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MONTEREY BAY STUDY

BIZZELL AND WADE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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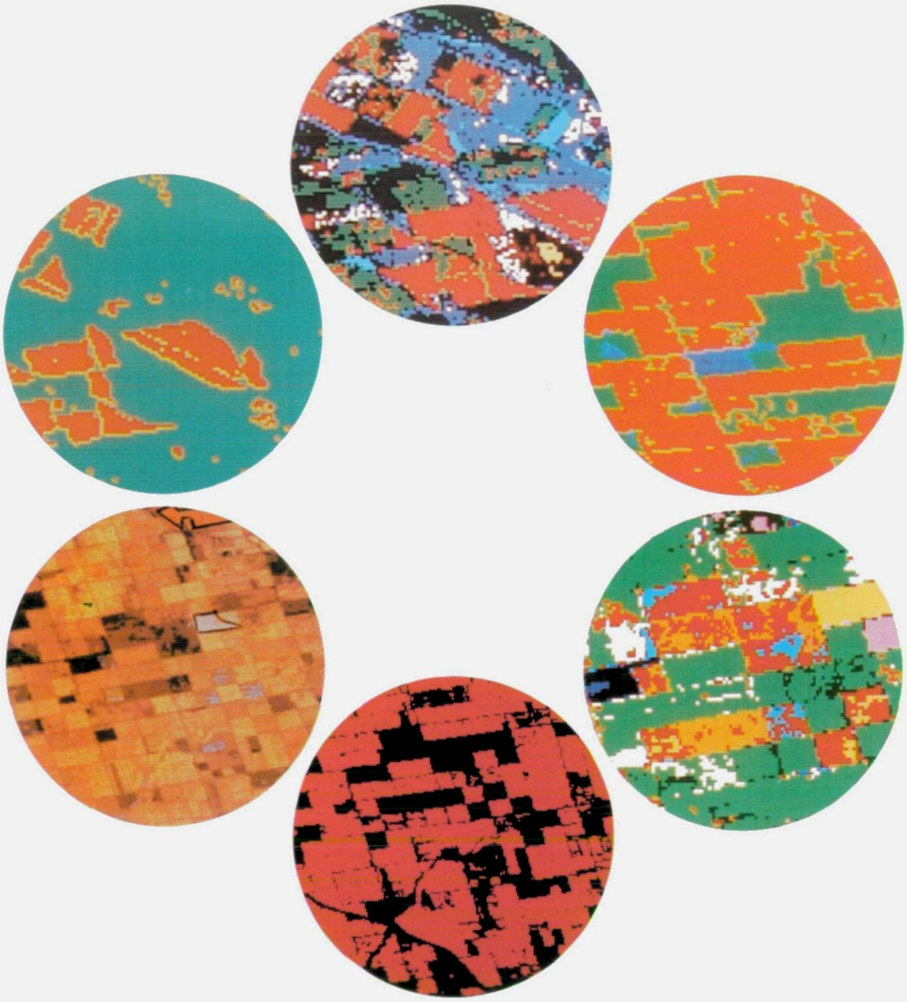

MONTEREY BAY STUDY

by

Robert M. Bizzell and Lewis C. Wade
Lyndon B. Johnson Space Center

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FOREWORD

An initial test of the multispectral scanner capabilities of the Earth Resources Technology Satellite-1 (ERTS-1) was performed in mid-1972 over California's Monterey Bay area and portions of the San Joaquin Valley. Using both computer-aided and image-interpretive processing techniques, the ERTS-1 data were analyzed to determine their potential application in terms of land use and, especially in this case, agriculture.

This report by Robert M. Bizzell and Lewis C. Wade of the Earth Observations Division at NASA's Lyndon B. Johnson Space Center gives ample evidence of that potential. Utilizing ERTS-1 data, analysts were able to provide the identifications and areal extent of the individual land-use categories ranging from very general to highly specific levels (e.g., from agricultural lands to specific field crop types and even the different stages of growth).

The Monterey Bay Study provides us with another manifest example of how the NASA earth satellite programs can have immediate benefits to those of us on earth. Given its demonstrated capabilities, it is easy to imagine the ERTS system being used for the identification of major crop species and the delineation of numerous land-use categories on a global basis. Repeated surveillance would permit the monitoring of changes in seasonal growth characteristics of crops as well as the assessment of various cultivation practices with a minimum of onsite observation. Thus, ERTS is a valuable addition to our technologies to improve the planning and development of resource programs on earth.

Anthony J. Calio
Director of Science and Applications
Lyndon B. Johnson Space Center

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INTRODUCTION

Data for Monterey Bay, California, were the first ERTS-1 multispectral scanner (MSS) data to be received at NASA's Lyndon B. Johnson Space Center (JSC). The JSC Earth Observations Division's ERTS project was focused on the Houston area test site, but data from that area were not expected for another 6 to 8 weeks. Thus, the Monterey Bay data allowed JSC to accomplish the following preproject general objectives:

(1) Cursory evaluation of the utility of satellite-acquired multispectral data in terms of discipline-oriented applications

(2) Checkout of the JSC earth resources computer-aided and image-interpretive data processing facilities

(3) Definition and development of the initial analysis techniques and procedures necessary to support the ERTS project

(4) Familiarization and orientation of the project analysis teams

ANALYSIS

Although both computer-aided and image-interpretive techniques were used independently in the analysis of the two study areas outlined in figure 1, each technique was directed toward land-use application objectives. Study Area I (46 by 185 km) consists of one complete ERTS-1 system-corrected computer-compatible tape (CCT). Study Area II —approximately 23 by 38 km—lies in the agricultural region of the San Joaquin Valley.

The classification scheme incorporated was defined by an ad hoc committee of personnel from selected universities and the U.S. Geological Survey. The Level I, II, and III classifications as published by Anderson, Hardy, and Roach[1] are shown in table I.

Study Area I

Image interpretation. The image-interpretive phase of the investigation was conducted first. Three different photographic sources were used: a false color infrared (IR) image from Goddard Space Flight Center (GSFC) using band 4 (0.5 to 0.6 μm), band 5 (0.6 to 0.7 μm), and band 7 (0.8 to 1.1 μm); an image reconstructed from the digital CCT using an Earth Observation Division data analysis station (DAS) and bands 4, 5, and 7; and a DAS image generated by computer-aided processing.

Basic image-interpretation equipment included tube magnifiers, zoom microscopes, and rear projection viewers. In addition, 1:250 000-scale topographic maps were used, and a small percentage of high-resolution aerial photography was used for verification after analysis.

[1]Anderson, James R.; Hardy, Ernest E.; and Roach, John T.: *A Land-Use Classification System for Use With Remote Sensor Data.* Geological Survey Circular 671, U.S. Geol. Survey, 1972.

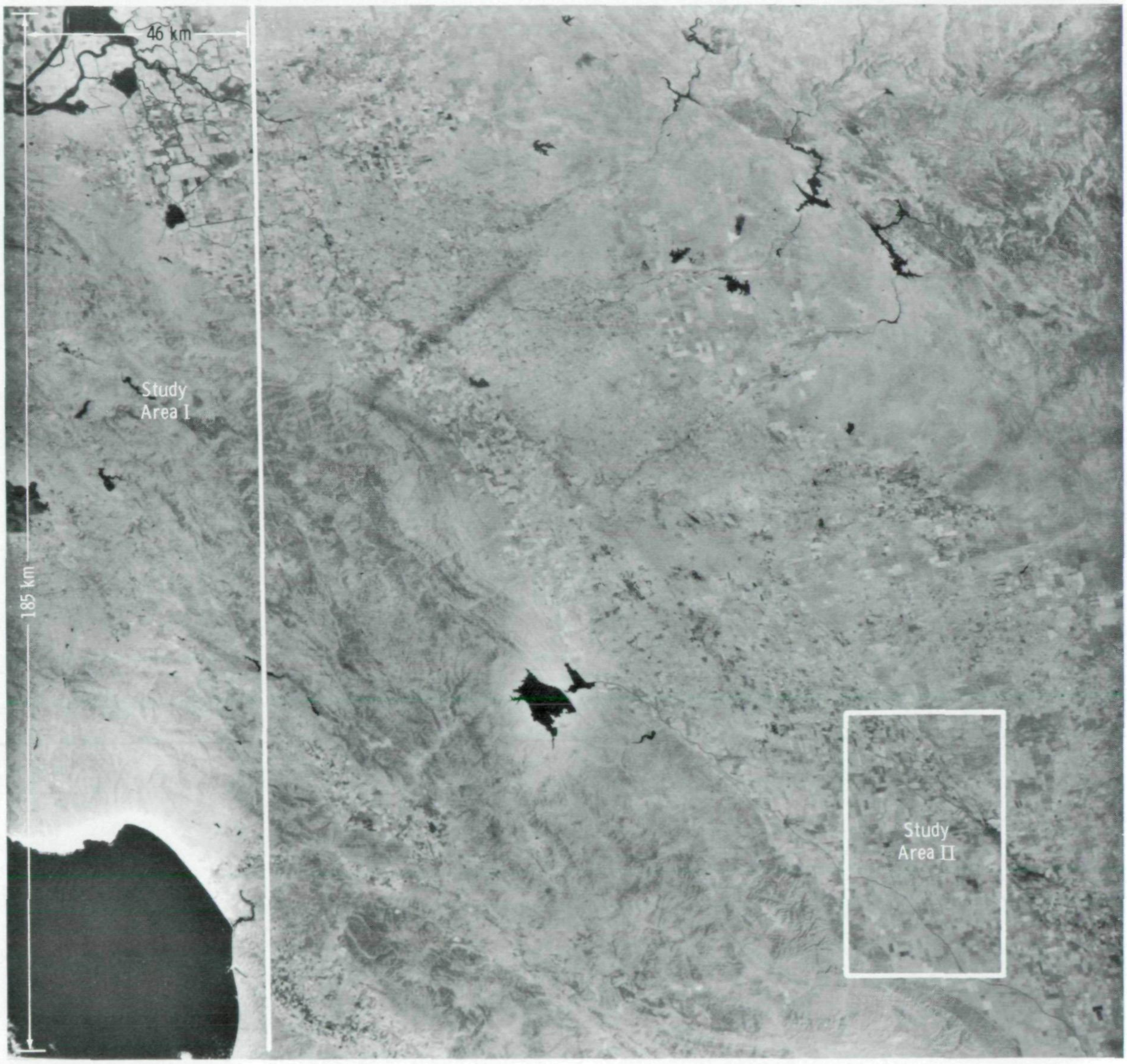

Figure 1.—*Black and white photograph of a complete ERTS-1 frame (185 by 185 km) from MSS band 5 over the Monterey Bay area.*

The purpose of the land-use analysis was to determine Level I land-use classifications at a scale of 1:1 000 000, using the manual techniques of image interpretation. Some of the problems encountered in Level I land-use classifications are given in table II.

The interpretation effort was used only in Level I classifications because of the detail (data content) available in the imagery. The analysis and mensuration phases each required approximately 8 man-hours for completion. A comparison of the classifications in figure 2 (obtained from the ERTS-1) with the same classifications on high-resolution data is shown in table III.

