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Abstract

The Gates to Gregg High Voltage Transmission Line Project was a cooperative effort between NASA/Ames Research Center and Pacific Gas and Electric Company to demonstrate and assess the utility of Landsat data in the planning of transmission line routes. Landsat digital data and image processing techniques, specifically a multi-date supervised classification approach, were used to develop a land cover map for an agricultural area near Fresno, California. Twenty-six land cover classes were identified, of which twenty classes were agricultural crops. High classification accuracies (greater than 80%) were attained for several classes, including cotton, grain, and vineyards. The primary products generated at the conclusion of the project were 1:24,000, 1:100,000 and 1:250,000 scale maps of the classification and acreage summaries for all land cover classes within four alternate transmission line routes.

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1.0 PROJECT OVERVIEW

1.1 Introduction

Pacific Gas and Electric (PGandE) provides electric services to over 3.4 million customers in 47 California counties within a 94,000 square mile service area. In providing electric power to PGandE customers, 13,434 miles of high voltage transmission lines have been constructed. New transmission lines are planned throughout PGandE's service area to serve projected growth. Planners and Engineers at PGandE are faced with complex economic and environmental considerations in locating routes for these lines. The complexity of this task is growing as a result of increasing public concern for protecting environmental quality and PGandE's desire to preserve the highest environmental quality possible. This concern is reflected by increasing needs for more and better information on the environmental effects of PGandE projects. This information is used to analyze the environmental effects of projects and provide regulatory agencies with objective data. The cost of providing this information is steadily increasing, and PGandE is constantly seeking new and cost effective ways to gather information used for decision making. Remote sensing technology, in particular the Landsat program, holds particular promise in providing better information for use in transmission line route selection and evaluation.

1.2 Problem Statement

Transmission line projects over 200,000 volts(200 kV) are routinely subject to review and approval by the California Public Utilities Commission (CPUC). When PGandE's application for the Gates to Gregg 500 kV Transmission Line was denied without prejudice by the CPUC on January 16, 1979, the Environmental Impact Report was faulted as having inadequate information on impacts to agricultural lands for all alternatives under consideration. Decision number 89851 stated:

"3. Impact to Agricultural Lands

> The analysis presented in this proceeding is inadequate. A study was offered showing the economic impact on agricultural lands but emphasized the loss of land on which actual facilities would be located. Potential significant impacts on farming activities such as crop dusting, cultivating, and harvesting were largely ignored."

PGandE is currently considering refiling an application with the CPUC for a Certificate of Public Convenience and Necessity for this project. Information collected on the extent and types of agricultural lands in the Gates to Gregg project area is limited to a one-mile band around the transmission line corridors collected in July of 1979. The extent of coverage and other information on crop types and agricultural land uses is deficient for much of the 1,000 square mile study area. This information, if it could be collected economically, would allow for more complete route evaluation in light of agricultural effects.

Practical and economical methods for collecting current information on crop types, agricultural land uses and the spatial distribution of these uses over a large area are limited. This type of information would allow for a more comprehensive review of project alternatives in light of the effects of a transmission line. Other projects requiring similar information are anticipated. PGandE's present Gates to Gregg data base consists of maps with crop types recorded within the boundaries of one-mile wide alternative corridors. No current information is available on crop types outside of this corridor.

1.3 Project Objectives

Landsat imagery and analysis methods have the potential for allowing classification, mapping and inventory of agricultural land uses over a large study area, in a cost effective manner. The objectives of this project included:

1. To identify agricultural land uses in the Gates to Gregg 500 kV Transmission Line project area.
2. To help identify the most desirable and economic route using Landsat in conjunction with other data.
3. Establish the potential uses of this information for other projects.
4. Determine the feasibility and desirability of acquiring a Landsat-based information system for internal use by PGandE personnel.
5. Assess compatibility of Landsat data with existing PGandE information systems.

In addition, the anticipated accomplishments of this demonstration project included:

1. A complete Agricultural Land Use map for the Gates to Gregg study area with proper ground registration.

2. Acreages of crop types within alternative transmission line corridors and along the centerline of the corridors.

3. Per acre costs for developing an acceptable classification of agricultural land use classes.

4. Evaluating the costs and requirements for transfer of software to PGandE computers and for using Landsat data.

5. A Land Use Classification in digital form compatible with PGandE's geographic software (i.e. ESRI's single or multiple variable grid file format).

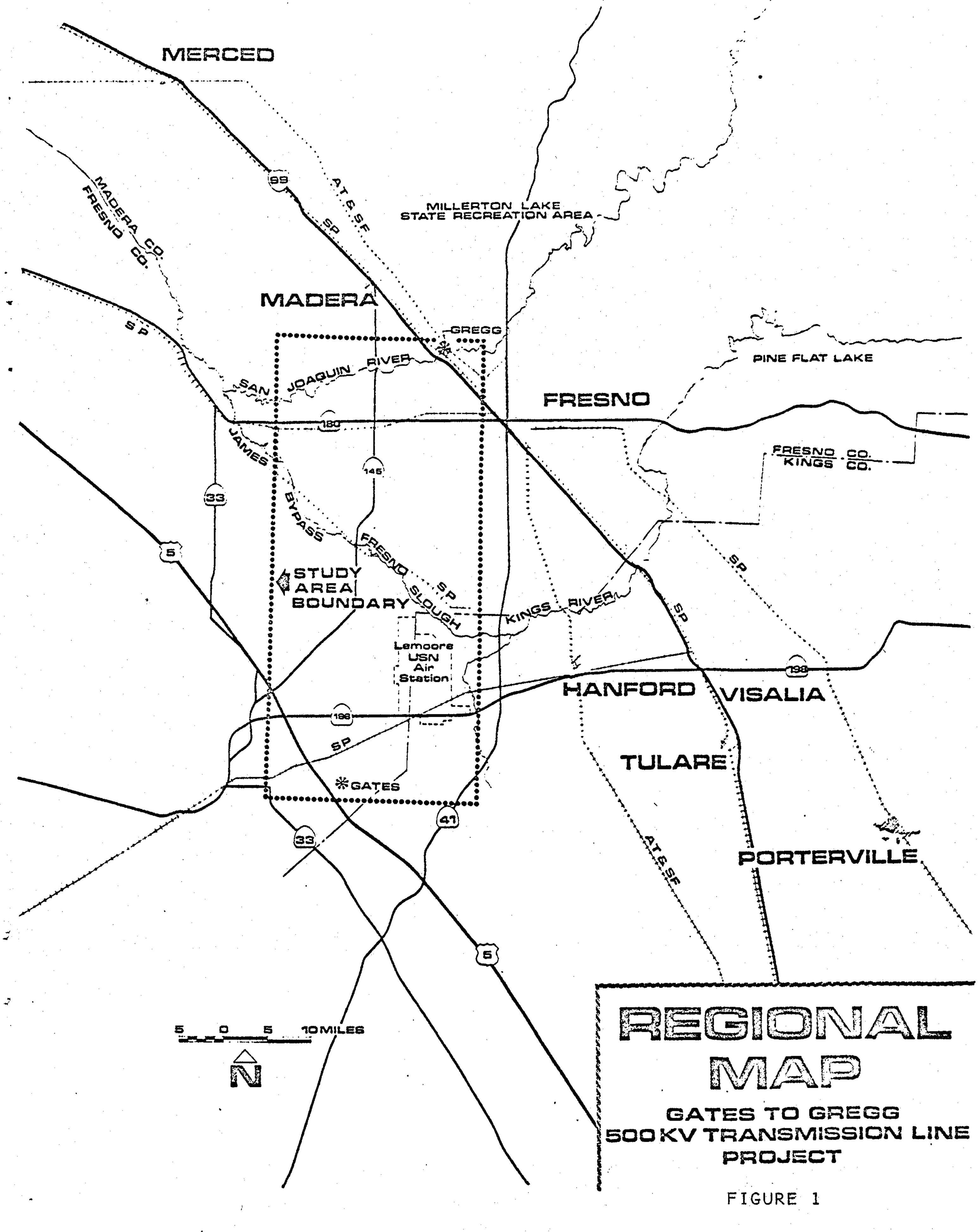
6. Maps of these land use classes: tomatoes, cotton, grains, sugar beets, rice, orchards, vineyards, corn, specialty crops, pasture - open or fallow, urban areas, residential areas, water, stock farming, crop duster strips, parks and native vegetation.

7. Evaluating the feasibility of monitoring crop changes within corridors periodically until project construction.

8. Deriving agricultural impact costs of each alternative transmission line alignment using statistical information on agricultural effects.

1.4 Study Area

The Gates to Gregg 500 kV transmission line project study area (Figure 1) is located in the San Joaquin Valley, which makes up the southern two-thirds of California's Central Valley. The San Joaquin Valley is drained by the San Joaquin River which



REGIONAL MAP

GATES TO GREGG
500 KV TRANSMISSION LINE
PROJECT

FIGURE 1

flows northward through the valley until it joins the Sacramento River and empties into San Francisco Bay.

The San Joaquin Valley is approximately 27,000 square miles in size and is 17 percent of the land area in the State. The major industry in the valley is agriculture. Important agricultural products are grapes, milk, cotton, beef, poultry, and citrus. Total gross value of these products in 1978 was $5.065 billion according to the California Department of Food and Agriculture.

There is a well developed transportation system in the valley. Major highways are Interstate 5 on the west side of the valley and U.S. Highway 99 on the east side. These highways are primary links between Northern and Southern California.

The Gates to Gregg transmission line project study area is one thousand square miles in size and includes portions of three counties. Approximately 900 square miles are in Fresno County, 70 square miles in Kings County, and 30 square miles in Madera County.

