summary of some of the significant findings that were developed in the course of this investigation. They are representative of the type of accomplishments that led to the formulation of the conclusions described in the next section of this document.

1. The usefulness of temporal data for detecting range features was demonstrated. Temporal analyses enhanced the discrimination between different classes; this conclusion conforms with mathematical theories.

2. Level I land use signatures were extended over an area of 4660 square kilometers (1800 square statute miles) with encouraging results. Data over the entire scene were sampled to develop classification training statistics instead of establishing training fields throughout the scene. This approach holds promise for classifying Level I land use over very large areas for which ground truth is not available.

3. Nonsupervised classification yielded information that could be related to various types of residential areas in part of Houston.

4. Computer-aided classification of a portion of the Sam Houston National Forest permitted identification of 14 classes of forest land conditions.

5. Level II classification was satisfactory for separating wooded rangeland, nonwooded rangeland, cropland, and water. A Level III classification was possible in separating marshhay cordgrass and gulf cordgrass.

6. The separation of crop types (Level III; i.e., small grains, truck farm crops, grasses, summer fallow) was accomplished by conventional interpretation as well as by computer-aided classification to a 95-percent classification accuracy. Further breakdown to crop species (Level IV) was accomplished by computer methods only, but the accuracy was reduced to 70 to 80 percent for single-date observations.

7. High spectral contrast between adjacent features permitted their distinction between each other. On the other hand, a "blooming effect" occurred in which the brighter element seemed to occupy a greater spatial extent than it should. This effect contributed to errors in areal measurements.

8. The smallest field detected using conventional image interpretation was 6.5 square hectometers (16 acres).

9. A technique was developed to eliminate the striping (banding) observed on all four channels of the ERTS-1 data and attributed to the residual differences (after GSFC calibration) in detector output. The striping is particularly evident when the scene is a large, homogeneous area such as a lake and is sufficient to affect sensitive, spectral-clustering algorithms. Use of the technique removes detector-to-detector differences while leaving the overall average value of the data unaltered.

10. An extensive phytoplankton bloom was detected in the ERTS-1 band 6 imagery obtained over Galveston Bay, Texas, February 24, 1973.

11. Changes in water coverage due to rice farming practices, flooding, and tidal-level changes were detected by temporal analysis of ERTS-1 data collected over the Trinity River delta and Trinity Bay area in Texas.

12. Coastal features exhibited unique and repeatable reflectance signatures as obtained from ERTS-1 MSS data. These signatures or characteristic reflectance properties of coastal features were obtained by the application of a computer routine, which was developed during the investigation.

13. Temporal signature extension was accomplished on large, relatively homogeneous features such as water bodies. Sun-angle changes insignificantly degraded temporal signatures with data sets separated by more than 36 days. Changes in turbidity caused the greatest difficulty in extending signatures of freshwater over time and distance.

1.6 CONCLUSIONS

Detailed conclusions are contained in the seven individual reports prepared by the investigation teams. The major conclusions drawn from these seven investigative areas are contained in this compendium in summary form. The highlights are as follows.

1. Data of the type provided by the ERTS-1 multispectral scanner will be of significant value for conducting extensive regional inventories and surveys in the areas of land use, cropland and range/forest resources, and for determining certain coastal and estuarine resources and conditions such as water turbidity, marshland, forests, and phytoplankton blooms.

2. Classification performance for various features using ERTS-1 data both by conventional image interpretation and by computer-aided methods compared favorably with classification performance historically achieved with high-altitude-aircraft data.

3. These investigations confirmed the assumptions that large crop and land resources inventories, as stated in USGS Circular 671 for Level I land use survey, can be conducted with ERTS-1 data using relatively little ground truth.

4. Field width, relative contrast, and orientation were important characteristics in accurately detecting the boundaries of individual fields.

a. Narrow fields oriented east-west (parallel to the scan lines) were more difficult to detect and measure than fields oriented north-south.

b. Fields less than 50 meters wide were not consistently detectable.

5. Low computer-aided classification accuracies occurred when a spectrally complex urban scene was classified with extensive nonurban areas containing spectrally homogeneous features. To increase classification accuracies of certain urban land use categories, it was necessary to develop separate computer inputs and regroup some spectrally similar clusters. Even so, classification accuracies of urban landscapes did not approach the accuracies achieved in classifying the land use categories containing more homogeneous features (agriculture, forest, water, etc.)

6. Some categories of land use appeared to be best determined by classifying at a detailed level and aggregating to more general levels.

7. Sun-angle effects were significant in distinguishing an absolute reflectance and in class discrimination. Temporal analysis of ERTS-1 data sets demonstrated a high degree of signature overlap in the various spectral classes. Removal of Sun-angle effects resulted in good discrimination of the same classes. Atmospheric effect may not have a pronounced impact on spectral discrimination of classes in a relative sense, but must be removed to determine absolute reflectance.

8. Temporal analysis was shown to provide better discrimination between certain features.

9. The computer-aided classification techniques were generally more accurate than conventional image-interpretation techniques for homogeneous features that could be differentiated by spectral contrasts. In separating urban and nonurban features, conventional image-interpretation methods proved advantageous for delineating small, heterogeneous features (urban, linear patterns, etc.). The choice of techniques may depend on the degree of classification accuracy acceptable, the computer time available, the skills of the analyst, and the quantity to be processed.

2.0 THE ERTS-1 AGRICULTURAL ANALYSIS

2.1 OBJECTIVES

The general objective of this investigation was to evaluate how well features of agricultural importance could be detected, identified, and located and their areal extent measured using ERTS-1 data. This general objective included the following specific objectives, which are listed in order of priority.

1. To separate agricultural areas from nonagricultural areas

2. To separate cropland from noncropland within the agricultural areas

3. To determine whether the existence of different crop types (e.g., rowcrops and small grains) could be detected within the cropland

4. To determine whether the existence of different crop species (e.g., wheat, barley, and oats) could be detected within the cropland

5. For each major crop, to determine the size of the smallest field that could be detected, identified, located, and measured

6. To determine the effect of varying field shape and field size on the accuracy of crop classification and field measurement

7. To determine the effect of the relative contrast of adjacent fields on boundary detection and crop classification

A general classification hierarchy of the agricultural features is shown in figure 2-1. Additional objectives were to evaluate the effect of atmospheric correction techniques on an agricultural analysis of ERTS-1 data and to become familiar with and to evaluate the capabilities of the JSC hardware, software, and procedures for processing and analyzing such data.

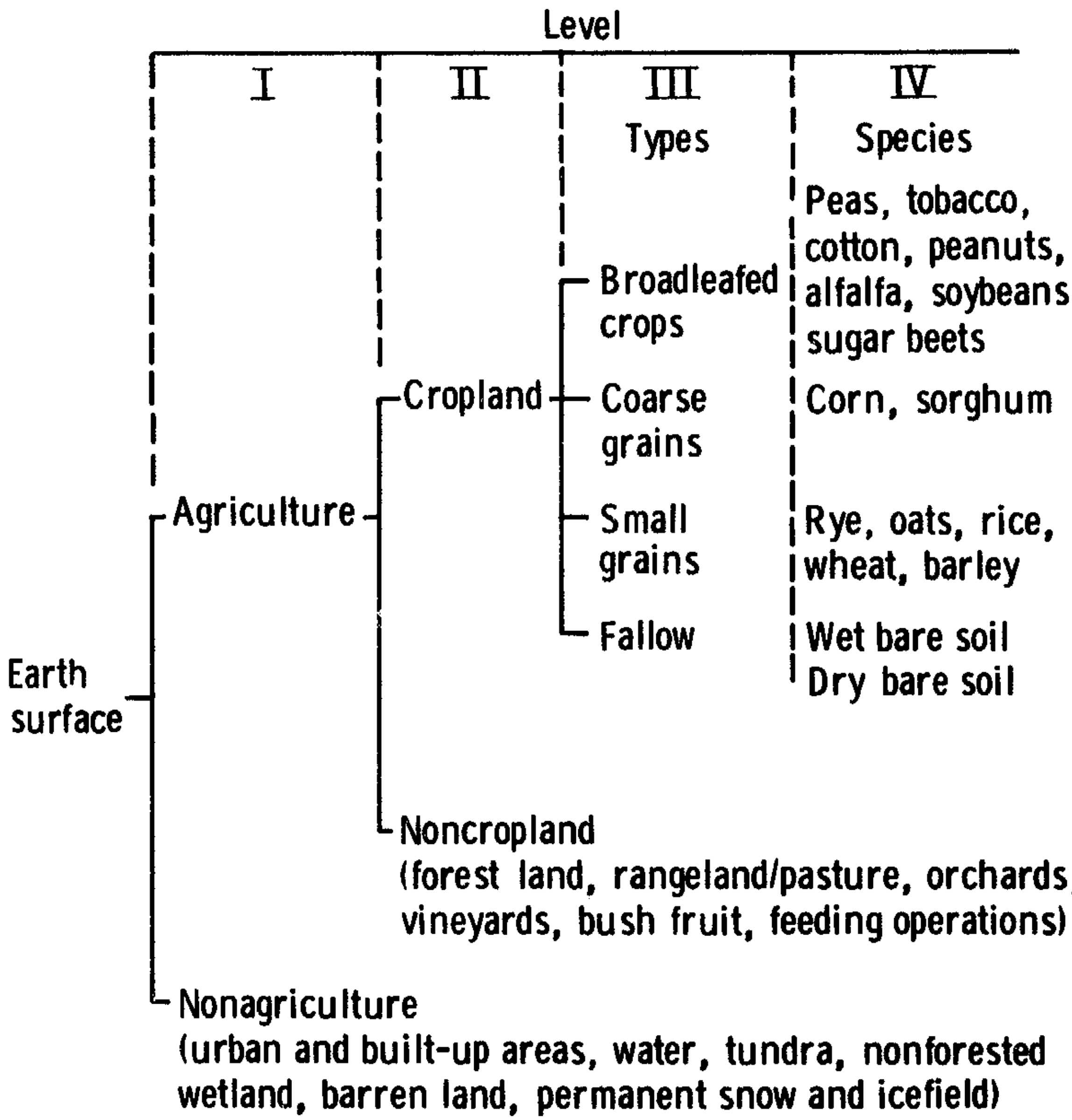


Figure 2-1.- Agricultural classification hierarchy.

2.2 ANALYTICAL APPROACH

2.2.1 Data Processing

The best ERTS-1 data set available from the 1972 crop year for each of six study areas was analyzed. The analysis included computer-aided and conventional image-interpretation techniques. During the analysis, one study area was selected for a temporal analysis.

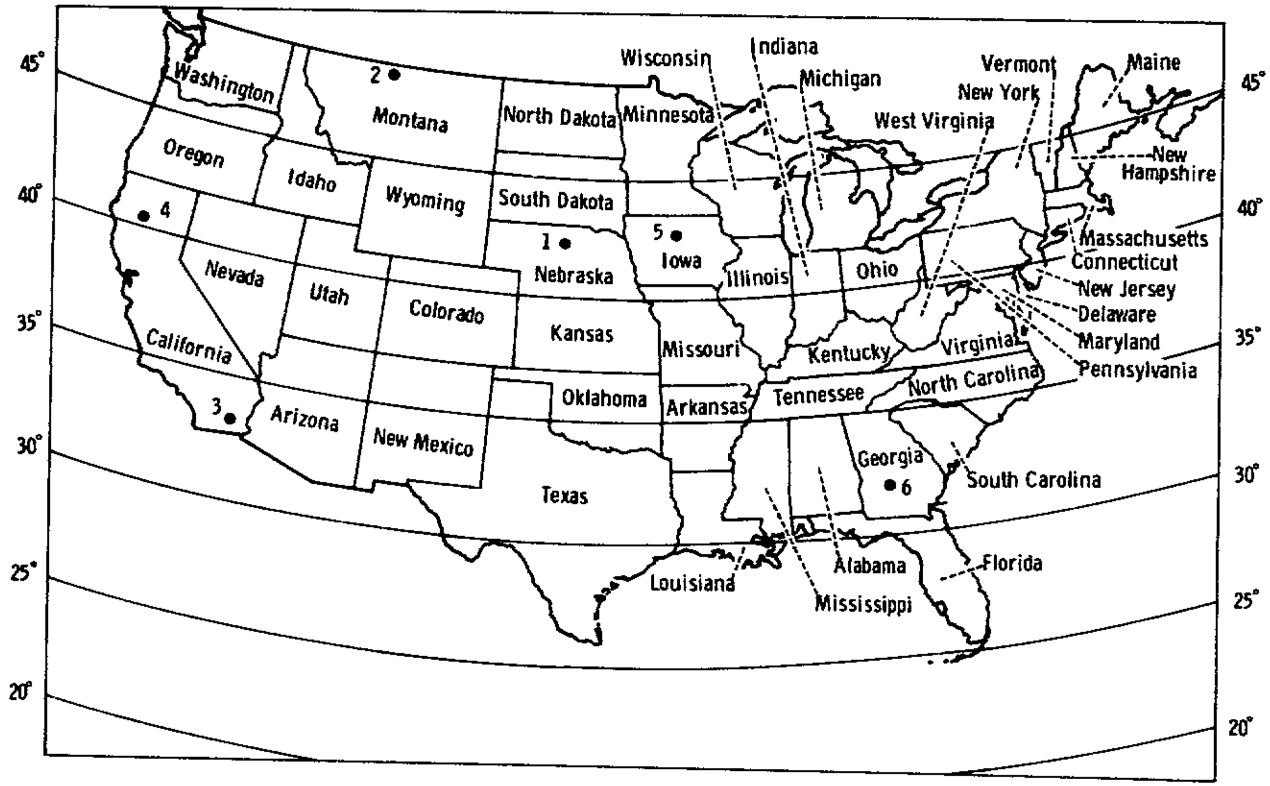
Area measurements of representative fields were made in the study areas using a mechanical-electronic planimeter to manually trace the field borders. Additive color-enhanced ERTS-1 imagery of approximately 1:130,000 scale was used for the measurements. Aircraft photography and other ground-truth data were used as a basis for comparison and for precise instrument calibration.

The Universal Transverse Mercator (UTM) coordinate system was selected for tract location. The UTM grids with 1000-meter increments were prepared for enhanced ERTS-1 imagery of approximately 1:130,000 scale. The grids were constructed with a programed XY-plotter, which was set to scale by comparing the measured distances between specific features on the imagery to USGS topographic maps.

2.2.2 Study Areas

Locations of the following six study areas within the United States are shown in figure 2-2.

Hill County, Montana.- Hill County, Montana, was selected for study because of the unique field patterns that resulted from the practice of "strip-fallow" farming. The result is a series of long, narrow, rectangular fields 91 to 107 meters wide by 798 to 1586 meters long. Wheat is the major crop in the area. However,



1. Holt County, Nebraska
2. Hill County, Montana
3. Imperial County, California
4. Butte County, California
5. Hardin County, Iowa
6. Worth County, Georgia

Figure 2-2.- Six agricultural study areas within the United States.

barley, other small grains, alfalfa hay, and some cultivated pastures are also found. Data from August 7, 1972, were analyzed.

Imperial County, California.- Imperial County, California, was selected because the yearlong growing season ensured a variety of crops in various stages of maturity (e.g., alfalfa hay, barley, sugar beets, cotton, grain sorghum, and winter vegetables). Most of the fields were well defined because they are bounded by roads, irrigation canals, or drainage canals. Data from November 6, 1972, were selected for detailed analysis.

Hardin County, Iowa.- The major crops of Hardin County, Iowa, a typical corn-belt farming area, are corn, soybeans, and oats. The earliest usable data pass occurred on August 13, 1972, with limited cloud cover in the north and south. The oats had been harvested by July, and a strong cover of secondary growth appeared mixed with some grasses and legumes. In most cases, the large blocks of corn represented a combination of several smaller fields with boundaries not visible from the ERTS-1 altitude.

Holt County, Nebraska.- The Holt County, Nebraska, study site was unique because of its center-pivot irrigation systems. These contrasting targets of 53 square hectometers (130 acres) and a limited variety of crops made Holt County one of the easier sites to analyze. The test site contained approximately 30 fields of field corn, the major crop. In addition, there were three popcorn fields, one sunflower field, several fields of alfalfa and fields of grass at various stages of growth, two fallow fields, and one sorghum field. Data sets from July 30 and August 16, 1972, were used for analysis.

Butte County, California.- Butte County, California, was selected primarily because rice was a major crop. Other crops in this county were fruit, nuts, and small grains. The fields were large and irregularly shaped with medium contrast. Data from September 19, 1972, were selected for analysis.

Worth County, Georgia.- The Worth County, Georgia, test site had approximately 30 percent of the 31-square-kilometer (12 square statute mile) study area in woods. The cultivated fields in the site were generally small, ranging in size from less than 0.4 square hectometer (1 acre) to 40 square hectometers (100 acres). The majority of the fields were smaller than 12 square hectometers (30 acres). Field boundaries followed natural contours, woods, and drainage patterns; thus, most of the fields were nonrectangular. Worth County was included in the analysis because it contained small and irregularly shaped fields of cotton, tobacco, and peanuts. The September 8, 1972, ERTS-1 MSS data were selected for analysis. This set of data was the earliest available in which the study area was sufficiently clear of clouds. These data were not optimum because it was late in the season and many of the crops were already at the mature or harvest stage.

2.3 RESULTS

The results of the investigation showed that ERTS-1 data generally could be used for crop classification, location, and area measurement. Although applications procedures must be developed, good classifications were achieved from the digital data processed by using clustering programs and the LARSYS program.

Spatial information contained in the imagery was primarily used at classification Level I (agricultural compared to nonagricultural). Generally, nonagricultural areas in the sites analyzed were irregular in shape, showed as line features, or had a reflectance characteristic similar to water or soil. Conversely, agricultural areas tended to exhibit regular shapes and high infrared (IR) reflectance if crops were growing.

Cropland was distinguishable from noncropland because virtually all cropland either consisted of regularly shaped fields or, if irregular, the boundaries were well defined and obviously manmade. The presence of other clues, such as canals, location with respect to other fields, and similarity to known cropland, was also useful. The ground-truth maps of all the counties show the distinct field boundaries.

The clustering routine ISOCLS was useful for a rough Level I and Level II qualitative classification; that is, for the separation of agriculture from nonagriculture and cropland from noncropland. However, crop types or crop species were not satisfactorily separated in Worth County using this technique. The smaller fields blurred into a hodgepodge that was not identifiable. Field sizes of 10 to 12 square hectometers (25 to 30 acres) were the minimum for computer crop identification. In this study area, approximately 30 of the total of 475 fields (less than 7 percent) were larger than 12 square hectometers (30 acres). If these fields had represented a cross section of the crops present, and if they had been at a stage of crop development making them suitable for use as training fields, fields as small as approximately 4 square hectometers (10 acres) might have been classified. Because of the inconclusive results of the classification, further analysis of the small fields of Worth County will not be discussed in this report.

The most significant results for Levels III and IV, as shown in the classification hierarchy (fig. 2-1), are discussed in the following sections. These levels will be treated together under conventional image interpretation and computer classification.

2.3.1 Conventional Image Interpretation

Conventional interpretation of the enhanced imagery revealed that the relative contrast of adjacent features and their geographical orientation were important in ascertaining their detectability. Linear features (such as long, narrow fields in Hill County) parallel to the scan lines on an MSS image were difficult to detect and define. The data for Hill County were acquired August 7, 1972, late in the growing season when most of the fields had already been harvested, and little contrast between the cultivated fields and the fallow fields remained. Fields 90 meters (300 feet) wide that were oriented north-south were detectable. The narrowest field detected with an east-west orientation was 135 meters (450 feet) wide. Table 2-I includes the results of the crop identification and the percentage accuracy.

TABLE 2-I.- HILL COUNTY CONVENTIONAL IMAGE INTERPRETATION

Crop	Number of fields				
	Total	Training	Test	Test fields identified	Accuracy, percent[a]
Summer fallow	91	11	80	70	88
Barley	34	7	27	16	59
Winter wheat	27	6	21	9	43
Sod	23	1	22	20	91
Spring wheat	22	7	15	5	33
Crested wheat grass	8	2	6	4	67
Oats	8	2	6	1	17
Totals	213	36	177	125	

[a]Accuracy of field identification equals number of test fields identified divided by total number of test fields.

On the Imperial County test site, crops having similar spectral reflectance characteristics were arranged together into classes on the ACVP false-color IR enhancement (fig. 2-3). The smallest field easily identifiable was 6.5 square hectometers (16 acres) wide, rectangular, bright, and bordered by contrasting fields. A dividing border, such as a dirt road at least 40 meters (132 feet) wide, was required to detect the boundary between fields of the same contrast. Examination of figure 2-3 indicates a good breakdown at classification Level II (cropland compared to noncropland), but further conventional interpretation was almost impossible. Using various training fields, correlation of a particular color to a single crop species was attempted. Again, the results quickly indicated that crop classification in this manner was almost totally ambiguous. The colors in figure 2-3 were found to be an indicator of the density of vegetative cover, and these results appear in table 2-II.

TABLE 2-II.- IMPERIAL COUNTY CONVENTIONAL IMAGE INTERPRETATION

Color	Crop species and height, cm
Red	Alfalfa 36, sugar beets 30, sudan grass 24
Moderately red	Alfalfa 21, 15, 9; sugar beets 30; asparagus 61
Dull red	Alfalfa 15, 9; sugar beets 9; carrots 21; sudan grass 21
Pink	Melon 15
Magenta	Sugar beets 27, 12
White	Bare soil; dry, plowed, or recently planted
Black	Bare soil; undisturbed with little or no ground cover
Gray	Sugar beets 9; grain sorghum stubble 61; bare soil; melons 15

Figure 2-3.- Imperial County conventional image interpretation ACVP false-color infrared enhancement (NASA S-73-28068).

The crops in Hardin County were identified in those fields that could be detected. The best color composite generated from a CCT at JSC (fig. 2-4) was used for crop identification. The ERTS band 6 was on the green gun, band 5 on the red gun, and band 4 on the blue gun. There is a cloud just south of the study area, and its shadow obscures the northern edge. Table 2-III shows the colors that were grouped for each crop type. The crop types were identified on the basis of color. These three crops (corn, soybeans, and oats) and bare soil make up 85 percent of the study area.

TABLE 2-III.- HARDIN COUNTY CONVENTIONAL IMAGE INTERPRETATION

Crop	Color	Number of fields				
		Total	Training	Test	Test fields identified	Accuracy, percent[a]
Corn	Dark green	89	12	77	73	95
Soybeans	Bright green	75	10	65	61	94
Oats	Lighter red and pink	62	14	48	41	85
Bare soil	Dark red	3	1	2	2	100
Totals		229	37	192	177	

[a]Accuracy of field identification equals number of test fields identified divided by total number of test fields.

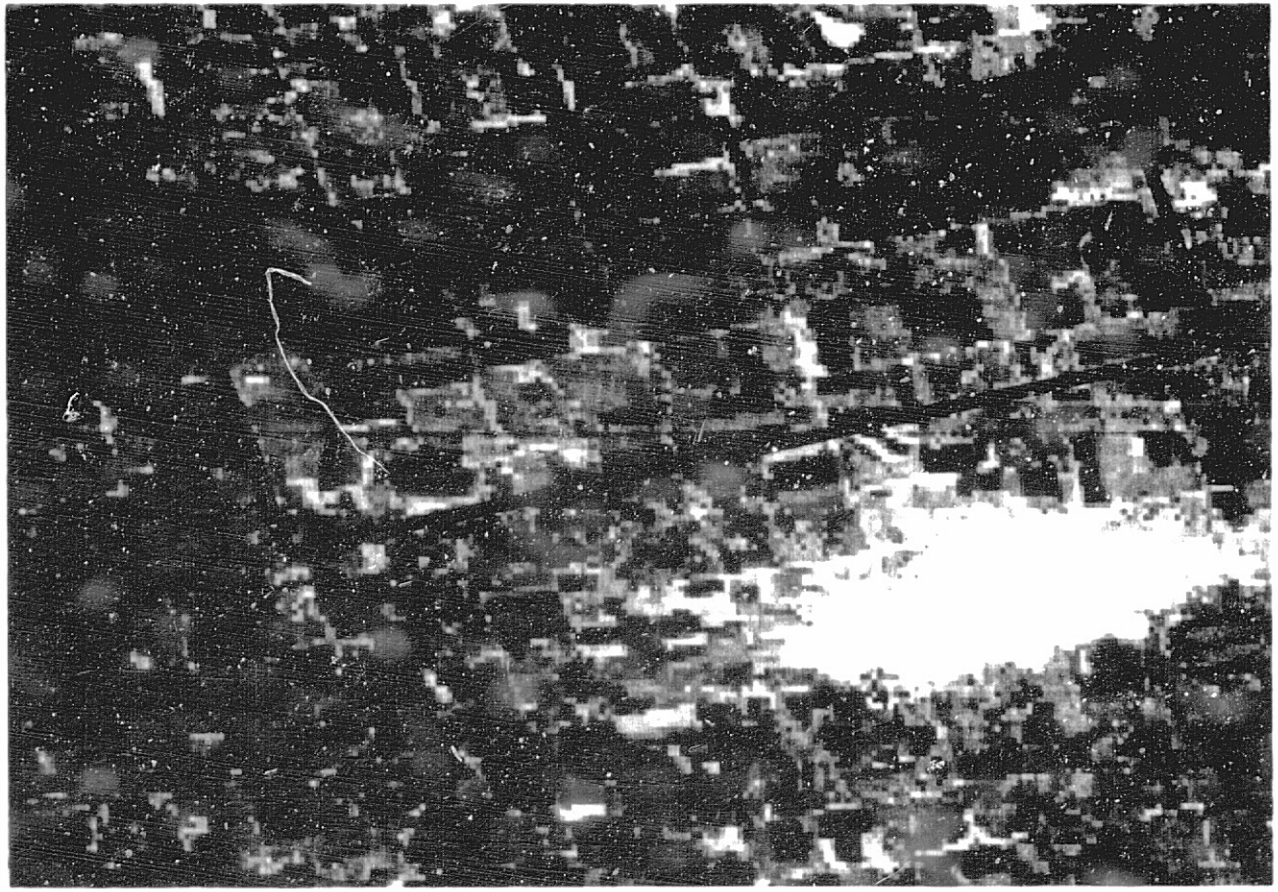


Figure 2-4.- Hardin County conventional image interpretation of JSC color composite (NASA S-73-28141).

2.3.2 Computer Classification

Because of the lack of ground data, atmospheric correction techniques were not used in the computer-aided analysis. Photometers, which would have measured the effect of the atmosphere on the solar energy reaching the Earth, were not available for the test sites during the ERTS-1 overpasses.

Hill County.- All the major crops grown on the Hill County site had either been harvested or were ready for harvest. In addition to the advanced stage of maturity, the narrow width of a majority of the alternating strips made it very difficult to select good training and test fields of sufficient size to achieve accurate classification.

An analysis of the results from the Hill County site in August indicated that fields smaller than 24 square hectometers (60 acres) that were longer than 800 meters (0.5 statute mile) could not be properly defined for use as training or test fields on the interactive classification system. These narrow fields had a higher percentage of picture elements (pixels) comprising the boundary and therefore might not represent the reflected data from that field. Many fields in the area were 1856 meters (1 nautical mile) long, which meant they must be larger than 40 square hectometers (100 acres) to be wide enough for use as a dependable training or test field. Very few of the fields could meet these criteria. In contrast, fields that were as small as 8 square hectometers (20 acres) made dependable training or test fields provided the strips were less than 400 meters long and adjacent to summer fallow strips. The high relative contrast between the small grain crops and summer fallow strips provided an excellent boundary discrimination until the crop was harvested, at which time the contrast was greatly reduced. The accuracy of classification in Hill County for the training and test fields is shown in table 2-IV.

TABLE 2-IV.- HILL COUNTY CLASSIFICATION PERFORMANCE SUMMARY

(a) Barley, spring wheat, and winter wheat

Class	No. samples	Barley	Spring wheat	Winter wheat	Fallow	Sod	Correct classification, percent
Training field							
Spring wheat	143	33	93	9	7	1	65.0
Winter wheat	184	34	8	135	4	3	73.4
Barley	147	129	9	4	4	1	87.8
Fallow	188	7	3	3	164	11	87.2
Sod	173	2	3	3	13	155	89.6
Test field							
Spring wheat	52	11	35	6	0	0	67.3
Winter wheat	99	18	49	27	5	0	27.3

(b) Barley and wheat

Class	No. samples	Barley	Wheat	Fallow	Sod	Correct classification, percent
Training field						
Wheat	327	67	245	11	4	74.9
Barley	147	129	13	4	1	87.8
Fallow	188	7	6	164	11	87.2
Sod	173	2	6	13	155	89.6
Test field						
Wheat	151	29	117	5	0	77.5

(c) Small grains

Class	No. samples	Small grains	Fallow	Sod	Correct classification, percent
Training field					
Small grains	474	454	15	5	95.7
Fallow	188	13	164	11	87.2
Sod	173	8	13	155	89.6
Test field					
Small grains	151	146	5	0	96.7

The classification results are best shown by the comparison of the ground-truth map for the 31-square-kilometer (12 square statute mile) test site (fig. 2-5) with the recognition map developed (fig. 2-6). Crop identification accuracy was computed using the following formula: percent accuracy of field identification equals number of samples (pixels) per feature (test or training field) identified divided by the total samples (pixels) per field (test or training) multiplied by 100. Oats were grown in the Hill County site; however, no classification attempt was made because the crop had been harvested at the time of the overpass and no oat field was large enough for use as a training field.

Imperial County.- Using the NSCLAS clustering routine and ground-truth information, eight different crop types and species were selected for classification training and testing in Imperial County. Although corresponding test fields were not available, additional training fields were selected so that the classification might be a fairly accurate representation of the actual ground truth as shown in figure 2-7. Table 2-V contains the percentage accuracy figures for the training and test fields outlined in yellow on figure 2-8.

The low percentage of classification accuracy for beets may be attributed to their being at a very early growth state. More ground was visible at this stage, and beets were misclassified as bare soil and sorghum. The low percentage of classification for bare soil was due to the similarity in spectral response of sorghum and bare soil.

- Sod
- Summer fallow
- Summer wheat
- Winter wheat
- Barley
- Oats
- Crested wheat grass
- Water, building sites

Section identification

13	18	17	16	15	14
24	19	20	21	22	23

Roads —

Figure 2-5.- Hill County 1972 annual ground truth (NASA S-73-23401).