Categories of the Level II classification were delineated from a DAS transparency. The resolution of this imagery was good. Streams, major transportation routes, high and low forest densities, agricultural regions, and urban centers were identified rather easily. Scattered urban developments, especially those surrounded by agricultural areas or bare sandy

TABLE I. —*Land-Use Determination*

Level I	Level II			Level III
			Phase I	
01 Urban and built-up (U)	0101	Ur	Residential[a]	
	0102	Uc	Commercial and services[a]	
	0103	Ui	Industrial[a]	
	0104	Ue	Extraction	
	0105	Ut	Major transportation routes and areas[a]	
	0106	Uk	Institutional	
	0107	Us	Strip and clustered settlement	
	0108	Um	Mixed[a]	
	0109	Uo	Open and other	
02 Agriculture (A)	0201	Ac	Cropland[a]	
	0201	Ap	Pasture[a]	
	0202	Ao	Orchards, vineyards, and groves[a]	
	0203	Af	Feeding operations	
03 Rangeland (R)	0301	Rg	Grass[a]	
	0302	Rs	Savannas	
	0303	Rc	Chaparral	
	0304	Rd	Desert shrub	
04 Forest land (F)	0401	Fh	Heavy crown cover (40 percent and over)[a]	
	0402	Fl	Light crown cover (10 to 39 percent)[a]	
05 Water (W)	0501	Ws	Streams and waterways[a]	
	0502	We	Lakes[a]	
	0503	Wr	Reservoirs[a]	
	0504	Wb	Bays and estuaries[a]	
06 Nonforested wetlands (N)	0601	Nv	Vegetation[a]	
	0602	Nb	Bare[a]	
07 Barren land (B)	0701	Bf	Salt flats	
	0702	Bs	Sand other than beaches[a]	
	0703	Br	Bare exposed rock	
	0704	Be	Beaches[a]	
	0705	Bo	Other	
08 Tundra (T)	0801	T	Tundra	
09 Permanent snow and icefields (P)	0901	P	Permanent snow and icefields	
			Phase II	
02 Agriculture (A)	0201	Ac	Cropland	Rice Barley stubble Burned barley stubble

[a]delineated for the Monterey Bay scene.

Figure 2. —*Color composite of ERTS-1 scene with interpreted land-use classifications.*

areas, could not be easily delineated. A small area of clouds near the city of Monterey is shown in figure 2.

Seven of the nine Level I categories were easily delineated. It should be noted that the other two categories, tundra and permanent snow and icefields, are not found in this particular region; however, areas of snow and ice should be easily recognized. Nineteen Level II categories were defined (fig. 3 and table I).

After the initial analysis and classification of the Monterey Bay imagery, Army Map Service 1:250 000- scale topographic maps and a 1:250 000-scale photomosaic of RC8 photography obtained in March 1971 were used for verification purposes. After the analysis of the color-enhanced image was completed, a computer-aided classification map (fig. 4) was analyzed. A Level I classification could be accomplished with little or no difficulty.

TABLE II.—*Problems Encountered in Level I Land-Use Classifications*

Classification	Area, km2	Comments
01 Urban and built-up	854	Small towns appear as barren land within the agriculture scene. Intercity and intracity transportation arteries or patterns are the most obvious characteristics.
02 Agriculture	9 347	Crops are very easy to delineate as long as the growth is green, the field is well defined, and the section boundaries are visible. Crops are difficult to classify when the fields are small or sparsely located.
03 Rangeland	7 916	Dull rust color of land causes difficulty in separating rangeland from forest land. Primarily, chaparral and desert shrub-range grass are brown (natural color) at this time of year (July).
04 Forest land	4 746	Forest land, like agriculture, is easy to classify because of the bright red tone of mature dense forest canopy. Graduation from forest stands to shrub rangeland makes placement of forest/range boundary difficult.
05 Water	197	Deep blue-black small linear lakes are hard to delineate because of shape and size. Small areas of wetlands could be misclassified as small lakes or reservoirs.
06 Nonforested wetlands	20	Only one area is classified in this category.
07 Barren land	4 611	Areas are void of all other classifications (vegetation, urban, water, etc.).
08 Tundra	0	None are present.
09 Permanent snow and icefields	0	None are present.
	27 691	

TABLE III.—*Interpreted Accuracy of Boundary and Area Identifications by Comparison With High-Resolution Data*

Classification	Boundary agreement	Area agreement, percentage difference
GSFC ERTS-1 color IR image		
Water area (lower San Francisco Bay)	Excellent	3
Urban area (San Jose area)	Good	20
Color IR image generated, enlarged, and enhanced by a DAS		
Urban area (San Jose area)	Very good	7

The major difficulty encountered was the defining of urban complexes, especially those with large residential areas intermixed with agricultural and range regions. Some Level II features could be recognized, such as major streams, lakes, intensive and broad agricultural cropland regions, some major transportation routes, and forest regions with dense crowns. Annotation of Level II categories on this imagery was not attempted; because the analyst had prior knowledge of the area, he was able to perceive an image that would be foreign to an analyst unfamiliar with the region. It should be noted that some type of topographic map is essential in delineating land-use categories on imagery generated from clustered spectral data.

Computer-aided processing. Computer-aided processing of the data was inititated during the image-interpretive phase of the investigation to evaluate the ability of computer-aided pattern recognition techniques to extract the defined land-use categories from the data.

To yield accurate classifications, the computer must be "trained" to recognize each of the categories by examining the digital data in each band. Such training is accomplished in either of two ways:

(1) Unsupervised classification: all data values that are spectrally similar are clustered. For example, all samples of corn will describe a unique cluster. After the required clusters have been defined, the defining parameters (means and covariance matrices) provide input to an automatic pattern recognition routine, thus making it possible to determine which other points in the data set belong to each cluster.

(2) Supervised classification: after known "training" fields are defined to the computer, all the data are submitted to the automatic pattern recognition routine for classification.

The main difference between these two methods is that the supervised technique requires a priori ground truth to operate, while the unsupervised technique does not. However, for error analysis, some ground truth would be required to correlate clusters to known ground features after classification.

Because of the lack of ground truth, the clustering approach was used in Study Area I. The area is described on the digital CCT by scan lines 1 through 2340 and samples 1 through 809. A comparison of the areas contained in figures 1 and 5 reveals a distortion across a scan line (east/west). This effect, created in the sensor data acquisition and subsequent digitization processing on the ground, distorts a square (such as a city block) so that it appears as a rectangle on the image reconstituted from the digital data. The effect was removed in subsequent output products generated by GSFC. However, because this study did not require accurate spatial information, the distortion did not significantly affect the analysis. In fact, the digital CCT maintained the highest fidelity of radiometrically (spectrally) correct ERTS-1 MSS data.

Results of the unsupervised pattern recognition analysis of Study Area I are shown in figure 5. The equivalent ground area related to each of the features described is shown in table IV. Values were computed by a pixel (picture element) count and by conversions to ground equivalent units. An indication of their probable accuracy can be derived from the results of an experiment conducted in Study Area II.

Evaluation of this first attempt to process ERTS MSS digital data led to the following conclusions:

(1) The ERTS system-corrected MSS digital data did contain data that could be transformed into information of user interest.

(2) Using automatic processing pattern recognition techniques, the data were transformed from the digital form to a user-related format (e.g., hard-copy recognition maps, listings of data-point assignments, and equivalent ground units). Thus, additional interpretation or analysis could be performed to achieve applications criteria (i.e., the Level I and Level II land-use categories).

(3) All results were achieved without the benefit of on-the-scene ground observations.

Although the analysis was successful, it would be difficult to provide adequate verification that a reasonable measure of reliability was achieved (i.e., whether the discerned land-use categories were real). This basic concern made it imperative that some type of actual performance evaluation be conducted. Obviously, the evaluation could not be exhaustive, but it was important that the investigation be meaningful and essentially thorough. Additionally, once Level I and Level II data categories had been extracted, could the analysis be continued? These considerations led to the analysis of Study Area II, Delta Mendota (figs. 1 and 6).

Figure 3a. —*Computer-aided enhanced color composite of portions of Monterey Bay scene showing 19 Level II Categories. (Top)*

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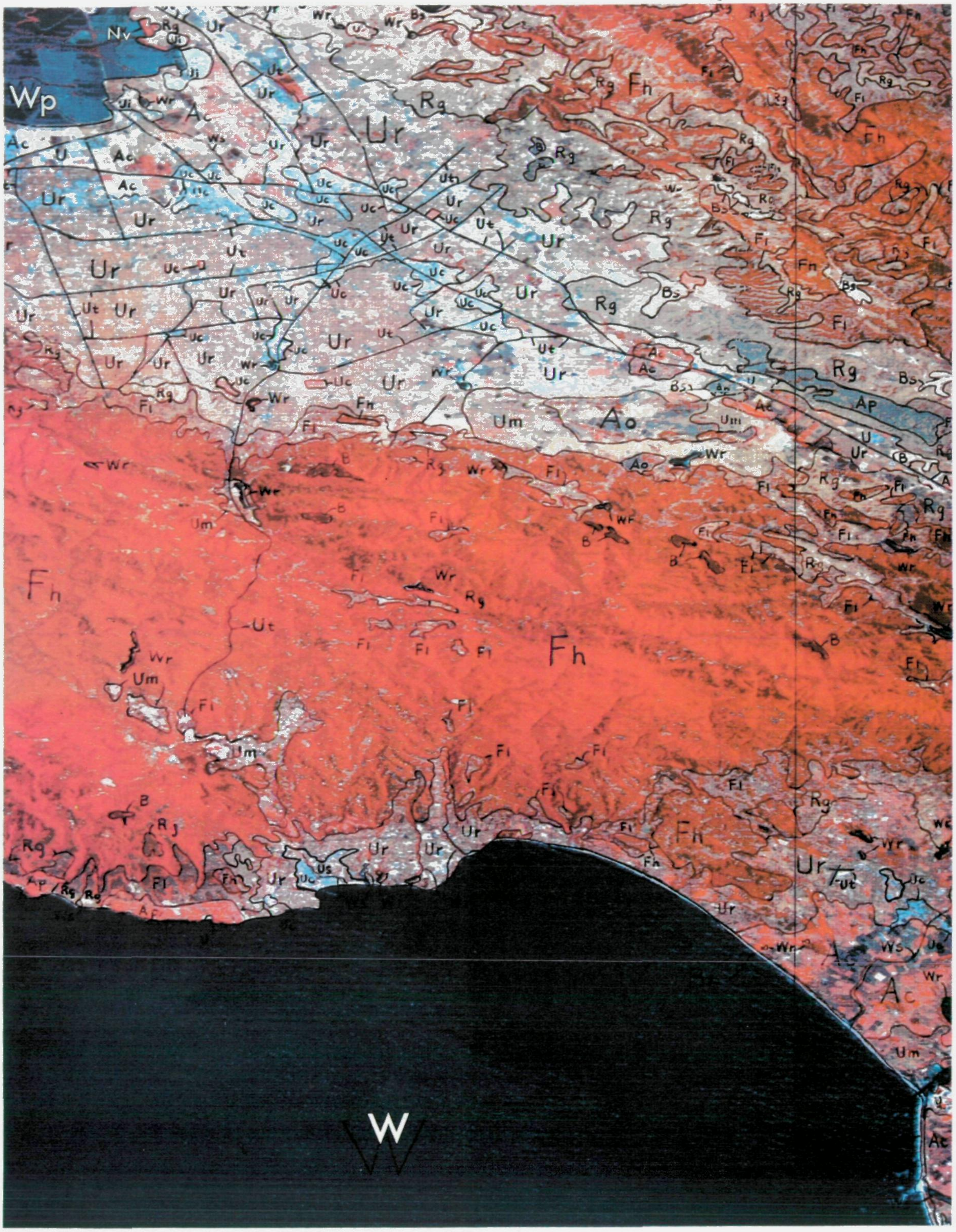