The San Joaquin Valley is an elongated basin or trough oriented on a northwest-southeast axis dropping slightly in elevation in a northwest direction toward San Francisco Bay. Most of the study area is drained by the Fresno Slough which flows in the center of the valley, approximately dividing the study area. The slough is a flat basin between one and six miles wide. The study area southwest of the Fresno Slough is composed of alluvial fans sloping from the Coastal Foothills. The average slope gradient in the area is less than one percent. Northeast of the Slough, the study area is part of the eastside alluvial plains of the San Joaquin Valley sloping from the Sierra Foothills. This plain consists of alluvial terraces, young alluvial fans, recent fans and flood plains. Slope gradients range between four and ten feet per mile on young alluvial fans, five to eight feet per mile on flood plains and recent fans, and level to two feet per mile on the Fresno Slough flood plain.

The study area has an even, gently sloping terrain. The lowest point is 160 feet above sea level at the Fresno Slough on the western edge of the study area. The highest point is 400 feet at the Gates Substation. The Gregg Substation is located at a midrange elevation of 280 feet and except for the bluffs fronting the San Joaquin River, there are no obvious topographic features. Between Gates Substation and the Fresno Slough, the land slopes uniformly downward at a rate of approximately nine feet per mile. Between the Fresno South and Gregg Substation, the land slopes upward at a rate of four feet per mile. A notable departure in the latter grade is the notch cut by the San Joaquin River.

The study area is entirely within the Great Valley geomorphic province. This is a long structural depression oriented on a northwest-southeast axis. This depression is filled with sediments which reach a depth of six miles. Twenty-seven soil associations are mapped in the study area. In general, all of these soils are highly rated in terms of their capability to produce commercial crops. The soils are divided about equally into Soil Conservation Service Capability Classes

I,II, and III. Some Class IV soils are present along stream courses.

1.5 Participants and Responsibilities

This demonstration project is a joint venture of Pacific Gas and Electric Company's Land Department, and the Western Regional Applications' Program (WRAP) of the NASA Ames Research Center. Personnel directly involved with the project and providing technical assistance are as follows:

Pacific Gas and Electric Company

J.R. Bonderud	Field Engineer
P.J. Easterwood	Planning Analyst
G.M. Thornbury	Planning Analyst, Project Manager

NASA/Ames Research Center and
Technicolor Government Services, Inc.

S. Norman	WRAP Coordinator(NASA)
D. Sinnott	Technical Manager(NASA)
W. Newland	Senior Remote Sensing Analyst(TGS)
V. Bergis	Remote Sensing Analyst(TGS)
K. Maw	Staff Remote Sensing Analyst(TGS)

PGandE personnel indirectly involved with the project through management and/or supervisory roles are as follows:

J.E. Whitacre	Senior, Planning Analyst
E. Hase	Supervisor, Permits & Environmental Planning
D.J. Foley	Supervisor, Field Engineering
P.K. Willerup	Director, Land Engineering
S.R. Kaderali	Director, Urban and Regional Planning
J.W. Page	Manager, Land Department

Project responsibilities for the two agencies are as follows:

Pacific Gas and Electric

Ground data collection and verification
Aircraft data (existing July, 1979 photography)
Evaluation of results

NASA/Ames Research Center

Training and technical assistance
Landsat data acquisition
Image analysis
Documentation of results

1.6 Training Workshops, Field Trips, and Demonstrations

During the course of the project, several training workshops and a demonstration were held to introduce PGandE personnel to the applications of Landsat data in the planning and routing of electric transmission lines. The Landsat demonstration was held at the PGandE general offices in San Francisco. The various workshops were conducted throughout the project to train two PGandE employees, in greater depth, on Landsat image processing techniques and procedures. Two field trips were made to the Fresno area for ground data collection at the study site.

To familiarize PGandE personnel with Landsat derived information, the first Landsat demonstration, held in San Francisco, used NASA's Mobile Analysis and Training Extension (MATE) van. Approximately 150 people attended including PGandE employees, California Public Utilities Commission (CPUC) staff members, and interested consulting firms. The hourly demonstrations, conducted on May 5 to May 8, 1981, included overviews of the Landsat satellite and the image processing techniques utilized in producing a land cover map. Eight images were displayed including three Landsat multi-spectral scanner images, a 7/5 band ratio image, a classified image, and several enlarged areas from the classified image.

Approximately eight workshops were conducted throughout the course of the project to train two PGandE employees on the various procedures used in the analysis of Landsat digital data. These procedures included training site selection, digitization, histogramming, clustering, classification evaluation, stratification, and accuracy assessment. These workshops gave PGandE personnel "hands-on" experience with the various computer systems at Ames. In addition, they acquired a good understanding of the uses and limitations of Landsat data for transmission line corridor analysis.

The two field trips conducted during the project were for the purpose of familiarizing the analysts with the general study area, observing the various crop patterns and textures from the air, and to "field-check" analysis results.

2.0 TECHNICAL METHODOLOGY

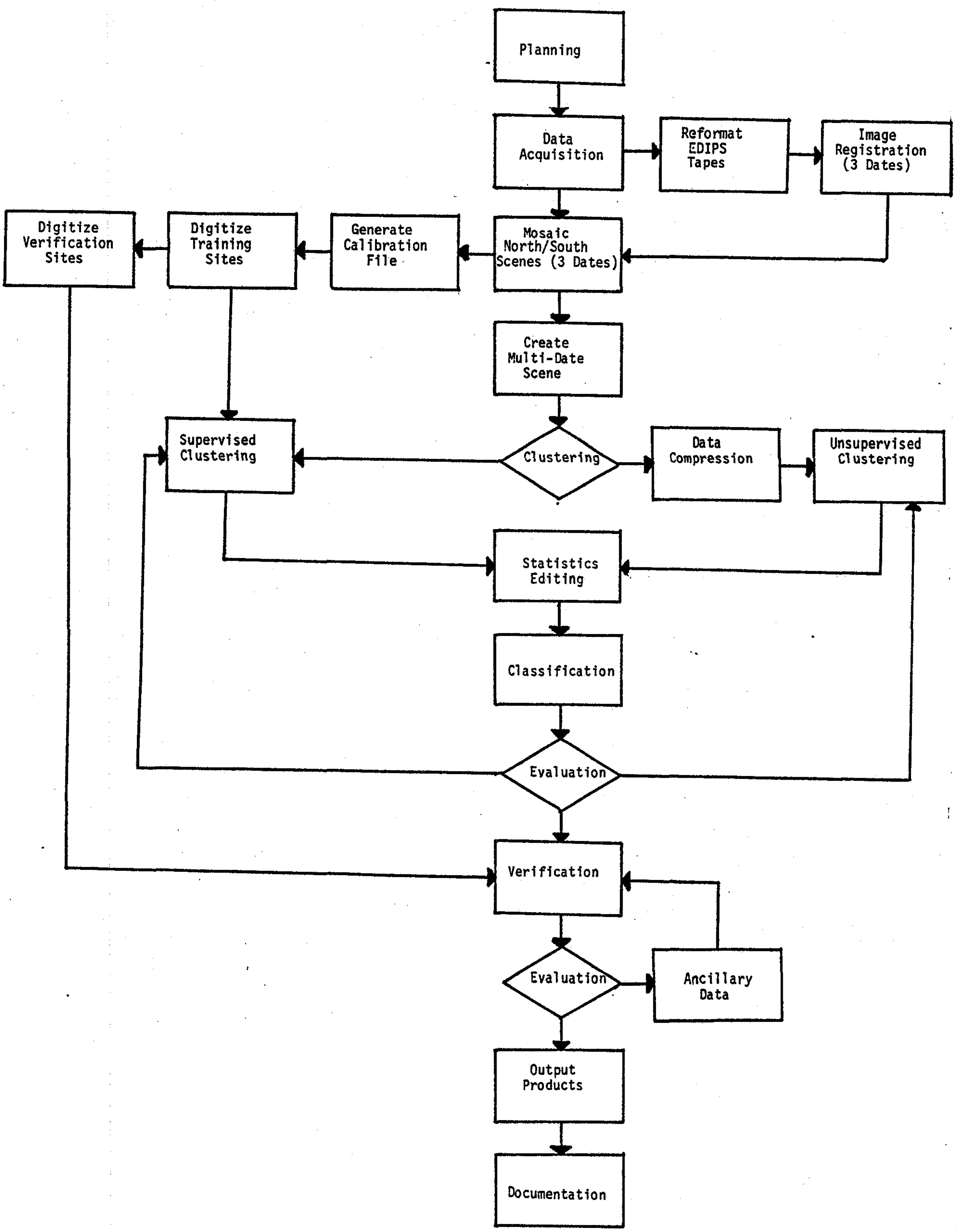
2.1 Overview of Technical Methods

A multi-date supervised classification of Landsat digital data was developed to provide a land cover inventory for the Gates to Gregg transmission line study area. The general project workflow is illustrated in Figure 2. Three dates throughout the growing season were selected for analysis and were combined to form one six-channel data set (two channels for each date). Portions of two Landsat scenes covered the study area and were mosaicked together to create one image. Originally, both an unsupervised and a supervised classification(1) were planned. During the course of the project, it was found that the data compression required for the unsupervised classification approach could not be performed with existing software, forcing the abandonment of that approach. In addition to the supervised land cover analysis, a band ratioing technique was used to estimate irrigated versus non-irrigated acreage within the study area. In the supervised approach, ground reference data was used to develop spectral clusters representing the designated cover types of interest. The resulting statistics were then used to classify the multi-spectral data into information classes, using a maximum likelihood classifier. Classification results were evaluated and

(1)An unsupervised classification implies that there is no analyst input regarding training site information, so that the computer partitions the data into a arbitrary number of spectrally unique clusters. In a supervised approach, ground training sites specified by the analyst used to "train" the computer for developing spectral clusters.