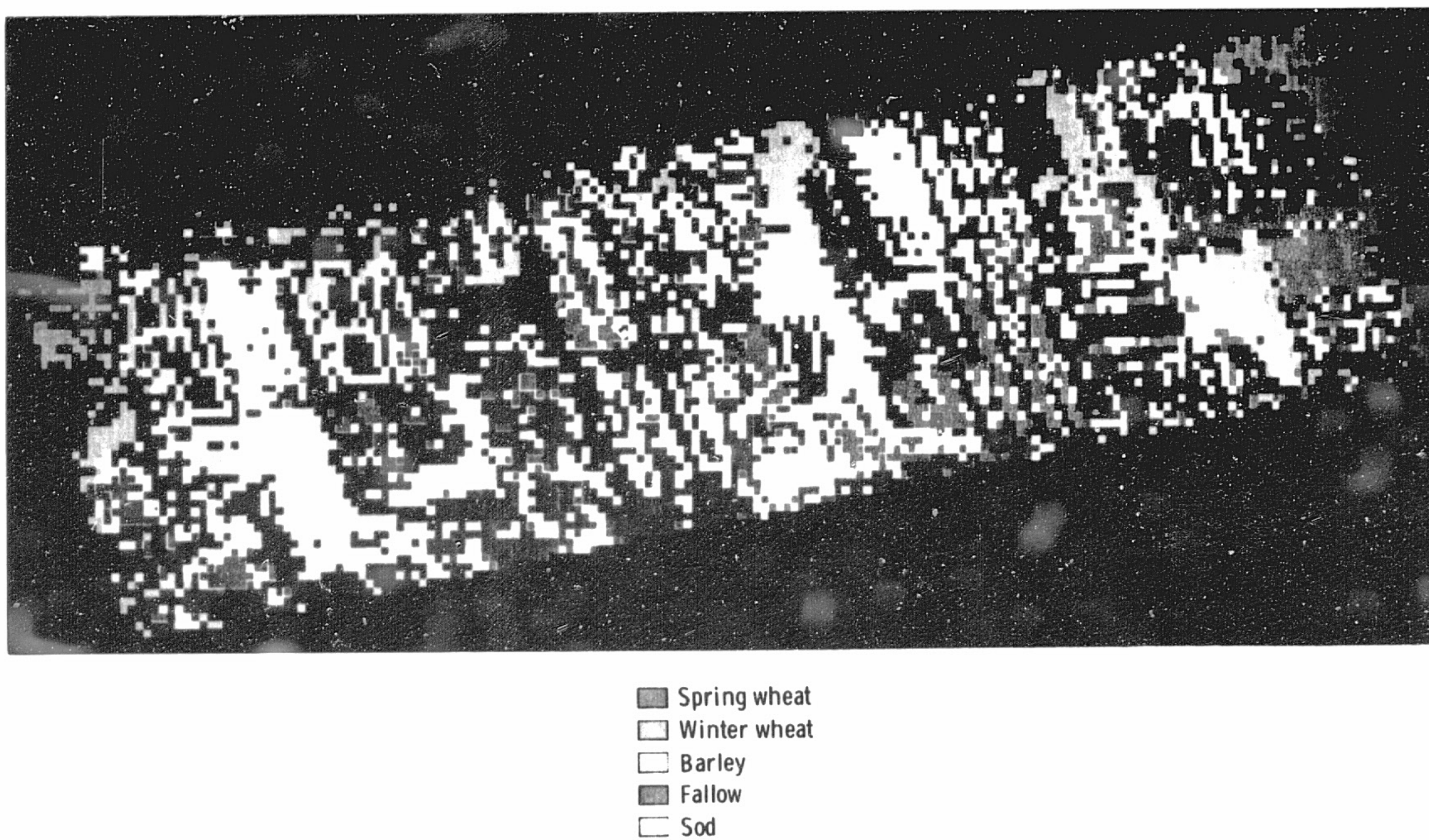


Figure 2-6.- Hill County computer classification (NASA S-73-28067).

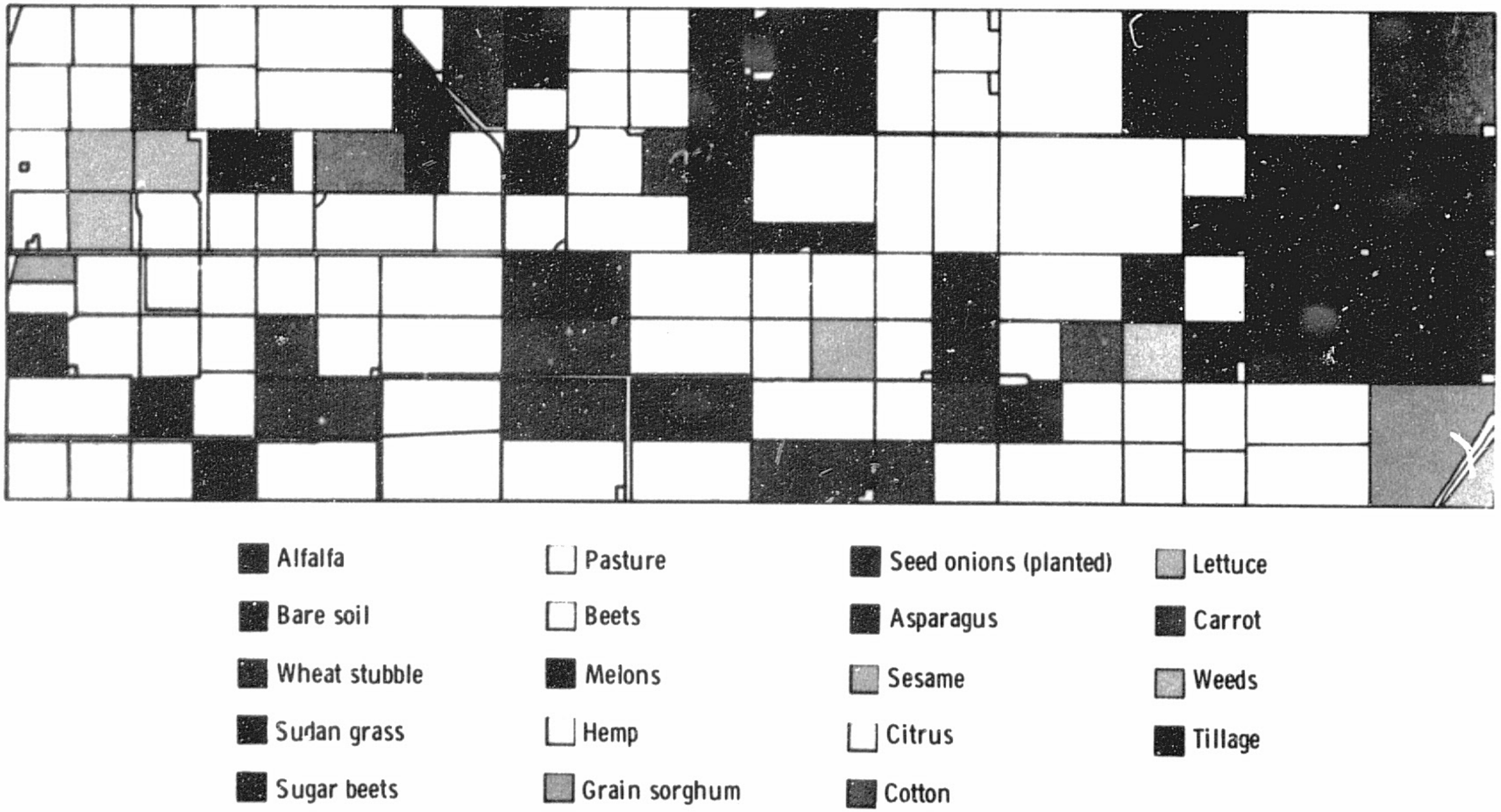


Figure 2-7.- Imperial County 1972 annual ground truth (NASA S-73-25512).

TABLE 2-V.- IMPERIAL COUNTY CLASSIFICATION PERFORMANCE SUMMARY

[Nov. 6, 1972]

Field designated group	No. samples	Percent correct	Carrots	Bare soil 1	Bare soil 2	Beets	Alfalfa	Asparagus	Cotton	Sudan grass	Sorghum	Melons
Training field performance												
Carrots	24	100	24	0	0	0	0	0	0	0	0	0
Bare soil 1	24	100	0	24	0	0	0	0	0	0	0	0
Bare soil 2	48	100	0	0	48	0	0	0	0	0	0	0
Beets	0	100	0	0	0	9	0	0	0	0	0	0
Alfalfa 1	12	25.0	1	0	0	0	3	6	0	2	0	0
Alfalfa 2	24	100	0	0	0	0	24	0	0	0	0	0
Alfalfa 1 and 2	36	75.0	1	0	0	0	27	6	0	2	0	0
Asparagus 1	42	97.6	0	0	0	0	0	41	1	0	0	0
Asparagus 2	32	62.5	1	0	0	0	9	20	1	1	0	0
Asparagus 1 and 2	74	82.4	1	0	0	0	9	61	2	1	0	0
Cotton	28	100	0	0	0	0	0	0	28	0	0	0
Sudan grass	16	100	0	0	0	0	0	0	0	16	0	0
Sorghum	15	100	0	0	0	0	0	0	0	0	15	0
Melons	12	100	0	0	0	0	0	0	0	0	0	12
Totals	286	(a)	26	24	48	9	36	67	30	19	15	12
Test field performance												
Carrots	32	71.9	23	0	0	0	3	3	0	3	0	0
Bare soil 1	32	65.6	0	21	0	0	0	0	0	0	11	0
Bare soil 2	70	90.0	0	0	63	0	0	0	7	0	0	0
Beets 1	20	95.0	0	0	0	19	0	0	0	1	0	0
Beets 2	25	0.0	0	9	0	0	1	0	0	0	14	1
Beets 1 and 2	45	42.2	0	9	0	19	1	0	0	1	14	0
Alfalfa	24	95.8	0	0	0	0	23	0	1	0	0	0
Asparagus 1	80	95.0	0	0	0	0	1	76	2	1	0	0
Asparagus 2	56	55.4	2	0	0	0	12	31	10	1	0	0
Asparagus 1 and 2	136	78.7	2	0	0	0	13	107	12	2	0	0
Cotton 1	27	63.0	0	0	0	10	0	0	17	0	0	0
Cotton 2	48	100	0	0	0	0	0	0	48	0	0	0
Cotton 1 and 2	75	86.7	0	0	0	10	0	0	65	0	0	0
Sudan grass	24	91.7	0	0	0	0	2	0	0	22	0	0
Totals	438	(b)	25	30	63	29	42	110	85	28	25	1

[a]Overall performance: 264/286 = 92.3 percent.
[b]Overall performance: 343/438 = 78.3 percent.

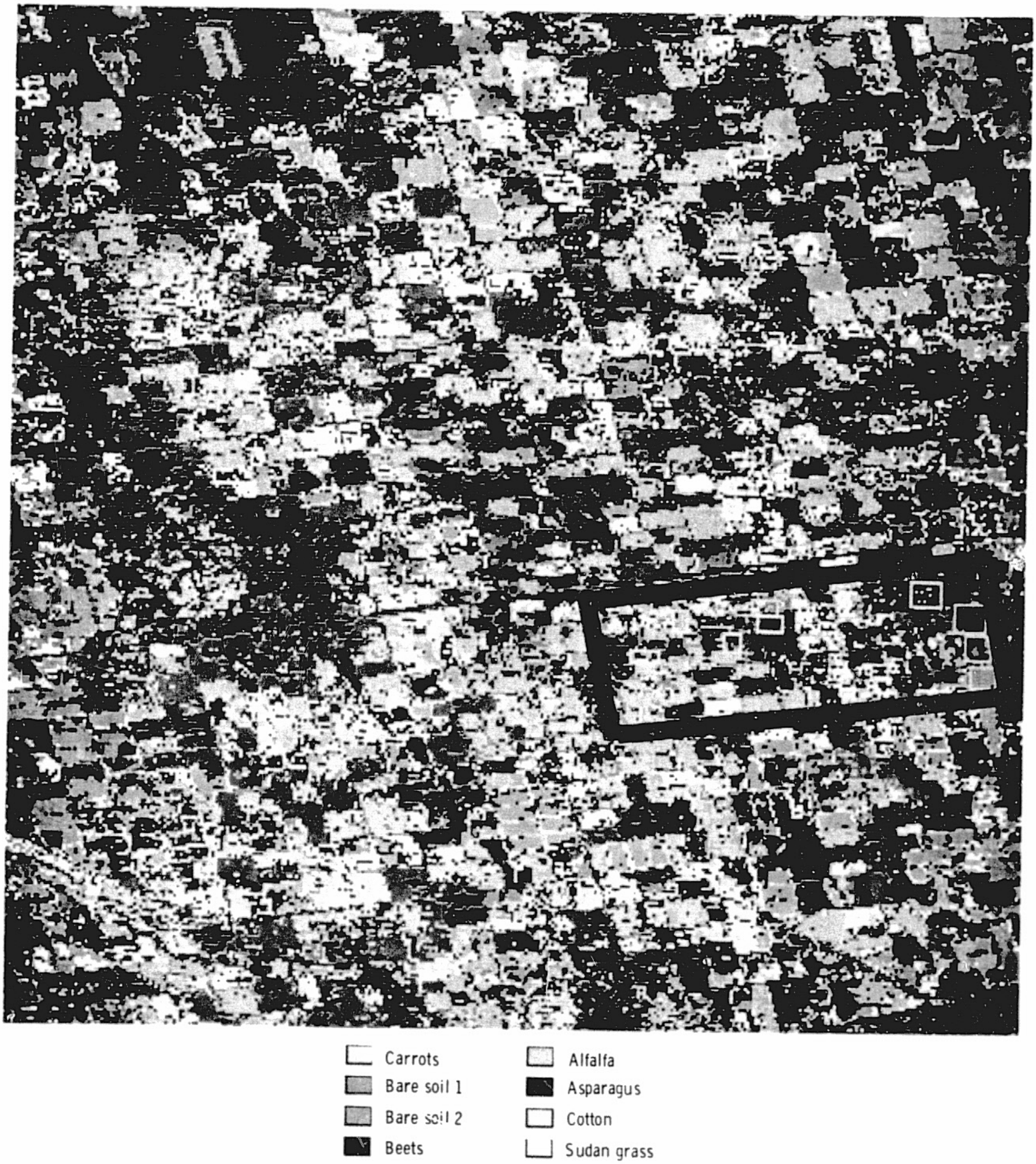


Figure 2-8.- Imperial County computer classification, November 6, 1972, data (NASA S-73-28070).

Hardin County.- Corn was the dominant crop in Hardin County and was readily recognized in a supervised classification. A total of 76 cornfields was represented on the ground-truth tabulation (fig. 2-9). Of these, 73 were classified correctly. The three fields unaccounted for were small, individual fields, beyond the expected resolution limit. The larger fields were fairly well defined with little extraneous data. The thin cloud to the south of the study area cast a weak shadow along the northern edge of the area and caused other crop types in this area to be grouped with the corn. One corn test field was partly shadowed. Removing the data for the shadowed field increased the corn test results to higher than 80 percent. Table 2-VI contains a breakdown of eight classes.

The classification results were reasonably good on a pixel-by-pixel basis and indicated that corn, soybeans, and oats could be separated at this maturity stage (table 2-VI). A review of the input showed that in almost all cases of low classification accuracy, one of three things happened. The most frequent occurrence was improperly defined training field boundaries overlapping another crop type. Because this area had many small fields (fig. 2-9), this problem was expected. Judicious screening of the training and test fields as shown in pink on figure 2-10 overcame problems with smaller fields. The second problem area was that all oats had been harvested nearly a month before the overpass and were in various stages of regrowth or in a bare-soil condition. Despite this condition, the classification was fairly successful, except for an inability to distinguish some oats from county and state roads. This difficulty was probably attributable to the fact that farm roads in Iowa are normally bordered by wide, shallow ditches of mowed bluegrass, which appeared spectrally similar to harvested oats. The third problem was presented by the cloud shadow that was cast over the northwest corner of the study area. No special attempt was made to develop unique signatures for this area.

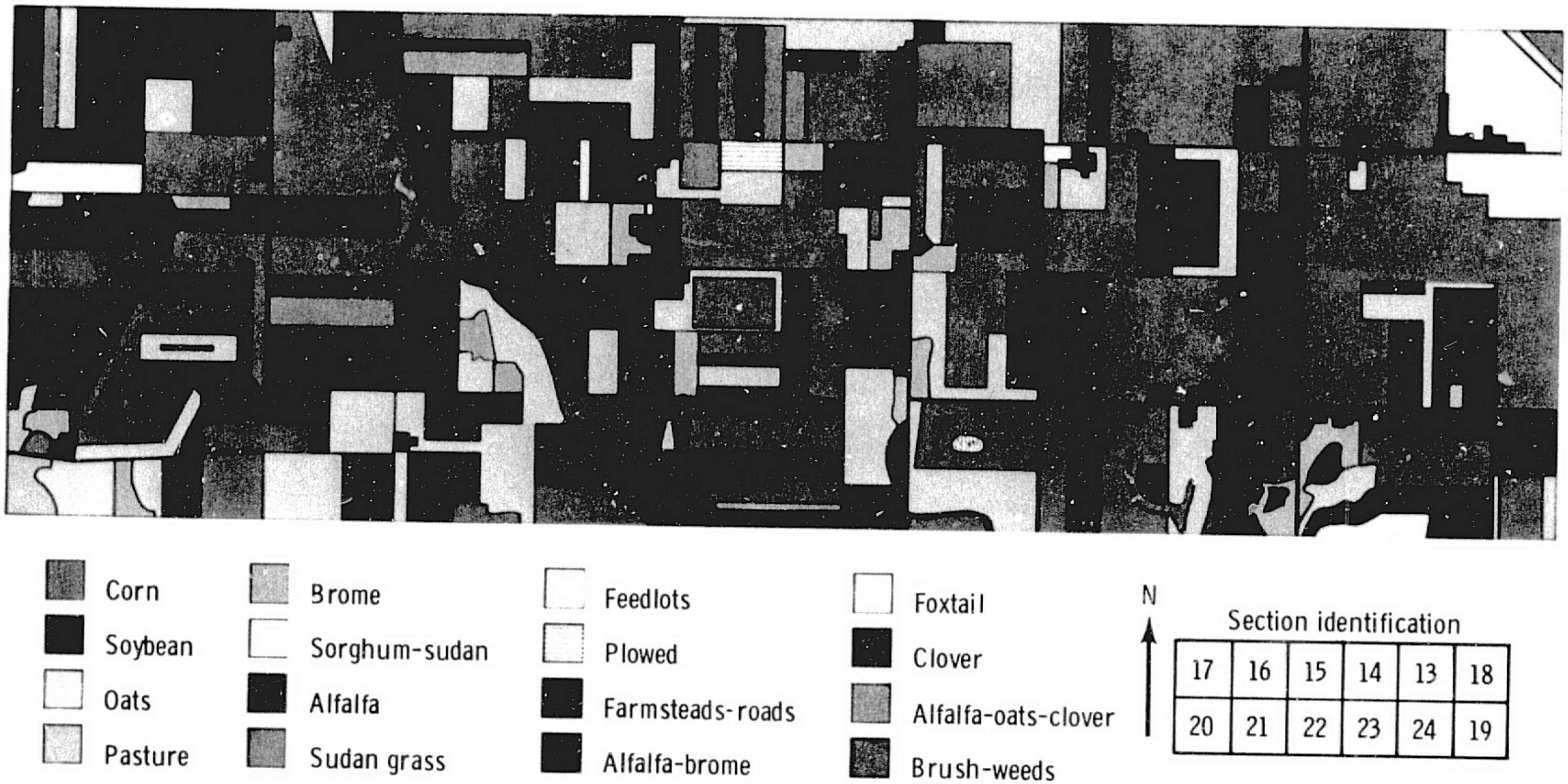


Figure 2-9.- Hardin County 1972 annual ground truth (NASA S-73-25510).

TABLE 2-VI.- HARDIN COUNTY CLASSIFICATION PERFORMANCE SUMMARY

[Aug. 13, 1972]

Field designated group	No. samples	Corn	Soybeans	Oats	Sorghum	Sudan	Bare soil	Cloud	Shadow	Accuracy, percent
Training field performance										
Corn	419	380	1	8	21	0	2	0	7	90.7
Soybeans	267	0	220	11	17	15	0	0	4	82.4
Oats	106	2	2	86	4	1	10	0	1	81.1
Sorghum	56	0	3	1	52	0	0	0	0	92.9
Sudan grass	47	0	4	0	2	41	0	0	0	87.2
Bare soil	58	3	0	6	0	0	49	0	0	84.5
Cloud	491	0	0	2	0	0	0	489	0	99.6
Shadow	131	1	3	0	1	0	0	0	126	96.2
Test field performance										
Corn	309	223	6	14	14	0	9	0	[a]43	72.2
Soybeans	141	1	128	0	5	5	0	0	2	90.8
Oats	85	1	5	64	4	2	8	1	0	75.3
Cloud	365	0	0	1	0	0	0	364	0	99.7
Shadow	98	5	0	0	3	0	5	0	85	86.7

[a]Corn test field partly shadowed; removal of these data increased corn test results to more than 80 percent.

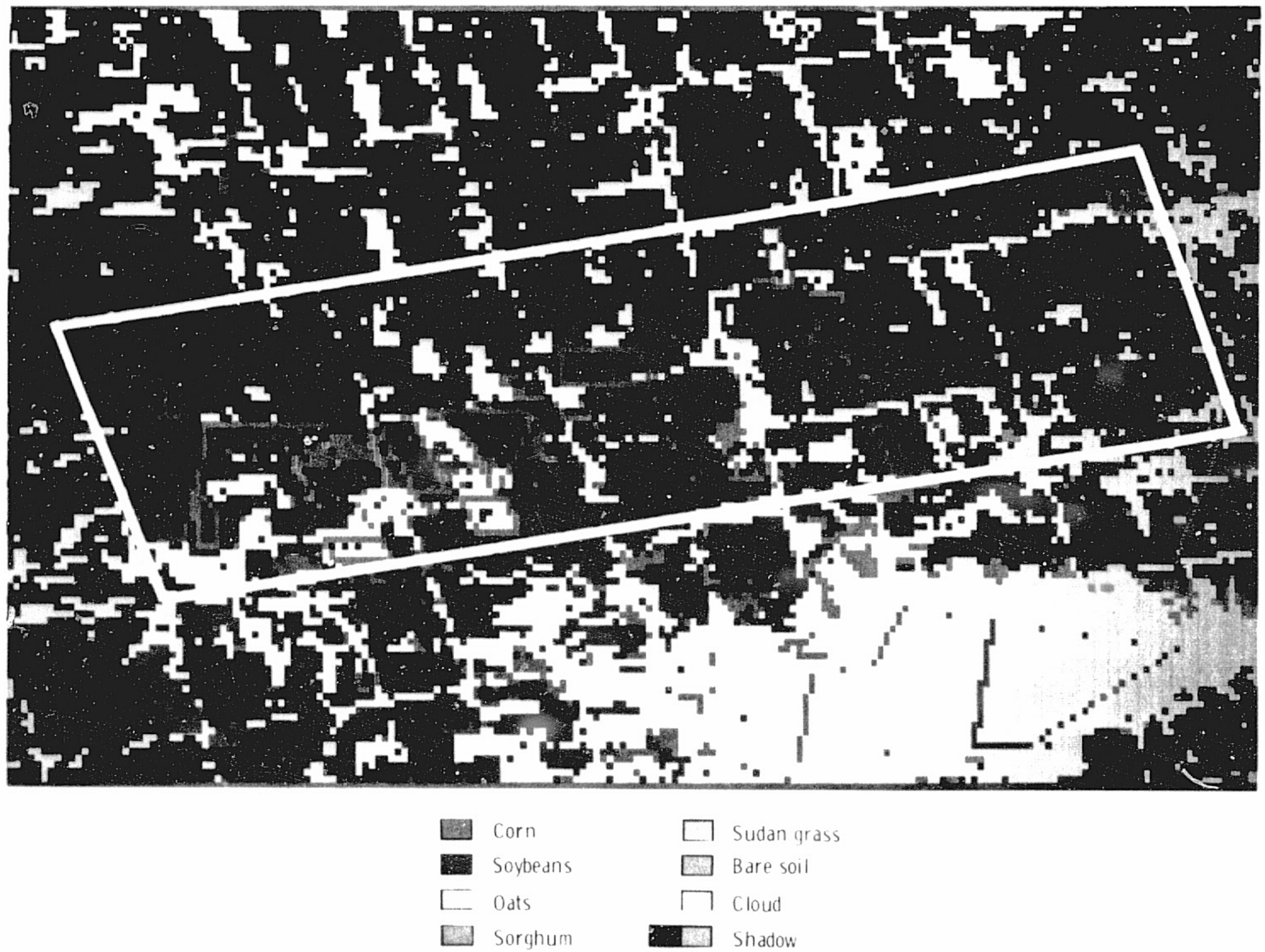


Figure 2-10.- Hardin County supervised computer classification, August 13, 1972.

Holt County.- The fields in Holt County were analyzed in two phases (fig. 2-11). In the first phase, four channels of ERTS-1 MSS data were analyzed for a single pass on July 30, 1972 (fig. 2-12(a)). In the second phase, the August 16, 1972, imagery was correlated and registered with the earlier imagery to form a single data set. Data from the second phase were analyzed using both a 0.5 and a 0.2 threshold. The 0.2 threshold was the best (fig. 2-12(b)). The results of the first and second phases of analyses are shown in table 2-VII. These results are summarized by crop species as follows.

Field corn or popcorn: The classification accuracy for the identification of known test cornfields was approximately 97 to 98 percent for both data sets. The single-pass data set did not contain the information necessary to separate popcorn from field corn. An attempt to distinguish field corn from popcorn using a two-pass data set was highly successful. This differentiation was possible because the reflectance of popcorn fields in channels 3 and 4 of the ERTS-1 MSS in the August 16 pass was higher than that of field corn. Such a spectral response may well be due to some peculiarity in the development of popcorn that is different from that of field corn. For example, popcorn matures faster than field corn.

Sunflowers: Sunflowers were separable from corn because of higher reflectance in the third channel of the single-pass data sets of July 30, 1972. At this stage, the sunflowers were blooming. Sunflowers were not separable from corn, particularly popcorn, using the August 16 data only.

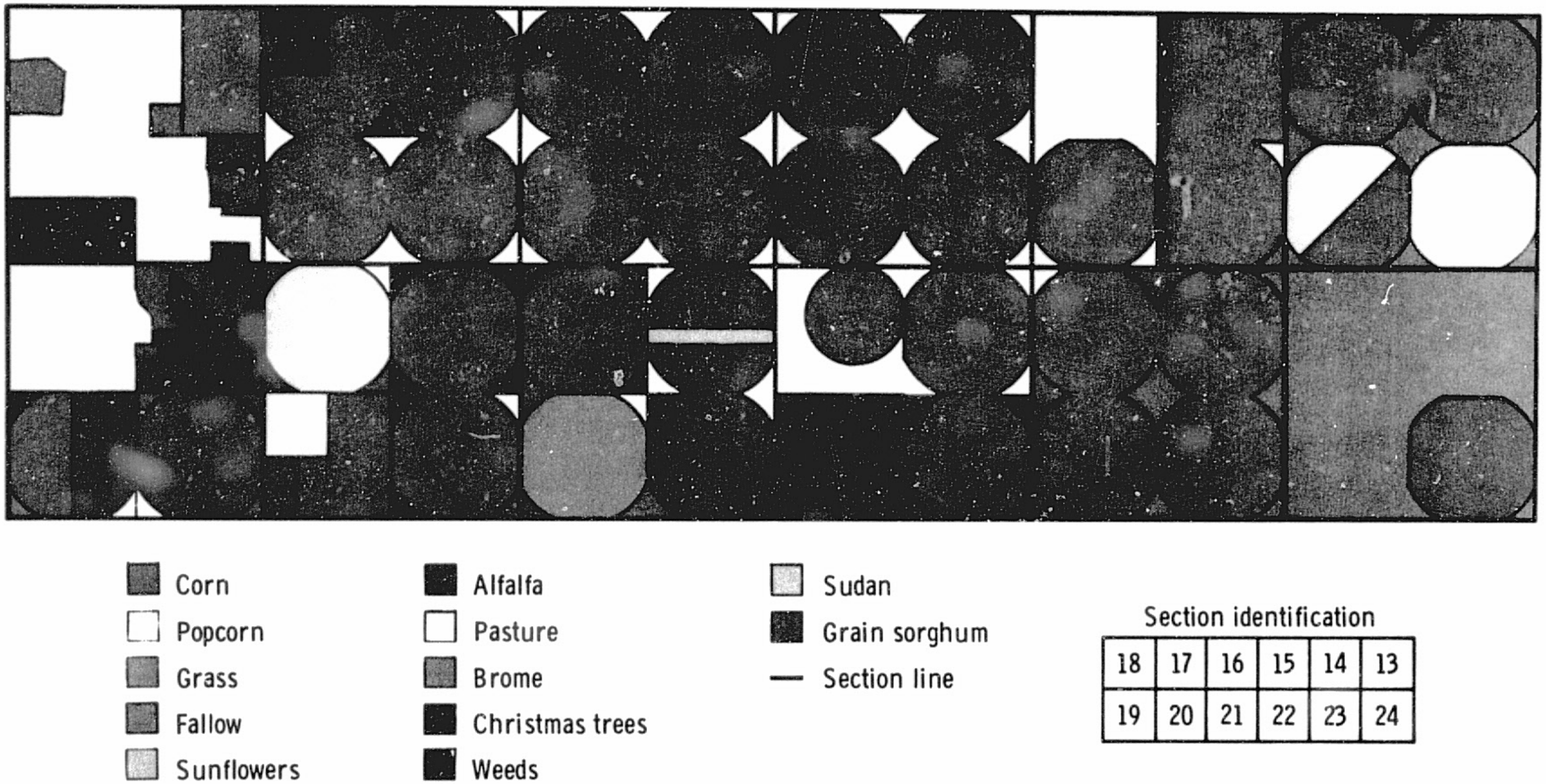


Figure 2-11.- Holt County annual ground truth.

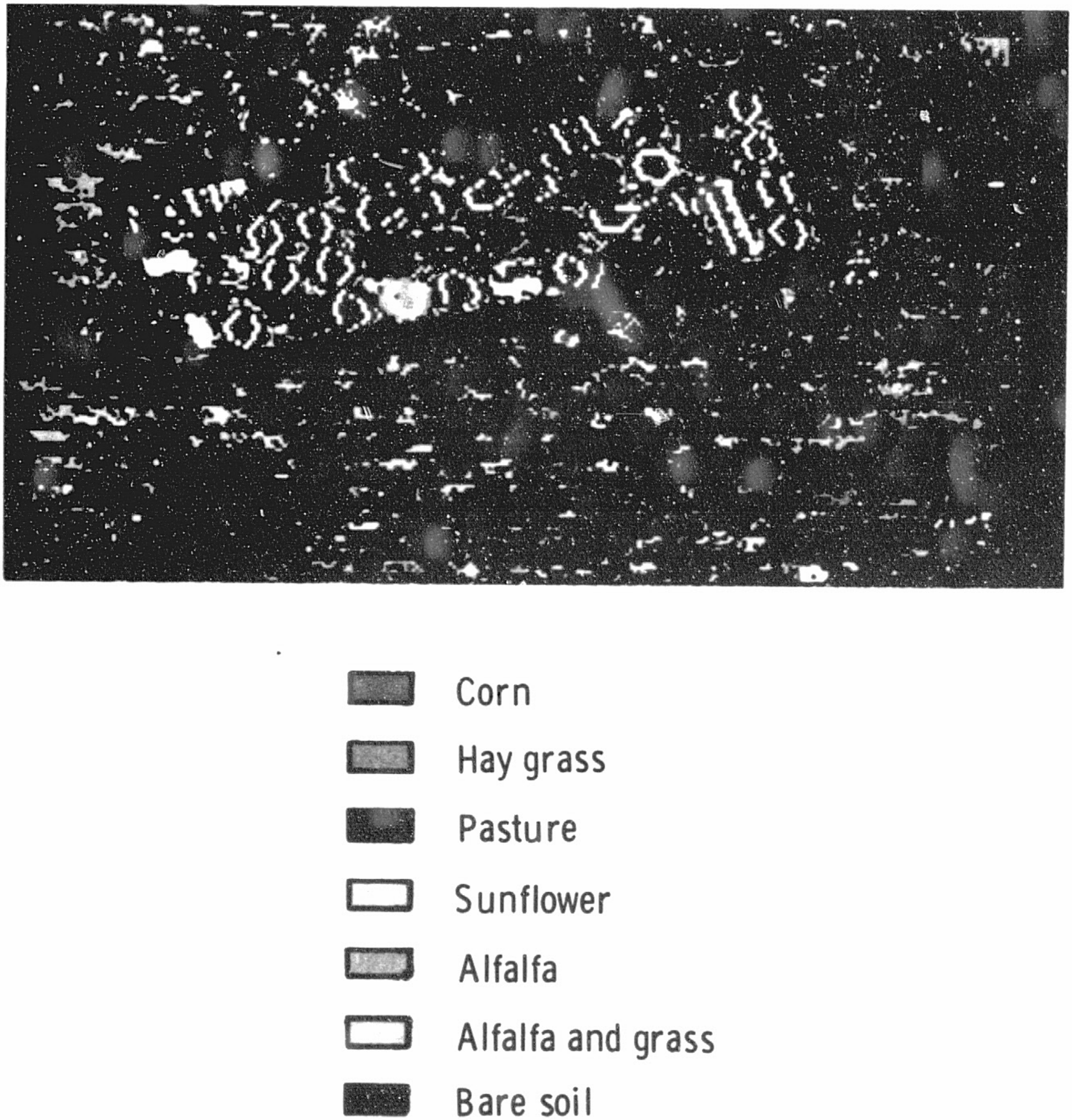
TABLE 2-VII.- HOLT COUNTY CLASSIFICATION PERFORMANCE SUMMARY

Field designated group	Data set 1 (single pass),[a] threshold = 0.5				Data set 2 (two pass),[b] threshold = 0.5				Data set 2 (two pass),[b] threshold = 0.2			
	Total samples	Misclassified	Threshold out	Percent correct	Total samples	Misclassified	Threshold out	Percent correct	Total samples	Misclassified	Threshold out	Percent correct
Training field performance												
Field corn or popcorn	789	4	4	99.0	1038	7	14	98.8	979	4	1	99.3
Field corn	--	--	--	--	768	31	10	94.7	745	13	1	98.2
Popcorn	--	--	--	--	270	13	4	[c]95.3	234	9	2	[c]95.3
Sunflowers	51	1	0	98.0	49	1	0	98.0	50	2	0	96.0
Alfalfa	34	5	0	85.3	29	0	2	91.2	34	1	0	97.1
Alfalfa and grass	25	7	0	68.0	29	1	0	96.6	18	0	0	100.0
Grass	96	3	1	95.8	97	4	1	94.8	109	3	0	97.3
Pasture	232	18	1	91.8	211	3	1	98.2	219	4	2	97.3
Fallow (bare soil)	34	0	0	100.0	44	0	0	100.0	50	0	0	100.0
Grain sorghum	--	--	--	--	--	--	--	--	14	1	0	92.9
Test field performance												
Field corn or popcorn	686	17	0	97.5	478	3	0	98.1	504	3	0	99.4
Field corn	--	--	--	--	428	20	9	93.2	456	13	0	97.0
Popcorn	--	--	--	--	50	0	0	[c]100.0	48	1	0	[c]97.9
Grass	39	0	0	100.0	50	0	0	100.0	54	0	0	100.0

[a]Four-channel classification, July 30, 1972.