Figure 3b. —*Computer-aided enhanced color composite of portion of Monterey Bay scene showing 19 Level II categories. (Bottom)*

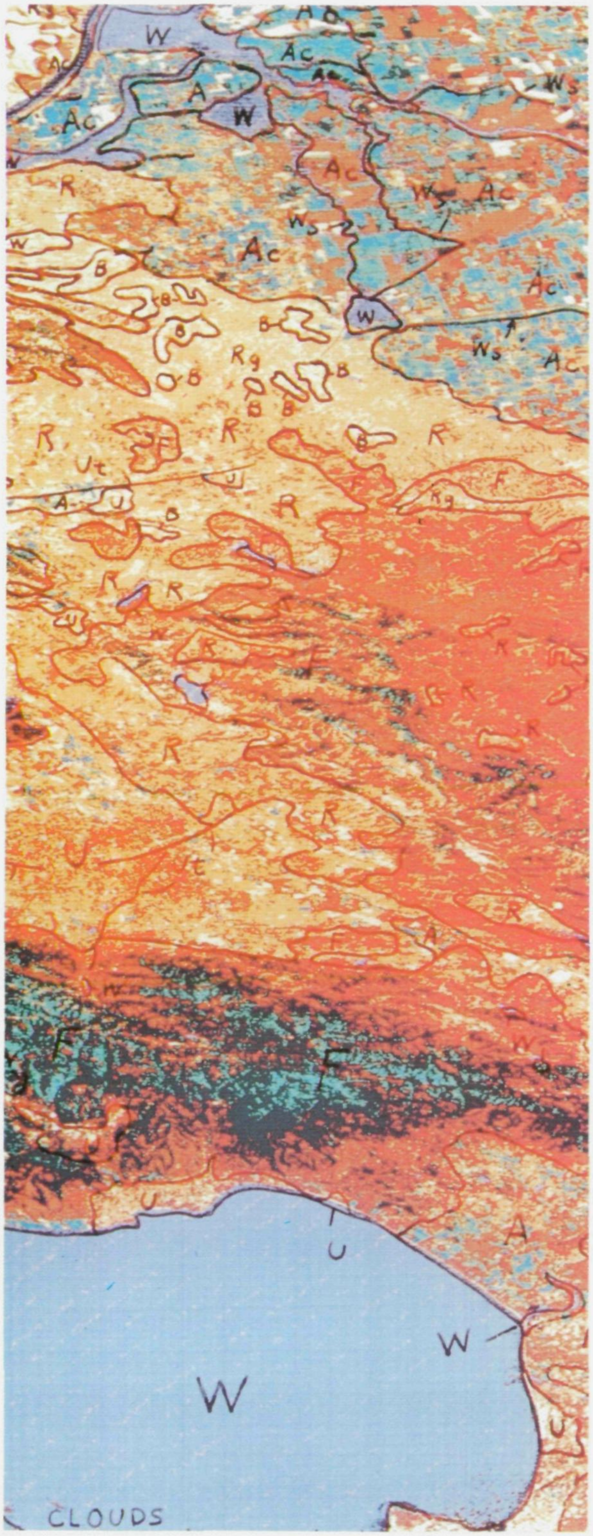

Figure 4.—*Image interpretation of a computer-aided unsupervised classification.*

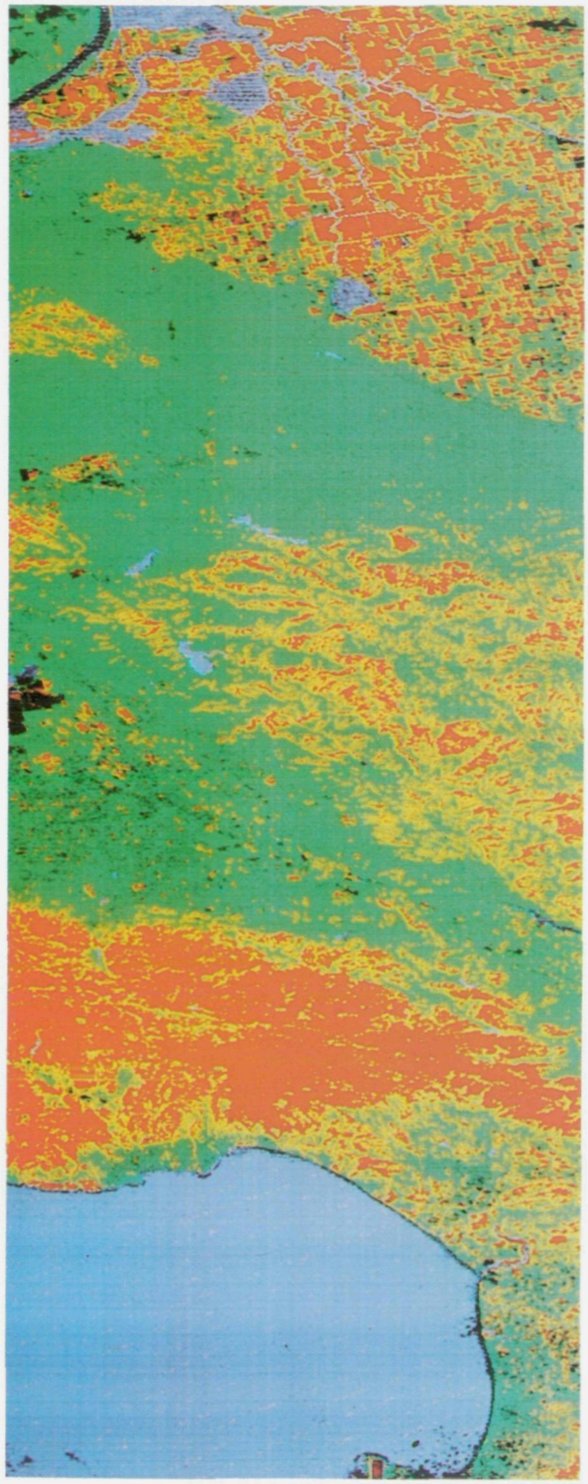

Figure 5.—*Color-enhanced image of Study Area I (fig. 1) showing results of unsupervised pattern recognition analysis (blue—water; red—vegetation; green—nonvegetation; black—other).*

TABLE IV.—*Equivalent Ground Units for Figure 5*

Feature	Pixels	Percent of total area	Equivalent ground units[a]		m^2
			km^2	acres	
Nonvegetation	1 022 252	54	4637	1 145 822	4 636 912 470
Vegetation	416 473	22	1888	466 816	1 889 110 989
Water	340 751	18	1545	381 941	1 545 638 839
Other	113 584	6	512	127 314	515 214 295
Total	1 893 060	100	8582	2 121 893	8 586 876 593

[a]Conversion from pixels to square kilometers and acres is based on a value of approximately 221 pixels/km^2 and 1.1208 acres/pixel.

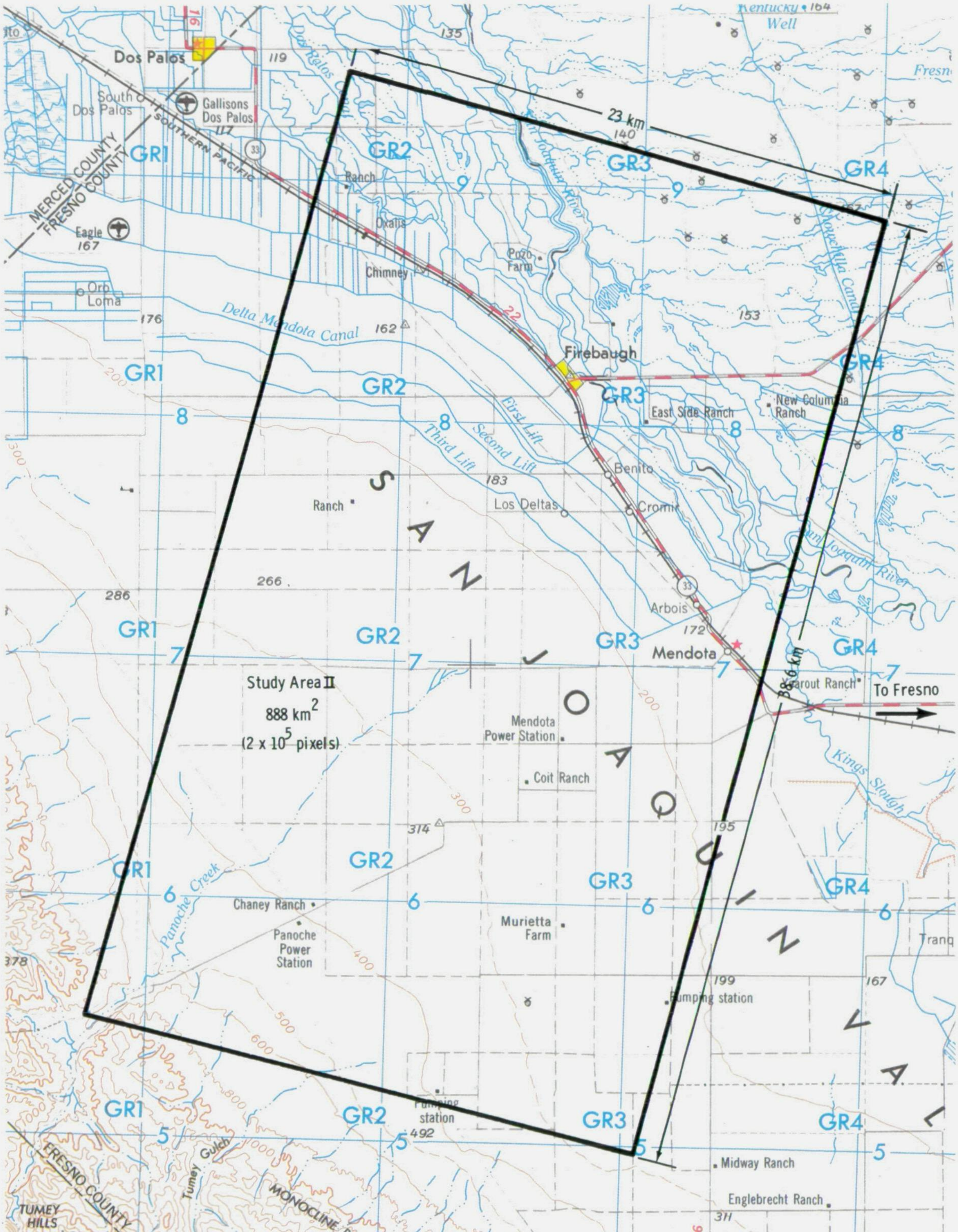

Figure 6. —*Color map showing location of Study Area II, Delta Mendota.*

Study Area II

Study Area II (23 by 38.6 km), consisting of 500 scan lines with 400 samples per scan line, lies in one of the major agricultural regions of the San Joaquin Valley. A higher level of detail on land use (e.g., the actual detection and identification of individual crop types) was the basic objective. The selection of an agriculturally related analysis was less than arbitrary. Many of the JSC earth resources future plans are correlated with the investigation of the utility of remote sensing for providing information relevant to the agricultural application. The availability of data over an agricultural area such as the San Joaquin Valley also made this a natural selection.

To gain a measure of success regarding the accuracy of results, it was necessary to secure actual ground-truth information. This information was obtained through the cooperation of Anderson, Clayton and Company, which owns and operates a large farming network involved in the use of remote sensing as an operational management aid. Monthly aerial photographic missions are currently being flown over the company's fields. The company uses an evaluation of the acquired photography to make decisions regarding the planning, scheduling, and implementation of operations to be performed on a per-field basis.