Figure 2

General Project Workflow



measures were taken to correct various errors. A stratification technique was incorporated to separate the major urban and native vegetation areas from the agricultural areas. A detailed accuracy assessment was performed on the four alternate transmission line corridors to evaluate the reliability of Landsat multi-spectral data. To summarize the land cover inventory, color coded maps were produced. Two versions of the classification were made - a detailed version showing the twenty-seven land cover categories, and a generalized version which grouped the twenty-seven categories into thirteen categories. In addition, acreage summaries by cover type were obtained for the four transmission line corridors.

2.2 Computer Hardware and Software Systems Utilized

Several different hardware and software systems were used during the course of project work. Because of the variety of computer systems at Ames, the analysts had the option to choose the most appropriate system for each image processing procedure. The use of multiple machines is not a requirement for the analysis work, but can increase project efficiency and reduce computer costs.

The primary hardware/software system used during this project was the ERTS Data Interpreter and TENEX Operations Recorder (EDITOR) software system which is implemented on a PDP-1Ø computer. This system is located at two facilities - NASA/Ames Research Center and Bolt, Berenak, and Newman (BBN) in

Cambridge, Massachusetts. The PDP-1Ø computer system, along with the IBM 36Ø/67 (located at Ames), is accessed through telephone lines via the Advanced Research Projects Agency (ARPA) Network. The EDITOR system is an interactive system developed to perform land use/land cover categorization and crop acreage estimation. The bulk processing computer associated with the Ames PDP-1Ø is the Illiac IV prototype parallel processor. The initial classification was completed on the Illiac IV, with the remaining classifications performed on the Ames CDC-76ØØ.

Another major computer system utilized was the Hewlett Packard (HP) 3ØØØ Series III mini-computer. Interactive Digital Manipulation System (IDIMS), Geographic Entry System (GES), and Environmental Systems Research Institute (ESRI) are the three software packages installed on the HP-3ØØØ computer and were utilized throughout the project. Peripherals associated with the HP-3ØØØ mini-computer are the Comtal color display monitor, the Dicomed D-47 film recorder, and the Dunn Color Graphic Camera System. The later two were used for final product generation, in the form of 4 x 5" negatives and positives, 35mm slides, and 8 x 1Ø" polaroids. Line printer maps were produced on the HP-3ØØØ using the IDIMS and ESRI softwares, along with the SEL 32/77 computer and Interactive Landsat Executive (ILEX) software. An image enhancement technique used in the project, band ratioing, was performed on the IBM 36Ø/67 using Video Image Communication and Retrieval (VICAR) software. The IBM 36Ø/67 computer was also utilized for various post-processing techniques, in addition to aiding in final product generation. Table 1 summarizes the major analysis steps and the hardware and software systems associated with those steps.

TABLE 1

HARDWARE AND SOFTWARE SYSTEMS UTILIZED FOR MAJOR LANDSAT ANALYSIS PROCEDURES

LANDSAT ANALYSIS	HARDWARE/SOFTWARE UTILIZED
Data Pre-Processing	
Image Registration	PDP-10,Illiac IV/EDITOR
Mosaic Scenes	HP-3000/IDIMS
Reformat Data for Multi-Date Scene	CDC-7600
Calibration File Creation	HP-3000/IDIMS & PDP-10/EDITOR
Band Ratioing	IBM 360-67/VICAR
Digital Analysis	
Training Site Digitization	PDP-10/EDITOR
Histogramming and Clustering	PDP-10/EDITOR
Classification	Illiac IV/EDITOR & CDC-7600
Evaluation of Classification	HP-3000/IDIMS & PDP-10/EDITOR
Reclustering	HP-3000/IDIMS & PDP-10/EDITOR
Data Post-Processing	
Stratification	PDP-10/EDITOR & IBM 360-67
Smoothing and Grouping	CDC-7600 & IBM 360-67
Registration to State Plane Coordinate System	HP-3000/IDIMS,GES
Accuracy Assessment	PDP-10/EDITOR
Final Output Products	
Film Products	HP-3000/IDIMS;Dicomed & Dunn
Line Printer Maps	HP-3000/IDIMS,ESRI & SEL 32-77/ILEX
Acreage Summaries	HP-3000/IDIMS,ESRI
Computer Tapes	HP-3000/IDIMS,ESRI

2.3 Landsat Data Acquisition

Due to the complex nature of agriculture in the San Joaquin Valley, it was felt that the use of multiple dates for digital analysis would provide a more accurate crop inventory. It is not uncommon to find many fields double-cropped in one year due to the long growing season and mild climate. The year 1979 was selected for image analysis because the Department of Water Resources (DWR) and PGandE had collected detailed ground reference data in Fresno County for the summer of 1979. In order to cover the variety of crops and their growing seasons, three 1979 Landsat dates were selected by UC Berkeley and UC Santa Barbara - May 7, July 6, and August 20 (Colwell et al., 1980). 1979 was selected because DWR collected ground reference data for the entire county, whereas, PGandE collected data for their transmission line study area. Different characteristics of the growing season were anticipated to be captured by selecting a spring, summer, and early fall date based on crop calendars, county cropping practices, historical cropping trends, and consultation with DWR personnel. The identification of early grains is possible using a spring date and many of the double-cropped fields can be identified with a fall date. A summer date is useful in Landsat analysis because the majority of crops are at the peak of their growing season and exhibit a high reflectance in the infrared wavebands (Maxwell et al., 1980). It was hypothesized that a unique spectral signature could be developed for the major San Joaquin Valley crops using this multi-date approach to Landsat digital analysis.

Landsat 3 multispectral scanner digital data was acquired from the Earth Resources Observation Systems (EROS) Data Center in the form of computer compatible tapes (CCT), and false color composite transparencies at a scale of 1:1,000,000. These products were in an EDIPS (EROS Digital Image Processing System) format, where geometric corrections have been applied to the Landsat data. Each Landsat picture element (pixel) represented a 57 x 57 meter area. Two multi-temporal Landsat scenes were required to completely encompass the designated study area and are listed in Table 2.

TABLE 2

LANDSAT SCENE IDENTIFICATION INFORMATION

Date	Path,Row	Scene Identifier
7 May 1979	45,34	21563-17454
7 May 1979	45,35	21563-17461
6 July 1979	45,34	30488-17541
6 July 1979	45,35	30488-17544
20 Aug 1979	45,34	21671-17484
20 Aug 1979	45,35	21671-17490

Color infrared photography, at an approximate scale of 1:65,000, was also available for much of the study area, through the High Altitude Missions Branch at Ames (Appendix A). The color infrared photography aided in the identification and checking of training fields in the training site selection process.

2.4 Ground Reference Data Utilized

Along with the Landsat data, two ground reference data sources were used for the analysis work. These data bases were compiled by different organizations and were used individually at different phases of the project.

The first of these data sets was supplied by the California Department of Water Resources and included complete ground reference data for Fresno County. The data was collected during the summer of 1979 using low altitude aerial photography. Cover types were determined by photo-interpretation, after which the information was coded and transferred onto U.S. Geological Survey 7.5' quadrangles. If positive identification of a cover type could not be made using the photos, a ground verification was done. In addition, fields that were double-cropped (and verified on the ground) were also noted on the maps. This data base was used primarily for training site selection, and preliminary classification evaluations.

The second source of ground reference data was provided by PGandE. This data was also collected during the summer of 1979 and therefore corresponded to both the Landsat data and the DWR ground reference data. The data collection procedure involved a windshield survey throughout the four alternate transmission line corridors and the collected information consisted of cover types, field boundaries, current crop duster strips, and land ownership. The information was coded and transferred onto thirteen Mylar maps at a scale of 1:24,000. Because ground coverage did not include the entire county, this data set was used only for the final classification accuracy assessment of the Landsat data within the transmission line corridors.

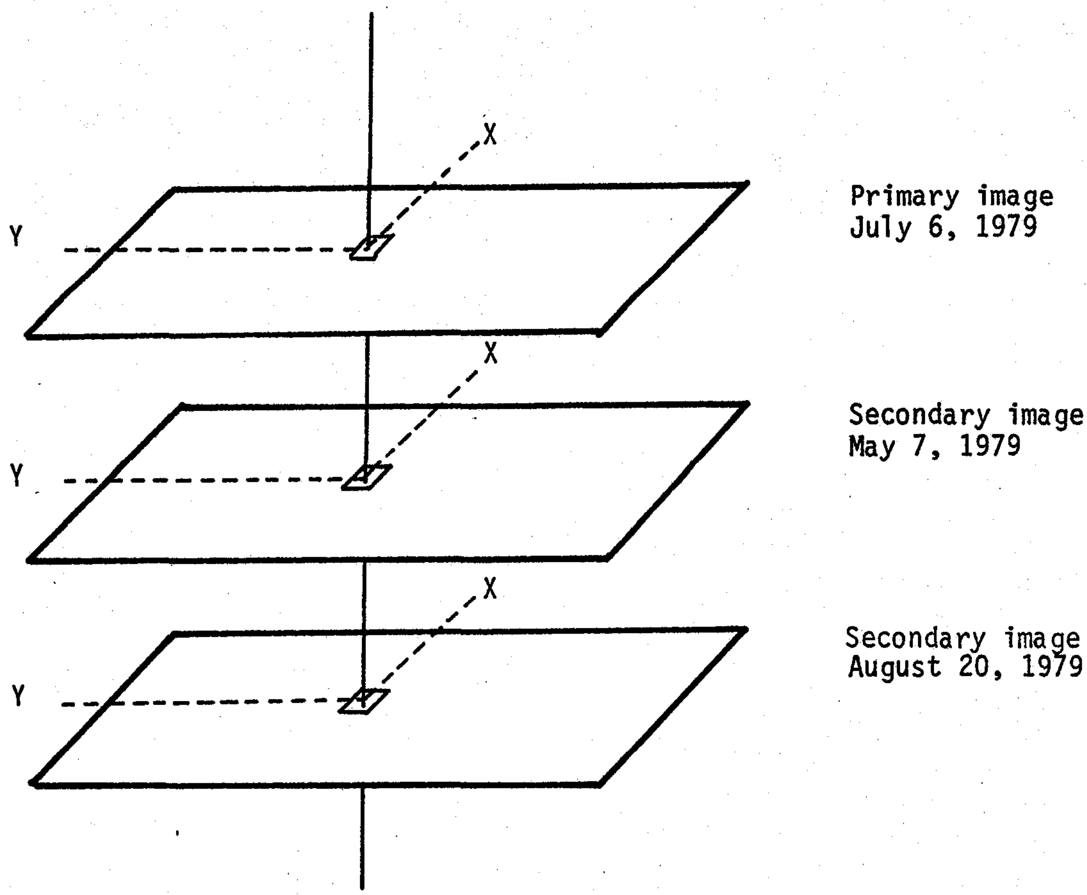
2.5 Data Pre-Processing

The various operations applied to the Landsat data before image analysis are considered to be data pre-processing steps. These operations can include the removal of scene noise, skew, image registration and enhancement. The pre-processing functions specifically used in this project were image registration, scene mosaicking, multi-image creation, and calibration file creation.