[b]Seven-channel classification, August 16 and July 30, 1972.

[c]Value does not reflect that one of seven known popcorn fields was misclassified as field corn.



(a) Supervised computer classification map of six classes using July 30, 1972, data.

Figure 2-12.- Holt County computer classification (NASA S-73-1506).

Field corn

Popcorn

Sunflower

Alfalfa and grass

Pasture

Grain sorghum

Alfalfa

Bare soil

(b) Temporal composite using July 30 and August 16, 1972, data.

Figure 2-12.- Concluded (NASA S-73-1506).

Alfalfa: The study site contained only a few small fields of alfalfa, some of which had recently been harvested at the time of both ERTS-1 passes. Alfalfa fields were classified as either pasture or grass in the second pass. Specifically, for the data of the first ERTS-1 pass, only two fields of usable size were identified at or near the blooming stage during the second pass. These two fields were used as training fields for both data sets. Together, they comprised a total of approximately 30 data points. The accuracy of classification for these fields was 85 percent for the single-pass data set and 90 percent for the two-pass data set.

Pasture and grass: Pasture and grass were easily separable from the other classes of the study site and were easily differentiated. The pasture was divided into three subclasses, one of which was bromegrass. The distribution of the bromegrass data overlapped the other types of grasses in the study site, in some cases by as much as 50 percent. Bromegrass was therefore not separable from other grasses in the area.

Fallow land (bare soil): Bare soil has a unique spectral response and was easily separable from all types of vegetation. The two fallow fields in the study site were assigned to the same class, although the combined distribution of the data was definitely bimodal. No difference between the fields was discernible in the classification maps, which were generated by assigning the two fallow fields to either the same or different subclasses. This similarity was true for the two-pass data set, even though some of the fallow fields seemed to be overgrown with vegetation during the second pass. Positive recognition of fallow fields may require that one of the two passes be made when the field is primarily bare soil.

Butte County.- Butte County displays a large variety of crop types. Analysis of the data from the ERTS-1 pass of September 19, 1972, revealed that corn, rice, and fallow land were the most separable of the 17 classes used for training. Only 8 of these 17 classes were selected for testing classification accuracy because of the limited representation of the remaining classes in the test site (table 2-VIII).

Three classes had classification accuracies of less than 70 percent: corn, native trees, and weeds. The low classification of corn could be partly attributed to the weeds and drowned spots in fields, which caused corn to be confused with pasture. Ten percent of the weedy corn (corn) was classified as good corn (corn 1). When the misclassifications into pasture and corn 1 are disregarded, corn had a classification accuracy of 84 percent. The low classification of weeds resulted from confusion with alfalfa and trees (plum, almond). The similarity of weeds and alfalfa was somewhat understandable. However, the confusion of weeds with trees can only lead to the conclusion that information was needed in the ground-truth reports to describe the density of the native trees. The five rice test fields had several distinct stages of growth, which accounted for the wide range (0 to 92 percent) of classification accuracy. The zero classification was in a test field where harvesting had begun, and the field was classified as wheat stubble. The other test crops (plums, corn, beans, and almonds) had very low classification accuracies that were not readily explainable.

TABLE 2-VIII.- BUTTE COUNTY CLASSIFICATION PERFORMANCE SUMMARY

Group	No. samples	Percent correct	Plums	Rice A	Corn	Fallow	Wheat S	Beans	Beets	Oats	Pasture	Alfalfa M	Alfalfa H	Grain sorghum	Sudan grass	Native T	Weeds	Corn 1	Almonds
Training field performance																			
Plums	20	80.0	16	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	1
Rice A	72	76.4	0	55	0	0	0	0	0	0	0	0	0	8	0	0	9	0	0
Rice A	60	53.3	0	32	0	0	28	0	0	0	0	0	0	0	0	0	0	0	0
Rice A	117	100	0	117	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rice A	70	68.6	0	48	0	0	0	0	7	0	0	0	0	6	5	0	4	0	0
Rice A	144	58.3	0	84	0	0	0	0	4	0	17	6	0	2	0	0	31	0	0
Corn	110	66.4	0	2	73	0	0	0	0	0	10	5	1	0	0	5	0	10	4
Fallow	40	100	0	0	0	40	0	0	0	0	0	0	0	0	0	0	0	0	0
Fallow	21	95.2	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	1
Fallow	56	98.2	0	0	0	55	0	0	0	0	0	0	0	0	0	0	0	0	1
Wheat S	36	77.8	0	0	0	0	28	0	0	1	0	0	0	0	2	0	2	0	3
Beans	21	100	0	0	0	0	0	21	0	0	0	0	0	0	0	0	0	0	0
Beets	20	75.0	2	0	0	0	0	0	15	0	1	0	0	0	0	0	0	0	2
Oats	8	100	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0
Pasture	36	72.2	1	0	0	0	0	0	0	0	26	4	3	0	0	0	1	0	1
Alfalfa M	25	88.0	0	0	0	0	0	0	0	0	2	22	0	0	0	1	0	0	0
Alfalfa H	16	81.3	0	0	0	0	0	0	0	0	3	0	13	0	0	0	0	0	0
Grain sorghum	16	75.0	0	1	0	0	0	0	0	0	0	0	0	12	3	0	0	0	0
Sudan grass	9	100	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0
Native T	12	58.3	1	0	0	0	0	0	0	0	1	0	0	0	0	7	0	1	2
Weeds	55	50.9	5	2	0	0	0	0	1	0	0	3	0	0	0	1	28	1	14
Corn 1	70	92.9	0	0	2	0	0	0	1	0	0	0	0	0	0	1	0	65	1
Almonds	20	95.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	19
Almonds	24	87.5	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0	21
Totals	1078	(a)	25	341	75	115	58	21	31	9	60	40	17	28	19	15	76	78	70
Test field performance																			
Plums	28	21.4	6	0	0	0	0	0	4	0	0	0	0	0	0	0	4	0	14
Rice A	30	.0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0
Rice A	99	92.9	0	92	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0
Rice A	30	73.3	0	22	0	0	2	0	2	0	0	0	0	2	2	0	0	0	0
Rice A	25	72.0	0	18	0	0	0	0	2	0	0	0	0	4	1	0	0	0	0
Rice A	63	54.0	0	34	2	0	0	0	1	0	5	3	0	3	0	1	11	2	1
Corn	56	37.5	0	0	21	0	0	0	0	0	30	1	0	0	0	1	0	3	0
Fallow	91	94.5	0	0	3	86	0	0	0	0	0	0	0	0	0	2	0	0	0
Fallow	105	36.2	0	0	7	18	41	0	1	0	0	0	0	0	0	0	12	0	6
Wheat S	24	41.7	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	14
Beans	22	54.5	0	2	0	0	0	12	0	0	0	0	0	0	0	0	8	0	0
Corn 1	25	80.0	2	0	0	0	0	0	1	0	0	0	0	0	0	1	0	20	1
Corn 1	24	70.8	0	0	1	0	0	0	2	0	0	0	0	0	0	1	0	17	3
Almonds	25	60.0	0	0	3	0	0	0	0	0	0	0	0	0	0	2	3	2	15
Totals	647	(b)	8	168	37	124	83	12	13	0	35	4	0	16	3	8	38	44	54

[a]Overall performance: 834/1078 = 77.4 percent.
[b]Overall performance: 391/647 = 60.4 percent.

2.3.3 Area Measurement

All area measurements were performed on imagery generated on the ACVP. The results were good with some qualifications. The Imperial County area measurement results are summarized in table 2-IX. Boundary definition was the key to accurate field measurement. Many fields were too small or too narrow to be clearly defined. Rectangular fields, especially long, narrow ones, that were oriented nearly parallel to the image scan lines were difficult to define. Accurate boundary definition was also difficult at high-contrast borders, such as those between a field with low spectral response and a field with high spectral response. This situation caused a blooming effect, in which the field with high response appeared larger and the field with low response appeared smaller. In Hill County, dimensions greater than 220 meters under optimum conditions of contrast and orientation were necessary for clear definition.

2.3.4 Field Location

Specific tracts were located by correlation to a UTM grid system. A technique was developed in which a UTM grid was overlaid on an ACVP enlarged image and matched to control points with known UTM coordinates on 1:62,500-scale maps. Slight variations in the scale of the enlarged image were compensated for by a family of grids, each varying slightly in scale. Matching the appropriate grid to the control points made possible the location of tracts in the 31-square-kilometer (12 square statute mile) study areas to within approximately 200 meters.

2.4 CONCLUSIONS

The following conclusions can be stated.

1. A hierarchal approach was generally followed in this investigation. Agricultural areas were easily separated, and cropland within these areas was easily identified. These general

TABLE 2-IX.- IMPERIAL COUNTY FIELD AREA MEASUREMENTS

[ERTS MSS imagery, Nov. 6, 1972]

Field designation	Description	Farm/field number	Measured area		Actual area		Percent error	Remarks
			hm^2	acres	hm^2	acres		
A	Small, square field with strong vegetation response; two good borders and two low-contrast borders	5/A142-6	13.2	32.7	13.7	33.8	-3.3	Alfalfa; good growth and good border on two sides
B	Small, square field with moderate vegetation; strong vegetation response on two borders, low contrast on two borders	39/A160-1	13.1	32.3	15.1	37.4	-13.6	Melons; poor border on three sides
C	Small, square field with strong vegetation response; good borders on three sides	441/A270-1	15.9	39.3	14.9	36.9	6.5	Alfalfa; good growth and borders
D	Very small, rectangular white field; two borders poorly defined	396/A436-4	6.1	15.0	6.3	15.6	-3.8	Bare soil; poor west border
E	Triangular field with strong vegetation; good borders	349/C511-4	20.5	50.6	19.3	47.6	6.3	Alfalfa; good growth and borders
F	Small, square field with moderate vegetation; good border on two sides, poor border two sides	587/C6-13	9.8	24.1	14.4	35.5	-32.1	Melons: poor north border
G	Rectangular, moderate size field with strong vegetation response and good borders	587/A44-11	29.5	73.0	28.3	70.0	4.3	Alfalfa (?); good growth
H[a]	Rectangular, moderate size field of bare soil; good borders	587/A64-1	29.2	72.1	29.5	73.0	-1.2	Bare soil: good borders
I	Rectangular, moderate size field of low vegetation response; good borders	1404/C515-4	28.1	69.5	27.2	67.3	3.3	Alfalfa; weak growth and good borders
J[a]	Large, square fields of bare soil; various border contrasts	1553/C545-1	59.3	146.5	60.1	148.6	-1.4	Bare soil; good borders
K	Small, square fields of low vegetation response; various border contrasts	745/C304-1	14.7	36.4	14.2	35.2	3.4	Light vegetation: difficult borders
L	Large, square field of moderate vegetation response; good border	1136/C308-3	57.2	141.3	58.4	144.4	-2.1	Asparagus; good border
N + M	Large, square fields of bare soil; various border contrasts	877/C342-1 877/C152-1	183.0	452.2	177.5	438.6	3.1	Bare soil; good border
S	Rectangular, moderate size field of low vegetation response; various border contrasts	102/C65-1	31.4	77.5	31.3	77.4	.1	Carrots; good to moderate borders
P + R	Large, square fields of moderate vegetation response; moderate to poor borders	1136/C308-3 A263-1 A282-2	180.8	446.7	178.2	440.4	1.4	Asparagus, total; good borders

[a]Used for image scale calibration; scale = 1:130,000.

separations were made primarily from spatial, rather than spectral, information gleaned from the ERTS-1 data. The separation of crop types (i.e., small grains, truck farm crops, grasses, summer fallow) was accomplished by conventional interpretation as well as by computer classification.

2. Conventional image interpretation was valid for Level I and Level II classification with at least 95-percent classification accuracy. Further breakdown into Level III and Level IV was accomplished, but the accuracy was reduced considerably when an identification of individual species was attempted.

3. For image-interpretation classification techniques, recombined false-color IR renditions were superior to all other additive false-color combinations that were attempted. Image enhancement and image interpretation revealed that colors related more to the density of vegetative cover than to crop type.

4. Boundary detection was found to be the key to field detection and field measurement. Field width, relative contrast, and orientation played an important part in the capability to accurately detect the boundaries of individual fields. In Hill County (where there are many long, narrow fields), fields less than 220 meters wide were not consistently detectable. Likewise, fields that had an east-west orientation (parallel to the scan lines) were much more difficult to detect and measure than those with a north-south orientation. Adjacent fields showing high relative contrast had boundaries that were very difficult to define. This condition was caused by what is known as the blooming phenomenon. Likewise, adjacent fields showing low reflectance were also difficult to define. The smallest easily detected field in the Imperial County study area was 6.5 square hectometers (16 acres). On an enhanced image, the small field appeared white and rectangular, bordered by contrasting fields.

5. Computer classification of the ERTS-1 data was demonstrated to be very successful for many important crops. Clustering maps and ERIPS displays with baseline photography and maps of the subject were the best tools for selecting training and test fields. Crop identification was accomplished to Levels III and IV in five of the test sites. Fields smaller than 12 square hectometers (30 acres) were not easily identifiable. Worth County, Georgia, had many such small fields, and the classification results were very poor. The long, narrow test fields of Hill County produced rather poor classification accuracies (less than 70 percent). The smaller fields of Imperial County had an overall test-performance average of 78.7 percent. Hardin County, which has larger fields with rather poorly defined field boundaries, had a test field accuracy of 79.1 percent. Butte County, California, with fields having a variety of shapes and sizes, had an overall test field accuracy of 60.4 percent. Holt County (with large, well-defined fields) had a test field accuracy of 98 percent.

6. Features on the surface could be located on ERTS-1 imagery by correlation with a UTM grid system. System-corrected (bulk) data in conjunction with base maps were suitable for this procedure. For each study area, the features were located to within approximately 200 meters by overlaying a grid on an ACVP enhanced image. This method is suitable for any test site covered by ERTS-1 for which large-scale base maps are available. Area measurements can be made of fields as small as 6.5 square hectometers (16 acres) under optimum conditions. In Imperial County, measurement error was in the ±3- to 4-percent range for fields having moderate to good border definition. In Hill County, the error was higher because of the long, narrow fields.

7. A general conclusion can be reached that only the large (12 square hectometers or more) well-defined fields should be considered for Level III and IV classification with the existing programs. However, with increased knowledge of the computer programs and of parameters affecting the signatures and with improved

spectral information (regardless of source), it is possible that Level III and IV classification can be obtained with reliable, repeatable accuracy.

3.0 THE ERTS-1 COASTAL/ESTUARINE ANALYSIS

3.1 OBJECTIVES

The specific objectives of this investigation were concerned with determining the performance of the ERTS-1 system in obtaining data capable of being used to map certain coastal features. To produce maps of a feature, one must be able to detect, identify, and locate the feature and to determine its areal extent. The subject coastal features are listed in figure 3-1 in a hierarchy designated Levels I, II, and III with each successive level corresponding to subclasses within a more general class. The hierarchy shown is not intended to be exhaustive but to show the major classes of features selected for this investigation.

3.1.1 Classification Accuracy

The first specific objective was to determine the accuracy with which specific features could be classified using ERTS-1 data. Refer to tables 3-I and 3-II.

3.1.2 Feature Detection and Location

The second specific objective was to determine the accuracy to which processed ERTS-1 data could be used to locate the position of detectable study features.

3.1.3 Spectral Uniqueness and Temporal Analysis

The third specific objective was to determine the spectral uniqueness of detectable features in the ERTS-1 spectral bands as a function of time. This objective was concerned with the identity of coastal features from the spectral and temporal properties of the feature as seen by ERTS-1 systems.

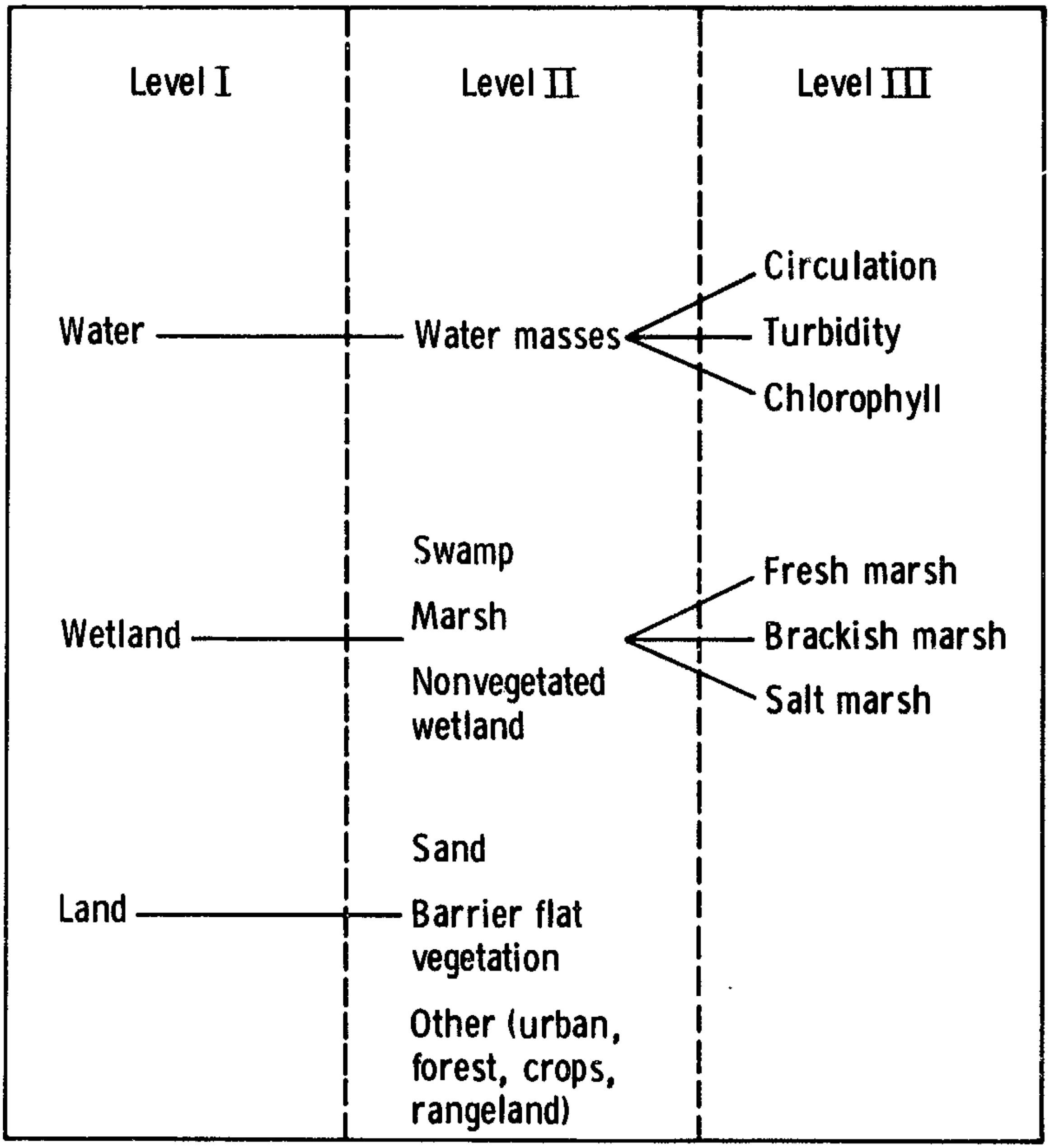


Figure 3-1.- Feature hierarchy for coastal investigation.

TABLE 3-I.- ACCURACY OF AREAL MEASUREMENT OF SALT MARSHES

Marsh	Area, hm^2			Accuracy, percent	
	Aircraft data	ISOCLS	NSCLAS	ISOCLS	NSCLAS
1	351	350	353	99.8	99.4
2	77.4	79.6	76.6	97.0	99.0
3	60.5	60.9	67.1	99.2	89.0

TABLE 3-II.- ACCURACY OF CLASSIFICATION OF BARRIER FLAT VEGETATED AREAS FOR GALVESTON ISLAND

Classification date, 1972	Accuracy, percent
August 29	100.0
August 29	97.3
October 3	93.1
October 3	91.3
November 26	100.0
November 26	86.6

3.1.4 Areal Measurement

The fourth specific objective was to determine the accuracy to which processed ERTS-1 data could be used to measure the area of detected and identified features.

3.2 ANALYTICAL APPROACH

The investigators analyzed ERTS-1 data acquired in the area of Galveston Bay, Texas, including the surrounding wetlands, barrier islands, and coastal mainland areas. The basis for the accuracy determinations of coastal feature mapping was high-altitude photography from the NASA WB-57F and NC-130B aircraft as supported by field surveys.

The selected coastal study area was viewed by ERTS-1 for 2 consecutive days at approximately 10:22 local standard time every 18 days, beginning August 28, 1972. The ERTS-1 data used for computer-aided and conventional analysis consisted of that acquired August 28 and 29, October 3, and November 26, 1972, over the Texas coastal study site. In addition, ERTS-1 data acquired January 19 and February 24, 1973, were used for conventional analysis. Since clouds block visible and near-infrared radiation, the team analyzed only the data acquired on predominantly cloud-free days. Of the ERTS-1 passes over the Texas coastal study site, 29 percent were on relatively cloudfree days.

In addition to conventional image interpretation of aircraft and ERTS-1 images, data received from GSFC on computer-compatible tapes were reformatted and subjected to several automatic pattern recognition techniques and postprocessing procedures. The automatic pattern recognition techniques included both supervised (ERIP and LARSYS) and nonsupervised (ISOCLS and NSCLAS) classification. After analysis and classification, the display options included cathode-ray tube, computer printout, and film transparencies. In subsequent postprocessing, an attempt was made to convert ERTS grayscale radiance to reflectance by using the ROTAR atmospheric correction algorithm.

3.3 ANALYSIS RESULTS

3.3.1 Water Features

Water areas were discriminated easily in the ERTS-1 data through the use of a nonsupervised classification algorithm that defined natural spectral information units in the data using all four channels. From an analysis of ERTS-1 data, surface turbidity was assessed to be the property of water most strongly indicated by water-reflectance differences. The maximum solid matter (particulate or sediment) content in the water of the coastal study area ranged between 20 and 120 p/m. Ground-truth radiance measurements using an Exotech radiometer indicated a strong linear relationship between turbidity and radiance levels in the 500- to 600- and 600- to 700-nanometer spectral bands, whereas the 700- to 800- and 800- to 1100-nanometer bands suggest a curvilinear relationship.

An example of the turbidity patterns in the ERTS-1 data is given in figure 3-2 in which land is red, wetland is yellow, and water turbidity zones are displayed by a sequence of colors from dark blue to medium blue, light blue, light green, and dark green to light brown. The least turbid water is dark blue, and the most turbid water is light brown. This display was processed on an EOD DAS using the results of an unsupervised classification analysis of the digital ERTS-1 data acquired November 26, 1972, over Galveston Island, Texas.

One set of imagery acquired February 24, 1973, shows a phytoplankton bloom (reddish-brown algae, *Exvella balteca*) in Galveston Bay. Figure 3-3 is MSS band 4, and figure 3-4 is MSS band 6. Note the bright area in the western half of Galveston

Figure 3-2.- Computer classification map of area surrounding Galveston Island, Texas, showing turbidity zones (ERTS-1 data acquired November 26, 1972) (NASA S-73-28182).

Bay in figure 3-4. This area is correspondingly dark in figure 3-3. The Texas Parks and Wildlife Service determined that the bright area was a nontoxic bloom of the reddish-brown algae that began spreading from Seabrook, Texas, in late January to the imaged occurrence on February 24, 1973. Also, a suspected area of oil pollution in Galveston Bay was detected by the nonsupervised classification algorithm in the ERTS-1 data obtained August 29, 1972. This detection was manifested by the misclassification of a known water area as salt marsh.

3.3.2 Wetland and Dryland Features

A number of wetland and dryland features of applications interest have been detected, identified, and mapped in the ERTS-1 data through the use of a nonsupervised classification algorithm. Figure 3-5 is a display of the classification map of the Galveston data. A comparison of figures 3-5 and 3-6 is invited to determine the excellent agreement between the processed ERTS-1 data and the aircraft imagery acquired November 7, 1972 (fig. 3-6).

3.3.3 Spectral Uniqueness

The analysis of the ERTS-1 data also demonstrated that coastal features exhibit unique and repeatable reflectance signatures. From a plot of the ERTS-1 reflectances of all coastal features (all 3 months and all three sites) in MSS bands 5 and 7 (fig. 3-7), it can be seen that the signatures are unique, even with time. The partitions in figure 3-7 are valid only for the data in the figure and may change when more data are added. The closeness of signatures in some cases indicates problem areas for spectral classification. The corresponding plot of grayscale signatures (fig. 3-8) shows that grayscale signatures are not unique except for water and most sand areas. The primary correction on the data was determined to be that of Sun angle.

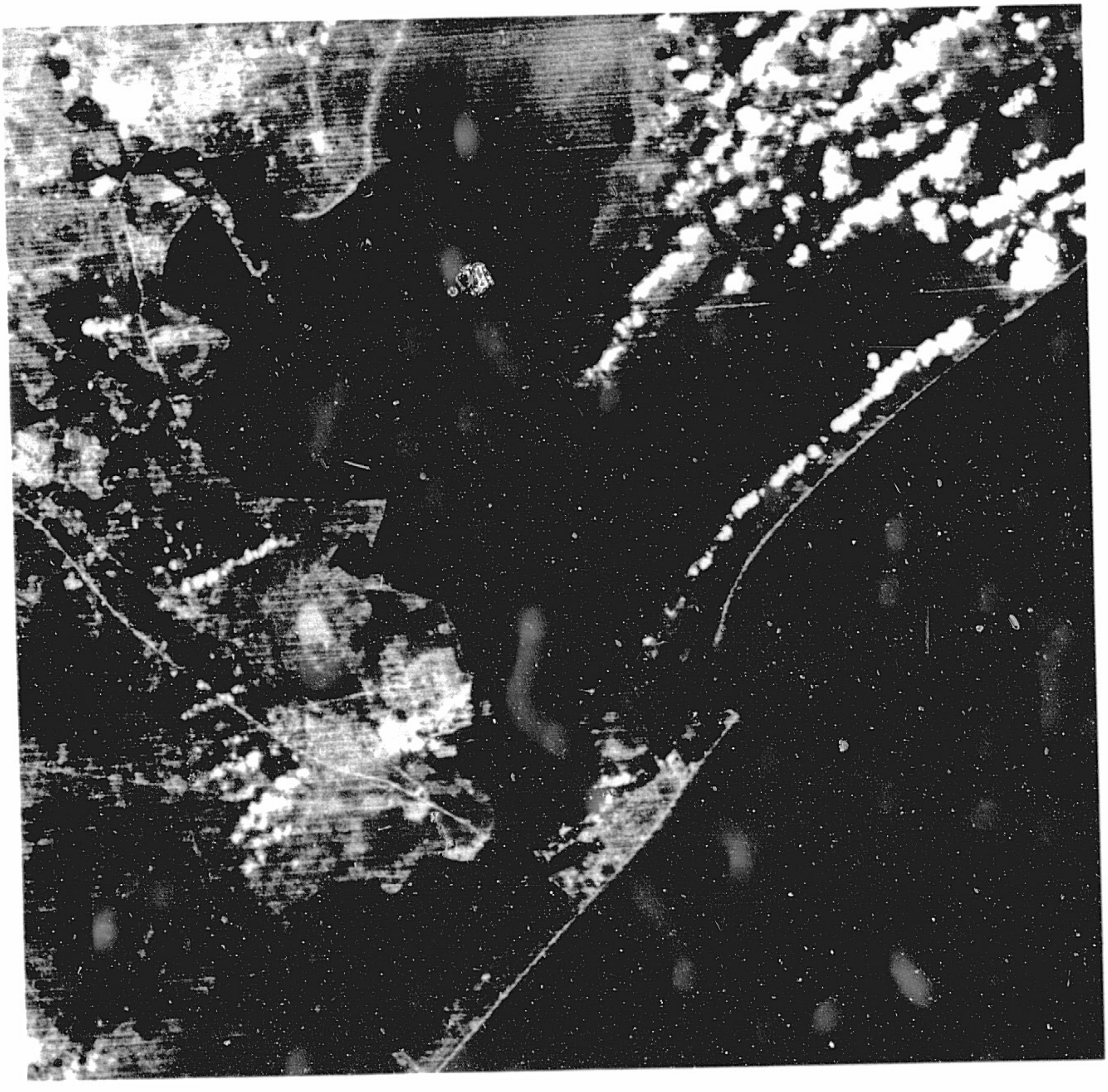


Figure 3-3.- Plankton bloom, February 24, 1973, MSS band 4.