Figure 7 is an example of some of the actual photography taken on July 13, 1972, over the company's Spring Creek Ranch, which lies within Study Area II and from which the ground-truth information was extracted. Figure 8 is a map of the area annotated with the crop type growing in each field belonging to Anderson, Clayton and Company, Where known, the crop condition has been indicated on the map.

To accomplish overall objectives in a reasonably short period of time, the following decisions were made on completion of the initial examination of the ground-truth information.

(1) Crop-type discrimination: to discriminate between crop types on the ERTS-1 data, a study was begun in which all efforts were concentrated on one specific crop. Rice was selected because of the number of known ricefields available and because rice is one of the major crop types within the Delta Mendota. As indicated in figure 9, rice is a warm-weather crop with a 120- to 175-day growing season. Thus, in late July, the rice crop was basically in its midstage of growth and was, supposedly, fairly uniform between fields.

(2) Detection of cultivation practices: the ground-truth information revealed that one crop, barley, was in the process of undergoing change in local farming priorities. Unfortunately, there were no known mature barleyfields in the study area. However, barley was found in three distinct phases that were selected for further analyses and performance evaluation:

(a) Barley stubble: the remains of a mature barleyfield after undergoing harvesting operations.

(b) Burned barley stubble: the common practice of burning off the harvest.

(c) Plowed-under barley: the preparation of the barleyfields for the next season's crop. In the case of the turned fields, it would be highly improbable to discriminate between a plowed-under barleyfield and a plowed-under wheatfield, and it was not the objective of this exercise to do so. The objective was to detect the condition of the known fields at the time of the ERTS-1 overpass (July 25, 1972) and to compare this condition with that acquired at the time of the ground-truth acquisition (July 13, 1972). This comparison should indicate the ability of ERTS-1 to monitor and provide an accurate history of temporal farming practices.

(3) Mensuration accuracy: an exercise was conducted to determine how efficiently the extent of a crop type could be measured. A few selected fields of various dimensions were studied after they had been detected and identified. Both computer-aided and conventional interpretation techniques were evaluated. The baseline or control data were generated in-house using the best high-resolution aerial photography available.

Image interpretation. Within the image-interpretation phase, four different images were analyzed. The first was a black-and-white image of MSS band 5, the red band. The triangular-shaped rice training field shown in figure 10 was used as a key in searching the entire study area for fields having a similar dark tone. Within the study area, 19 fields or groups of contiguous fields were identified as rice. Limited ground truth was available in the study area. The two known ricefields, in addition to the training field, were correctly identified by using this one black-and-white image. No attempt was

Figure 7.—*Aerial photograph taken on July 13, 1972, of Anderson, Clayton and Company's Spring Creek Ranch in Study Area II.*

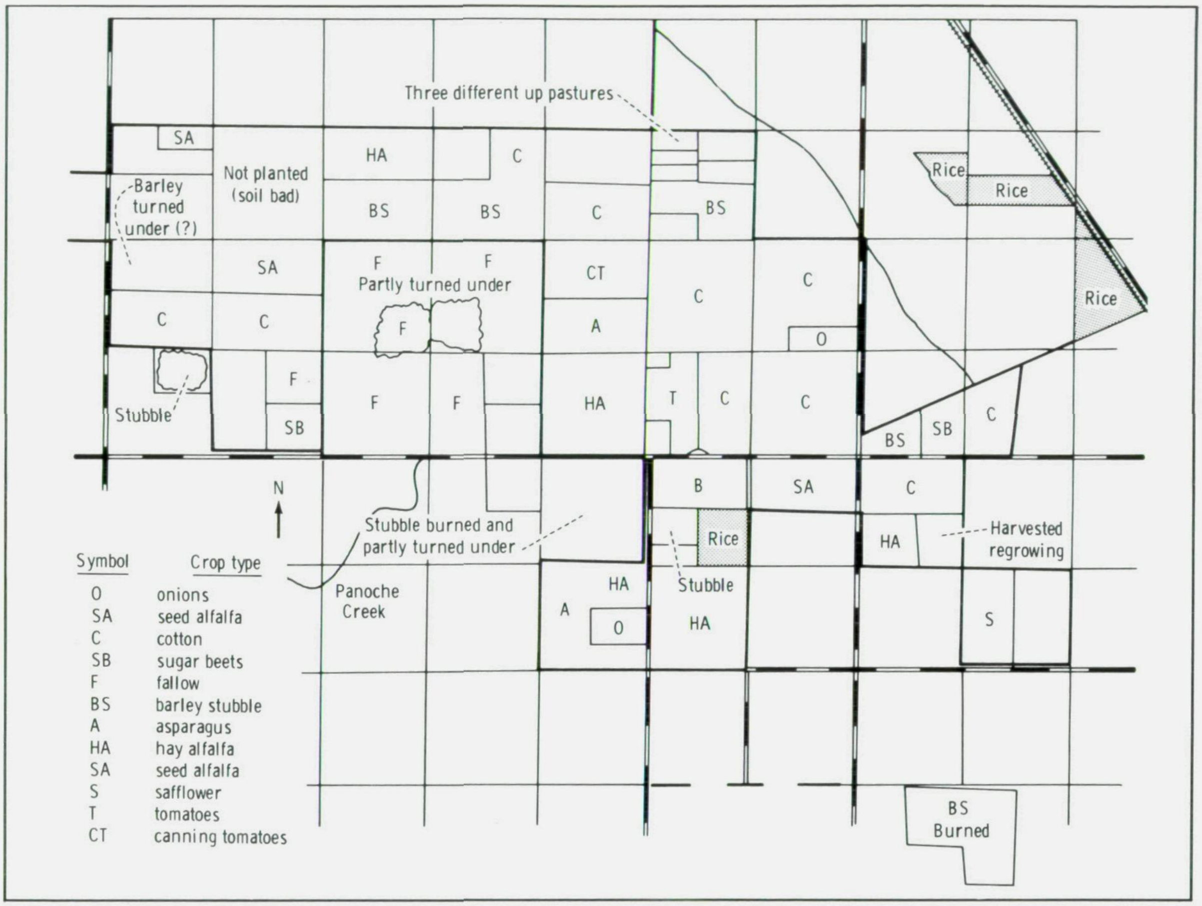

Figure 8. —*Ground-truth map annotated with known crop types.*

made to identify the other two categories by using this imagery.

The second image analyzed was an optically enhanced color IR image composed from MSS bands 4, 5, and 7 on an additive color viewer printer (ACVP). This viewer permits individual filter densities to be selected and enlarges the original image approximately eight times. Because of this enlargement factor, only a part of the study area is covered in this image (fig. 11). Only rice was interpreted with this imagery. The same triangular-shaped field was used as a key. Seventeen fields or contiguous areas were identified as ricefields by using the dark red tone of the triangular field as a key. When checked against the ground truth, two fields were correctly identified and the others could not be validated.

In the third analysis, two images generated on the DAS were used to identify the Level III categories. One image was a pseudo- or false-color composite was a color IR composite of MSS bands 4, 5, and 7. The keys used to interpret these images were the triangular-shaped ricefield, a trapezoidal field of barley stubble, and an L-shaped three-field combination of burned barley stubble. The characteristics of these key areas were a red to dark red on the color IR (MSS bands 4, 5, and 7) and an orange on the false color (MSS bands 4, 5, and 6) for the rice; white on both the false color and the color IR for barley stubble; and a dark gray to black on the false color and a black on the color IR for burned barley stubble.

These key characteristics were used to interpret the images shown in figures 12 and 13. The red tone of the key ricefield on the color IR could be confused with other fields; however, the orange tone of the ricefield on the false color appeared to be unique. of MSS bands 4, 5, and 6 (0.7 to 0.8 μm); the other This image was used to identify and classify all the ricefields in the study area. Eighteen fields, or areas

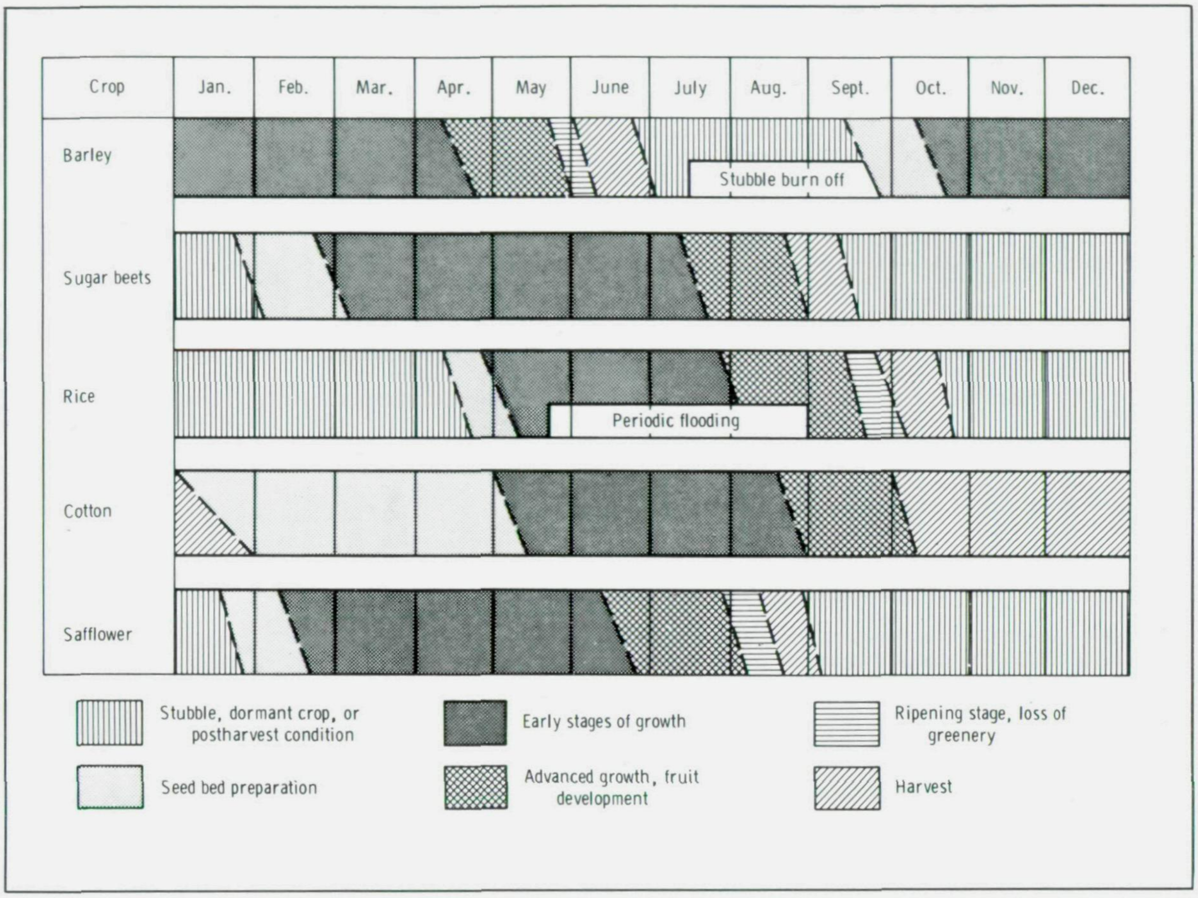

Figure 9.—*Crop calendar for some major crops grown in Study Area II, Delta Mendota.*

of contiguous fields, were identified as rice on this image. Two of these, where ground truth was available, were confirmed as rice. Both images were scanned by using the white tone as the key for barley stubble. Some white areas on the color IR image were not white on the false-color image; therefore, the false-color image was used to identify all the barley stubble fields. Twenty-two fields, or contiguous field areas, were identified. Only one could be confirmed with the limited ground truth, and this field was correctly identified. The burned barley stubble was delineated by using its key characteristics. The color IR image was the principal image used to identify the burned barley stubble because of variability in the false-color imagery. Twelve burned barley stubble fields were identified.