<u>2.5.1 Image Registration.</u> Multi-temporal image registration is a procedure which correlates each picture element (pixel) in a "secondary" image to a corresponding pixel in the "primary" image. Simply stated, the "secondary" image is "superimposed" onto a "primary" image, resulting in the ability to access the same pixel in multiple images by a unique pair of line/sample, or row/column coordinates (Figure 3). The need to perform this registration between Landsat scenes of the same area acquired on separate dates is due to the changes in the track of the satellite in its orbit, which varies due to earth rotation and satellite orbit movement. The image registration process

FIGURE 3

MULTI-TEMPORAL IMAGE REGISTRATION



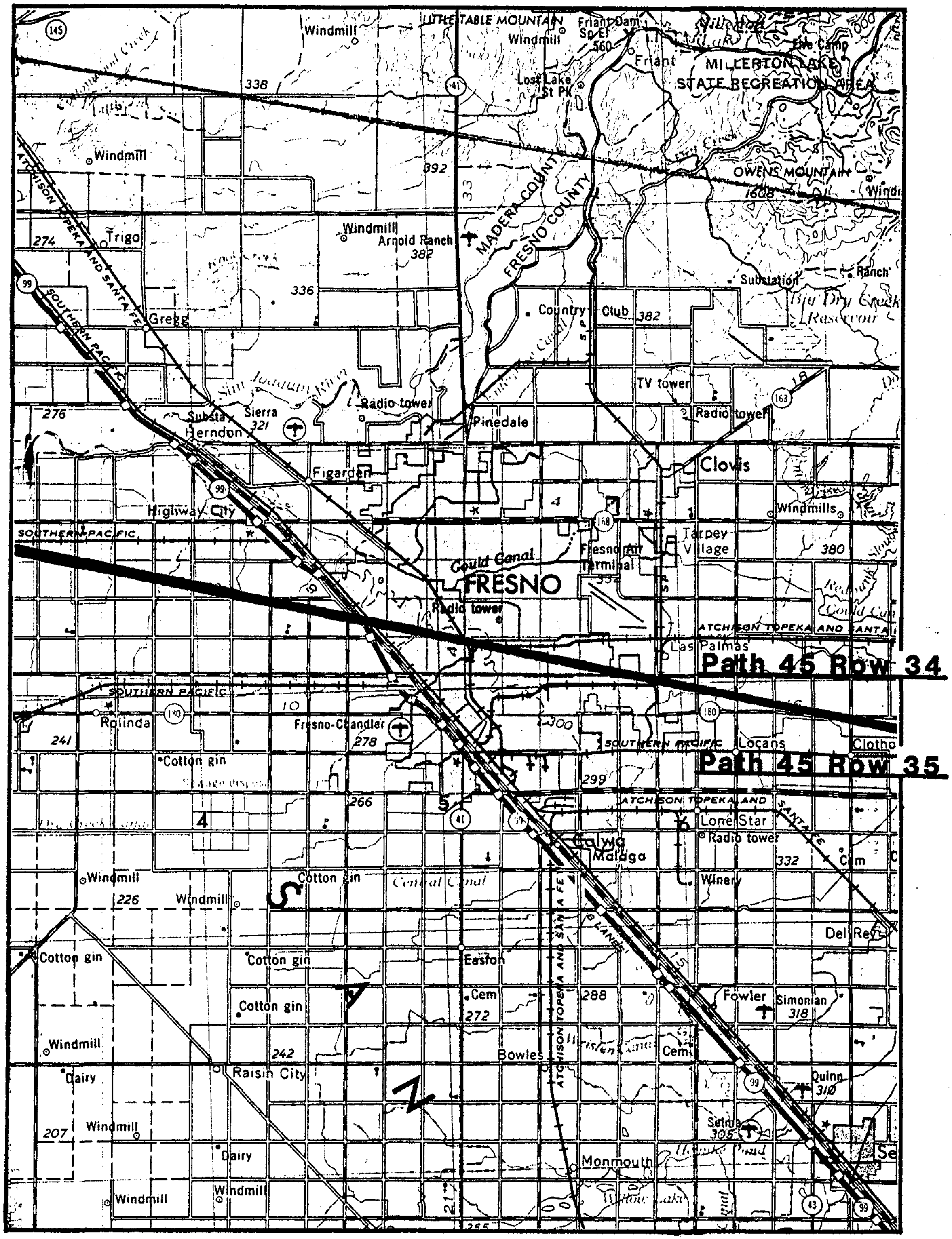
corrects for these variations in movement. This registration procedure consists of two steps: 1) The selection of corresponding points from the multiple images and 2) The geometric transformation of the images so that registration of each pixel is accomplished (Moick, 1980). For this pre-processing phase of the project, a relative registration is used, whereby one image is selected as a reference, or "primary" image, to which the other "secondary" images are registered. The July 6, 1979 date was used as the "primary" image for both images (Path 45, Row 34 and Path 45, Row 35).

The first step in the image registration process is the selection of corresponding points. These points were manually selected from 9" x 9" (1:1,000,000 scale) transparencies for each image. Each corresponding point represented a physical feature (i.e., major road intersections, stream confluences) that was distinguishable on all images. Approximately twenty points were selected. Using the EDITOR software, the corresponding points were digitized for the primary (July 6) and secondary (May 7) images. The points were used to generate an initial overlay parameter file, which contained coefficients (calculated by a least-squares regression analysis) that transformed secondary image coordinates into primary image coordinates (Ozga, Faerman, and Sigman,1979). This represented an approximate overlay, or registration, between the two images. 64 by 64 pixel and 32 by 32 pixel blocks, from the primary and secondary images respectively, were then extracted from an area common to both images. A block correlation function was run on the Illiac IV computer to correlate the 32 by 32 secondary block with all possible 32 by 32 sub-blocks in the 64 by 64 primary block. The result of this correlation was a collection of control points relating the two images, with each control point having a set of coordinates for the primary image and a corresponding set of coordinates for the secondary image. These control points were then evaluated using a third order least-squares polynomial, and edited until the maximum residual error for all block pairs was less than one pixel. Finally, the WARP program on the CDC-7600 computer was run to register the secondary image to the primary image, using the final set of block correlation coefficients to re-map the secondary images's pixels. A nearest neighbor interpolation rule was used to avoid modifying pixel reflectance values. The entire process was repeated to correlate the August 20 date to the primary image. The root mean square (RMS) error factor in this registration was approximately three-tenths of a pixel for each of the three images.

2.5.2 Landsat Scene Mosaic. As mentioned earlier, the study area included portions of two Landsat scenes. The north and south scenes for each date had to be joined, or mosaicked together to create one image. Figure 4 shows the approximate boundary between the two Landsat scenes. Because the overlap between Landsat scenes is approximately 120 lines of data, a control point representing a physical feature common to both scenes was selected to accurately complete the mosaic. The reflectance value of the control point in each scene was

Figure 4

Location of Landsat Scene Boundaries



Scale 1:250,000

▬▬▬ = approximate location of common boundary between Path 45 Row 34 and Path 45 Row 35 scenes compared, and when the points proved to be identical, the line, or row, coördinate was obtained. This line represented the common boundary between the two scenes. The sample, or column, coordinates for both scenes were obtained and the necessary shift in samples was made for accurate scene alignment. The appropriate subsections from each scene were then extracted and mosaicked together, creating one continuous image (Figure 5).