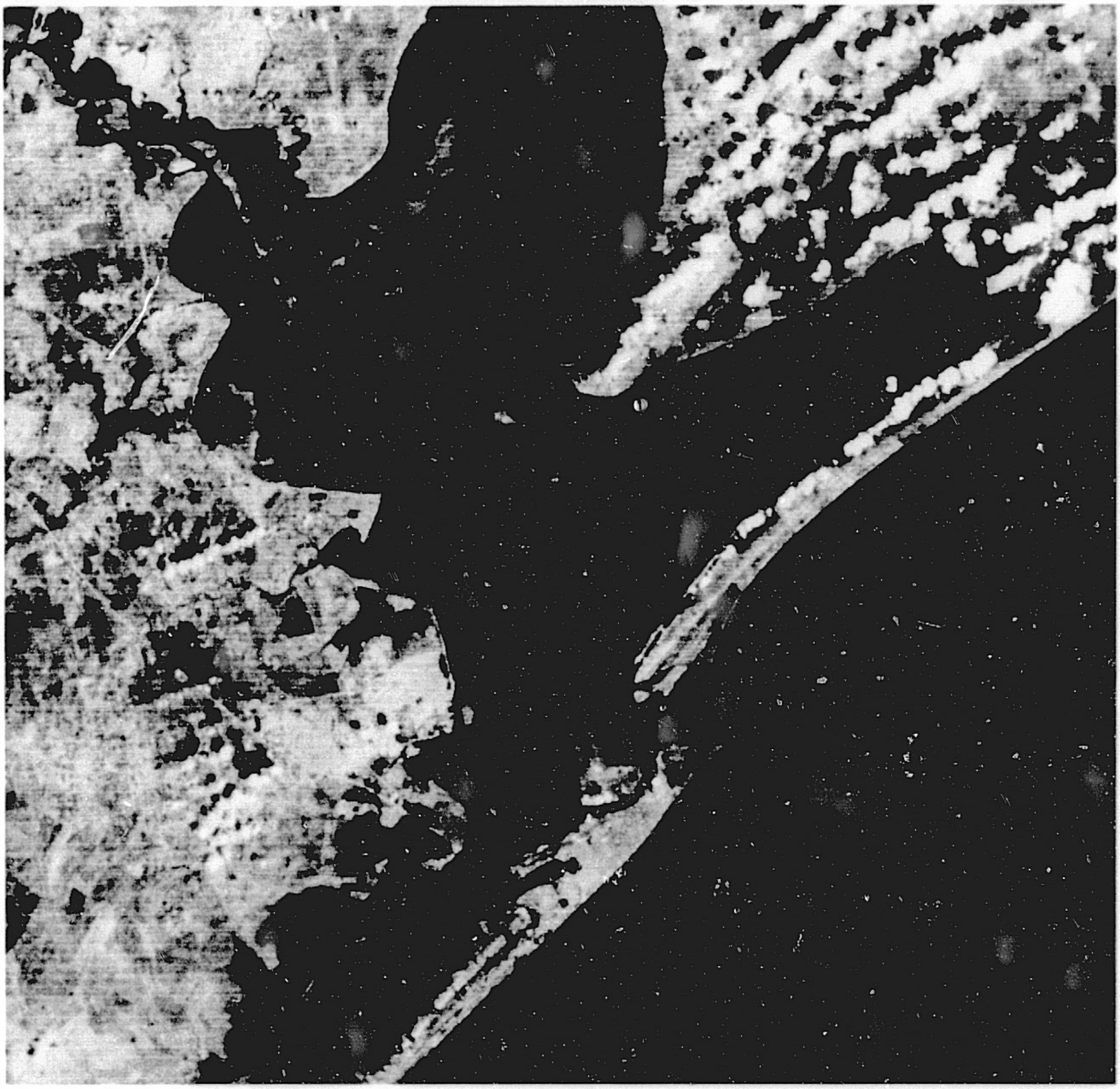


Figure 3-4.- Plankton bloom, February 24, 1973, MSS band 6.

Figure 3-5.- Classification map of areas surrounding Galveston Island, Texas, showing wetland and dryland features. Nonsupervised classification of ERTS-1 data acquired November 6, 1972 (NASA S-73-28154).

Figure 3-6.- Aircraft photograph of area surrounding Galveston Island, Texas. Imagery acquired November 7, 1972, from NASA WB-57F aircraft at an altitude of 18 288 meters (60 000 feet); RC-8 metric camera, 2443 estar base Aerochrome infrared film (NASA S-73-28101).

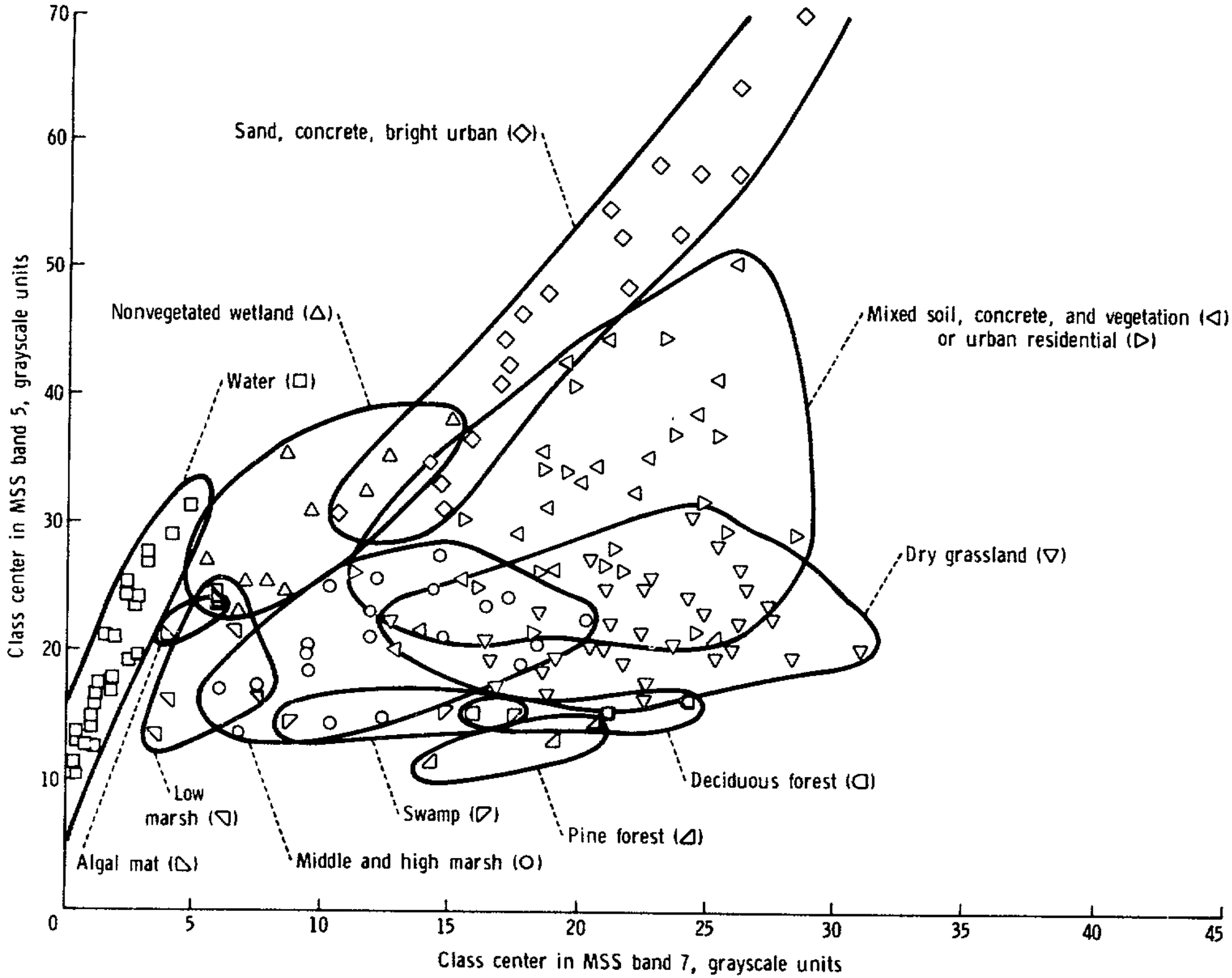


Figure 3-7.- The ERTS-1 reflectance signatures of coastal features in MSS bands 5 and 7 before corrections were made. (Data taken from all cluster analyses.)

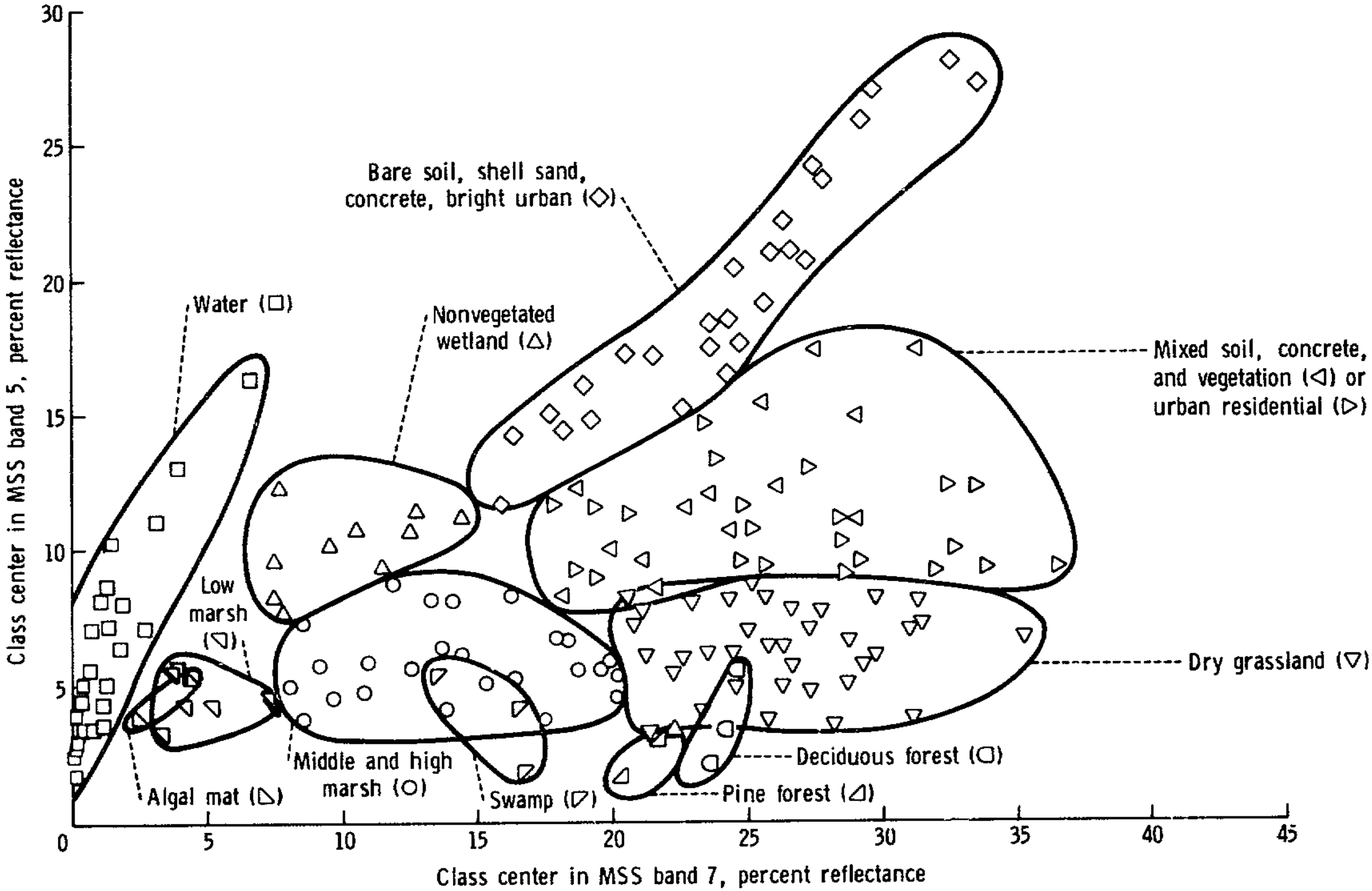


Figure 3-8.- The ERTS-1 reflectance signatures of coastal features in MSS bands 5 and 7 after corrections were made. (Data taken from all cluster analyses.)

3.3.4 Areal Measurement

As a result of accurate discrimination of water bodies, an areal measurement technique was developed to estimate the area of lakes and ponds. To determine accuracy, areal measurements computed from the ERTS-1 data were compared with carefully measured areas computed from aircraft photography. An average error (i.e., the difference between area determined from ERTS-1 and aircraft data) in water body areal measurement was 2 square hectometers (5 acres) and uncorrelated with the size of the water body in the study area. The size of the lakes ranged between 2 and 243 square hectometers (5 and 600 acres) and a variety of slopes.

3.4 CONCLUSIONS

The following conclusions can be stated.

1. It was possible to use ERTS-1 data to map swamp features. Swamp areas were mapped to accuracies ranging from 33 to 96 percent. The lower accuracies were observed in swamp areas that had a significant forest cover. Such areas were classified as forest rather than swamp. This capability for wetland surveys could lead to better flyway management for waterfowl and a better understanding of the ecology of wetland systems.

2. Computer-aided processing products were superior to those of conventional processing. The coastal features were surveyed by ERTS-1 in the following order of accuracy: water, salt marsh, grass vegetation, forest vegetation, marsh, nonvegetated wetland, sand, and swamp. The ERTS-1 data are recommended for use as a basis for the specific application of detecting and mapping water bodies and coastal wetlands, for verifying circulation models for bays, and for measuring turbidity levels in estuarine water.

3. Ground surveys of turbidity in Galveston Bay strongly suggest that ERTS-1 data can be used to differentiate densities of undifferentiated particulate matter. In particular, channel 5 (wavelength 600 to 700 nanometers) of the ERTS-1 photometer indicated a highly significant linear response to turbidity levels ranging between 20 and 120 p/m. Both supervised and nonsupervised classifications of ERTS-1 MSS data demonstrate relative differences in a radiance as a function of water turbidity in Trinity Bay.

4. The ERTS-1 data could be used as a basis for surveying wetland areas to assist in management of tidelands. The areal extent of salt marsh areas was mapped to accuracies ranging from 89 to 99 percent for three sets of ERTS-1 data (table 3-I).

5. Long-term mapping of barrier island features (beach, urban, barrier flat vegetation zones, and bayside marshes) can be used to establish trends in barrier island evolution. Barrier island vegetation areas were mapped to accuracies ranging from 87 to 100 percent for three sets of ERTS-1 data (table 3-II).

6. Water, low marsh, medium and high marsh, nonvegetated wetlands, pine forest, deciduous forest, grassland, sand/concrete/industrial-urban, and mixed vegetation and nonvegetated areas exhibited unique reflectance signatures for ERTS-1 data taken from August to November 1972, when atmospheric, Sun-angle, and instrument calibration corrections were made.

7. Peak reflectance of water shifted from the green band to the red band for the highly turbid waters (particulate range of 20 to 120 p/m).

8. Turbidity changes affected the IR reflectance as well as the visible reflectance of water for highly turbid water (>50 p/m).

9. A phytoplankton bloom in Galveston Bay was discriminated best in ERTS-1 IR MSS band 6.

10. Water coverage changes were detected from two sets of ERTS-1 data that were overlaid by digital processing means. Changes were related to flooding, tidal changes, and rice farming practices.

4.0 THE ERTS-1 FOREST ANALYSIS

4.1 OBJECTIVES

The forest investigation was performed (1) to determine the minimum size of forest features that could be detected in ERTS-1 data under varying conditions, (2) to determine the suitability of the data for making forest classification maps by conventional and computer-aided methods, (3) to test the extension of feature classifications from one area to another, and (4) to determine the accuracies of the classification results.

4.2 ANALYTICAL APPROACH

The Sam Houston National Forest in Texas (fig. 4-1) was selected as the test site because of the existing knowledge of the area and its accessibility to JSC for making field checks. The site comprises a primary study area surrounded by a secondary study area. The primary study area was used as a training area to develop methodology and techniques under closely controlled conditions. The secondary study area was used to verify those methods under conditions approximating an operational situation.

Ideally, ground truth collected during the same time period as the acquisition of the ERTS data is necessary for a detailed evaluation of the data. The ground-truth map of the primary area (fig. 4-2) was prepared from available aerial photography collected during April, October, and November of 1972. The map was field checked on the ground and by helicopter. The ground-truth map of the secondary area was compiled after the area had been classified to ensure independent classifications.

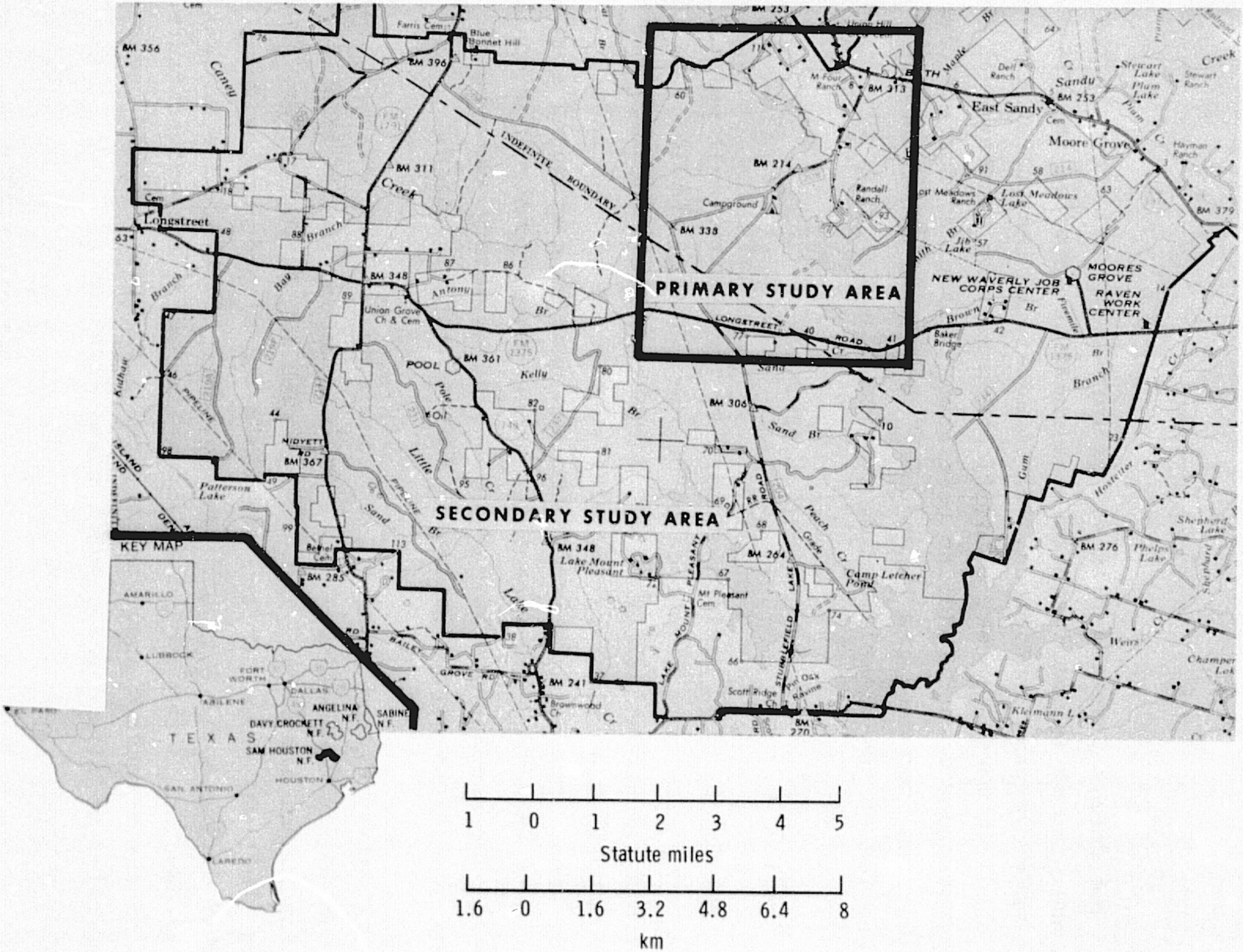


Figure 4-1.- The ERTS-1 forest test site locations (NASA S-73-18483).

- Pine
- Hardwood, cutover
- Streams and lakes
- Right-of-way, paved road
- Pine, cutover
- Impoundment
- Bare soil and sand
- Pine, regenerated
- Cutover, bulldozed
- Rural settlement
- Right-of-way, pipeline, or dirt road
- Hardwood
- Grass
- Pine, site prepared/vegetated

Figure 4-2.- Ground-truth classification map of the primary area (NASA S-73-28187).

The hierarchy of forest land features established for this investigation (table 4-I) was based on expected ERTS-1 detection capabilities and on the needs of forest land management. The first three levels were established before ERTS-1 imagery had been received. On receipt of the data, it was apparent that the third level could be achieved and that a fourth level was a distinct possibility. Therefore, several Level IV classes were added to the hierarchy. This hierarchy of study features diverges from the USGS hierarchy (table 1-I) at Level II. The USGS scheme was established to fulfill the requirements of a general land use classification effort over the full gamut of possible landscapes. The scheme established for this investigation was restricted both to the requirements of forest management and to conditions that exist within the test site.

The August 29, 1972, set of ERTS-1 MSS data was analyzed in this investigation. The data format evaluated included black-and-white film images from each of the four MSS bands, JSC color composites derived from digital tapes, GSFC color composites, and the digital data.

The evaluation of ERTS-1 detection capabilities was performed with conventional image-interpretation techniques. The criteria established for the minimum size of features in the study area were as follows: 8 square hectometers (20 acres) for timber types, 15 meters (50 feet) for width of streams and rights-of-way, and 2 square hectometers (5 acres) for lakes and rural settlements. Thirty test targets (features) with known dimensions were established in the test site. Then, each of the four bands of black-and-white imagery, the JSC color composite, and the GSFC color composite were interpreted. The six image sources then were ranked, based on the number and size of test features detected (tables 4-II and 4-III).

TABLE 4-I.- HIERARCHY DEVELOPED FOR THE FOREST INVESTIGATION

Level I	Level II	Level III	Level IV
Forest	Standing timber	Pine, established Hardwood, established	Pine, established Hardwood, established
	Cutover timber	Pine, cutover Pine, site prepared Pine, regenerated Hardwood, cutover	Pine, cutover Pine, site prepared Pine, site prepared/ vegetation Pine, regenerated Hardwood, cutover
Nonforest	Water	Streams and lakes Impoundments	Streams and lakes Impoundments
	Other land use classes	Brush Cultivated Grass Rights-of-way Rural settlement	Weeds Brush Cultivated Rights-of-way, dirt roads, or utility lines Grass Rights-of-way, paved roads Cut and bulldozed Bare soil Rural settlement

TABLE 4-II.- NUMBER OF TARGETS DETECTED

Media	Targets detected	Percent detected
JSC color composite	21 of 30	70
Band 5	20 of 30	67
Band 6	16 of 30	53
GSFC color composite	15 of 30	50
Band 7	11 of 30	36
Band 4	4 of 30	13

Classification of forest features involved both conventional image-interpretation and computer classification techniques. A black-and-white image of band 7, JSC and GSFC color composites, and multiband composites derived from the ACVP and the MCFV were classified using conventional interpretation techniques. Computer classifications included an unsupervised clustering algorithm (ISOCLS) and a supervised classification procedure using a maximum-likelihood method (LARSYS). The basic classification procedure involved establishing feature signatures in the primary study area, where 100-percent ground truth was used, then extending these signatures to the secondary area, where ground truth was not compiled until the classification was completed.

Accuracy of each classification was determined by comparing each classification map with ground truth, using two procedures. In the first procedure, each classification map was overlaid with a 0.64-centimeter (0.25 inch) grid that was also registered to the ground-truth map, and grid points of agreement between the two maps were counted. The total agreement point (correct classification points) divided by all points in the grid resulted in the correct classification percentage for the classification.

TABLE 4-III.- MINIMUM SIZE OF FOREST FEATURES DETECTED

Feature	Smallest size detected, hm^2	Band or composite used	Contrast with background
Pine, established	4	5	Good
		7	Fair
		JSC	Fair
Pine, regenerated	8	5	Poor
		JSC	Fair
Pine, site prepared/vegetated	8	5	Fair
Pine, cutover	24	5	Good
		JSC	Fair
Hardwood, established	12	JSC	Fair
Brush	4	5	Fair
		7	Poor
Grass	6	JSC	Good
Cultivated	4	5	Good
		JSC	Fair
Streams and lakes	2	5	Poor
		7	Good
		JSC	Poor
Impoundments	1	7	Fair
		JSC	Poor
Rights-of-way	(a)	5	Fair
		JSC	Fair
Rural settlement	40	5	Poor

[a]28 meters wide.

The second measure of accuracy for each classification map entailed computing the area of each class in the classification map and in the ground-truth map. The differences between the area totals enabled computation of an accuracy percentage.

4.3 RESULTS

The detection results are summarized as follows. Band 4, green (500 to 600 nanometers), was the poorest of the four bands. Band 5, red (600 to 700 nanometers), was the best for most features but was poor for detecting hardwoods and water bodies. A pine stand as small as 4 square hectometers (10 acres) was detectable when there was a good contrast with the surroundings. In band 6, near infrared (700 to 800 nanometers), hardwoods and water bodies were discernible, but pine stands diminished in detectability because they faded into the background and mingled with all classes except hardwood and water. Band 7, near infrared (800 to 1100 nanometers), had detection characteristics similar to band 6, with hardwoods and water bodies displayed even more prominently and other features displayed less prominently. The smallest features distinguished in band 7 were 1-square-hectometer (2.5 acre) ponds. These ponds were not distinguishable in the other bands or color composites. The composite image made at JSC produced the best detection results overall, and the GSFC composite rated between bands 6 and 7 (tables 4-II and 4-III).

4.3.1 Conventional Image Interpretation

Only seven classes could be distinguished in band 7. The classification accuracy of the seven classes was 58 percent (table 4-IV). Ten classes of forest features were distinguished using the ACVP. The resulting map (fig. 4-3) was analyzed, and the classification accuracy by the point-count method was 55 percent and by the area-computation method was 64 percent.

TABLE 4-IV.- SUMMARY OF CLASSIFICATION ACCURACIES

Technique	Number of classes	Classification accuracy,[a] percent	Accuracy by grid-point count, percent	Accuracy by area computation, percent
Primary area				
Single band	7	50	66	58
Optical multiband	10	72	55	64
MCFV	7	50	56	82
JSC color composite	10	72	--	67
Clustering	14	100	66	81
Maximum likelihood	12	86	67	73
Secondary area				
Single band	11	79	63	83
Optical multiband	10	72	63	84
MCFV	7	50	56	60
JSC color composite	10	72	--	78
Clustering	14	100	60	75

[a]Classification accuracies equal number of features identified divided by number of possible features (14).

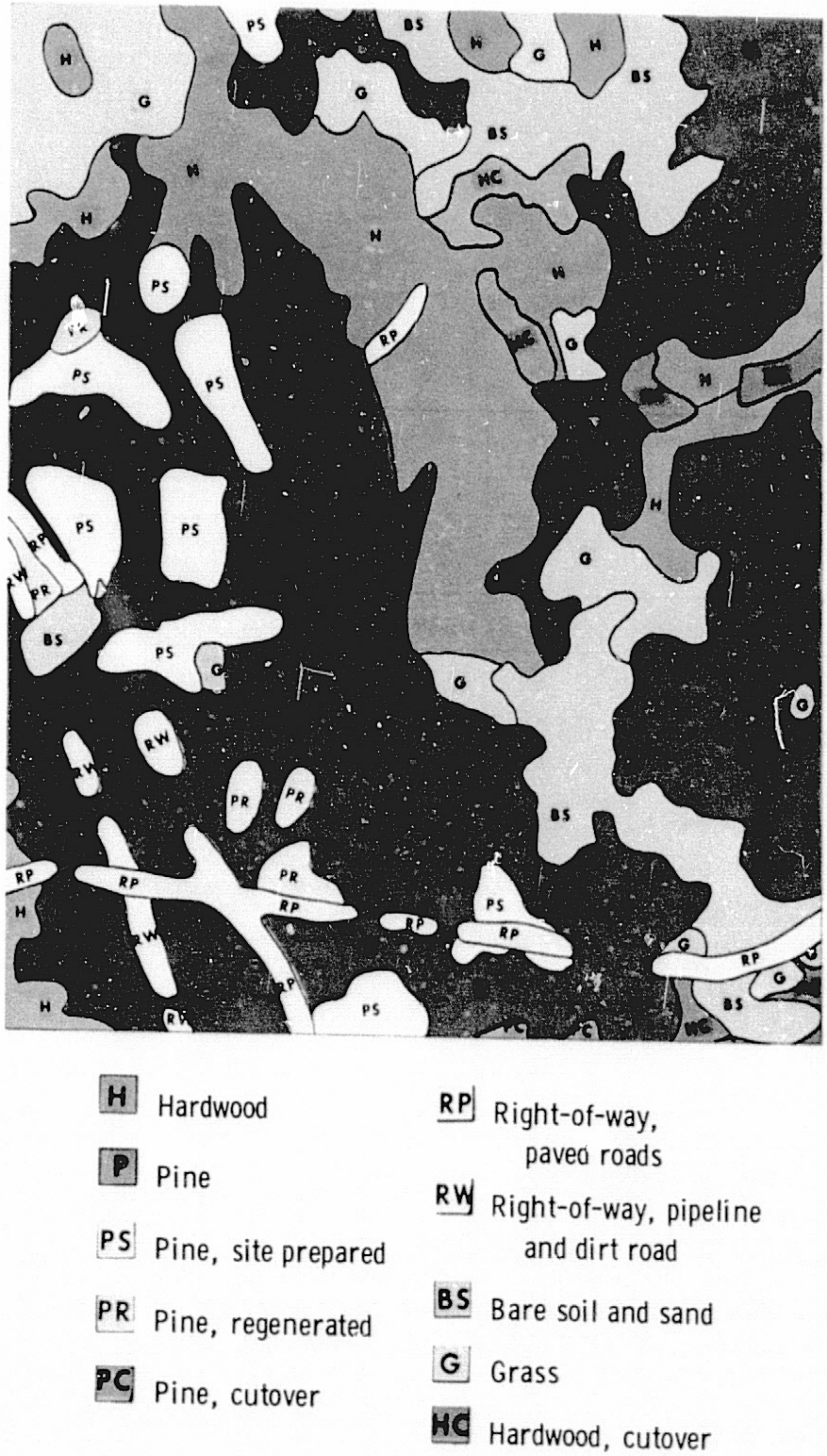


Figure 4-3.- Optical multiband classification map of the primary area (NASA S-73-28195).

Seven forest features (fig. 4-4) were classified using the MCFV. Accuracy by the point-count method was 56 percent and by the area-computation method was 82 percent.

Ten classes of features were distinguished by using the JSC color composite. These classes were annotated directly onto the DAS film recording (fig. 4-5), for which distortions had not been corrected. A skew distortion was introduced by the lag in each scan line, and a scale distortion was caused by different horizontal and vertical scales. Since no geometric correction was made, only the area method of accuracy computation could be used. Accuracy was 67 percent.

4.3.2 Computer Classification

Using nonsupervised techniques, 14 classes were recognized. The resulting printout map shown in figure 4-6 was converted to a cartographic format (fig. 4-7) at the scale of the ground-truth map. Accuracy by the point-count method was 66 percent. By the area-computation method, accuracy was 81 percent. The most prevalent error was the classification of regenerated pine as cutover hardwood. This error is understandable because the regeneration areas are cutover and the ground cover is a mixture of small pines and dense hardwood.

Supervised classification techniques were also employed. First, a computer printout was produced by the LARSYS method. The printout was then changed to a cartographic format to match the ground-truth map. Accuracy by the point-count method was 67 percent. By the area-computation method, accuracy was 73 percent. A tape of the LARSYS classification was then processed on the DAS and recorded on film. This product is shown without geometric corrections in figure 4-8.