Computer-aided processing. The first computer-aided processing performed was the separation of the gross land use—in this case, vegetation as opposed to nonvegetation (fig. 14). With this basic tool, the user can readily identify those agricultural fields which contain crops in an active stage of growth and those which are dormant or fallow (e.g., the burned barley stubble fields outlined in figure 13 appear nonvegetative as expected). The gross crop calendar (fig. 9) could be used to decide which particular 18-day pass to submit to this procedure in determining when a farming practice had actually taken place over a large area (185 by 185 km). This technique may be expanded to include other land-use categories as well (fig. 15). As indicated on the crop calendar for rice, periodic flooding of the

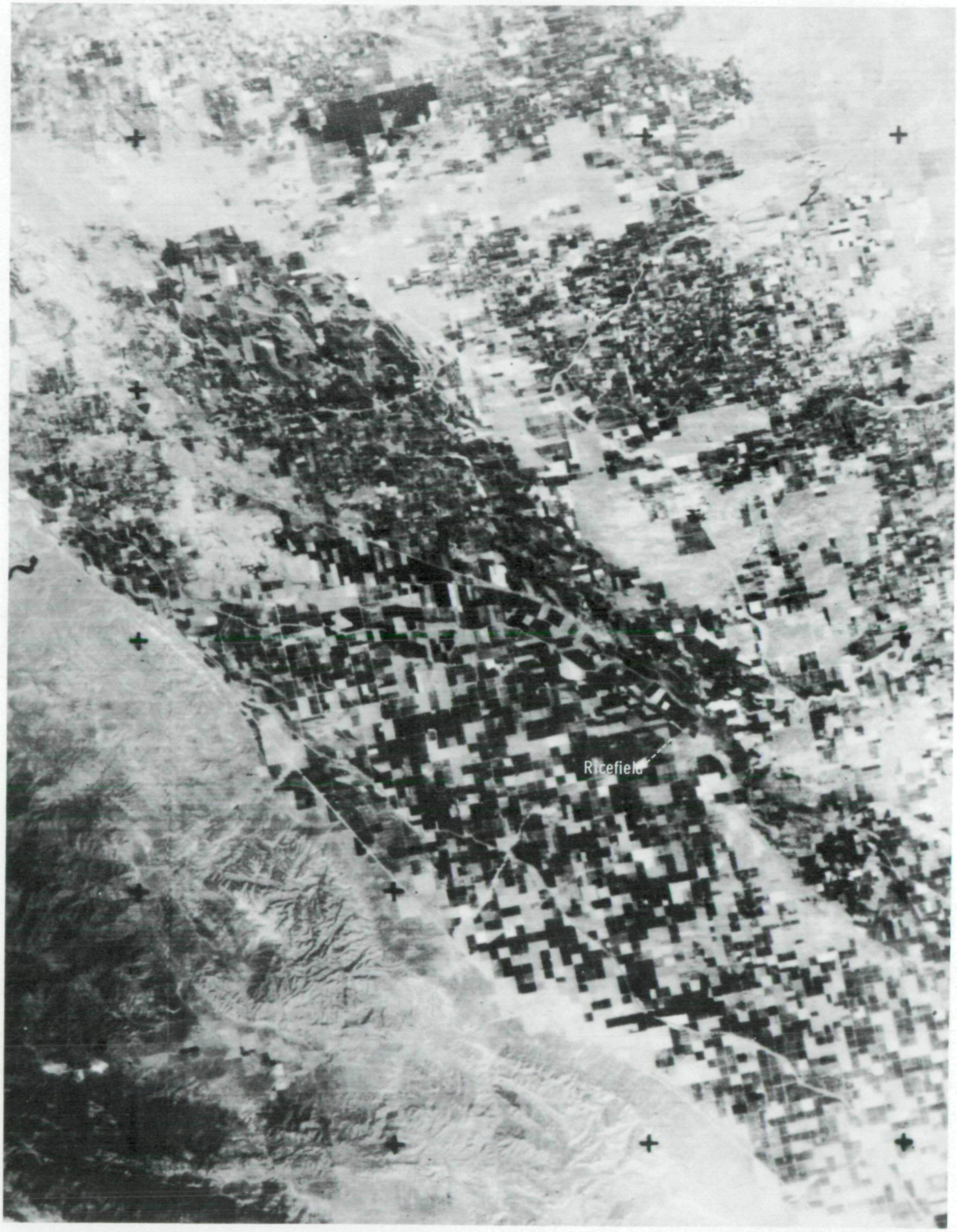

Figure 10.—*Black-and-white image of MSS band 5 showing triangular-shaped ricefield.*

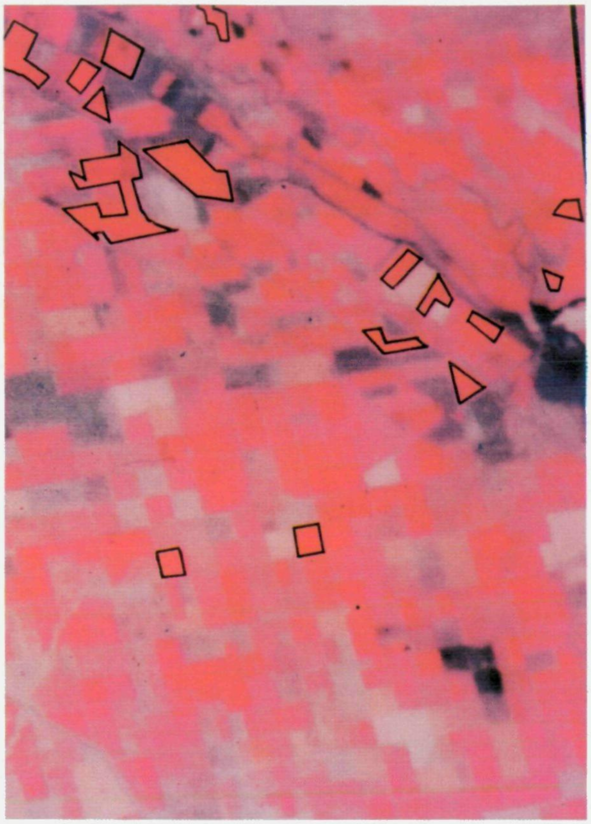

Figure 11. —*Optically enhanced color IR image composed from ERTS-1 MSS bands 4, 5, and 7 on an ACVP (outlined areas are ricefields).*

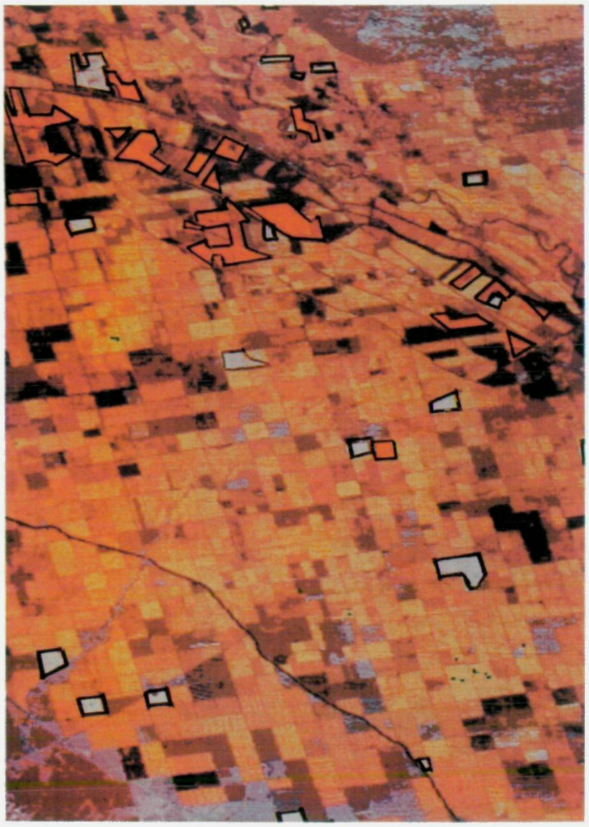

Figure 12. —*Rice and barley stubble as interpreted from DAS-enhanced imagery composed from ERTS-1 MSS bands 4, 5, and 6 (reddish brown—rice; white—barley stubble).*

ricefields may occur intermittently during the active growing period. The three-category display (vegetation, nonvegetation, and water) in figure 15 classifies various fields in the water category. Although the lack of ground-truth information prohibits verification of this deduction, it is very probable that these fields have been subjected to some type of extensive water addition, such as flooding or heavy irrigation.

The approach used was the same as that described for Study Area I. The entire data set was clustered, the clusters were correlated to their respective known ground features, and statistics for clusters of the classes of interest were then used to train the classifier. All the data points were examined by the classifier for class determination. This technique would be used again to extract the higher levels of land use—in this case, the crop types. However, with the acquisition of ground-truth data from Anderson, Clayton and Company, it was possible to use the supervised pattern recognition technique. In this case, the class signature was determined by the data values of the training fields (e.g., the three ricefields in figure 7 were combined to define the class "rice").

The results of the unsupervised classification are shown in figures 16, 17, and 18. The supervised classification results are shown in figures 19, 20, and 21. Figures 16 and 19, which depict the class "rice" as opposed to all others, indicate that comparable results were achieved with both techniques. In both techniques, there is a random distribution of isolated pixels that have been classified as rice. There are a number of possible explanations for this effect:

(1) The spectral signature of these isolated features is the same as that for rice at this time of year.

(2) There was an improper assignment of training fields or thresholding levels.