2.5.3 Multi-Date Image Creation. The next step in the pre-processing phase of the project was the generation of a multi-date data set. This data set was created by combining the four channels of data from each of the three dates to produce a twelve channel data set. Because the clustering and classification algorithms available at Ames allowed only four to eight channel data sets, a reduction in the number of channels was necessary. It was decided that the original twelve band data set would be reduced to a six band data set, utilizing two channels from each date, Landsat bands 5 (red) and 7 (infrared). Studies show that 80 to 90% of the spectral information contained within a Landsat scene can be found in bands 5 and 7, and because these bands are uncorrelated, very little information in a Landsat scene is lost when bands 5 and 7 are the only bands used in an analysis. Until this point in the process, the multi-date data set had been in a band-by-band format, where each band is represented as an individual file on the computer tape or disk. When the data was compressed from twelve to six channels, it was also reformatted from the band-by-band format to a pixel

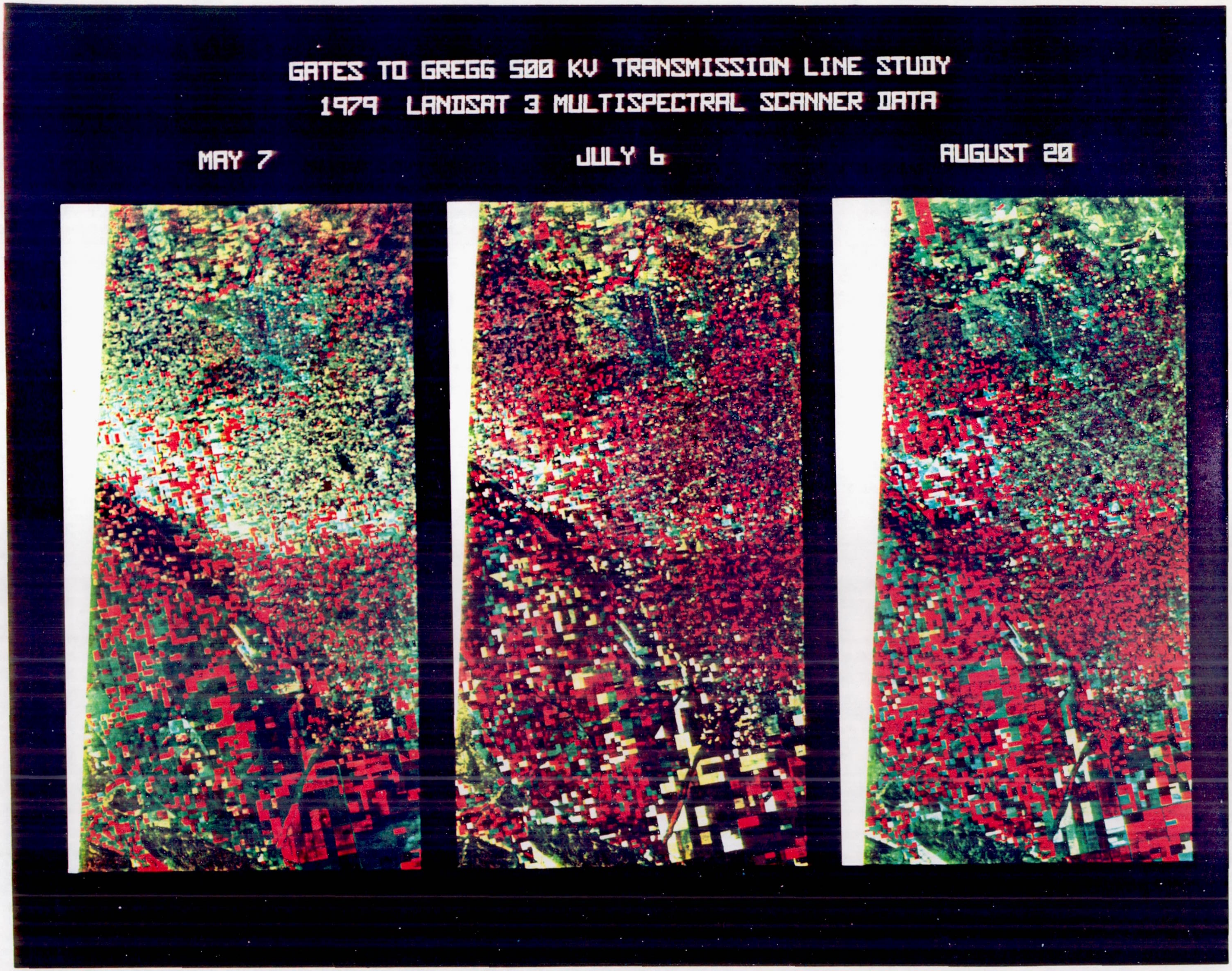


Figure 5. Raw Data

interleaved format to make it compatible with the EDITOR software system. This reformatting created a one-file data set, where all the data for each pixel (one byte of data for each of the six channels) is stored in adjacent space on computer tape or disk.

2.5.4. Calibration File Creation. Another pre-processing function performed during the project was the creation of a calibration file. Similar to image registration, where one image coordinate system correlates with another, the calibration file relates the Landsat coordinates (line/sample) to ground coordinates (latitude/longitude). The calibration file allows for digitized training sites (from USGS quads) to be accurately located on the Landsat image. The creation of this file was accomplished using the mosaicked image and USGS 7.5' quadrangles covering the study area. The Landsat image was displayed using the IDIMS color monitor. Control points that could be identified on both the Landsat image and the 7.5' quadrangles were manually selected. Again, these points were physical features such as road intersections, stream confluences, and field boundaries. When located, the point was marked on the map, along with the corresponding line and sample coordinate. Fifteen control points were selected throughout the study area and entered into the computer using the EDITOR software system. Regressions were run on the two sets of coordinates using first and second order general polynomial equations. The regression residuals were evaluated and control points were edited until a satisfactory root mean square (RMS) error was attained. For this project, the RMS error was 46 meters, which means that a pixel on the Landsat image and its corresponding point on the ground were within 46 meters (slightly less than one pixel).

2.6 Digital Analysis

Digital analysis is a set of procedures and computer processes used to manipulate and interpret Landsat digital data into a useable format for conveying specific information. In this project, the digital analysis process involved two major techniques: band ratioing and supervised land cover analysis. The band ratioing technique was used to estimate the number of irrigated and non-irrigated acres within the study area. The supervised land cover analysis technique was used to examine the spectral response characteristics of the pixels and to correlate them to specific information classes. The information classes were based on two items: 1) the various crops that PGandE was interested in throughout the Fresno area, and 2) the ability to spectrally distinguish the desired information classes to obtain an accurate classification of the Landsat data. The major steps in the analysis included training site selection, digitization, clustering, statistics editing, classification, and evaluation. The following sections describe these analysis procedures in some detail.

2.6.1 7/5 Band Ratio. Band ratioing is an image enhancement technique used to extract additional information from remotely sensed data. Vegetation can be measured as to its relative health or biomass using this technique. Appropriate Landsat Multi-Spectral (MSS) bands to use for this image enhancement are band 5 (0.60-0.70 um) and band 7 (0.80-1.10 um), and a ratioed image is generated by dividing each pixel in band 7 by each corresponding pixel in band 5. Green, healthy vegetation, containing a high amount of chlorophyll, strongly absorbs incident radiation in the red region (MSS band 5) of the electromagnetic spectrum. Conversely, MSS band 7, the near-infrared region of the spectrum, is minimally absorbed by green vegetation. (MSS band 7 appears to be more effective than MSS band 6 because band 7 is more highly and directly correlated to green leaf density (Tucker, 1978).) Therefore, green vegetation exhibiting high absorption in MSS band 5 and high reflectance in MSS band 7 indicates healthy, highly productive vegetation.

Because of the climate in the San Joaquin Valley, the majority of crops are irrigated throughout the growing season. Non-irrigated vegetation tends to be classified as native vegetation, fallow fields, or just-harvested fields due to the similarity in spectral reflectance. In general, irrigated vegetation appears very green or healthy in contrast to non-irrigated vegetation, so the assumption was made that irrigated cropland in the San Joaquin Valley would correlate directly with a high 7/5 ratio value.

A ratioed image was generated for each date - May, July, and August - in the data set and a threshold value was determined to discriminate irrigated from non-irrigated vegetation. A high ratio value indicated "healthy", or irrigated vegetation and a low ratio value indicated "less healthy", or non-irrigated vegetation. The threshold value was established by visually examining each ratioed image on the IDIMS color monitor. The threshold value, or cut-off point for irrigated versus non-irrigated vegetation, was 65 for all three dates.(2) Values below 65 were categorized as non-irrigated and values 65 and above as irrigated.

A composite ratioed image was also generated for the data set, combining the three dates to show all possible combinations of irrigation dates. In the process of summing the three images, each "non-irrigated" pixel was assigned a value of 1 and each "irrigated" pixel was assigned a value of 2, 4, or 8, for May, July and August respectively. This was done so that all combinations of irrigated and non-irrigated pixels for the three dates would be unique, using the Boolean addition function. Table 3 shows how the summation of the three dates was accomplished, and Figure 6 displays the composite ratioed image.

(2)The equation used in the VICAR 7/5 ratio was: Band 7 - Band 5 (or 1.0 if Band 5 is 0) x 50. Consequently, 65 is the "stretched" ratioed value and 1.3 is the true ratioed value.

Table 3

Summation of 7/5 band ratio images

Back-ground	May 7	July 6	August 20	Total	
Ø	1	1	1	3	not irrigated
Ø	2	1	1	4	irrigated in May
Ø	1	4	1	6	irrigated in July
Ø	1	1	8	1Ø	irrigated in August
Ø	2	4	1	7	irrigated in May &July
Ø	2	1	8	11	irrigated in May &August
Ø	1	4	8	13	irrigated in July &August
Ø	2	4	8	14	irrigated in May, July &August

Ø = Background value
1 = Not irrigated value
2 = May irrigated value
4 = July irrigated value
8 = August irrigated value