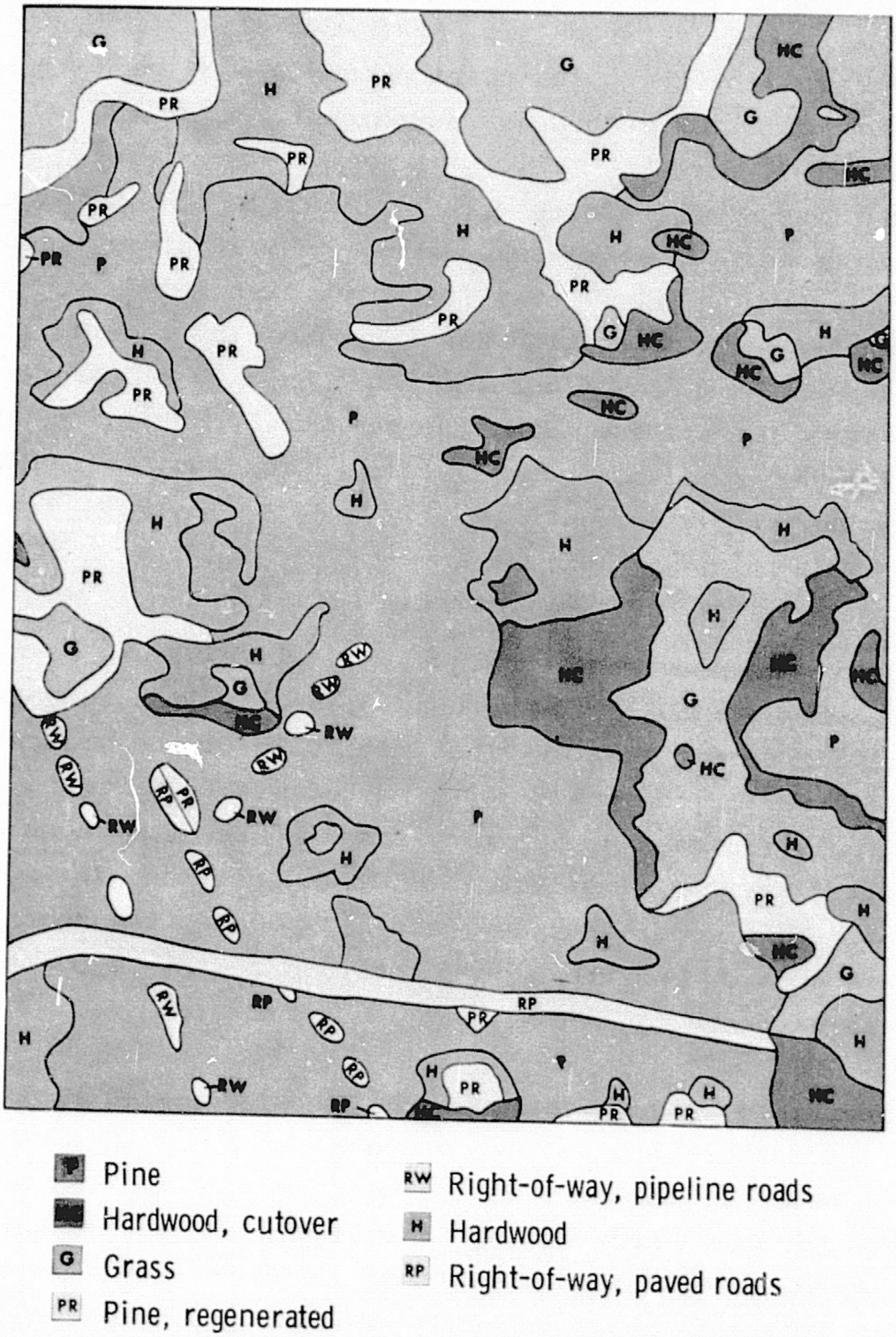
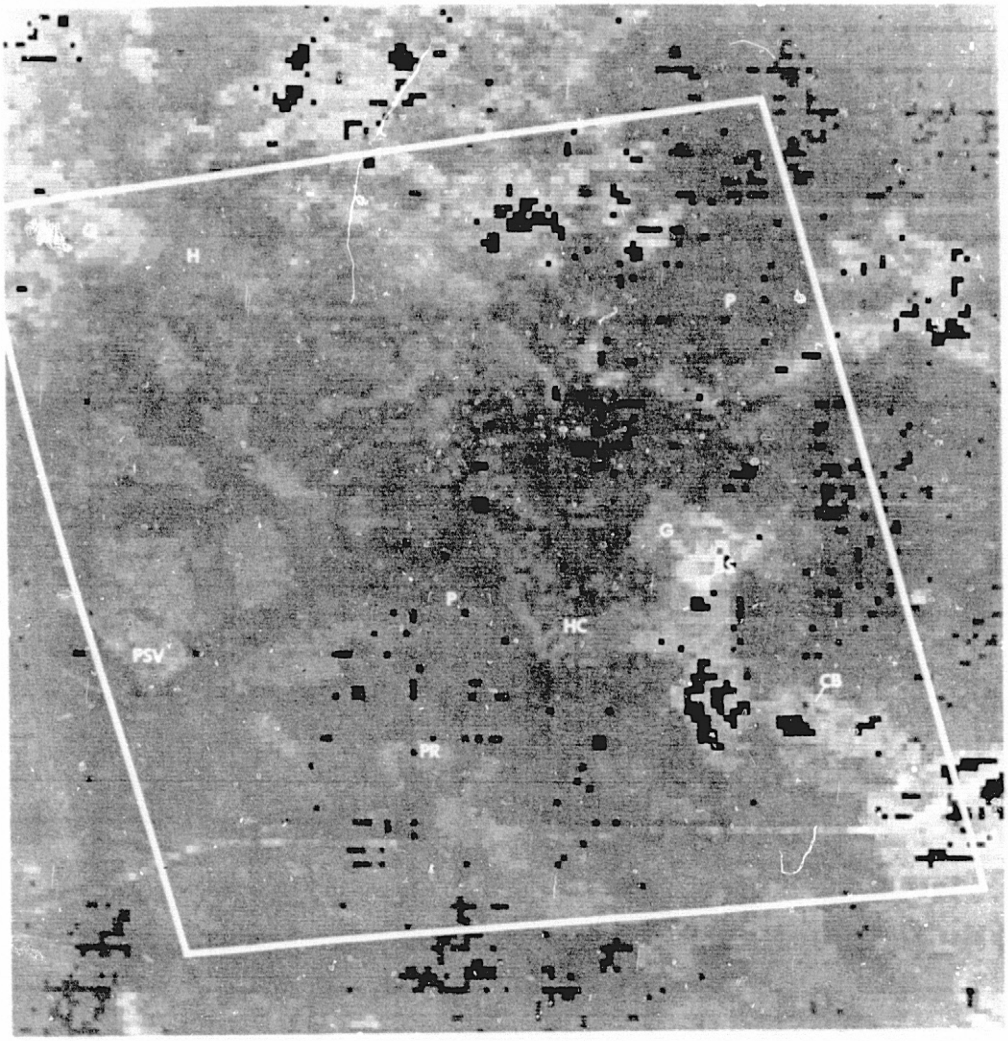


Figure 4-4.- The MCFV multiband classification map of the primary rea (NASA S-73-28188).



▬	P	Pine, established
▭	PR	Pine, regenerated
▭	PS	Pine, site prepared
▭	PSV	Pine, site prepared/vegetated
▭	H	Hardwood
▬	HC	Hardwood, cutover
▭	G	Grass
■	I	Impoundments
▭	BS	Bare soil
▭	CB	Cutover and bulldozed

Figure 4-5.- The DAS multiband classification map of the primary area (NASA S-73-1124).

PR	Pine, regenerated	R	Rural settlement
PC	Pine, cutover	PSV	Pine, site prepared/vegetated
P	Pine	CB	Cutover and bulldozed
H	Hardwood	RP	Right-of-way, paved road
HC	Hardwood, cutover	RW	Right-of-way, pipeline, powerline, or dirt road
I	Impoundment	U	Unidentified
G	Grass	BS	Bare soil and sand

Figure 4-6.- Computer printout of cluster classification of the primary area (NASA S-73-28214).

Approximate scale 1:63,360

0 1 2 3

Statute miles

0 1 2 3

km

- Pine
- Grass
- Hardwood
- Cropland
- Rural settlement
- Impoundment
- Right-of-way, paved roads
- Unidentified
- Hardwood, cutover
- Pine, regenerated
- Pine, site prepared/vegetation
- Bare soil and sand
- Cutover and bulldozed
- Right-of-way, pipeline and dirt roads
- Pine, cutover

Figure 4-7.- Cluster classification map of the primary area (NASA S-73-28189).

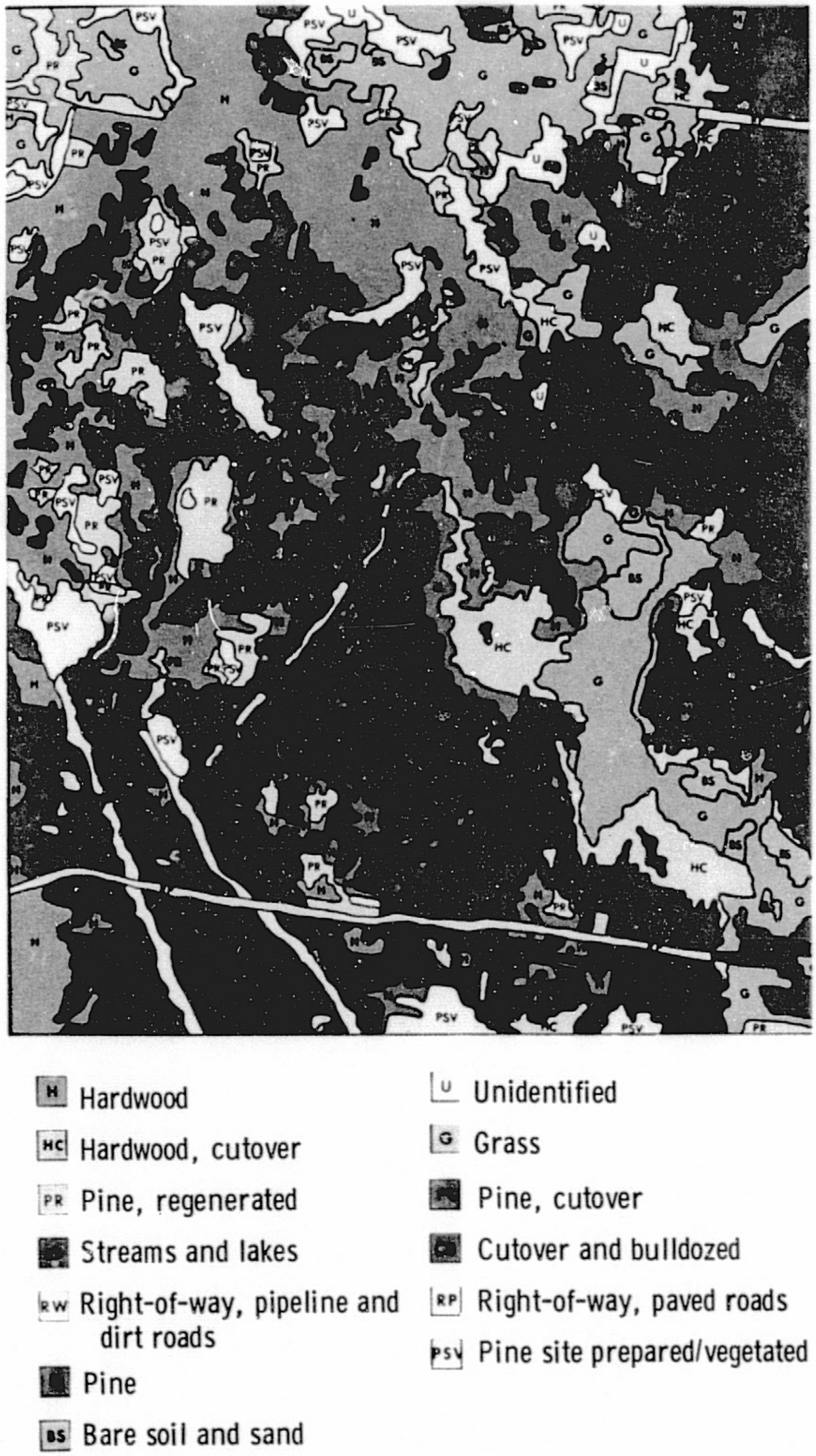


Figure 4-8.- The LARSYS classification map of the primary area (NASA S-73-28190).

The techniques previously described (except for the LARSYS classification) were applied to the secondary area using primary-area, spectral-signature data. The accuracies achieved were comparable to those in the primary area (table 4-IV). The accuracy results in table 4-IV tend to support the feasibility and validity of extending signatures under the conditions of this investigation.

Table 4-IV is a summary of the classification accuracies achieved in this investigation. Comparison of the results of the various classification procedures is difficult because not all parameters could be held constant. Clustering and maximum likelihood ranked higher than the conventional interpretation techniques in terms of the accuracy measures performed.

The forest under investigation did not lend itself well to precise classification. Timber classes occurred in mixtures of species, age, vigor, and size, blending gradually from one to another. Even under these conditions, the area-computation accuracies achieved were quite high. Table 4-V contains the class (feature) accuracies achieved in the primary study area. Both in terms of the number of features classified and individual feature accuracies, the computer-aided classification techniques were better than the conventional image-interpretation techniques.

Other items of interest to foresters, but incidental to the investigation, were found in the ERTS-1 data. For example, a light ground fire, a prescribed burn of approximately 40 square hectometers (100 acres) to clear brush, was discovered. A JSC color composite of this coverage (fig. 4-9) shows the burn as a rusty brown area. The precision with which the effects of this light fire were registered indicates that ERTS-1 data could be used in fire-damage assessment to map the perimeter of large burns.

TABLE 4-V.- ACCURACY OF FOREST FEATURE CLASSIFICATIONS BY THE AREA-COMPUTATION METHOD IN THE PRIMARY STUDY AREA

Feature	Accuracy, percent						
	Single band	Optical multiband	MCFV multiband	JSC color composite	Clustering (small area)	Clustering (large area)	Maximum likelihood
Pine, established	93	99	95	87	98	85	92
Pine, regenerated	76	20	33	0	8	57	65
Pine, cutover	0	41	0	[a]21	5	[a]33	73
Pine, site prepared/ vegetation	27	0	0	0	47	45	0
Hardwood	0	78	73	100	78	88	45
Hardwood, cutover	0	32	97	(a)	52	(a)	62
Grass	51	57	93	40	93	82	80
Bare soil	0	0	0	86	86	0	0
Cut and bulldozed	0	0	0	66	0	0	93
Rural settlement	0	0	0	0	50	0	0
Impoundments	20	0	0	0	0	0	0
Lakes and streams	0	0	0	0	0	33	66
Rights-of-way, utility	0	41	0	60	85	0	23
Rights-of-way, paved	0	0	50	0	69	0	71

[a]Pine, cutover, and hardwood, cutover, were combined into a single class.

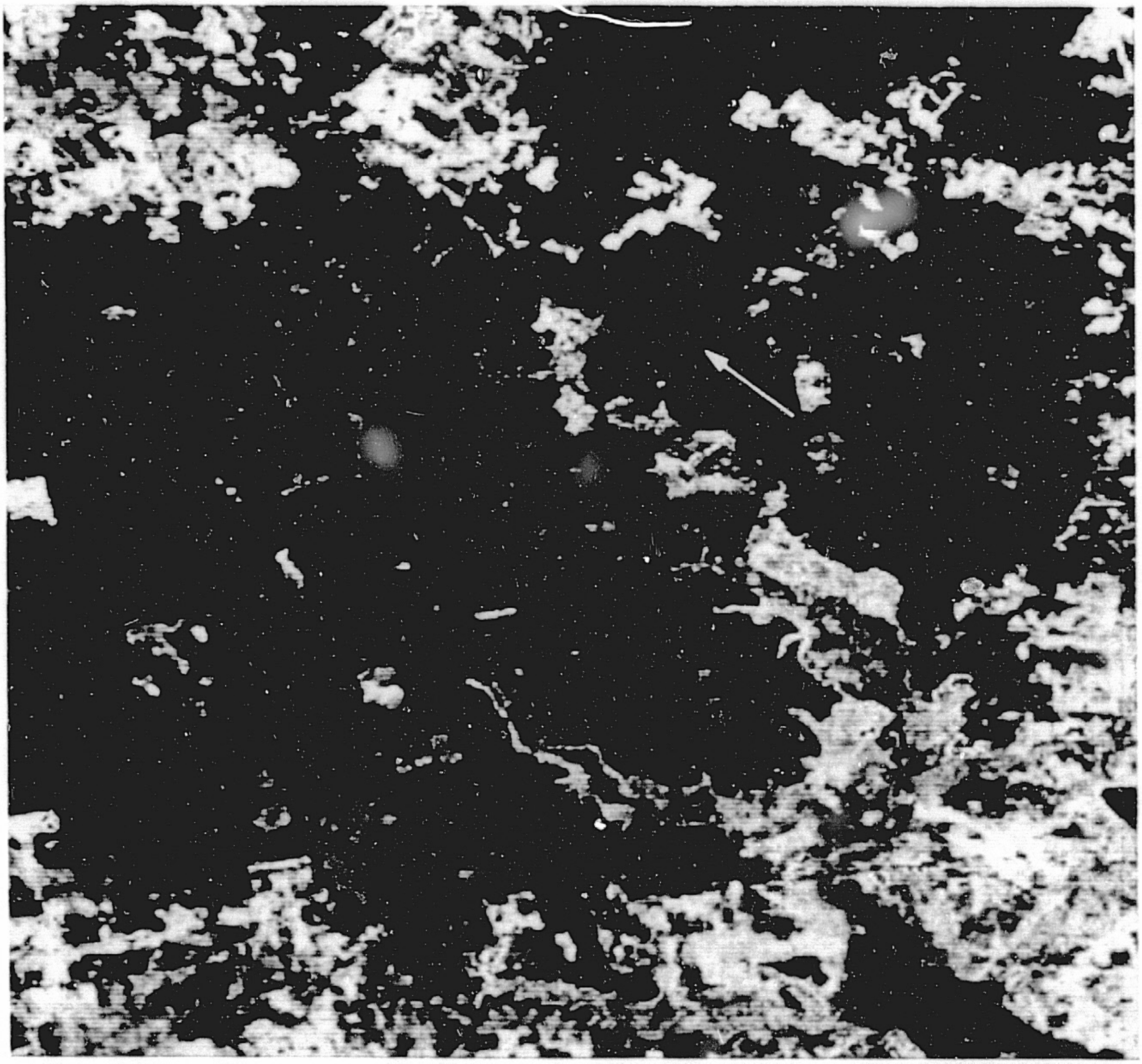


Figure 4-9.- The DAS enhancement of light ground fire in the Sam Houston National Forest (NASA S-73-25467).

During the investigation, a pine bark beetle infestation occurred within the test area. Damage was detected indirectly in one case; pines covering an area of approximately 2 square hectometers were killed in a stand classified as hardwood, although nearly 50 percent of the stand was pine. The LARSYS program classified this portion of the stand as cutover hardwood. Because LARSYS is a supervised program, a beetle-infested training field would have to be included to enable investigation of such a classification.

4.4 CONCLUSIONS

The following conclusions can be stated.

1. The ERTS-1 data can probably best be used in forestry applications if the data are used for extensive surveys in which broad, generalized classes are needed, rather than for intensive surveys in which detailed stand conditions must be portrayed.

2. The clustering and maximum-likelihood methods of classification are both efficient, and differences in accuracies achieved are not significant enough to rank one above the other. However, computer methods as a group can probably be ranked as superior to conventional methods for forest classification.

3. In addition to the possibilities of producing timber inventory maps, the ERTS-1 data have the advantage of providing sequential coverage and thus providing an increased capability to classify certain categories such as evergreen, deciduous, and mixed.

5.0 THE ERTS-1 RANGE ANALYSIS

5.1 OBJECTIVES

The primary objective of the ERTS-1 Range Analysis Team investigation was to determine the usefulness of ERTS-1 MSS data in classifying types of vegetation for mapping range and related grazing lands. Assessment of the capability to use ERTS-1 MSS data to detect, identify, locate, and determine the area of rangeland vegetal types was therefore required.

In USGS Circular 671, Anderson and others define the land use category "rangeland" as being composed essentially of grass and shrub vegetation types. Current management practices define rangeland more broadly, as consisting of both nonwoodland and woodland vegetation types. In this study, the latter definition was adopted and many species of trees, brush, grasses, shrubs, and forbs associated with the two broad categories were considered. The rangeland classification hierarchy adopted by the ERTS-1 Range Analysis Team to meet the primary investigation objective is shown in table 5-I.

Specific objectives in the classification of rangeland subgroups reflected the broad definitions of rangeland described previously and included the following.

1. To classify the Level II rangeland classes of woodland and nonwoodland, as opposed to nonrangeland such as cropland, water, and urban areas

2. To classify Level III classes

3. To consider an assessment of

   a. The accuracy of vegetation type identification

   b. The precision of areal measurements from ERTS-1 data

   c. The use of temporal signatures in classification

TABLE 5-I.- RANGELAND CLASSIFICATION HIERARCHY

Level I	Level II	Level III[a]
Rangeland	Woodland	Post oak stands Mesquite stands Bottom land hardwood
	Nonwoodland	Wetland, marshhay cordgrass Gulf cordgrass Smutgrass Burned gulf cordgrass Cultivated bermuda fields Abandoned cropland
Nonrangeland	Water	Deep seawater Coastal water Inland water
	Urban areas	Residential and the like
	Cropland	Rice fields and the like

[a]Although not necessarily representative of the rangeland features in the United States, Level III features in this table were chosen because they were dominant in the study sites of this investigation. Since nonrangeland was not of interest in this study, Level III categories were not defined in detail.

5.2 ANALYTICAL APPROACH

Two study sites in the Houston Area Test Site were selected for the rangeland investigation. These sites were designated the Snook site and the San Bernard site. The Snook site occupies the boundary between the Texas black-land prairie region and the Texas claypan savannah. Features of interest in the Snook site are native stands of post oak, bottom land hardwood, mesquite, native grassland, and planted pastures of bermuda grasses. The San Bernard site is typical of the gulf coast marsh region along the Texas and Louisiana coasts. Two distinct vegetation zones existed in this site, a marshhay and smooth cordgrass zone (the salt marsh zone) and a gulf cordgrass zone (the slightly higher zone). Both sites offered the opportunity for Level II classification, whereas the San Bernard site provided a potential for Level III classification of vegetation types.

Conventional image-interpretation techniques and computer-aided data-processing techniques were used for analyzing MSS imagery and digital tape data. Color enhancements were obtained by conventional film data processing. Three photointerpreters who were not familiar with the study areas were asked to delineate the features of interest in the enhancements to obtain unbiased interpretations. The delineated features then were planimetered three times and the areal measurements averaged. Ground-truth information from low-altitude-aircraft photography was used to check the measurements obtained. A regression analysis also was made to investigate the significance of the results.

5.3 RESULTS

A temporal color enhancement of the Snook site, created on an MCFV, is shown in figure 5-1. Figure 5-2 is a classification map

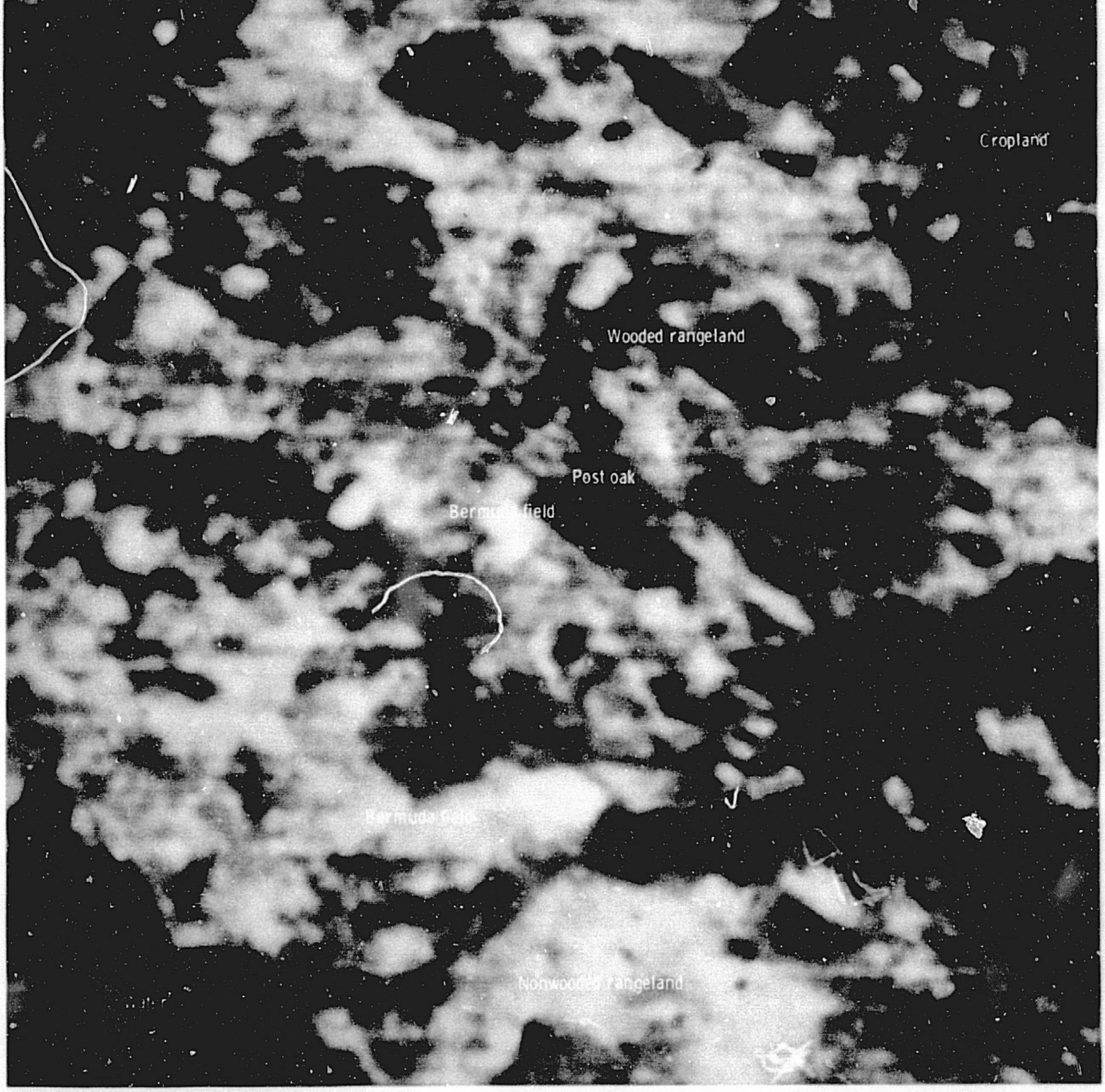


Figure 5-1.- Color enhancement of the Snook site created on an MCFV. (Temporal composite of ERTS-1 August 30, November 10, and December 16, 1972, film imagery.)

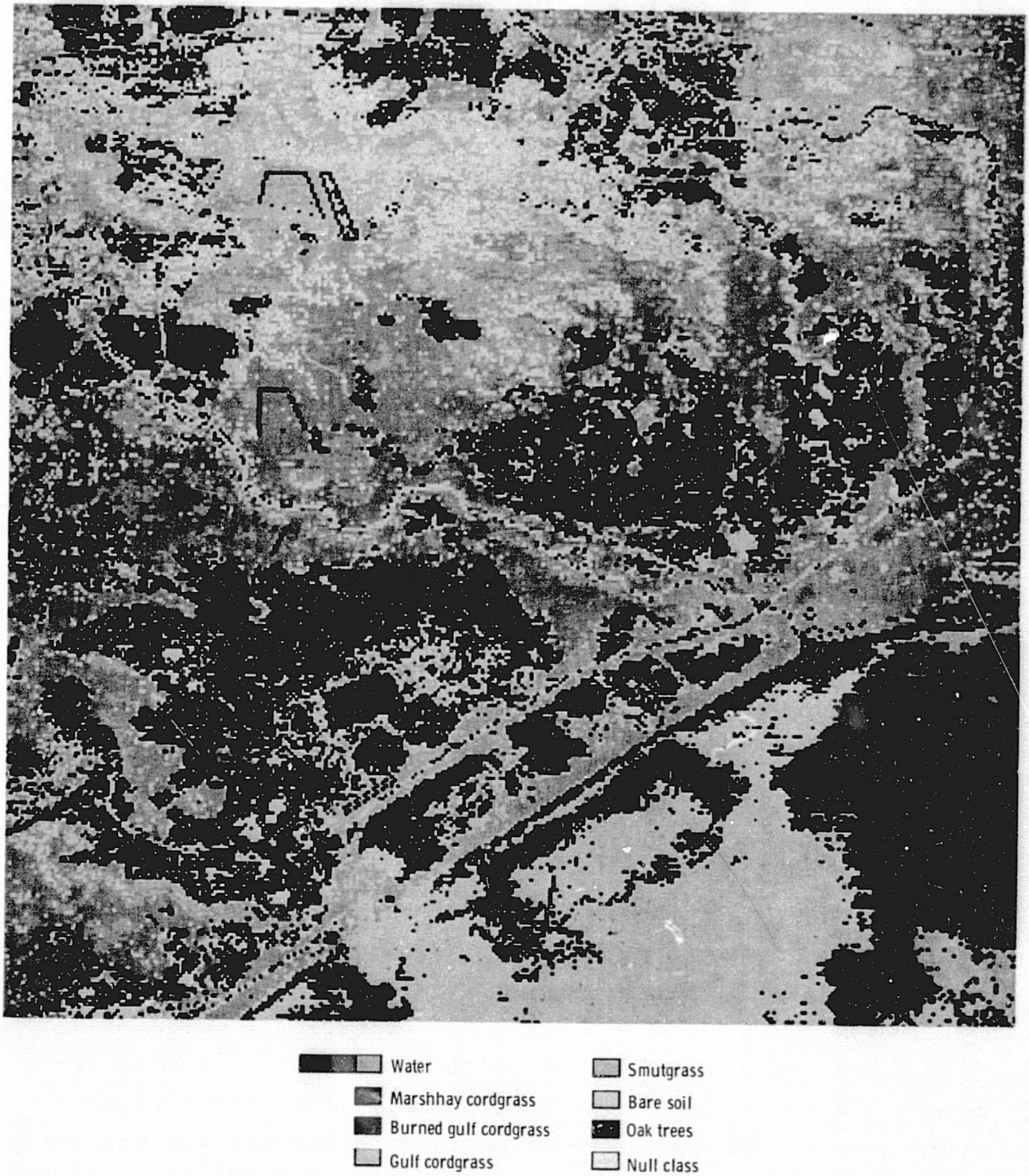


Figure 5-2.- Classification map of the San Bernard site made using supervised computer classification techniques (ERTS-1 October 4, 1972, digital data) (NASA S-73-28326).

of the San Bernard site made using supervised computer classification techniques. Figure 5-3 is a classification-like clustering map of the Snook site made using nonsupervised computer classification techniques. Figure 5-4 is a representative bar-chart illustration of the computer classification accuracies for the Snook single-date and temporal data. The team also performed a linear regression analysis of areal measurements obtained by planimetering color enhancements of ERTS-1 film imagery.

5.3.1 Conventional Data Processing

The following was accomplished or determined using conventional data processing.

1. An examination of the color enhancements created on the film viewers indicated that Level II classification of both sites appeared satisfactory. The sites were separated into wooded rangeland, nonwooded open rangeland, cropland, water, and urban areas.

2. The Level III features of wet lowland marshhay were separated from the drier upland zone of gulf cordgrass in the San Bernard site.