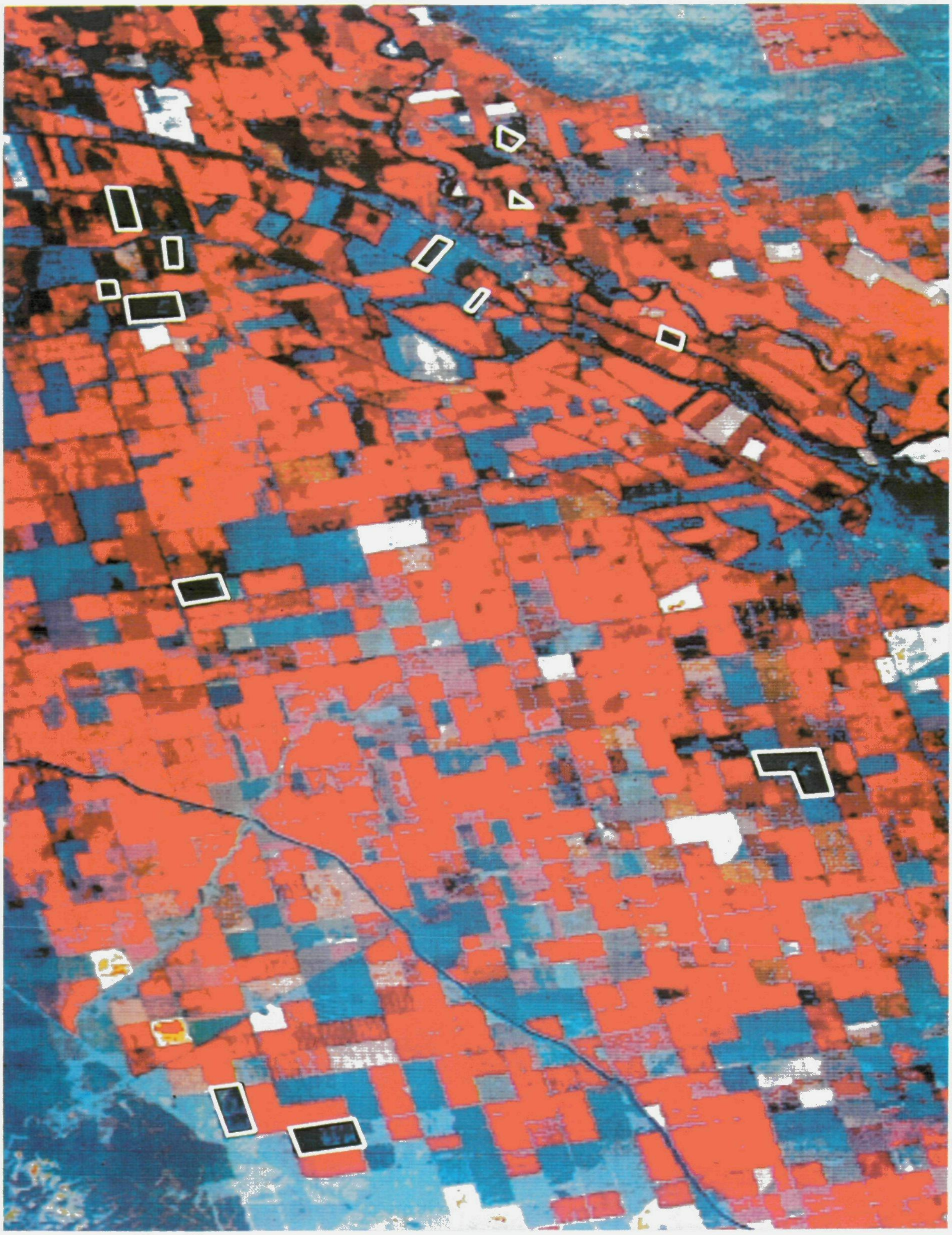

Figure 13.—*Burned barley stubble interpreted from ERTS-1 MSS bands 4, 5, and 7.*

(3) The resolution of the ERTS MSS data is inadequate for discriminating between features.

(4) The automatic pattern recognition techniques used need improvement and/or better application by the user.

The objective was merely to determine the potential of the ERTS data and the processing techniques used at JSC and not to attempt an exhaustive search for maximum results. Illustrations in this report verify that the investigations were reasonably successful. Figures 17 and 20 depict the results of using the two techniques to determine the barleyfield conditions Notably, the burned barley stubble has been identified; however, a certain amount of water, as indicated by the canal patterns, has been included in this class. Figure 18, which depicts the results of unsupervised techniques, shows where an additional cluster was used in an attempt to distinguish between these two categories. Obviously, for this time period, the ERTS MSS data do not detect a measurable difference between the spectral signatures of these two categories. The photointerpreter can use the spatial information (rectangular-shaped fields as opposed to meandering patterns and irregular boundaries) to distinguish between burned barley and water.

In these figures, fields other than barley are included in the "turned under" category. This is to be expected because the appearance of soil that has been plowed is basically independent of the crop type that has been growing on it. The basic objective—determining if this type of field condition could be detected—was met.

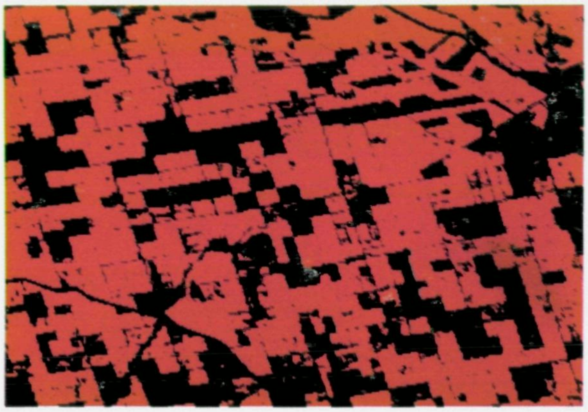

Figure 14. —*Computer-aided classification map delineating vegetative and nonvegetative land-use categories.*

Figures 18 and 21 are composites of all the classes that were carried in the investigation for both the supervised and unsupervised techniques. Table V is a summary of the classification results achieved in Study Area II for all these classes. A conversion of the pixel counts to equivalent ground units has also been included. Table VI describes in detail the classification of each training and/or test field that was

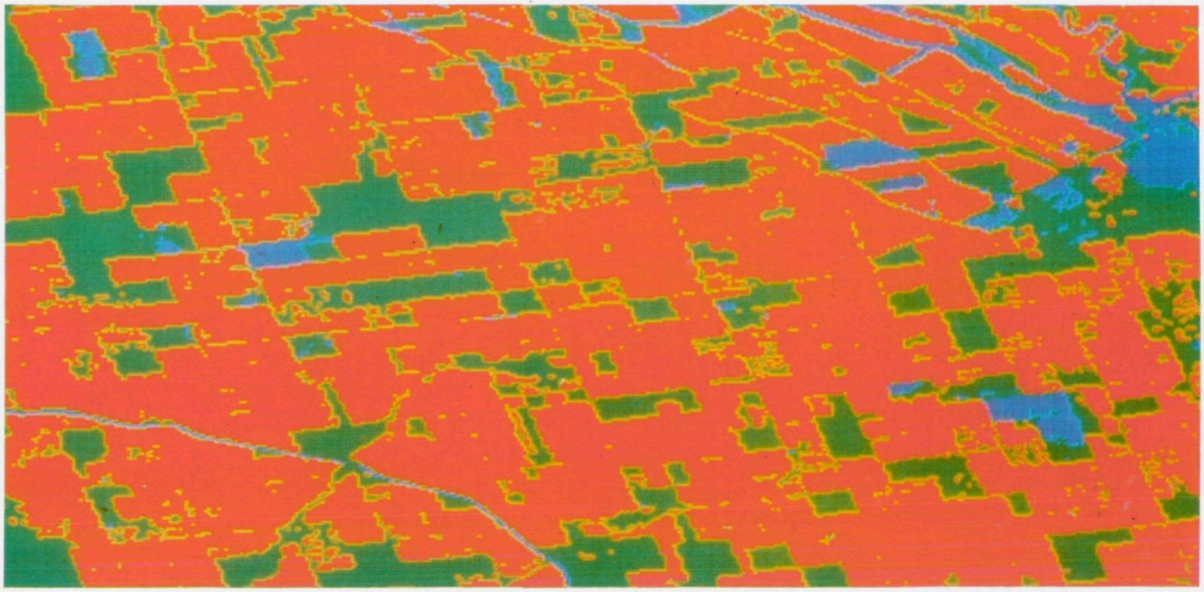

Figure 15. —*Three-category computer-aided classification map (red—vegetation; blue—water; green—nonvegetation).*

used in the analysis. Training fields are known fields selected from the available ground-truth map provided for each class and are used to define the statistical parameters used by the automatic classifier in discriminating one class from another. The test fields are also known fields that are used after the classification process is completed to determine how successfully or unsuccessfully the classifier performed.

Table VI, referred to as the "confusion" matrix, indicates the classification accuracies achieved for each field, together with the class assignment of each pixel for each field. Thus, classes that are being confused with others can be readily distinguished. For example, the lowest accuracy, 75.8 percent, was achieved for test field BTEST1. This was a test field for the class "burned stubble." Of the 198 pixels contained in this field, 45 (approximately 25 percent) were classified or confused with the water and flooded fields class. This confusion could have been anticipated before the actual classification process by an examination of the training fields used for the BURN1 and BURN2 classes. A significant number of pixels in the BURN1 category were classified as water and flooded fields; therefore, the confusion exemplified by BTEST1 would be expected. In fact, the use of training field BURN2 that had a 100-percent correct classification of its pixels would result in a better discrimination of the burned stubble class.

An examination of the confusion matrix identifies where other improvements to the overall classifications could be made. The key point is the apparent ability of the ERTS MSS to discriminate these crop types. The overall accuracy of 94 percent is comparable to the results achieved from higher resolution aircraft multispectral data for this type of application. Errors in Sun angle, look angle, and reduced signal-to-noise ratios may result in a high variation in the pixel radiance values from a high resolution, so the small instantaneous field-of-view airborne scanner is included in the total radiance of the ERTS MSS field of view. Thus, the ERTS-MSS-acquired spectral signature may be more uniform for an entire crop field; this would result in better overall discrimination characteristics where the application is basically crop-type detection and/or identification.

The last activity conducted was an investigation of the ability of ERTS MSS data to provide a measure of the ground area coverage of each of the classes deleted. The ground equivalent units occupied by various features were supplied in preceding paragraphs by using a simple pixel count and multiplying this count by a conversion factor. (In this case, a value of 4454 m^2/pixel was used.) The following discussion describes the attempt to determine the accuracy achieved by using such a procedure.

Figure 7 delineates three ricefields (R1, R2, and R3) that were used in this mensuration accuracy investigation. These same fields were located on high-resolution photographs acquired in April 1971. By using ground control points from 1:250 000-scale topographic maps and performing a leveling and scaling operation with a precision analytical plotter, the actual ground area of these fields was determined. The area was also determined by using the same technique previously described, but it was only applied to the ERTS MSS reconstituted imagery where the field boundaries have been determined by conventional photointerpretation. The results acquired for the three fields, using all three techniques, are given in table VII.

The significance of the converted pixel count discrepancy with the aerial photograph measurement lies not only in the 60 702 m^2 average difference but also in the fact that the pixel count was smaller in all cases. This smaller pixel count could be attributable to two factors:

(1) The aerial photographic measurements were relative based on the accuracy of actual registration, especially in scale to the map positions used for the initial control; for example, the values derived from the aerial photograph were, in all cases, larger than the true ground measurements.

(2) The only pixels converted were those that were actually classified as rice. Postanalysis communications with Anderson, Clayton and Company for field R3 revealed that, although the field size was listed as 647 497 m^2 this figure included a fringe area outside the actual growing rice boundary, which extended to the center of the road adjacent to the field. Thus, the area determined by the converted pixel count of actual rice should be less than the listed field size.

In any case, this simple study indicates that accuracies of 5 to 10 percent are not unrealistic. Although no attempt was made to rectify the classification images and thus remove the known geometric distortions, previous experience showed that these accuracies could be improved. Additional studies in the mensuration area should be conducted to obtain verification of the accuracies that may be achieved.