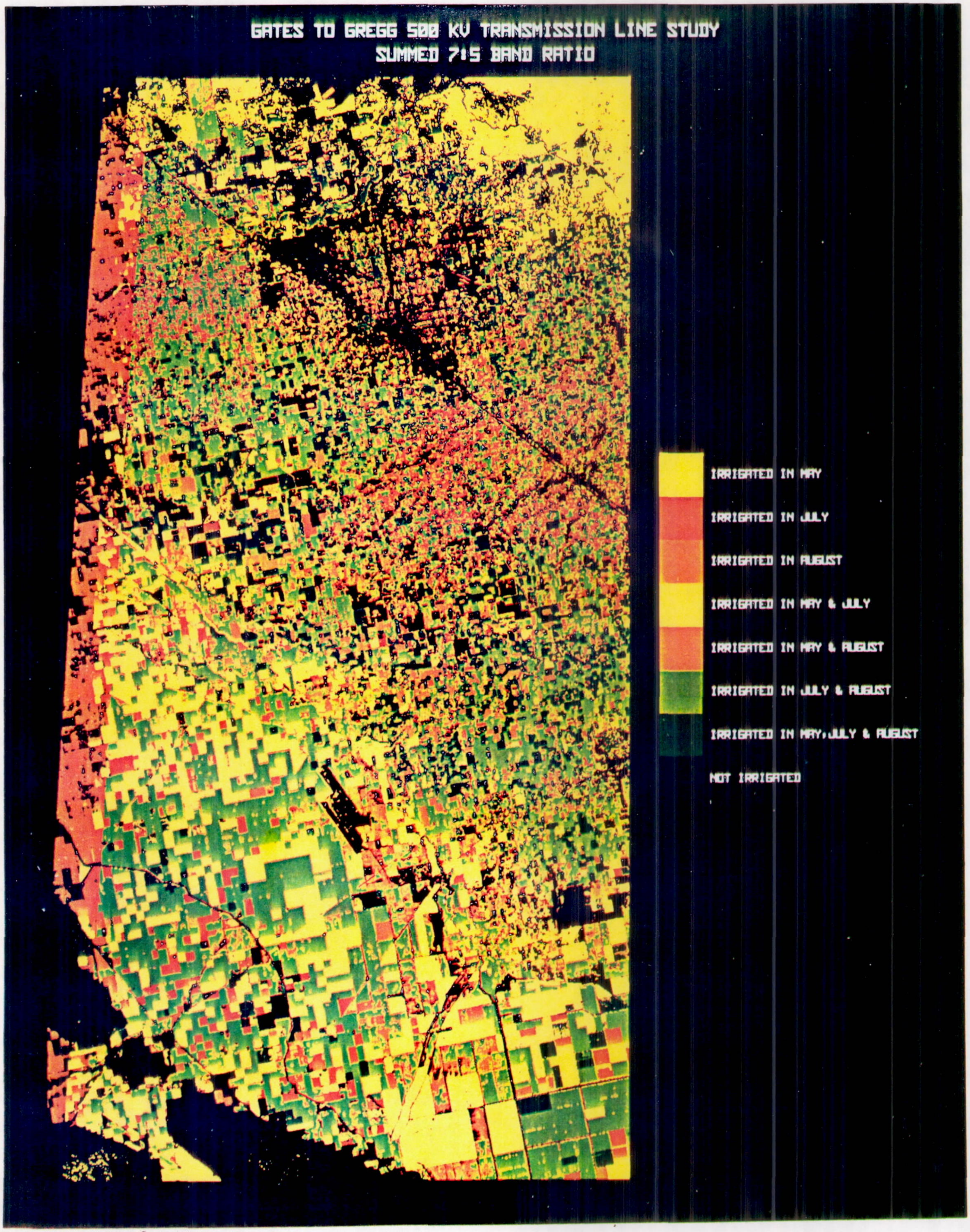


Figure 6. 7/5 ratio photo

General irrigated land acreage estimates can be obtained from a 7/5 ratio. Table 4 shows the estimated number of irrigated acres for each date and combinations of dates. An application for this information is the extrapolation of water consumption rates from the amount of acreage. A general classification scheme could also be developed from the composite ratio image if crop types are known for each cycle in the growing season. For example, in this data set, grain is the major crop displayed as being irrigated in May. (Grain, in Fresno County, is harvested primarily in June and July and therefore would not be present in the July and August scenes.)

Table 4

Irrigated Acreages for Study Area

	Acres
irrigated in May	204,049
irrigated in July	195,583
irrigated in August	69,647
irrigated in May & July	54,248
irrigated in May & August	26,776
irrigated in July & August	431,075
irrigated in May, July & August	155,606
not irrigated	394,427
Total	1,531,411

<u>2.6.2 Training Site Selection and Digitization.</u> The first step in digital analysis is the determination of spectral response characteristics of the desired information classes.

This process begins with the selection of training sites, or areas known to contain a specific information class. It is critical that these areas are representative, homogeneous examples of a specific information class or crop type because these sites will be used to develop a "spectral signature", or a statistical description of multi-band reflectance, to be used in the clustering and classification process. The training sites are extracted from the image itself, and therefore, the spectral signatures developed may not be typical of, and should not be extended into regions outside the general study area. The unique spectral signature of each crop may differ from one region to another because of varying atmospheric and illumination conditions, sensor system effects (Lillesand & Kiefer, 1979), soil characteristics, and plant phenology. Consequently, training sites should be distributed throughout the specific study area to minimize these effects.

The training sites for this project were selected using the California Department of Water Resources 1979 ground reference data for Fresno County. Specific crop types were located throughout the county and actual field boundaries were delineated on USGS 7.5' quadrangles (Table 5).

Table 5

Crop Types Selected for Digital Analysis

Grapes	Sugar beets
Citrus	Beans
Peaches	Safflower
Fig	Corn
Olives	Alfalfa
Almonds	Grain
Melons	Pasture
Garlic	Native vegetation
Lettuce	Dairy
Carrots	Feedlot
Tomatoes	Residential
Cotton	Commercial/industrial
	Water

The majority of training sites were located in the southern portion of the study area due to the larger field sizes (Figure 7). The assumption was made that fields greater than 40 acres would contain a more representative sample of each crop type due to fewer border pixels that would be associated with smaller fields. Appendix B contains a list of the number and size of fields selected for each information class. Border pixels are those pixels that cover an area containing more than one cover type (i.e., roads, field boundaries). An individual pixel's reflectance value is a weighted average value of the individual cover type reflectance values.

After the training sites were selected and transferred to the quadrangles (Figure 8), they were entered into the PDP-10 computer using the Talos electronic digitizing system and EDITOR software. Using the precision calibration file created earlier, the field boundary coordinates (latitude/ longitude) were transformed into Landsat coordinates (line/ sample). For each

Figure 7

Location of Selected DWR Training Sites

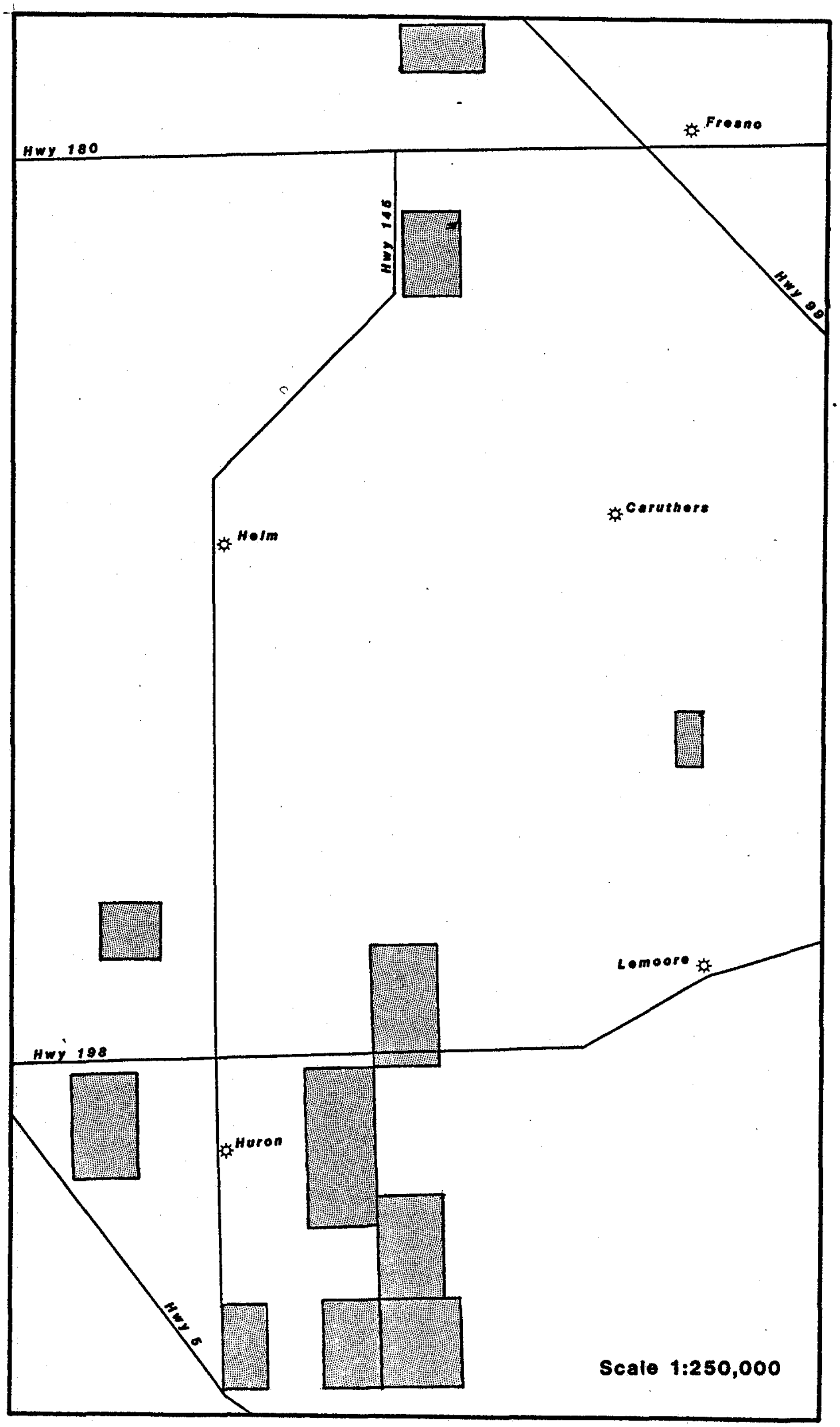
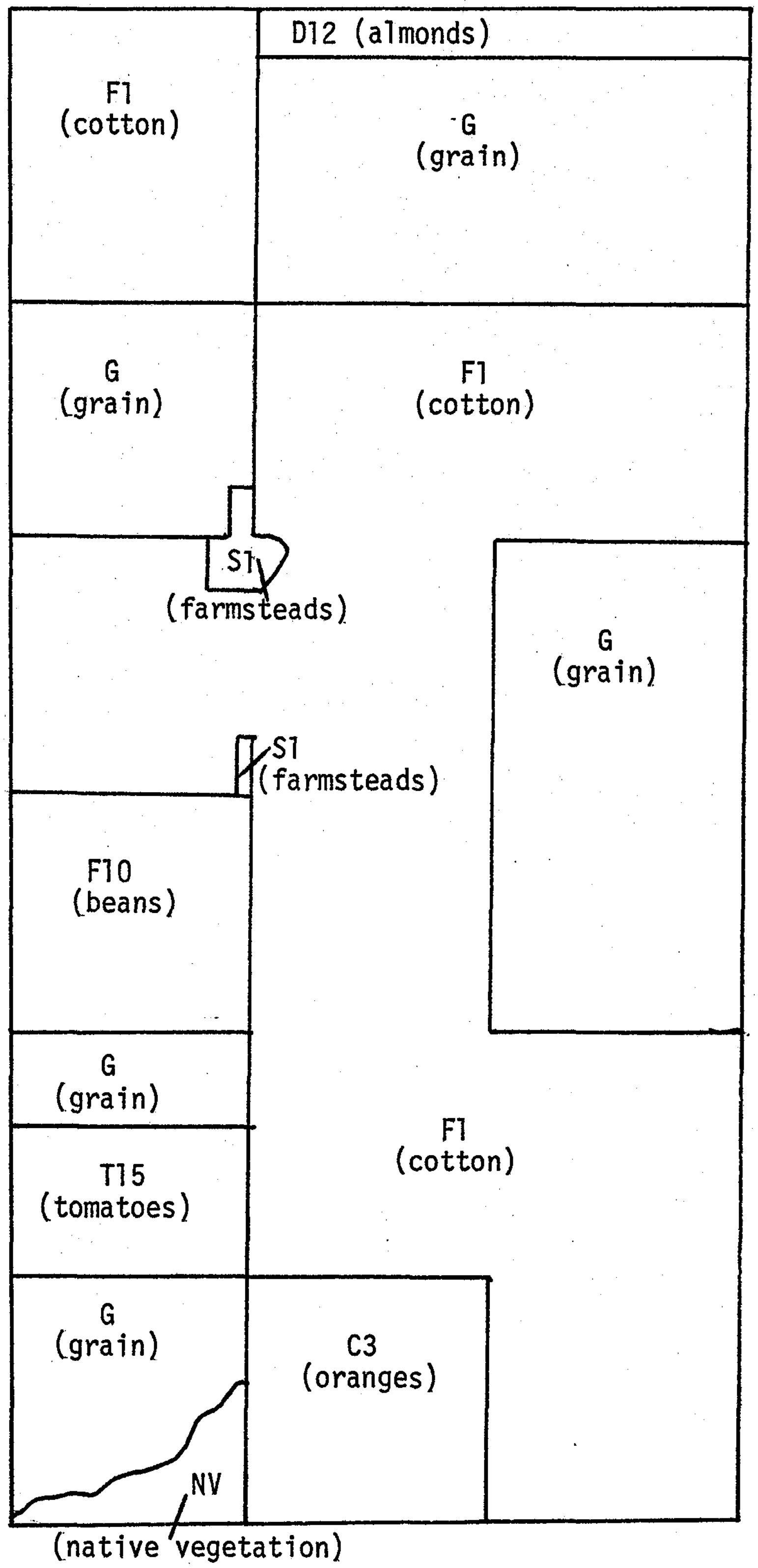