3. Regression analyses were performed to correlate the areas interpreted from color enhancements with ground truth. A linear model was developed that would predict the true areal measurement using a measurement obtained from a color enhancement created on available film viewers. However, the errors of the areal measurements were found to be as high as 214 square hectometers (530 acres) when measuring areas as large as 9100 square hectometers (22 500 acres). The inordinately large error figures were attributed to the fuzziness of boundaries between the extremely complex vegetation zones, and to the less than ideal quality of the color enhancements created.

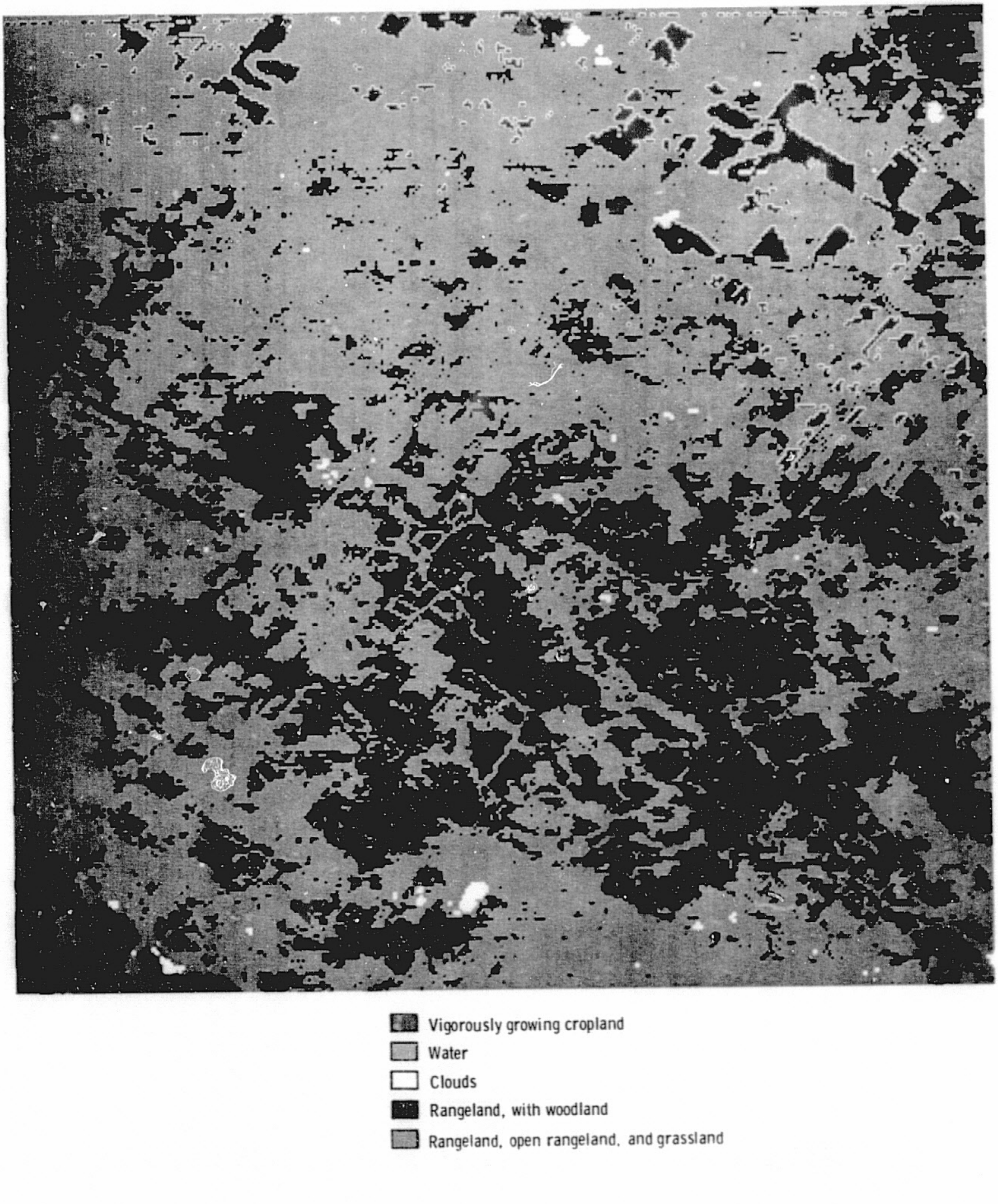


Figure 5-3.- Classification-like clustering map of the Snook site made using nonsupervised computer classification techniques (ERTS-1 August 30, 1972, digital data) (NASA S-73-28028).

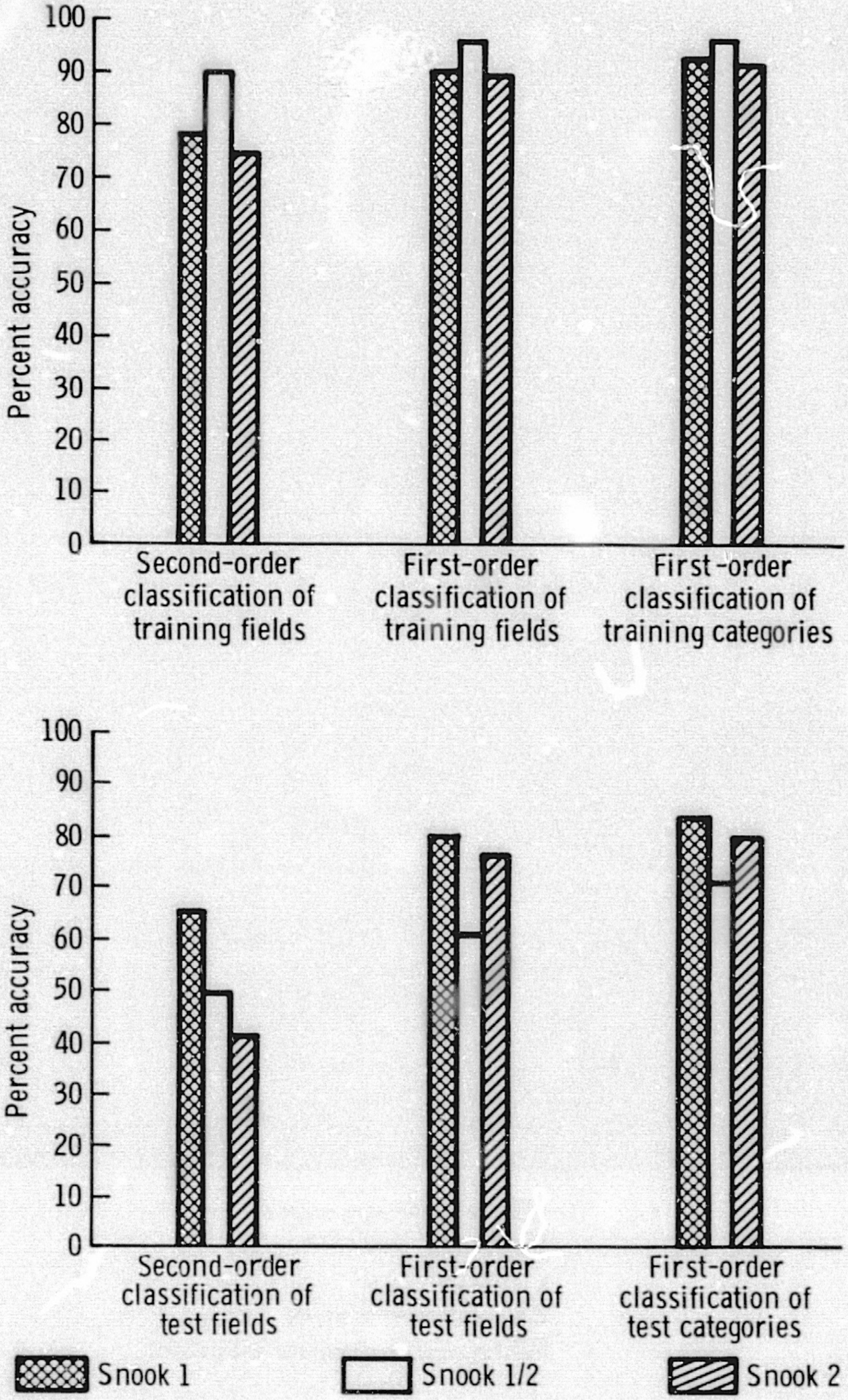


Figure 5-4.- Snook data overall classification accuracy. Snook 1 and Snook 2 ERTS-1 data were taken August 30 and November 28, 1972, respectively. The Snook 1/2 category is the temporal composition of Snook 1 and Snook 2 data.

4. Some features (e.g., cropland) were enhanced and accented from the background more sharply in temporal enhancements than in single-date enhancements.

5.3.2 Computer-Aided Data Processing

The following was determined using computer-aided data processing.

1. Classification accuracies of training fields were high. When the fields classified at Level III were aggregated into Level II categories, the Level II classification accuracies appeared even higher, as high as the mid-90-percent range (fig. 5-4).

2. Temporal analyses gave even better classification accuracies for the training data. Furthermore, confusion between training classes was reduced.

3. Because of the lack of intensive ground-truth data and a deficiency of spot checks, many test fields were not statistically representative. Consequently, classification accuracies of test fields were not as high as those of training fields. Level II classification accuracies appeared higher than those for Level III.

4. In general, Level II classification was satisfactory for both sites (i.e., the separation into wooded rangeland, nonwooded rangeland, cropland, and water). In the San Bernard site, the soil moisture content of marshhay, cordgrass, and gulf cordgrass was sufficiently different to permit separation between the two classes.

5. Clustering results were very useful because no a priori information was required to identify spectrally homogeneous areas in the data. Furthermore, this nonsupervised technique allowed the grouping of features for which ground truth was not available into spectrally unique groups. Further analysis could, in many cases,

result in assigning significance to these classification-type cluster maps. An attempt to use a sampling technique to reduce the computation time of the clustering process also was made.

6. Clustering results appeared to be very satisfactory for Level II classification and, to some extent, for Level III classification. Because of a lack of extensive ground truth, a quantitative analysis of the classification accuracies was not made.

5.4 CONCLUSIONS

The following conclusions about the rangeland study resulted from an analysis of ERTS-1 MSS data using conventional image-interpretation and computer-aided processing methods.

1. The ERTS-1 Range Analysis Team demonstrated the usefulness of ERTS-1 MSS data for satisfactory classification of vegetation types into broad Level II categories. Rangeland comprising woodland and nonwoodland was distinguished from nonrangeland comprising water, urban areas, and cropland.

2. Finer Level III classification also was possible but depended on the existence of certain characteristics of features such as soil moisture content that are not yet fully understood. The demonstrated capability to separate the wet lowland zone from the drier upland zone (e.g., in the San Bernard site) should be of significant value to users interested in mapping wetland features in coastal areas.

3. Temporal analysis, particularly using computer-aided techniques in processing digital data, resulted in enhanced discrimination between nearly all vegetation types encountered in this investigation. This conclusion is in accord with the prediction from mathematical theories.

6.0 THE ERTS-1 LAND USE ANALYSIS

6.1 OBJECTIVES

The general objective of the ERTS-1 land use investigation was to evaluate how well data from the ERTS-1 MSS could be used to detect, identify, and delineate land use features within the HATS, an 18-county area around Houston established previously as a land use test area. A more specific objective was to determine whether the land use classification scheme proposed in USGS Circular 671 could be used as the basis for delineating land use by conventional image interpretation and computer-aided classification of ERTS-1 data.

6.2 ANALYTICAL APPROACH

An analysis of the entire 41 000-square-kilometer (16 000-square-statute-mile) HATS area was not feasible with the available man-hours and computer time allotted to this investigation. Consequently, a 4660-square-kilometer (1800-square-statute-mile) study area was selected to correspond to the data on one CCT. The study area is oriented generally north-south and represents one-fourth of a scene of ERTS imagery (fig. 6-1).

An attempt was made to delineate Level I land use categories as urban and built-up land, agricultural land, rangeland, forest land, nonforested wetland, water, and barren land by conventional image-interpretation techniques. Black-and-white images of the study area from ERTS-1 MSS bands 5 and 7 (October 4, 1972, pass) were enlarged to a scale of approximately 1:250,000, and delineations of land use were recorded on transparent overlays of these enlargements. A comparative study was conducted by using similar interpretative techniques to delineate land use categories on

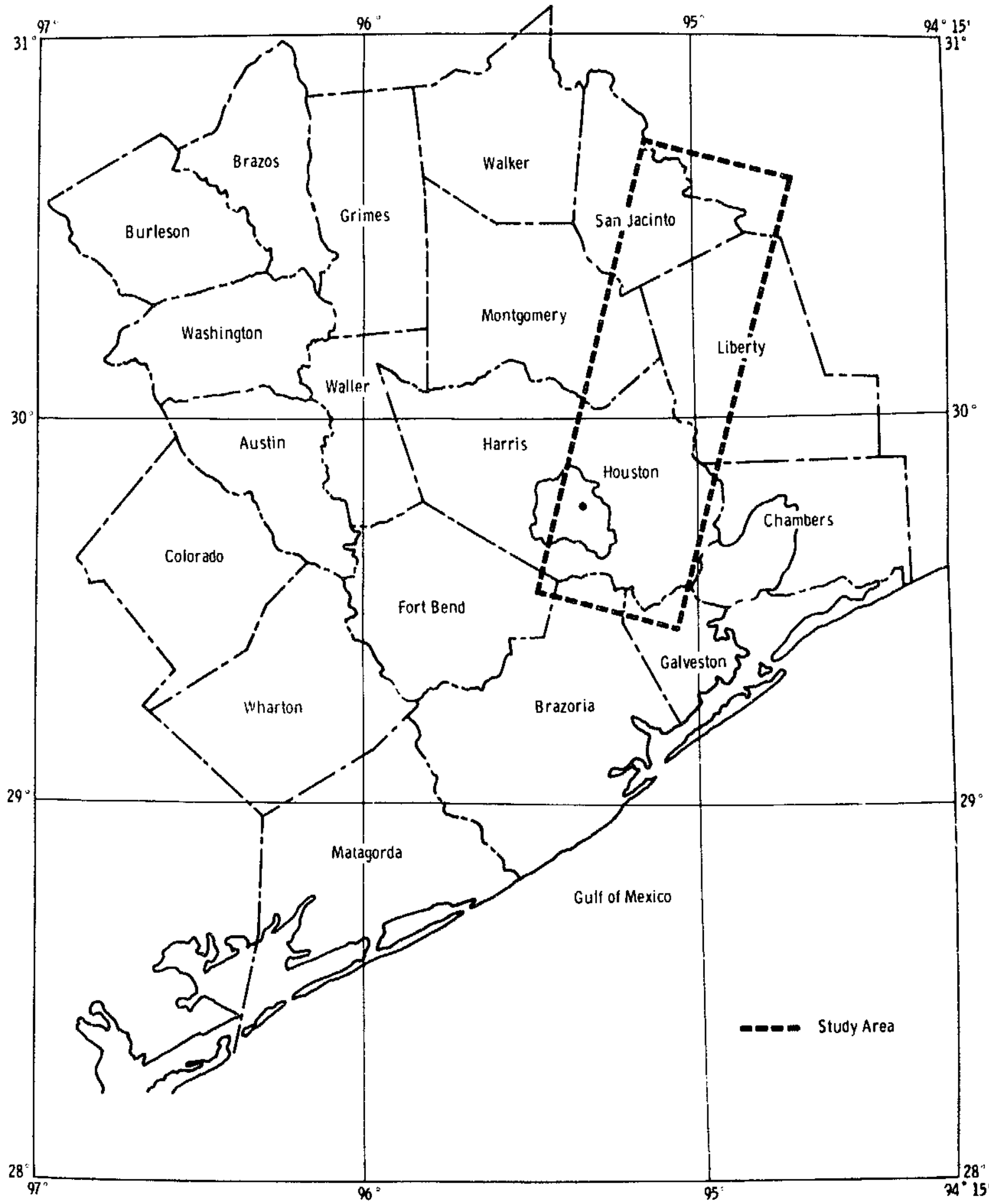


Figure 6-1.- Houston Area Test Site.

enlargements made from first-generation color composites obtained directly from a DAS film recorder at JSC. These enlargements were also at a scale of approximately 1:250,000 and were simulated color-IR composites of bands 4, 5, and 7. The same techniques were used in delineating some Level II land use categories.

Two basic computer-aided classification techniques (supervised and nonsupervised) were used in classifying the study area into land use categories. The ISOCLS, a nonsupervised clustering algorithm, was used to group every sixth picture element (pixel) from every sixth scan line into clusters of pixels having similar spectral characteristics. This reduction in the number of data points (40 000 pixels) was necessary because the capacity of the computer was not sufficient to process the total number of data points (1.3 million pixels) covering the entire study area. This 3-percent systematically alined sample of data points, uniformly distributed over the entire study area, was grouped into spectral clusters, each representing a portion of the full range of spectral variations found in the study area. The input parameters to the cluster program could be adjusted to provide more clusters or fewer clusters. However, after considering the amount of detail needed for the proposed land use hierarchy and the estimated computer time required, it was reasoned that input parameters providing 13 clusters would be a reasonable compromise. Graymap printouts depicting the spatial distribution of the pixels grouped into each cluster were generated on the computer. Each cluster was identified and assigned to a specific land use category by correlating the cluster delineations on the graymaps with existing land use maps and aerial photographs, and by analyzing pertinent cluster statistics that had been plotted on graphs. After grouping the clusters into the desired land use categories, a color-coded cluster map in the form of a color transparency was produced on the JSC DAS film recorder.

Once the clusters had been grouped satisfactorily into the Level I land use categories, the means and covariance matrix statistics from the cluster analyses were substituted for training field statistics as inputs in the LARSYS II supervised classification approach. The use of cluster statistics in lieu of training field statistics eliminated some of the difficulties that would have been encountered in selecting representative training fields for such a large study area for which intensive ground truth or large-scale aerial photography was not readily available for analysis. Because of the relative spectral complexity of much of the study area landscape, it was deemed desirable to be able to classify every pixel (instead of every sixth pixel) within the entire study area. To do so, however, it was necessary to divide the entire area into north-south linear strips, with the number of data prints in each strip not to exceed the storage capacity of the computer memory drum. Level I land use classification maps of each strip were subsequently mosaicked to form a classification map of the entire study area. Experience gained in delineating Level I land use categories by both supervised and nonsupervised classification techniques indicated that a potential existed for dividing the urban and built-up category into some Level II categories. Because some urban features (vegetated residential areas) have spectral characteristics similar to some nonurban features, such as forest and agricultural areas, it was necessary to reassign the 13 original clusters to land use categories that would represent three Level II urban and built-up categories (residential, commercial/industrial/transportation, and open) when a Level II classification was made of only the urbanized portion of the study area.

The accuracy of the three classification approaches was assessed by measuring the agreement between the classified data and the base reference data established for the accuracy analysis. Five accuracy test sites, ranging in size from 21 to 104 square kilometers (8 to 40 square statute miles), were established in the study area. Base reference data were established by visually classifying land use in each accuracy test site from high-tude, infrared-Ektachrome photography acquired April 22, 1972. Each site was divided into 2.6-square-kilometer quadrats, and the percent occurrence of each class in each quadrat was measured using a dot-sampling technique. The same procedure was performed on each class for each classification product except for the computer-aided classification maps, for which pixels in each class were counted and converted to percent occurrence. The percent agreement (class-by-class comparison of accuracy) between classification products and base reference data was calculated on the basis of the percent occurrence.

6.3 RESULTS

The following results were obtained.

1. A visual comparison of all the classification results (figs. 6-2 to 6-7) shows a strong correlation in the areal patterns of land use between the three analysis approaches used in the investigation. However, there is a significant difference in detail. Because of the relatively small scale (1:250,000) of the manually interpreted imagery, many of the smaller features were difficult to portray. The result is a pattern of relatively homogeneous tracts of land use classes (figs. 6-2 to 6-3).

2. The computer-aided classification maps display a finer texture in the land use patterns (figs. 6-5 to 6-7). This finer precision is a result of the capability of the computer to classify each pixel (approximately 0.45 square hectometer).

3. The image interpreter can compensate for his inability to resolve fine details with the ability to resolve spatial patterns and relationships in the land use features. This capability was particularly prominent in the urban areas, where many linear

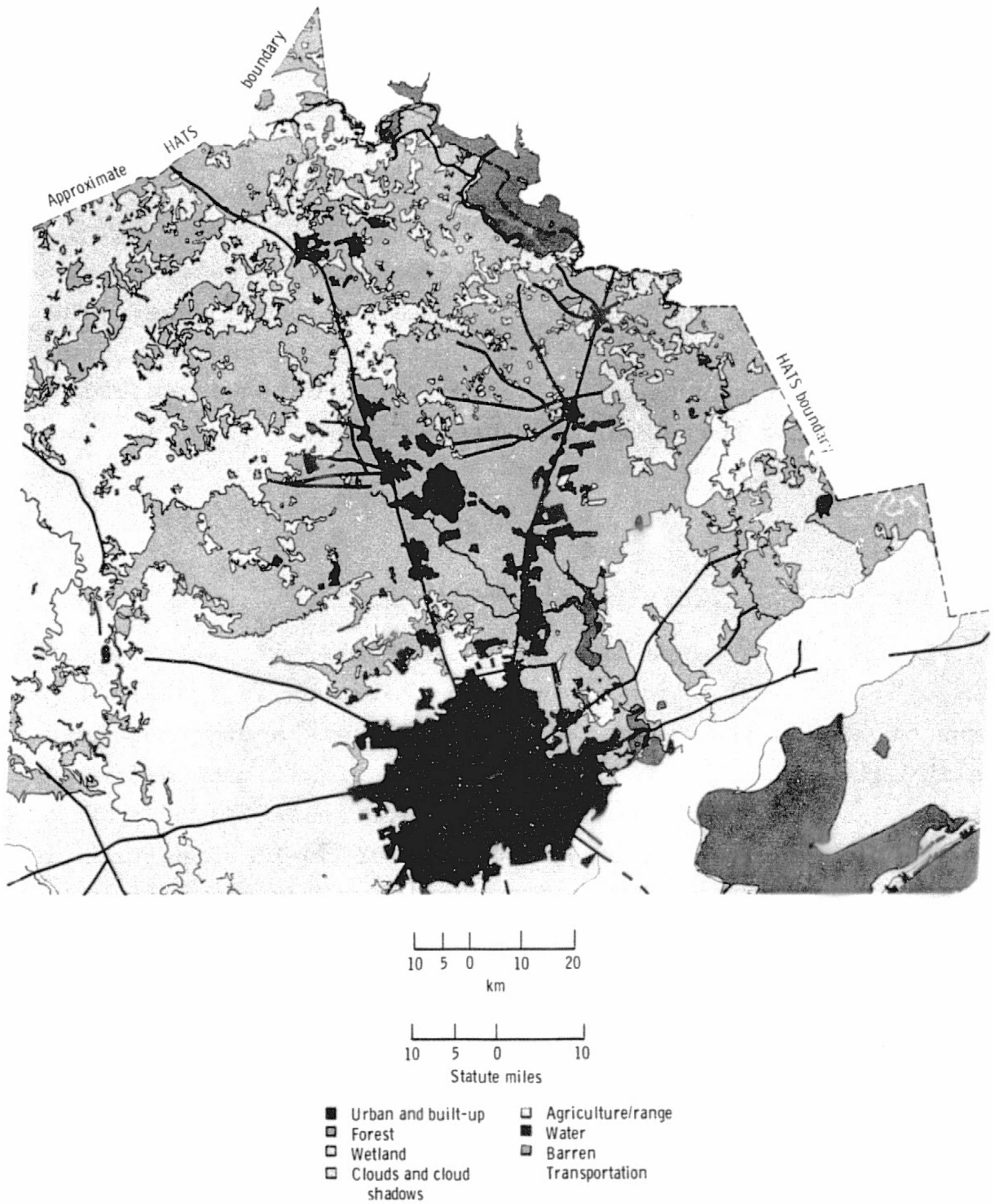


Figure 6-2.- Level I land use classification of study area (ERTS-1 bands 5 and 7 from October 4, 1972) (NASA S-73-31699).

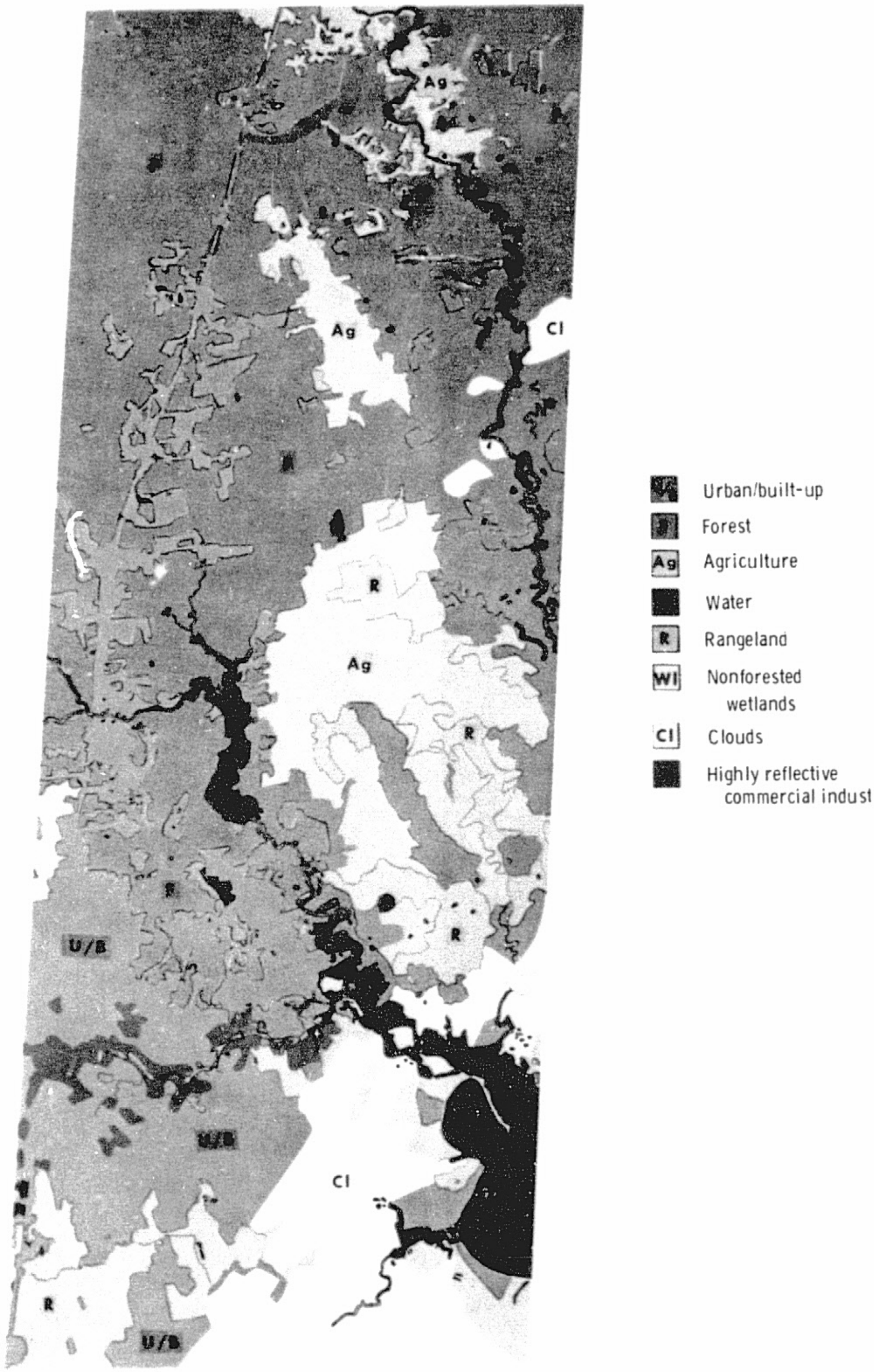


Figure 6-3.- Level I land use manual interpretation of study area (ERTS-1 bands 5 and 7 from October 4, 1972) (NASA S-73-25517).

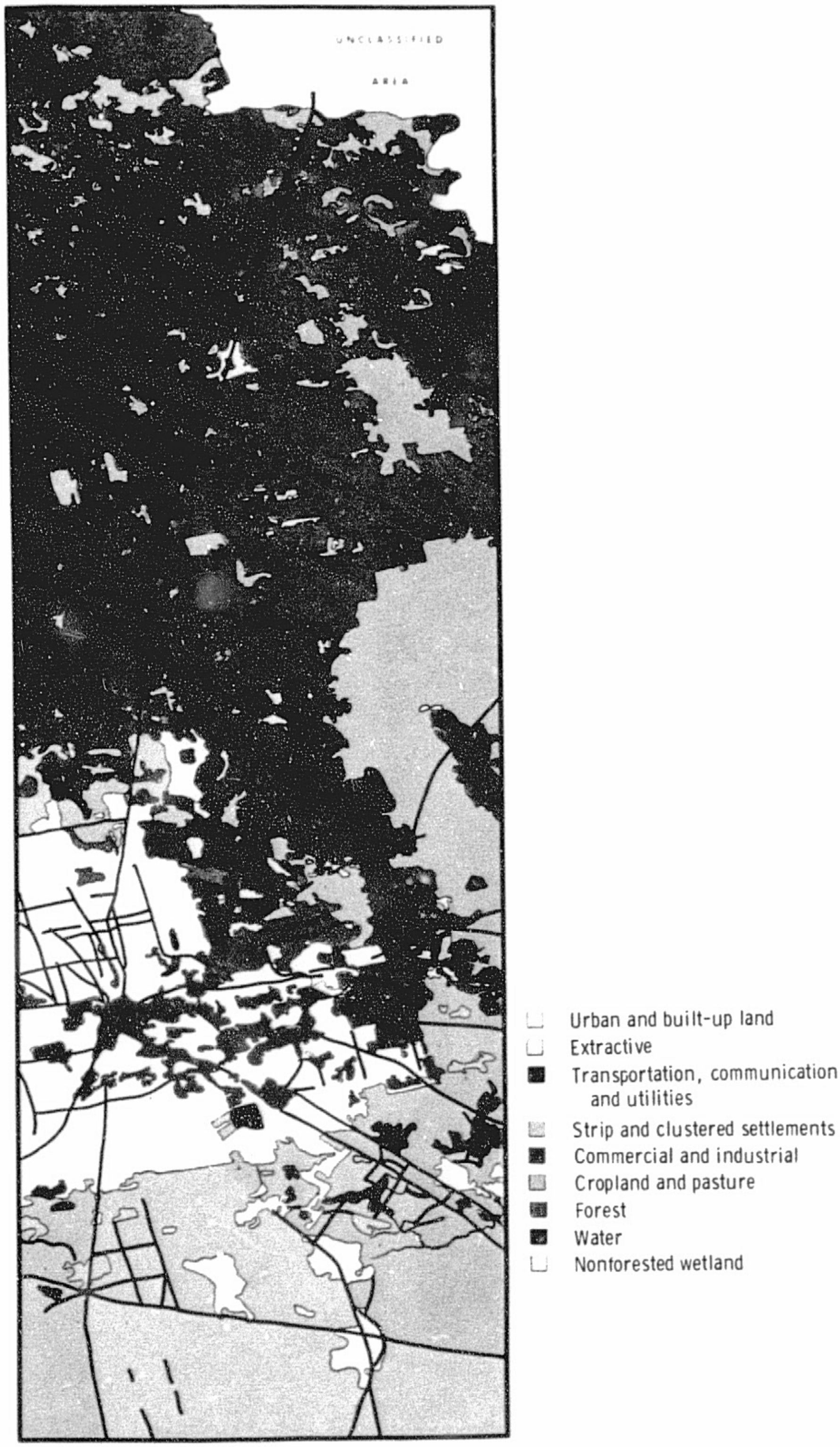


Figure 6-4.- Level I and II classification of land use study area (ERTS-1 bands 4, 5, and 7 from August 29, 1972) (NASA S-73-28191).