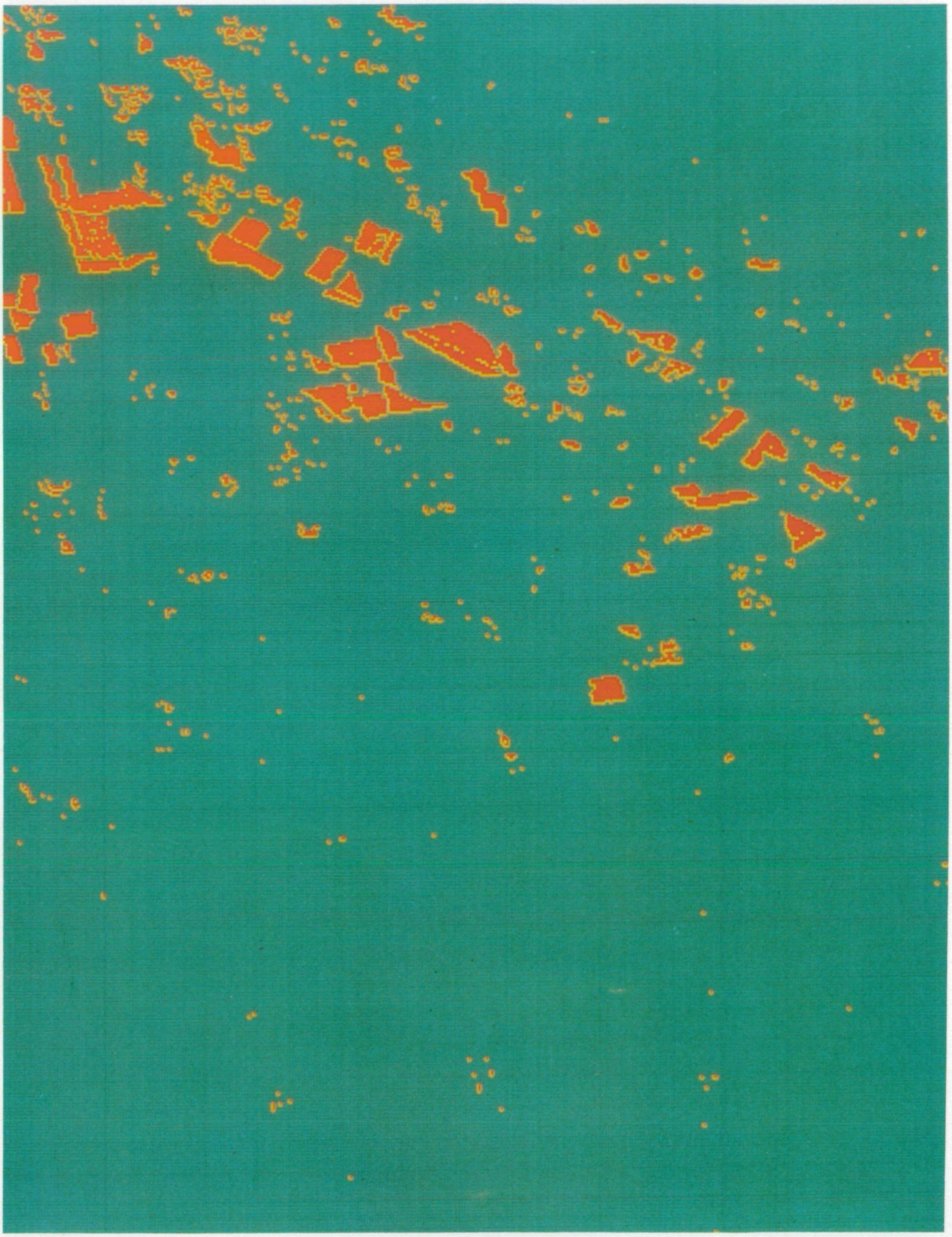

Figure 16.—*Color-enhanced image showing results of unsupervised classification (red—rice; green—all others).*

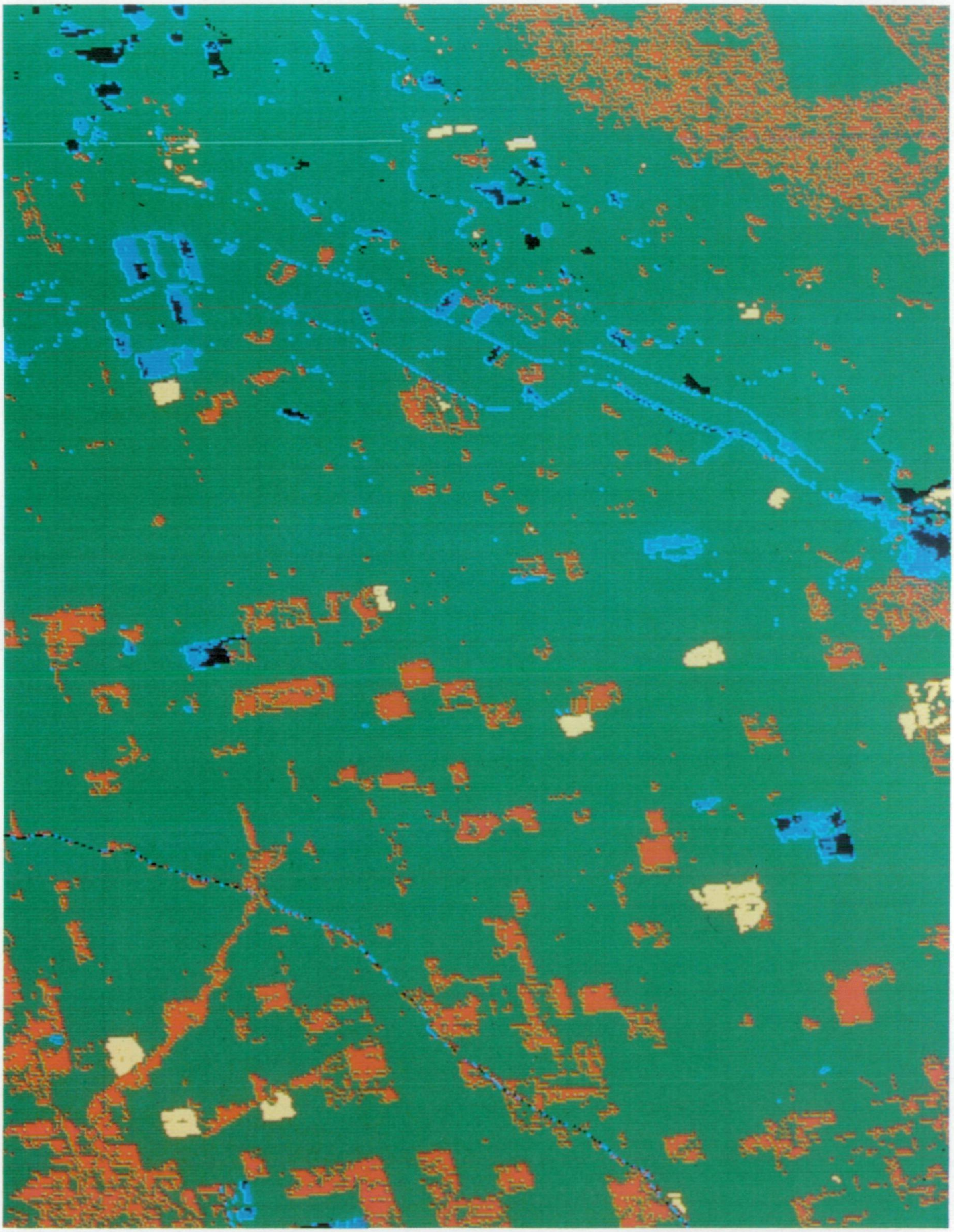

Figure 17.—*Color-enhanced image showing results of unsupervised classification (yellow—barley stubble; black—burned stubble; red—fallow; blue—water; green—all others).*

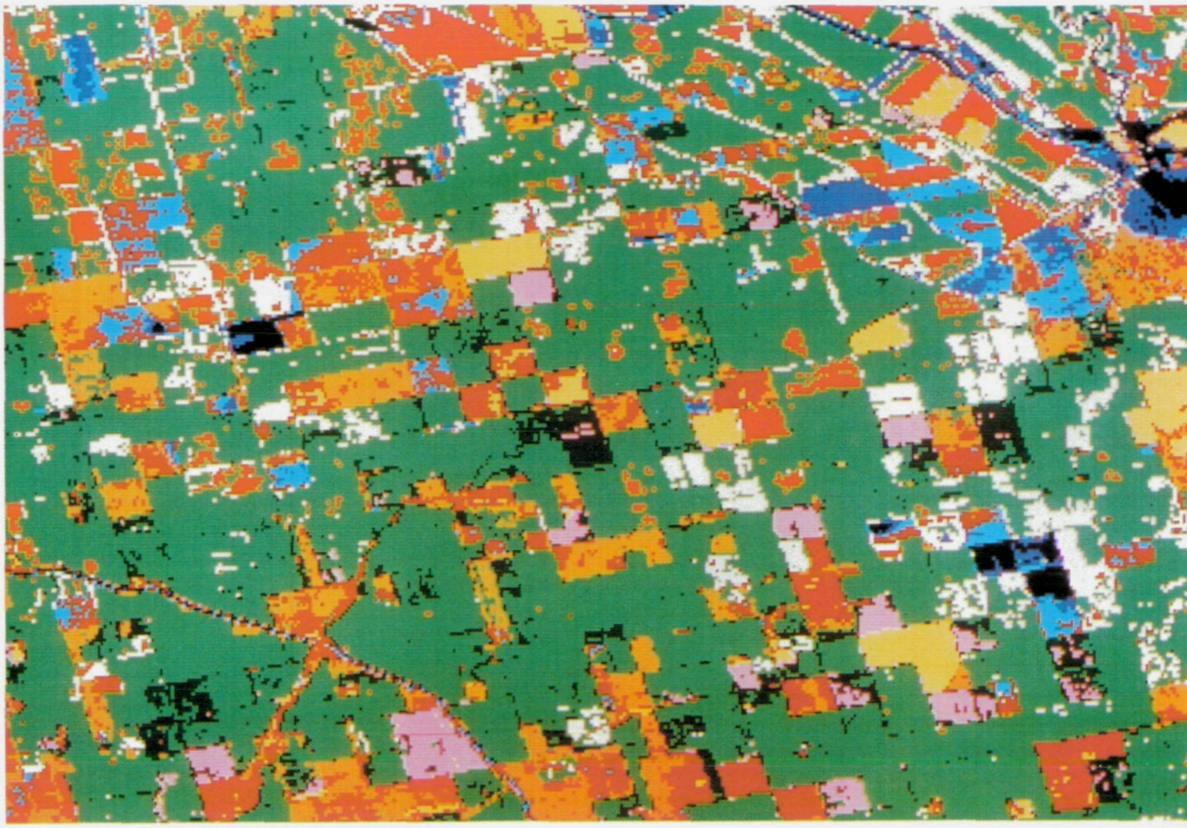

Figure 18.—*Color-enhanced image showing results of unsupervised classification (yellow—stubble; red—rice; light blue—flooded ricefields; brown—plowed ground; dark blue—water and fields under heavy irrigation; rust—fallow ground; white—hay, alfalfa, and similar crops; dark green—harvested safflower; pink—mature safflower).*