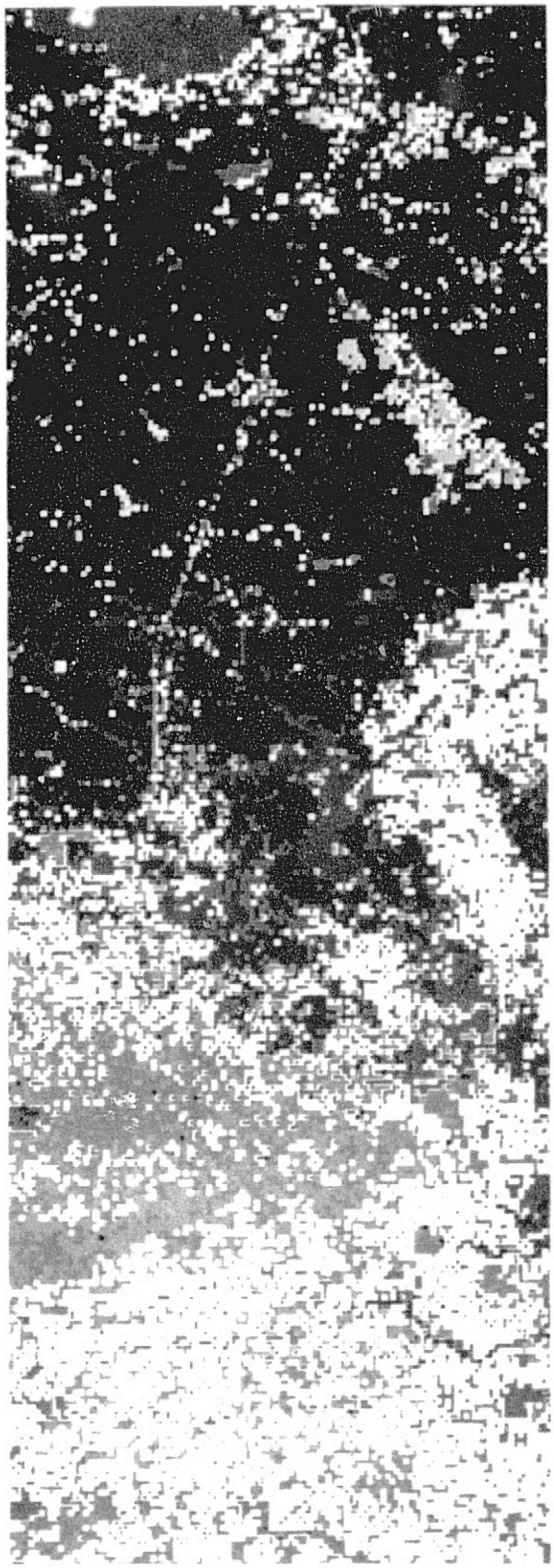


Figure 6-5.- Land use cluster map developed from a 3-percent data sample (NASA S-73-28073).

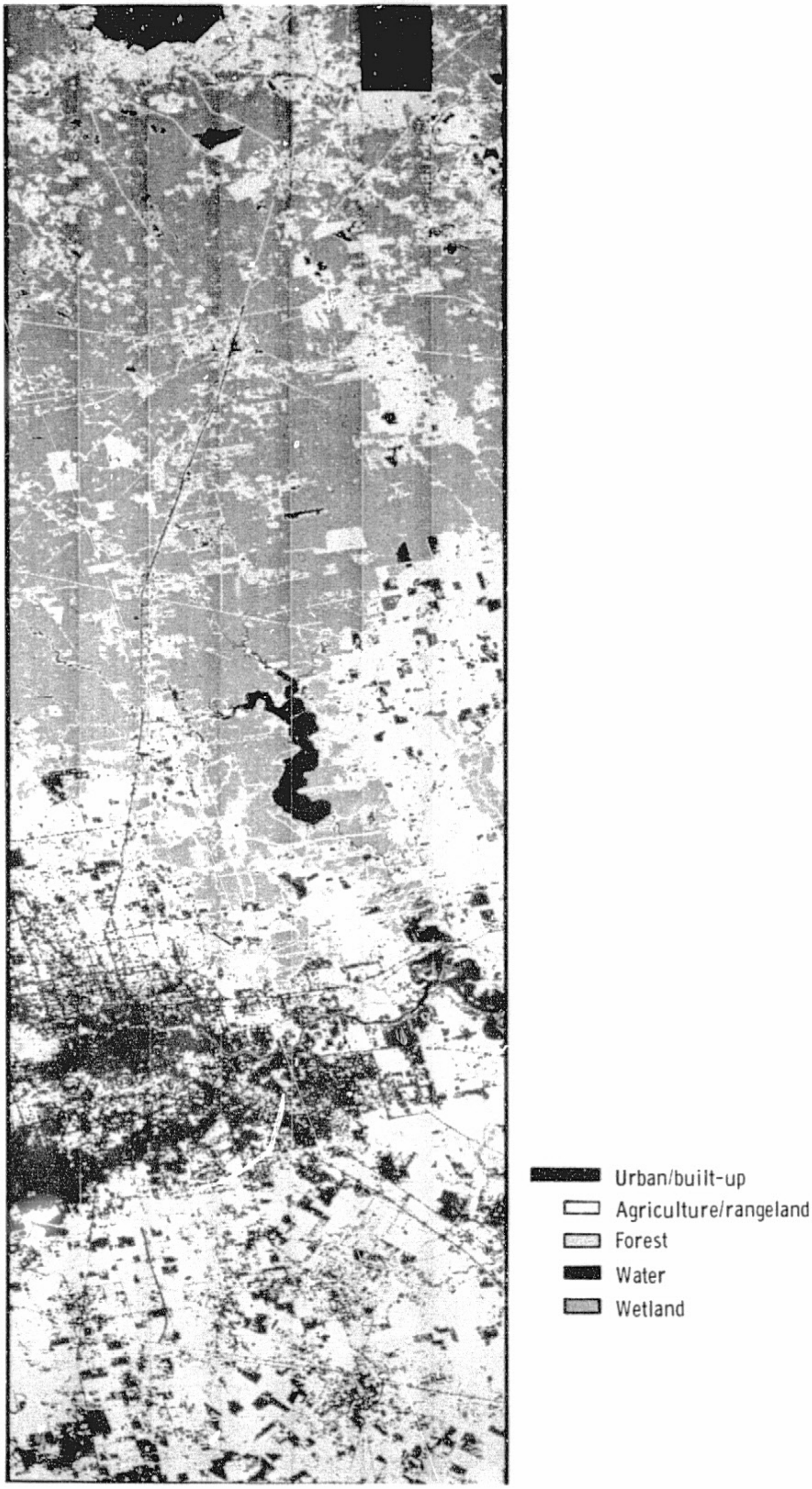


Figure 6-6.- Computer classification of Level I land use (NASA S-73-2853).

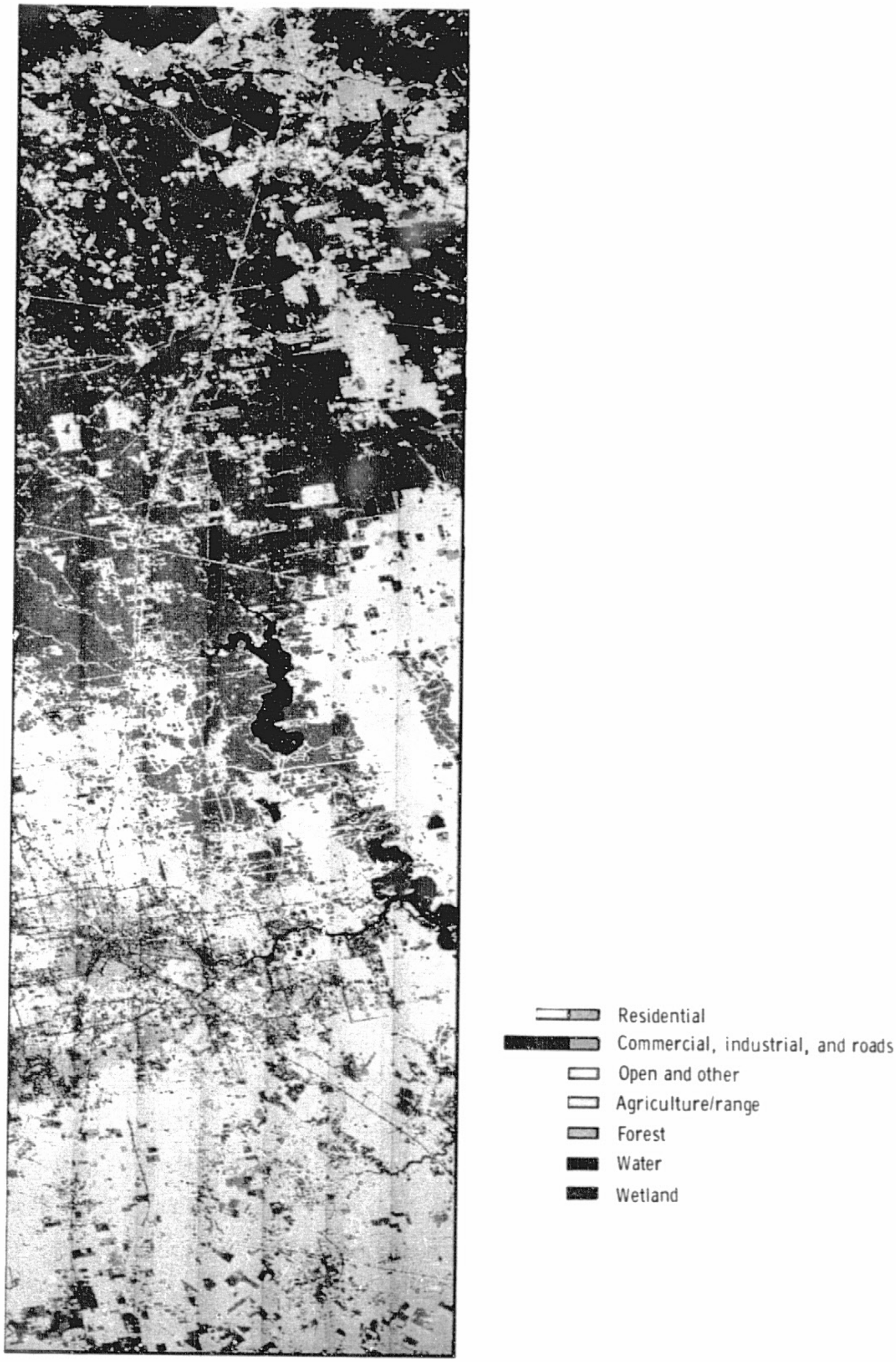


Figure 6-7.- Computer classification of land use Levels I and II (urban) (NASA S-73-2866).

features (secondary roads for instance) could be visually distinguished by conventional image interpretation even though the widths of the features were well below the spatial resolution threshold of the scanner.

4. Relatively high classification accuracies for Level I land use categories (table 6-I) were achieved by conventional image interpretation and computer-aided classification techniques, with the exception of the urban and built-up category when it was derived from computer classification of the entire study area. When only the preselected urban area was classified in Level II categories, considerably better computer classification accuracies were attained (table 6-II). This apparent discrepancy in accuracies was probably due to the spectral heterogeneity of the urban scene which also contained vegetated agriculture-rangeland features.

6.4 CONCLUSIONS

The following conclusions can be stated.

1. It was concluded from this investigation that general land use categories as suggested for Level I and some Level II categories in USGS Circular 671 could be obtained over relatively large areas from ERTS-1 MSS data by conventional image interpretation and computer-aided classification techniques.

2. In the computer-aided processing, a small (3 percent) sample of the available digital data was sufficient to identify the general land use categories throughout the entire study area. This conclusion indicates that even larger geographic areas could be similarly classified without exceeding nominal computer capacities.

3. Where greater classification accuracies or more detailed land use categorizations of larger areas are desired, it may become necessary to define categories of land use by geographic

TABLE 6-I.- LEVEL I AND II LAND USE PRODUCT AGREEMENT WITH BASE DATA

[Based on percent occurrence]

Land use class	Sample test site	Base quadrats			Conventional image interpretation				Computer classification class occurrence	
		Number (100 point counts each)	Class occurrence		Black-and-white imagery class occurrence		Color composite imagery class occurrence			
			Count	Percent	Count	Percent	Count	Percent	Count	Percent
Forest	1	33	2427	73.5	2394	72.5	2800	84.8	2383	72.2
	2	38	3319	87.3	3473	91.4	3455	90.9	3340	87.9
	3	15	367	24.5	293	19.5	265	17.7	240	16.0
	4	4	209	52.3	267	66.8	286	71.5	192	48.0
Cumulative total	--	90	6322	70.2	6427	71.4	6806	75.6	6155	68.4
Agriculture/rangeland	1	17	736	43.3	552	32.5	270	15.9	719	42.3
	2	7	299	42.7	100	14.3	219	31.3	214	30.5
	3	35	3009	86.0	2981	85.2	3245	92.7	2825	80.7
Cumulative total	--	59	4044	68.5	3633	61.6	3734	63.3	3758	63.7
Water	4	6	325	54.2	259	43.2	247	41.2	296	49.3
Level I urban	5	[a,b]39	[a,b]3724	[a,b]95.5	[b]1100	[b]100.0	3855	98.8	1642	42.1
Level II urban										
Residential	--	19	1293	68.1	--	--	1750	92.1	1514	79.7
Commercial/ industrial/ transportation	--	8	137	17.1	--	--	60	7.5	82	10.3
Open and other[c]	--	12	200	16.7	--	--	--	--	124	10.3

[a]August 29, 1972, ERTS-1 data used for all analyses except those using October 4, 1972, data.

[b]October 4, 1972, ERTS-1 data base covered only part of test site in black-and-white imagery. For base quadrats, number = 11; class occurrence count = 1035; and class occurrence percent = 94.1.

[c]Category not delineated by conventional image interpretation.

TABLE 6-II.- LEVEL II URBAN LAND USE PRODUCT AGREEMENT WITH BASE DATA

[Based on percent occurrence]

Land use category	Classification product					
	Sample size		JSC color composite, percent	Sample size, percent		Computer aided, percent
	Base	Counted		Base	Counted	
Residential	1293	1750	64.7	68.1	79.7	83.0
Commercial/ industrial/ transportation	137	60	43.8	17.1	10.3	60.2
Open and other	--	--	--	16.7	10.3	61.7

region, perform sampling within each region, and classify the entire large area into the desired land use categories using computer-aided techniques.

7.0 THE ERTS-1 URBAN LAND USE ANALYSIS

7.1 OBJECTIVE

The objective of the ERTS-1 urban land use 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, Texas, metropolitan area.

7.2 ANALYTICAL APPROACH

Because of the complexity of urban landscapes and the estimated amount of computer time required, the scope of the investigation was restricted to four separate residential study areas and to the major transportation network around Houston. During the computer-aided 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.

The set of ERTS-1 MSS data covering the subject area obtained August 29, 1972, 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 USGS Circular 671 (table 1-I).

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

Conventional image-interpretation techniques were used to analyze ERTS-1 enlarged black-and-white imagery and color composite imagery generated from the digital data. Supervised and nonsupervised computer-aided classification techniques were used with ERTS-1 computer-compatible tapes.

Two data-processing procedures were used in the supervised computer-aided techniques. In one procedure, the Earth Resources Interactive Processing System developed at JSC was used in conjunction with the LARSYS II classifier on the IBM 360 series computer. In the second procedure, the Module Training Field Option (MTFO) was used on the Univac 1108 series computer. A LARSYS II classifier also was used in this procedure, but the investigator could modify the statistical inputs.

The nonsupervised computer-aided classification investigations involved the use of ISOCLS clustering to examine the spectral composition of picture elements of clusters within a complex urban scene, and to determine the accuracy to which the various clusters could be correctly grouped to identify specific urban land use categories. The accuracy analyses of the various computer-aided classification techniques were performed by correlating samples of individual picture elements to specific geographic areas as identified and delineated on aerial photography by a picture-element-correlation grid technique developed during this investigation.

A separate attempt was made to delineate the major transportation routes in the Houston metropolitan 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, band 5, black-and-white imagery (scale approximately 1:250,000). Both the LARSYS and the ISOCLS computer-aided classification techniques were also used to produce maps of the major transportation routes. Two approaches were used in classifying with the ISOCLS technique. In one approach, clustering based on ERTS-1 bands 5 (red) and 7 (infrared) was used. In the second approach, clustering based on ERTS-1 bands 4 (green), 5 (red), 6 (infrared), and 7 (infrared) was used.

7.3 RESULTS

In the conventional image-interpretation investigations, the importance of using spatial pattern recognition clues for interpreting the extremely small-scale ERTS-1 imagery was emphasized. The following results were obtained.

1. The spatial resolution of the multispectral scanner 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 textural pattern characteristic of 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. Linear patterns indicating the major highways and streets were also 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 differentiate visually certain urban features from the surrounding nonurban landscapes by interpreting the extensive linear and crosshatched patterns as spatial surrogates of urban features.

2. 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.

3. 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.

4. The residential land use category was actually one of the most complex and least consistent categories to be delineated by spectral classifications. 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 available, in addition to those adjacent to the residential areas.

5. The accuracy to which the original selection of residential study areas could be differentiated from the surrounding land use categories by means of computerized classification techniques is shown in tables 7-I and 7-II. Table 7-I contains a comparison of three computer classification techniques used in classifying various urban land uses associated with selected residential study areas. The ERIPS and MTFO techniques were the two approaches used in the supervised classification programs. In the ISOCLS technique, nonsupervised classification programs were used. The accuracy of these computerized techniques for 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.

6. 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

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

Residential study area	Land use category	Percent of boundary length correctly differentiated —		
		By ISOCLS techniques	By ERIPS techniques	By LARSYS techniques
Cloverleaf (area L)	Major transportation	0	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	24	27
	Major transportation	57	(a)	(a)
	Institutional	78	(a)	(a)
	Water (channel)	24	(a)	(a)
	Open fields	22	(a)	(a)
	Other residential	(a)	0	18

[a]No comparative analysis was made.

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

Residential study area	Ratio of area acreage C/B[a]
Cloverleaf (area L)	1.12
Pasadena (area M)	(b)
Garden Villas (area N)	1.16
Center City (area P)	.91

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

[b]No comparative analysis was made.

output maps. Table 7-II includes 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, whereas a ratio less than 1.0 shows that the area classified by the computer was smaller than the actual size of the area.

7. Determining classification accuracies of areas encompassed by boundaries arbitrarily selected from panchromatic aerial photographs may have imposed unreasonably stringent requirements on the classification techniques. 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. To determine the accuracy of the land use map generated by using nonsupervised classification, a misclassification error matrix was generated for the categories developed from the 32 clusters (table 7-III). The misclassification error matrix was established by comparing the nonsupervised classification with a base developed from 1:120,000-scale high-altitude-aircraft photography (ground truth) of the same area. Table 7-III includes the overall accuracies obtained when the residential land use category was not limited to arbitrary boundaries but was integrated with other land use categories over a major portion of the entire Houston metropolitan area.

8. Figures 7-1 to 7-3 provide an overview of the complexities of the urban land use categories delineated by the ISOCLS classification techniques and the two LARSYS classification techniques. A cursory comparison of the three figures indicates an impressive overall similarity of urban land use patterns. A more detailed examination of figures 7-1 to 7-3 discloses some differences in the areal extent of certain categories. Most of these differences can be attributed to the manner in which a

TABLE 7-III.- MISCLASSIFICATION ERROR MATRIX

[Percent agreement with base]

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)	--	.7	.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

Figure 7-1.- Urban nonsupervised computer-aided classification.

Figure 7-2.- The ERIPS supervised computer-aided classifications delineating urban land use (NASA S-73-25486).

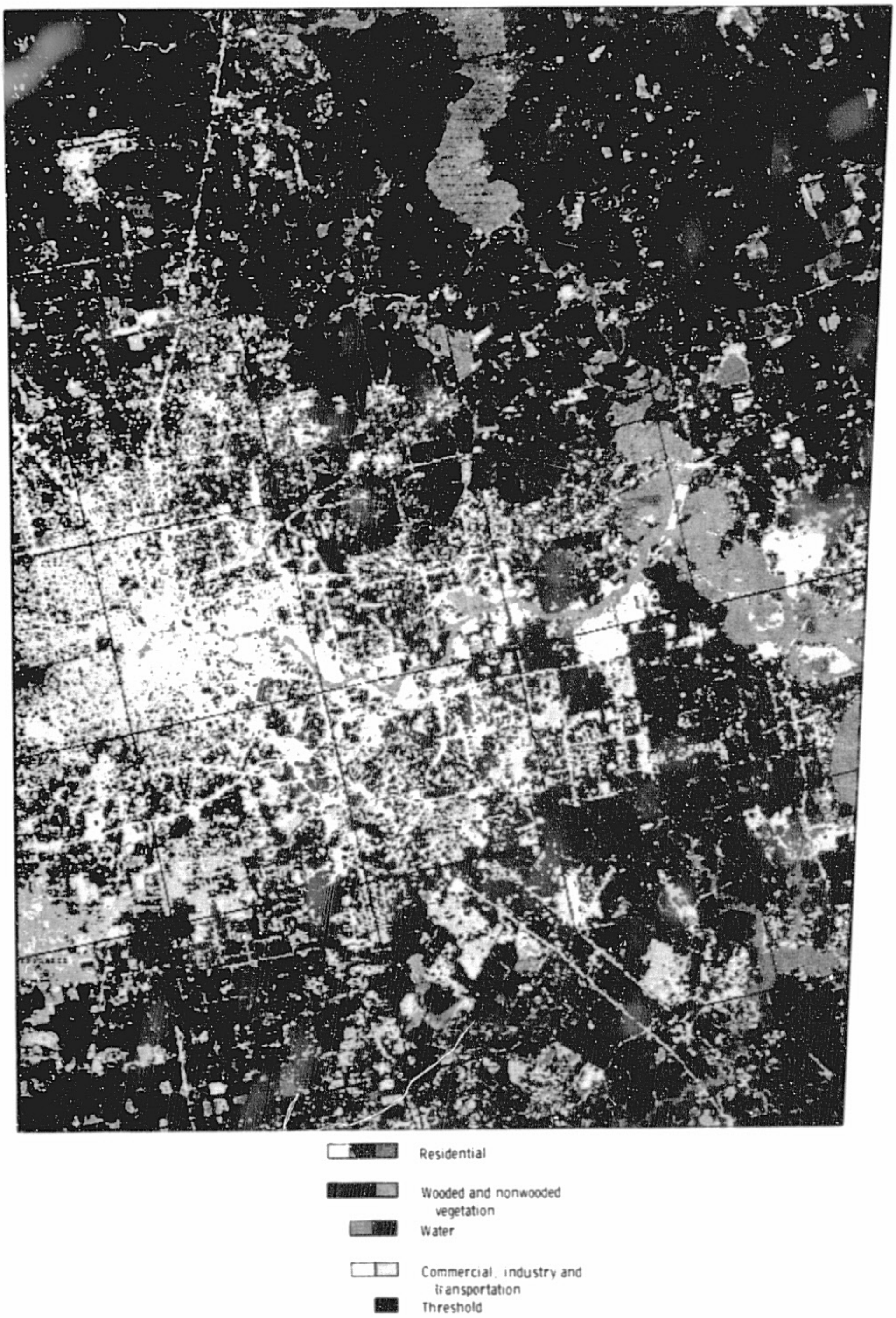


Figure 7-3.- The MTFO supervised computer-aided classifications delineating urban land use.

specific spectral cluster was assigned to a particular land use category. In the supervised classification, certain differences, especially in the residential category, could be attributed to difficulties in finding specific training areas representative of that class of features. Ellington Air Force Base, located near the lower right corner of each figure, illustrates consistency among the three techniques. Note that the area to the left that contains barracks and other buildings is classified as residential, whereas the hangars and runways on the right are classified as commercial/industrial/transportation. Some vegetated areas are indicated between the runways.

9. Only a qualitative study was made to evaluate the usefulness of ERTS-1 MSS data for delineating the major transportation routes within the metropolitan Houston area. Maps produced both by conventional image interpretation (fig. 7-4) and by cluster-map computer classification procedures (fig. 7-5) were compared with a base highway map of Houston (fig. 7-6). This comparison revealed that major freeways, highways, and many major Houston streets could be delineated from the ERTS-1 imagery and digital data. This result suggests that automated 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.

10. The investigations involving the correlation of computer graymaps 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 picture element could be correlated from a computer printout map to its precise location on an aerial photograph. This procedure made possible interpretation of the meaning of the classification anomalies encountered in the computer

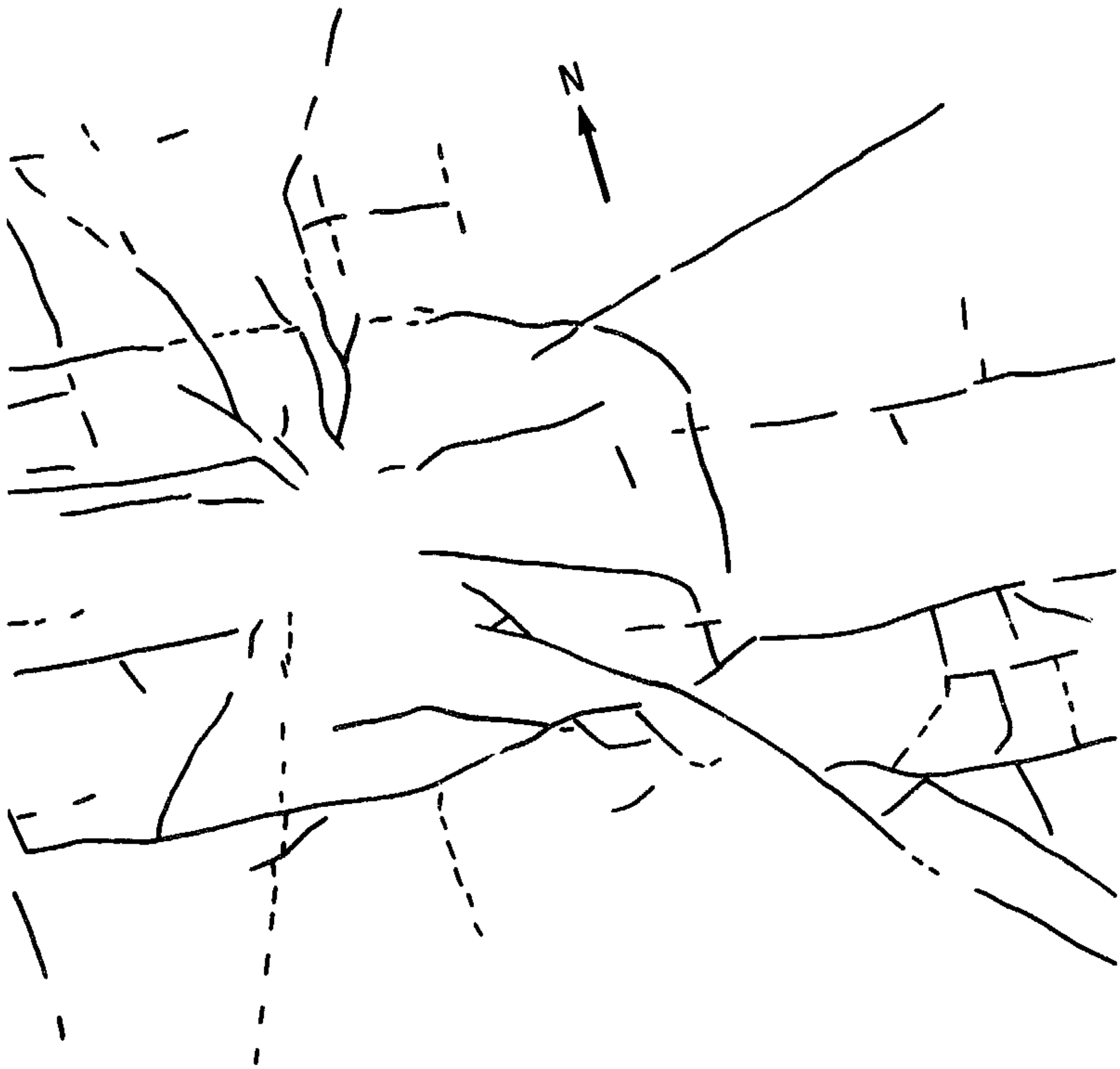


Figure 7-4.- Major transportation routes in the Houston area. (Conventional image interpretation from an ERIPS supervised classification of ERTS-1 MSS data, August 29, 1972.)

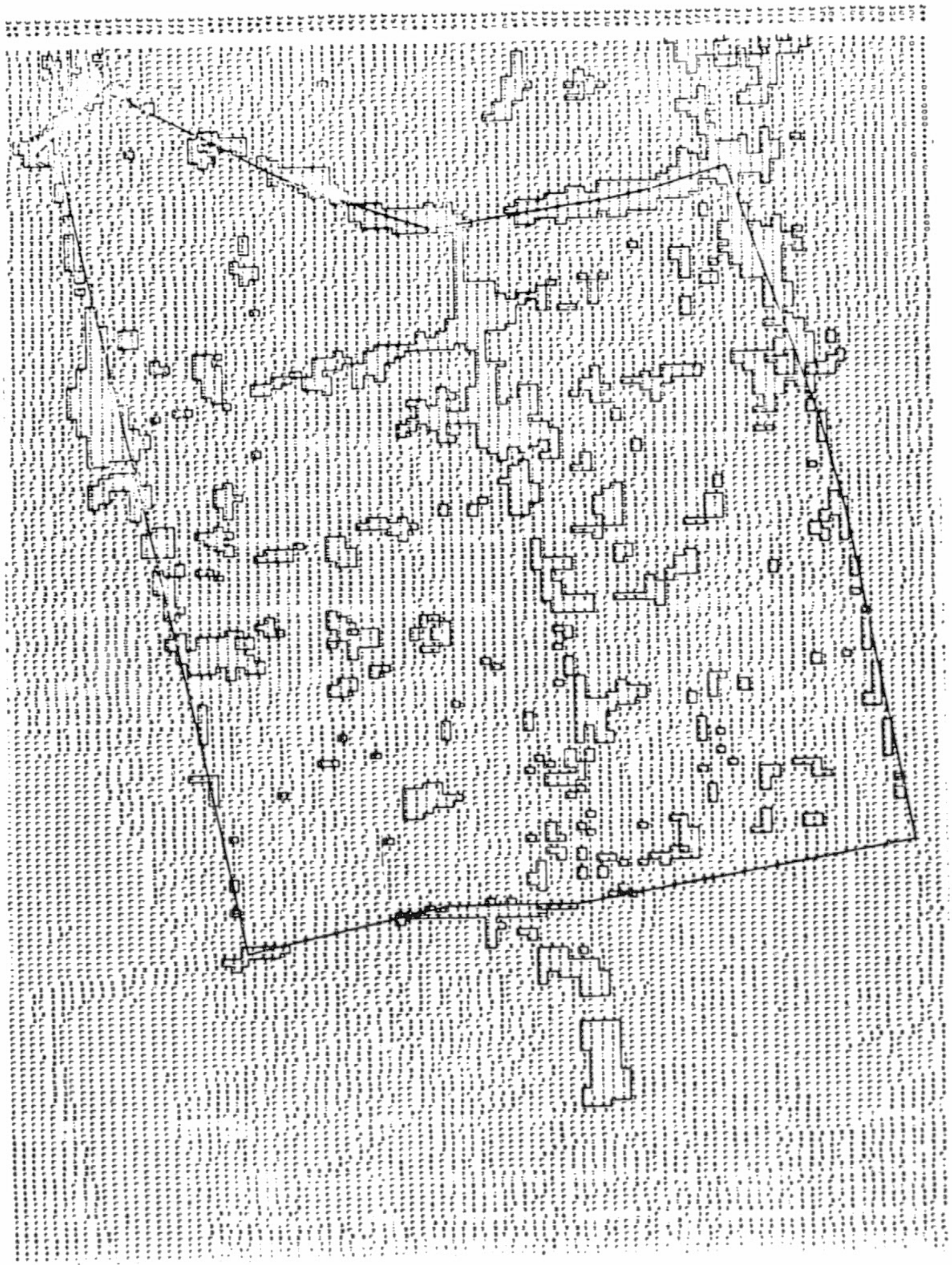


Figure 7-5.- Cluster map of urban residential area showing high-reflectance areas from nonsupervised classification August 29, 1972.