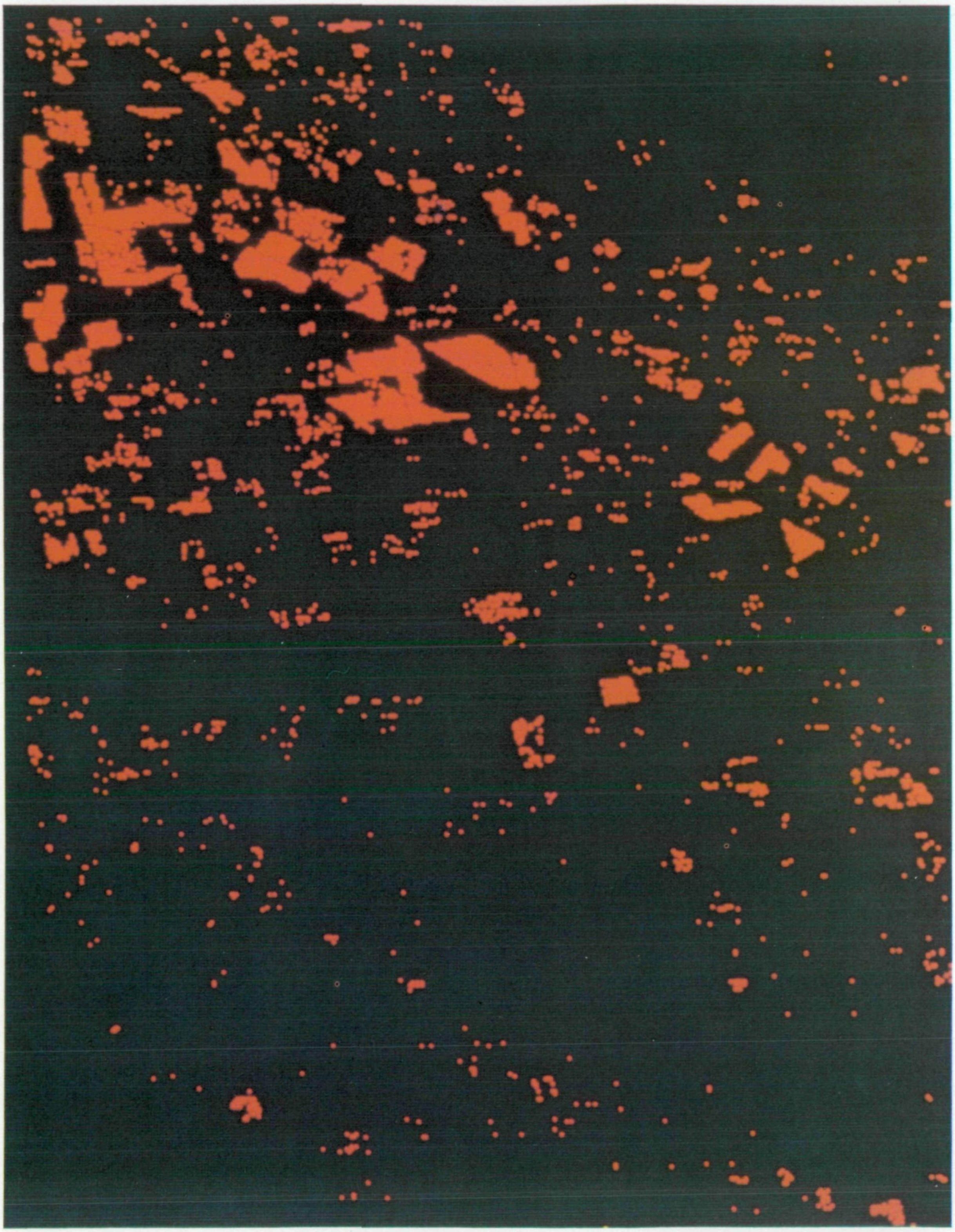

Figure 19.—*Color-enhanced image showing results of supervised classification (red—rice; black—all others).*

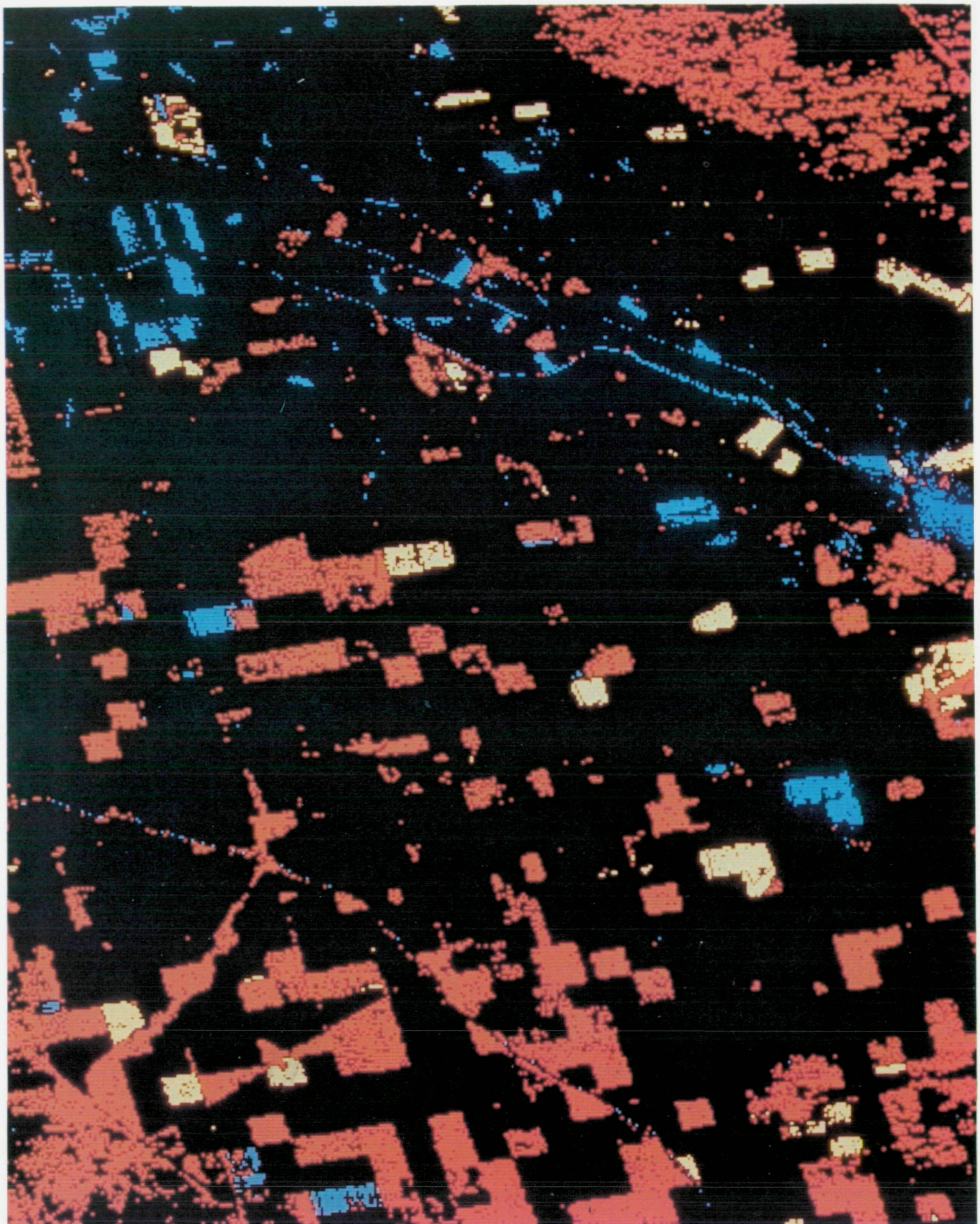

Figure 20. —*Color-enhanced image showing results of supervised classification (yellow—stubble; blue—burned; brown—plowed under).*

Figure 21.—*Color-enhanced image showing results of supervised classification (yellow—barley stubble; brown—turned barley stubble; white—fallow; light blue—burned barley stubble; dark blue—water and flooded fields; pink—safflower; red—rice; green—mature crops; black—all others).*

TABLE V.—*Classification Summary Report for Study Area II (Delta Mendota)*

Measurement	Rice	Water and flooded fields	Stubble	Burned stubble	Fields turned under	Fallow	Mature crops	Safflower	Other/ thresholded	Total
Pixels	13 528	29 574	6483	4155	22 820	11 253	52 127	7495	53 466	200 901
Percent of total area	6.7	14.7	3.2	2.1	11.4	5.6	26.0	3.7	26.6	100
Equivalent acres	14 703	32 143	7046	4516	24 802	12 231	56 655	8146	58 110	218 352
Classification accuracy, percent training fields	92	88	97	90	98	96	89	98	Not applicable	94
Test fields	97	96	98	76	94	87	98	100	Not applicable	94

TABLE VI.—*Training and Test Field Summary*

Class name	Field identification	Number of pixels	Percent correct	Number of pixels assigned to each class								
				Fallow	Burned stubble	Fields turned under	Safflower	Vegetation	Water and flooded fields	Stubble	Rice	Thresholded
Fallow	FA111	219	100	219								
	FA112	185	91.9	170		14			1			
	FTEST1	223	87.4	195		28						
Burned stubble	BURN1	205	84.9		174		1		30			
	BURN2	106	100		106							
	BTEST1	198	75.8	1	150	2			45			
Fields turned under	TURN1	123	99.2			122						1
	TURN2	60	96.7	2		58						
	TTEST1	102	94.1			96				3		2
Safflower	SAFF1	332	97.6			1	324			1		6
	SAFF2	95	100				95					
	STEST1	173	100				173					
Vegetation	VEG1	153	84.3					129			24	
	VEG2	80	97.5					78			1	1
	VTEST1	81	97.5					79			2	
Water and flooded fields	WRICE1	103	93.2	1	6				96			
	WRICE2	88	83.0	3	11			1	73			
	WTEST1	77	96.1	2	1				74			
Stubble	STUB1	100	98.0							98		2
	STUB2	94	96.8				1			91		2
	STEST1	261	98.5				1			257		3
Rice	RICE1	98	98.0					2			96	
	RICE2	122	86.9					12	1	1	106	2
	RTEST1	61	100								61	
	RTEST2	95	93.7					5			89	1
Overall performance	Training fields	2035[a] (2163)[b]	94.1	389 (404)	280 (311)	180 (183)	419 (427)	207 (233)	169 (191)	189 (194)	202 (220)	14 (0)
	Test fields	1200 (1271)	94.4	195 (223)	150 (198)	96 (102)	173 (173)	79 (81)	74 (77)	257 (261)	150 (156)	6 (0)

[a] Number of pixels classified correctly.
[b] Total number of pixels defined.

TABLE VII.—*Results of the Mensuration Accuracy Investigation*
(All values in square meters)

Field	Aerial photograph (April 1971)	Imagery from ERTS MSS	Converted pixel counts	Differences between aerial photograph and pixel counts [a]	Differences between aerial photograph and ERTS MSS imagery [b]
R1	663 675	607 020	582 739	80 936	56 655
R2	768 892	687 956	712 237	56 655	80 936
R3	651 535	651 535	607 020	44 515	0

[a] Average difference between aerial photograph and pixel count for all fields was 60 702 m^2.
[b] Average difference between aerial photograh and ERTS MSS imagery was 68 806 m^2.

CONCLUSIONS

The ERTS-1 multispectral scanner data contain information that may be used effectively to accomplish agricultural application objectives. Specifically, from this preliminary study, the following assessments were made:

(1) The use of digital data as opposed to imagery has resulted in improved success for detection and identification activities because of an inherently better radiometric fidelity.

(2) The ERTS-1 system can be used to detect and identify major crop species on a global basis and to delineate numerous land-use categories.

(3) The repeat coverage aspect allows for the monitoring of changes in seasonal growth characteristics of crops and for the assessment of various cultivation practices.

(4) Using crop calendars and supporting materials, ERTS system operational procedures can be defined to optimize the planning and development of earth resources programs, thus minimizing onsite ground observations and the related man-hour resources.

(5) The accuracies achieved in the detection and identification of crop species were equivalent to those derived from low-altitude multispectral scanner data, with the areal determinations achieved to within 5 percent; thus, a better utilization of data acquisition resources can be determined.

Results achieved from analysis of the ERTS-1 data demonstrate the utility of such a system for providing land-use and agricultural application information that has been unavailable from other remote-sensing sources.

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