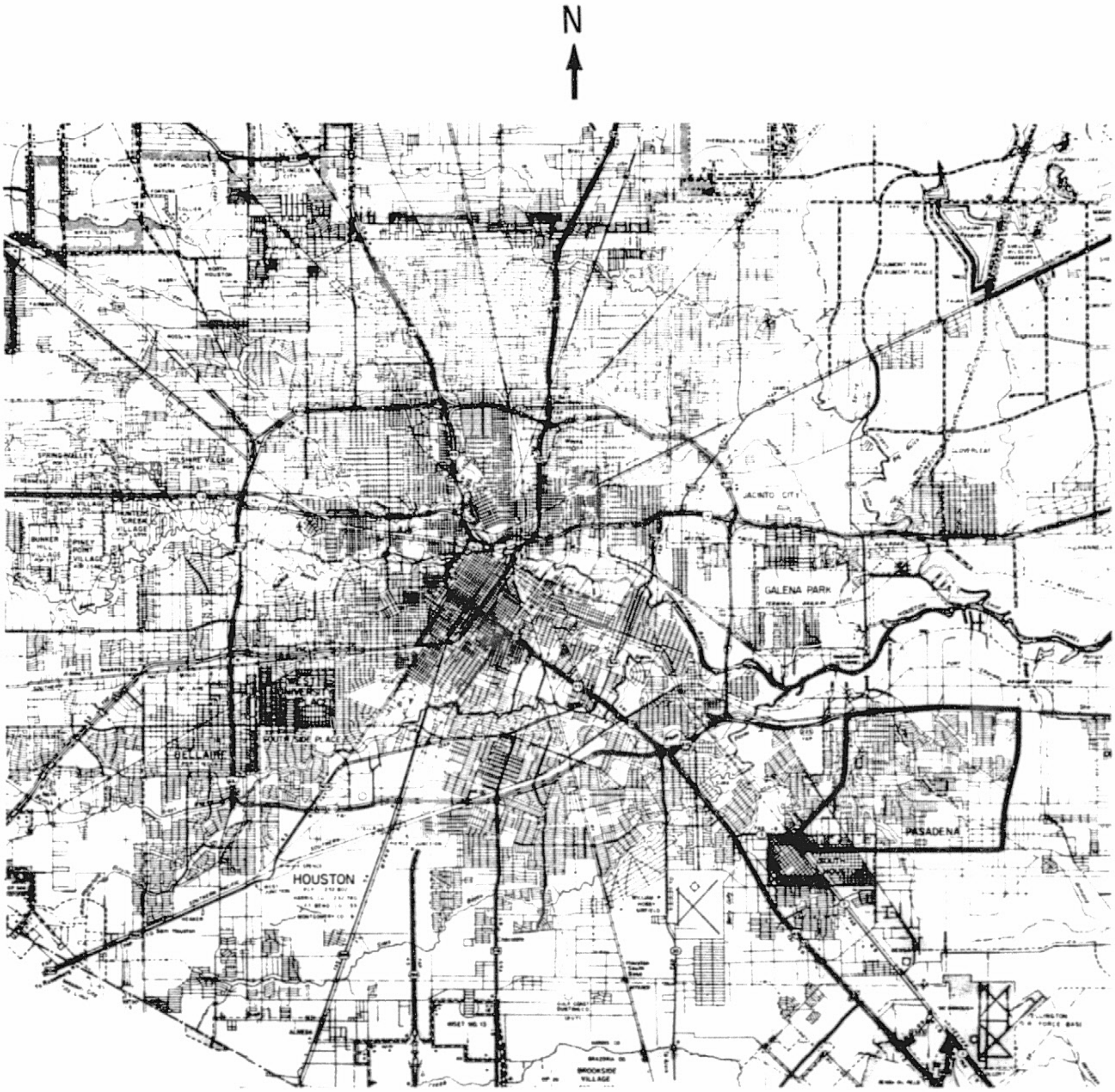


Figure 7-6.- Base highway map of Houston. Heavy outline (lower right) encloses area shown in figure 7-5.

classification programs, and also aided in evaluating the accuracies of the various outputs from these programs.

11. The initial guidelines for this investigation stipulated the USGS proposed land use scheme as the goal for classifying urban land use. This conventional land use scheme was not appropriate when the computer classification programs had ERTS-1 spectral data as the only input. Table 7-IV is the classification hierarchy developed on the basis of spectral contrast levels that appeared to correlate most consistently with the capability of the various computer classification programs. 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-1 investigators of urban areas in other geographic regions.

TABLE 7-IV.- COMPUTER-AIDED CLASSIFICATION SCHEME

FOR LEVEL I AND II URBAN LAND USE

<table>
<tr><th>Level I</th><th colspan="2">Level II</th></tr>
<tr><td rowspan="2">Nonvegetated land areas</td><td colspan="2">Commercial/industrial/ transportation</td></tr>
<tr><td rowspan="2">All other urban</td><td>Residential</td></tr>
<tr><td rowspan="3">Vegetated land areas</td><td>Mixed urban</td></tr>
<tr><td colspan="2">Nonwoody vegetation</td></tr>
<tr><td colspan="2">Woody vegetation</td></tr>
<tr><td>Water</td><td colspan="2">Water</td></tr>
<tr><td>Clouds</td><td colspan="2">Clouds</td></tr>
<tr><td>Shadows</td><td colspan="2">Shadows</td></tr>
</table>

7.4 CONCLUSIONS

The following conclusions can be stated.

1. The ERTS-1 multispectral scanner is 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 level of information that could be extracted by using conventional image-interpretation techniques. The spatial resolution of the scanner was not adequate to resolve the details of the many relatively small objects in an urban scene.

2. The spectral energies recorded by each picture element were integrated measurements the magnitude of which depended on the proportion of the picture element 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.

3. 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 were used to group these heterogeneous picture elements 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.

4. The greatest source of classification error was the computer classification of urban features in which 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 statement 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.

5. Although some Level II urban categories can be classified to varying degrees of accuracy, the current ERTS-1 system and the analytical procedures used in this investigation would find the most immediate utility for urban and regional planners in providing frequent boundary revisions of the urban fringe. 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.

8.0 THE ERTS-1 SIGNATURE EXTENSION ANALYSIS

8.1 OBJECTIVES

The objective of the signature extension analysis was to measure the spectral signature of a ground feature and use the measured signature to identify a similar ground feature in another location or at another time. The simplest form of such a procedure was to use constant signatures that depended only on ground features. One objective of the signature extension analysis was to test the usefulness of such constant signatures.

The second major objective was to identify the sources of variability in the ERTS-1 data to understand how the signatures changed from scene to scene for a constant, unchanging target. Freshwater was selected as the test feature because of its homogeneity over large areas and its invariability over periods of time. Five water bodies were selected for ground-truth data acquisition, statistical training fields, and test sites. These bodies were Lake Houston, Lake Livingston, Sheldon Reservoir, Lake Somerville, and Steinhagen Lake (fig. 8-1).

8.2 ANALYTICAL APPROACH

The feasibility of extending spatial and feature classification was evaluated by analyzing 1972 ERTS-1 MSS data of the Houston Area Test Site. Atmospheric haze and Sun angle were evaluated because they can affect feature classification. The standard data set was the ERTS-1 MSS data for August 29, 1972, of Lake Houston, Lake Livingston, and Sheldon Reservoir. Extension data sets included the standard data set plus August 28 and 29 and October 3 and 4 data for Steinhagen Lake; October 4 and

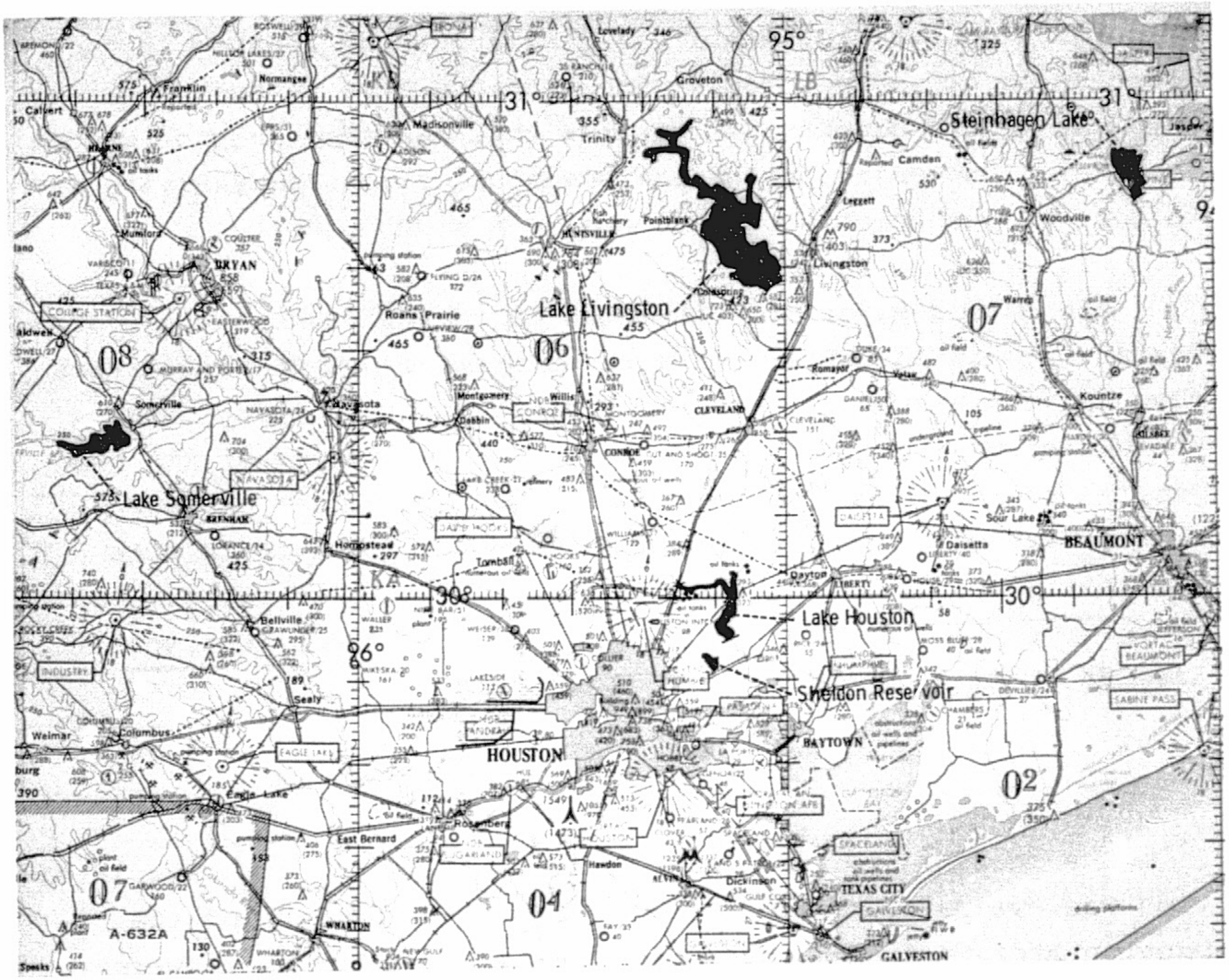


Figure 8-1.- Locations of water bodies.

November 27 data for Lake Livingston, Lake Houston, and Sheldon Reservoir; and July 25 and August 30 data for Lake Somerville.

Several degrees of extension in both time and distance were attempted, and the reasons for changes in classification performance were analyzed. Extensions from 1 day to 90 days were tried, and distances of nearly 160 kilometers (100 statute miles) could be evaluated within one ERTS-1 frame.

8.3 RESULTS

The following results were obtained.

1. The largest feature-dependent variable affecting spatial and short-term extension was water turbidity measured in parts per million of suspended solids. This parameter varied from 2 to 5 p/m in Lake Livingston and Lake Somerville to 90 p/m in Lake Houston and Steinhagen Lake.

2. Application of a semiparametric, untrained, discriminant technique (ISOCLS) to the ERTS-1 MSS data resulted in seven classes of water. These classes described the areas of Lakes Livingston and Houston and Sheldon Reservoir more than 0.6 meter (2 feet) deep.

3. Figure 8-2 is an example of the output obtained from ISOCLS for Lake Houston and Sheldon Reservoir. The shades of gray in the main portions of both sites indicate the five classifications of water that were obtained from these sites as a function of turbidity. Two more classes of water were similarly obtained from Lake Livingston. (Statistics are provided in table 8-I.)

4. Seven other classifications of water also were obtained from these three lakes as functions of shallow water, vegetation in the water, and the ratio of water to land in the picture element.

Figure 8-2.- The ISOCLS output for Lake Houston and Sheldon Reservoir.

5. The signatures of the five lakes were extended for the same day. The same lake signatures were extended for 36 and 90 days using a maximum-likelihood (LARSYS) technique. This is a parametric, trained classification method that includes the statistical means, variances, and covariances that describe each class. The normal operation of LARSYS involves selecting training fields from which the statistics are calculated. This approach did not work well, however, because training fields could not be found that yielded unimodal statistics and at the same time represented the various types of water in the lakes (fig. 8-3). Therefore, the types of water were determined using the previously mentioned ISOCLS technique and these statistics then were used in LARSYS to classify the water of the other lakes and subsequent data sets (fig. 8-4). With one exception, use of this type of extension (ranging from same-day coverage by ERTS-1

TABLE 8-I.- STATISTICS DERIVED FOR SEVEN TYPES OF WATER FROM ISOCLS

[MSS units, Aug. 29, 1972]

Water type	Mean value of MSS channel no.				Turbidity level	Site
	1	2	3	4		
1	35.3	29.7	17.1	3.2	Highest	Lake Houston (West Fork of San Jacinto River)
2	33.1	26.9	13.9	2.5	--	Lake Houston
3	32.1	24.7	14.4	2.5	--	Lake Houston
4	31.8	24.4	12.6	2.4	--	Lake Houston
5	26.6	18.2	12.9	2.9	--	Sheldon Reservoir and Lake Houston
6	23.5	12.9	9.1	1.8	--	Lake Livingston
7	23.2	12.8	7.5	1.1	Lowest	Lake Livingston

Figure 8-3.- The LARSYS output based on one training field and one type of water.

Figure 8-4.- The LARSYS output for October 4, 1972, data using ISOCLS statistics of August 29, 1972, data.

to 36 days later) revealed that the variations in atmospheric haze were insignificant in water classification, especially when considered with respect to the changes in the water caused by recent rain and wind disturbance. The exception was a relatively thick cirrus cloud that covered the western portions of Lake Somerville August 30, 1972. This cloud raised the radiance levels of that portion of the lake as much as 10 MSS units. Another possible exception, which was unverifiable, occurred on the August 28 and 29 coverages of Steinhagen Lake. The radiance of the lake was changed approximately three ERTS-1 MSS units over a 1-day period (table 8-II). At that time, no ground truth was being acquired from this site. Therefore, there was no way to be sure whether this change was due to atmospheric haze or some physical change such as increased wind. A ground-truth effort was established at this site, but the phenomenon was not recorded again. Special-purpose computer programs were developed to augment the available software in performing specific signature extension investigations.

TABLE 8-II.- STATISTICAL MEANS DERIVED USING ISOCLS FOR STEINHAGEN LAKE[a]

Water type	Aug. 28, 1972, channel no.				Aug. 29, 1972, channel no.			
	1	2	3	4	1	2	3	4
Least turbid	23.4	14.5	9.0	1.5	26.0	17.9	11.3	2.3
Most turbid	34.5	27.8	13.2	2.2	37.0	30.8	16.6	3.3

[a]Possible haze effect at same locations in lake.

6. The MSS data tapes received from GSFC had a cyclic striping related to the MSS sensors that was very evident when the data were displayed. A computer program was developed that eliminated this condition without affecting the data statistics.

7. A computer program was developed that made it possible to merge two strips of MSS data edge to edge, a significant accomplishment with regard to signature extension because in the satellite groundtrack, Lake Livingston always appears in two computer-compatible tapes.

8. A computer program was developed that enabled selection of specified picture elements and output of their respective data values in the four channels of the MSS.

9. A technique was developed that is much faster than LARSYS and ISOCLS for finding water in an ERTS image. In the linear discriminant technique for locating water, the data levels of only the first and last channels of a picture element from the MSS data are evaluated and a determination of whether that element is water is made. This technique was later used by the State of Texas for their water impoundment study for the National Program of Inspection of Dams.

10. The ISOCLS was modified to include a larger number of classes in the low-radiance region. This modification was necessary for a better evaluation of water, which has relatively low reflectances in all four channels.

8.4 CONCLUSIONS

The following conclusions can be stated.

1. A capability to do short-term temporal (same day to 36 days) and moderately long-term spatial (within and between three ERTS-1 MSS frames) signature extension has been verified with respect to large, relatively homogeneous features.

2. Ninety-day temporal signature extension for a single lake was degraded by the change of Sun angle. The lower Sun angle of late fall and winter caused the radiance levels of the five sites to decrease by as much as 10 MSS units, even in the green band, in which random changes are usually 1 to 2 units (table 8-III). No attempt was made to compensate for this type of change. Long-term signature extension would require modification of the ERTS-1 MSS data for significant changes of Sun angle. Therefore, a data bank of spectral signatures would have to be developed on a seasonal basis.

3. Normally occurring variations in atmospheric haze conditions appeared to have no major effect on the feature signatures in this study.

4. Haze changes the absolute signature significantly; however, in this investigation, it was always by the same amount and thus the measured signature of water was always the same.

TABLE 8-III.- THE MSS CHANNEL 1 (GREEN BAND) DATA LEVELS IN MSS UNITS

Site	Aug. 29, 1972	Feb. 25, 1973
Lake Houston (West Fork of San Jacinto River)	35.3	27.0
South-central Lake Houston	33.1	28.0
Inlet, northeast Lake Houston (cleanest water in lake)	26.6	21.0

5. The greatest difficulty in extending the signature of freshwater is caused by turbidity. To recognize a turbid body of water, the signature data must be derived from another body of water with similar turbidity.

Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas, November 20, 1974
641-14-07-50-72

APPENDIX A

ACKNOWLEDGMENTS

Organizations and activities furnished the Earth Observations Division (EOD) analysis teams with equipment, facilities, data, or consultation services that contributed materially to the success of the investigation. The assistance and information so generously provided by these activities are also gratefully recognized. Acknowledgment of these organizations and the types of assistance are noted as follows.

1. Agricultural Stabilization and Conservation Service - An integral part of the agriculture investigation was a data utilization experiment conducted with the participation of the Agricultural Stabilization and Conservation Service (ASCS) of the U.S. Department of Agriculture (USDA). The purpose of this experiment was to evaluate the usefulness of Earth Resources Technology Satellite 1 (ERTS-1) and aircraft data for identifying crop species, categories of land use, and field boundaries and for estimating crop and land use acreages. An important contribution to this evaluation was the establishment by the ASCS of a test program in 18 counties located in 15 states. Six areas, which represented a cross section of agriculture in the United States, were selected from the 18 counties for intensive study. Within each of these areas, smaller tracts were chosen for highly detailed ground-truth collection and examination. Ground-truth information was collected on an annual and a periodic basis by local ASCS/USDA personnel. These observations were recorded on a ground-truth summary form and submitted to the EOD analysis team. The information provided by the ASCS/USDA organization was an essential element in the analysis and evaluation.

2. The U.S. Forest Service - The National Forest Service of Texas provided a part-time member to the Forest Analysis Team.

Their assistance in providing selective ground-truth information from the Sam Houston National Forest is gratefully acknowledged.

3. The U.S. Army Corps of Engineers (Galveston District)

4. Rice University

5. The Texas Parks and Wildlife Commission provided a swamp-buggy ype vehicle to the EOD analysis team scientist for use in identifying wetland vegetation and other environmental parameters.

6. The National Oceanic and Atmospheric Administration provided a member to the EOD analysis team, in addition to providing a fluorimeter for use during the water surveys.

7. The Water Pollution Division of Texas A&M University furnished personnel, boats, and equipment to expedite the collection of water samples and related data.

8. The Soil Conservation Service, USDA EOD, provided a part-time member to the Range Analysis Team and also furnished ground-truth information and interface services with private ranch owners in the test area.

9. The Public Works Department, City of Houston, provided the Signature Extension Team with information on the source and types of water inflow into lakes and dams, vegetation types, turbidity data, historical information, physical properties of lakes and dams used in the analysis, and other data affecting this portion of the investigation.

10. The Trinity River Authority of Texas provided boats and the services of personnel in conducting surface surveys and acquiring data, in addition to providing laboratory facilities.

The following personnel of the ERTS-1 investigation, EOD, Lyndon B. Johnson Space Center (JSC), have made significant contributions to the processing and analysis of the data contained in the main body of this document, either in its preparation or

in managing the various aspects and activities that have culminated in this report: Dr. J. E. Dornbach, coinvestigator, JSC; G. E. McKain, Project Manager, EOD ERTS-1 Project, JSC; Dr. S. B. Cousin, Manager, Lockheed Electronics Company, Inc. (LEC), ERTS-1 Project Office; D. B. Avery, LEC; R. M. Bizzell, JSC; J. R. Donaldson, LEC; G. E. Graybeal, JSC; F. J. Herbert, JSC; T. M. McPherson, JSC, ERTS-1 Project Management Team; D. W. Annis, U.S. Coast Guard; Dr. L. M. Flores, LEC; G. L. Kraus, JSC; R. L. Nance, JSC; H. L. Prior, JSC; M. L. Ratcliff, LEC; L. D. Schulze, LEC; B. E. Spiers, ASCS, Agriculture/ASCS Analysis Team; Dr. S. B. Hixon, LEC; Dr. J. F. Paris, LEC; C. A. Reeves, LEC; R. J. Thoben, JSC; Dr. J. B. Zaitzeff, National Oceanic and Atmospheric Administration; Dr. E. A. Weisblatt, LEC, Coastal/Estuarine Analysis Team; J. F. Beal, U.S. Forest Service; N. J. Clinton, LEC; G. R. Heath, LEC; W. A. Kunkel, LEC; R. Pinter, LEC; J. E. Weaver, LEC, Forest Analysis Team; J. M. Disler, LEC; Dr. E. P. Kan, LEC; Dr. H. D. Parker, LEC; D. Pendleton, Soil Conservation Service; A. Simon, LEC, Range Analysis Team; A. C. Anderson, LEC; C. A. Helmke, LEC; W. A. Holley, LEC; A. A. Holth, LEC; C. J. Liszcz, LEC; F. W. Solomon, LEC, Signature Extension Team; W. P. Bennett, LEC; Dr. C. M. Chestnutwood, JSC; V. L. Cook, LEC; J. G. Garcia, JSC; H. V. Johnson, LEC; M. A. Lundelius, LEC; D. P. McGuigan, LEC; S. H. Tunnell, LEC, Urban/Land Use Analysis Team.

APPENDIX B

GLOSSARY OF TERMS, ABBREVIATIONS, AND ACRONYMS

across-track - across the direction of the spacecraft groundtrack, sometimes called horizontal when referring to output product coordinates

ACV - additive color viewer, a device enabling the color enhancement of one or more black-and-white images of the same scene by film density slicing and/or additive color procedures

ACVP - additive color viewer printer, an ACV that incorporates a photographic printing device

ADP - automatic data processing, such as computer-aided computation

along-track - in the direction of the spacecraft groundtrack, sometimes called vertical when referring to output product coordinates

ASCS - Agricultural Stabilization and Conservation Service, an agency of the U.S. Department of Agriculture

CCT - computer-compatible tape containing digital ERTS-1 data. The tapes are standard 1.27-centimeter (0.5 inch) wide magnetic tapes in 9-track or 7-track format. Four CCT's are required for the 4-band multispectral digital data corresponding to one scene in the ERTS-1 images.

clustering - a mathematical procedure for organizing multispectral data into spectrally homogeneous groups. Clusters require identification and interpretation in a postprocessing analysis. Both ISOCLS and NSCLAS are spectral clustering programs.

contrast - the ratio of two adjacent scene radiances expressed as a number equal to or greater than one

DAS - data analysis station, a computer system consisting of tape drives and computer, a display and control console, and a film recorder. The DAS is used to reformat, analyze, and review digital remotely sensed data.

EOD - Earth Observations Division of the NASA Lyndon B. Johnson Space Center, Houston, Texas

EREP - Earth resources experiment package consisting of the Earth resources remote sensors mounted on the Skylab spacecraft

ERIPS - Earth Resources Interactive Processing System, a JSC system that allows real-time interaction by an investigator with several digital spectral analysis procedures. Major subsystems include pattern recognition by maximum-likelihood classification, image registration, image composition, image manipulation, and display.

ERTS-1 - the first Earth Resources Technology Satellite. The ERTS-1 was launched into a circular, Sun-synchronous, near-polar orbit at an altitude of approximately 915 kilometers (494 nautical miles) in June 1972. It orbits the Earth 14 times a day and views the same scene every 18 days.

geometric accuracy, geographic (latitude-longitude) - based on the standard Earth-fixed coordinate reference system, which employs latitude and longitude

geometric accuracy, positional - the capability to locate a point in an image with respect to a map

grayscale - a scale of gray tones between white and black broken into an arbitrary number of segments. The ERTS-1 images have a 15-step grayscale exposed on every frame of imagery. The scale gives the relationship between the gray level on the image and the electron beam density used to expose the original image.

ground-control point - any point that has a known location on the Earth surface and can be identified in ERTS imagery

GSFC - NASA Goddard Space Flight Center, Greenbelt, Maryland

GSFC color composite - color composite of three channels of ERTS-1 MSS digital data supplied to users by GSFC. They are third- or fourth-generation images as compared with first-generation composites produced from CCT's using a film recorder.

HATS - Houston Area Test Site encompassing 18 counties in southeast Texas. Houston is the primary urban area in the test site.

image skew - image distortion caused when the scan of the sensor is not perpendicular to the plane formed by the spacecraft and the instantaneous groundtrack velocity vector

IR - infrared

irradiance - the amount of energy impinging upon a unit normal surface, per unit time, per unit wavelength, per unit solid angle

ISOCLS - Iterative Self-Organizing Clustering System, a computer program developed at JSC that uses a clustering algorithm to group homogeneous spectral data. Several controlling inputs allow investigators to control the size and number of clusters. Because the system produces a classification-type clustering map in which clusters require postprocessing identification and interpretation, the system is frequently referred to as a nonsupervised classification system.

JSC - NASA Lyndon B. Johnson Space Center, Houston, Texas

λ - lambda, the Greek symbol used to designate a wavelength of the electromagnetic spectrum

LARSYS - the name designating the set of classification programs developed at the Laboratory for the Applications of Remote Sensing (LARS) at Purdue University

maximum-likelihood ratio - the maximum-likelihood ratio in remote sensing is a probability decision rule used to classify a target from multispectral data. Two types of errors are feasible: failure to classify the target correctly and misclassification of background as the target. In its simplest form, the likelihood ratio is P_t/P_b or the probability P of an unknown spectral measurement being classified as target t, to the probability of an unknown spectral measurement being classified as background b. When $P_t/P_b \geq 1$, the decision is t; when $P_t/P_b < 1$, the decision is b. Probability density functions are computed from spectral samples, often referred to as training samples. As the number of training samples increases, the mathematical computations of the maximum-likelihood ratio increase in complexity. As a result, digital computer analysis is required, and the entire process is referred to as automatic data processing (ADP) of multispectral remotely sensed data, or automatic spectral pattern recognition of multispectral remotely sensed data.

MCFV - multichannel film viewer, a device used to electro-optically enhance several bands of black-and-white imagery of the same scene. Enhancement is achieved through film density slicing and/or additive color viewing.

MSDS - multispectral data system, which includes an aircraft 24-channel scanner and a ground data analysis station. The latter is one of the two major data analysis stations in the EOD/JSC Data Analysis Laboratory. (See DAS.)

MSS - multispectral scanner system, sometimes referred to simply as the multispectral scanner; usually refers to the operational scanning system on ERTS-1

MTFO - module training-field option, a supervised computer-aided technique using the LARSYS classifier to allow modification of the statistical inputs

multispectral scanner spectral bands - the division of the visible and near-infrared portions of the electromagnetic spectrum into discrete segments

MSS channel	ERTS-1 band	Wavelength, nm	Spectral segment
1	4	500 to 600	Green
2	5	600 to 700	Red
3	6	700 to 800	Reflective
4	7	800 to 1100	infrared

nautical mile - equivalent to 1/60° at the Earth Equator, or approximately 1852 meters (6076 feet)

nonsupervised classification - a procedure by which spectral data are grouped into homogeneous clusters. Identification and interpretation are achieved in a postprocessing analysis.

NSCLAS - the name of a clustering computer program developed by the Laboratory for the Application of Remote Sensing at Purdue University (See clustering.)

pixel - picture element, refers to one instantaneous field of view (IFOV) as recorded by the multispectral scanning system. On the ERTS-1 system, a pixel is equivalent to approximately 0.44 square hectometer (1.09 acres). One ERTS-1 frame contains approximately 7.36×10^6 pixels, each described by four radiance values.

radiance - a measure of the radiant energy emitted by a radiator in a given direction

reflectance - the ratio of the radiance of the energy reflected from a body to that incident upon it; commonly measured in percent scene registration - the capability to superimpose points on two images of a scene taken at the same time

SHNF - Sam Houston National Forest, located in the Houston Area Test Site

spectral response - the spectral radiance of an object sensed at the satellite and recorded by the multispectral scanner system

Sun azimuth angle - angle in degrees measured in the horizon plane from true north to a vertical circle passing through the Sun

Sun elevation angle - angle of the Sun above the horizon measured in degrees

supervised classification - a classification procedure in which data of known classes are used to establish the decision logic from which unknown data are assigned to the classes. The ADP supervised classification procedure used at JSC during the ERTS-1 project incorporated a Gaussian maximum-likelihood decision rule.

swath path - the dimension on the ground scene transverse to spacecraft velocity and within the sensor field of view

system-corrected images - film images generated by a data-processing subsystem that makes initial radiometric and geometric corrections as the video-to-film conversion images are recorded on 70-millimeter film through an electron beam recorder; formerly referred to as bulk images temporal - that which exists in the physical world as it relates to time

temporal registration - the capability to superimpose two images of the same scene taken at different times (same or different spectral bands)

test field - the spatial sample of digital data of a known ground feature selected by the investigator used to validate the statistical parameters generated from training field samples

threshold - the boundary in spectral space beyond which a data point (pixel) has a sufficiently low probability of being included in a given class and, therefore, is purposely excluded from that class

training field - the spatial sample of digital data of a known ground feature selected by the investigator from which the spectral characteristics are computed for use in supervised multispectral classification of remotely sensed data. The statistics associated with training fields form the input to the maximum likelihood ratio computations and, in a sense, "train" the computer to discriminate between samples.

USDA - U.S. Department of Agriculture

USGS - U.S. Geological Survey of the Department of the Interior

UTM grid - Universal Transverse Mercator grid, a rectangular coordinate system derived from a transverse mercator projection by which points or areas on the Earth surface can be readily described and located within a unique quadrilateral area on a map. Precision processing of the ERTS-1 imagery corrects the imagery scene by scene so that its geographic orientation will conform to this UTM grid system.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1975 — 673-135