Figure 8

Example of a training site located on the La Cima 7.5' USGS quadrangle



Scale 1:24,000

*Ground reference data was supplied by the California Department of Water Resources collection of cover types on a 7.5' quadrangle, the computer generated a separate file for each map, called a "segment file", so that the pixels for each cover type could be extracted and analyzed for their spectral response characteristics.

In order to analyze these characteristics, the "segment files" needed to be rearranged into files containing individual cover types. These new "cover type files" contained the irradiance values for all the pixels digitized as a specific cover type, and have no spatial orientation to the image. Border pixels (the actual digitized lines separating the fields) were excluded from the creation of these new files to avoid any erroneous spectral values.

2.6.3 Clustering. Each "cover type file" was then histogrammed to visually analyze the distribution of pixels over a range of spectral values (0-127). Histograms were generated for each of the six channels and each crop type. Figures 9a through 9f are examples of the histograms generated for the digitized safflower fields. Ideally, each histogram should be normally distributed, an important factor when using the maximum likelihood classifier. Noting that the safflower histograms, along with the majority of the other crop types were not normally distributed, (indicative of the heterogeneity and/or different growth stages within each of the selected cover types), clustering techniques were used to separate out the individual elements that contributed to the heterogeneity of each cover type.

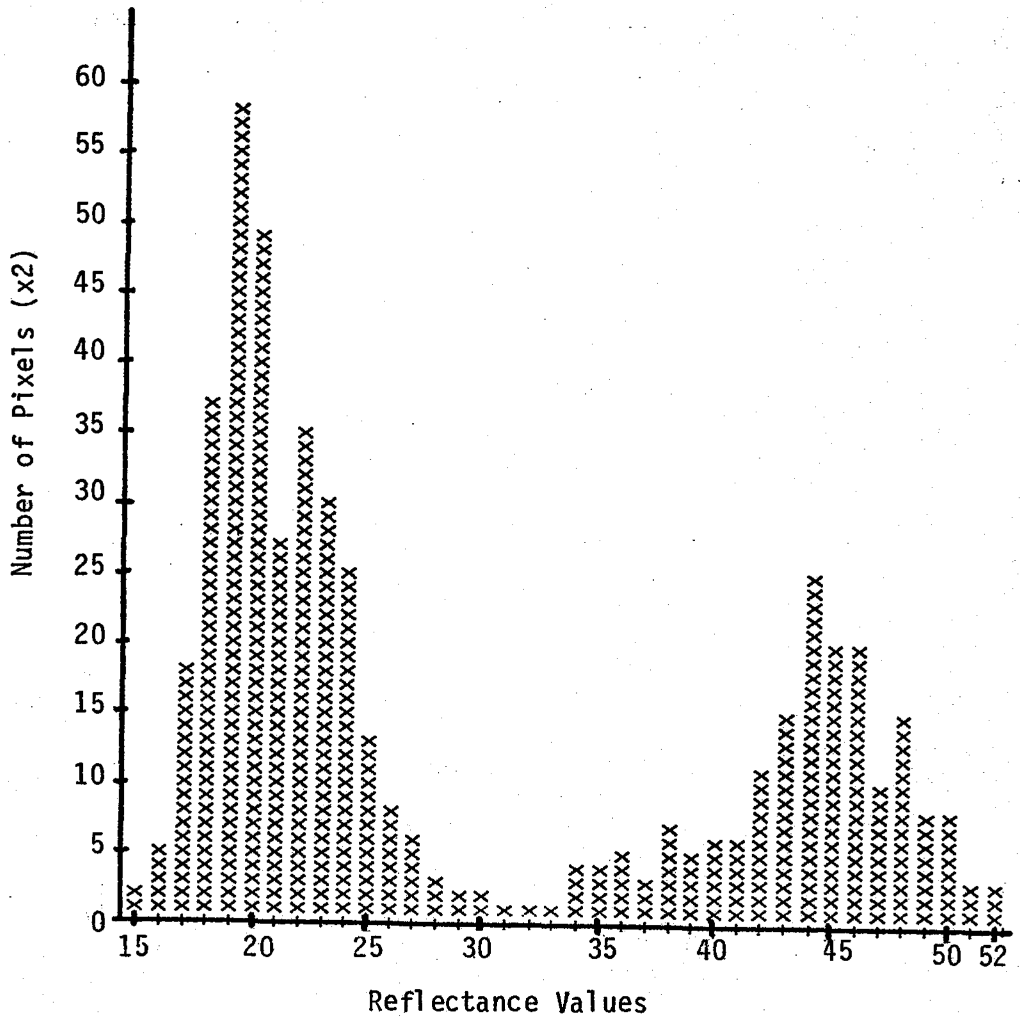


Figure 9a. Histogram representing safflower training site. May 7, 1979 Band 5

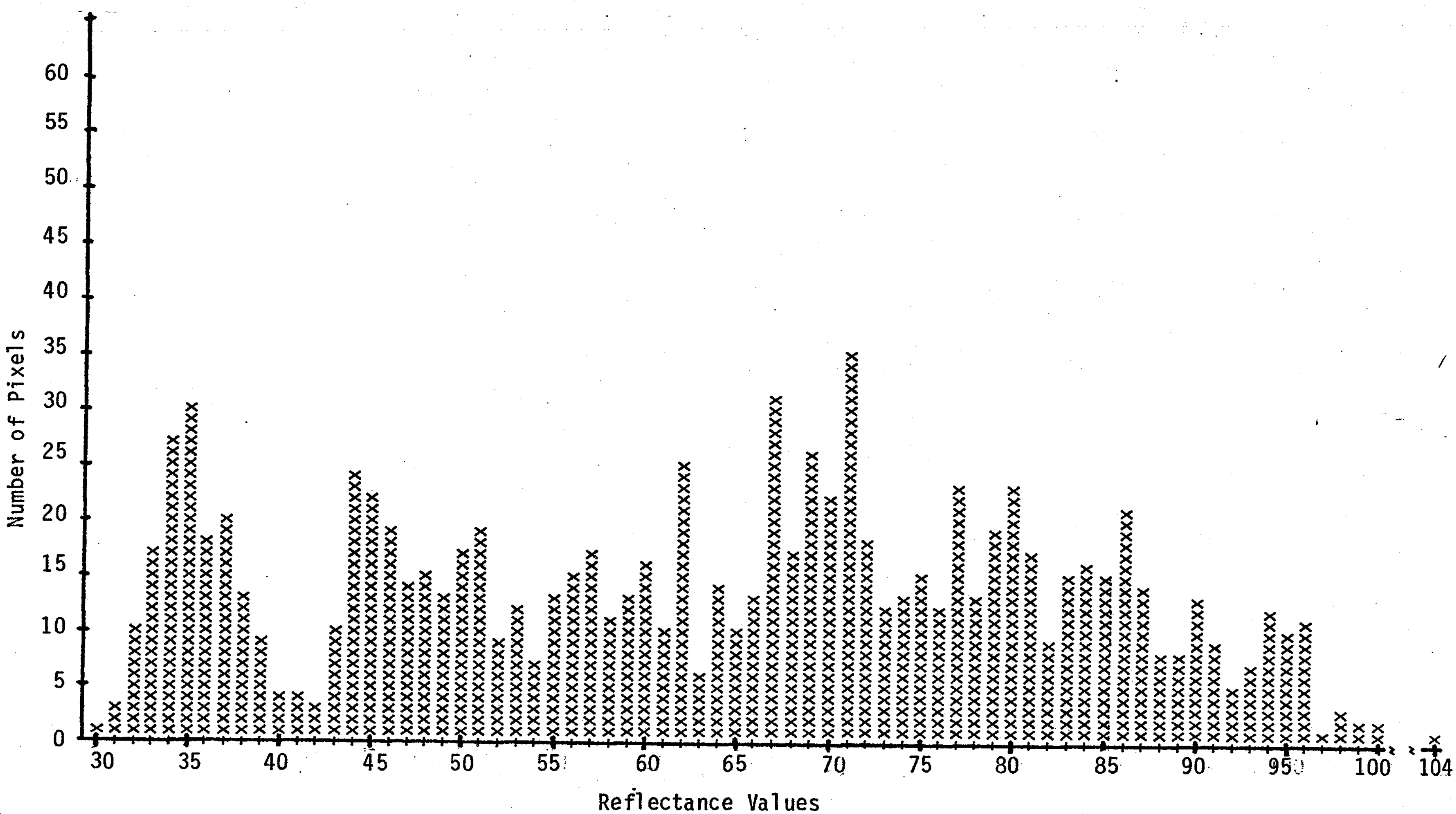


Figure 9b. Histogram representing safflower training site. May 7,1979 Band 7

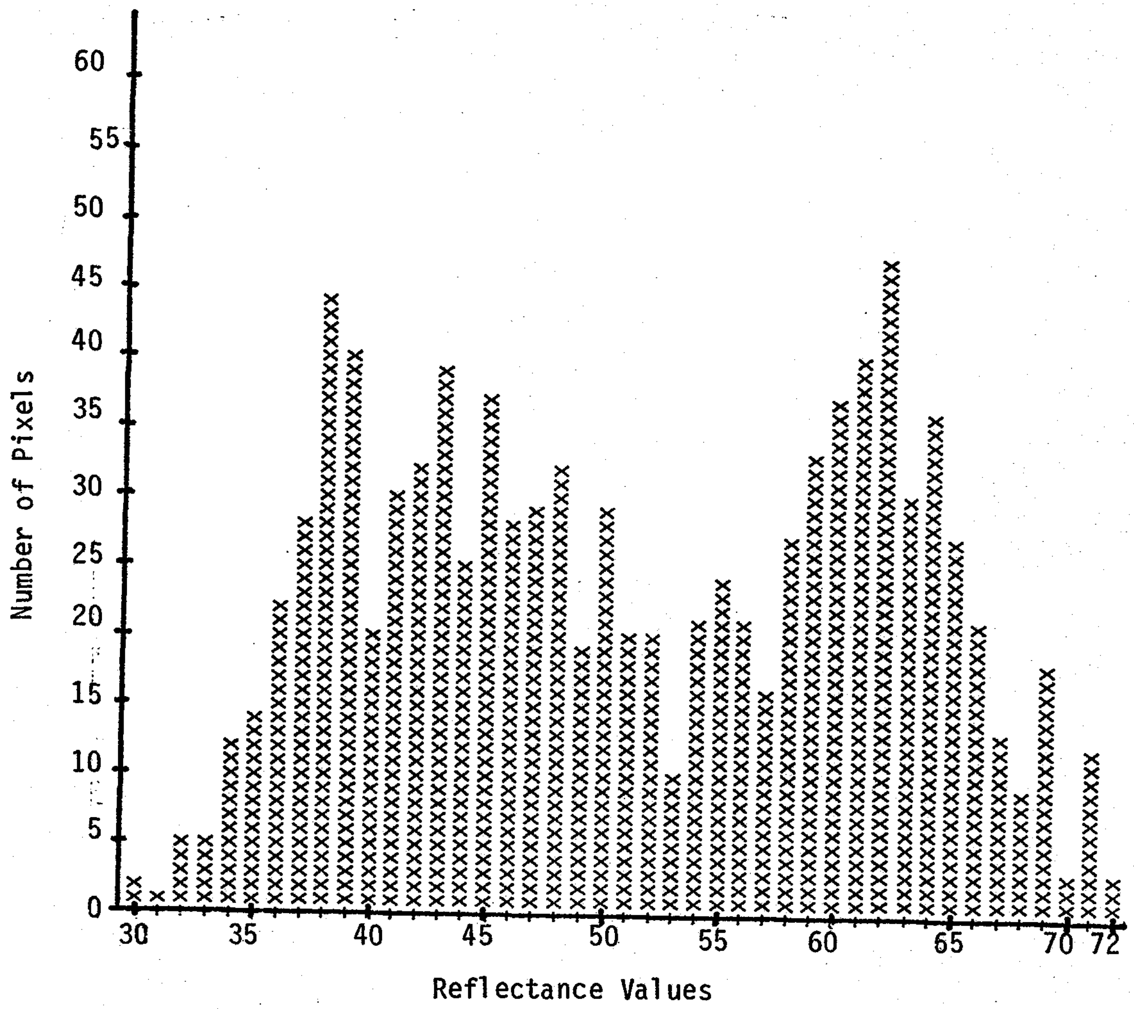


Figure 9c. Histogram representing safflower training site. July 6, 1979 Band 5

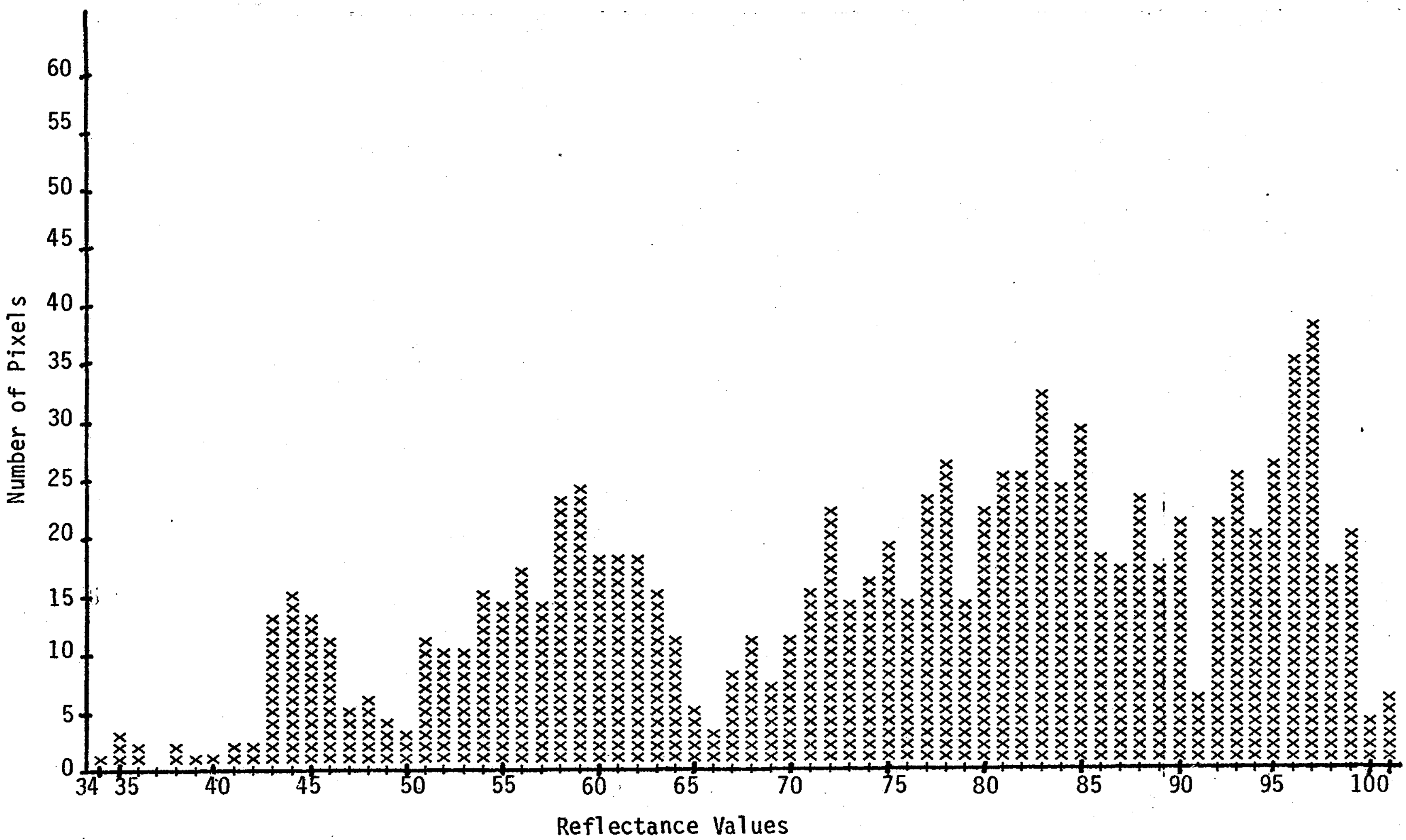


Figure 9d. Histogram representing safflower training site. July 6, 1979 Band 7

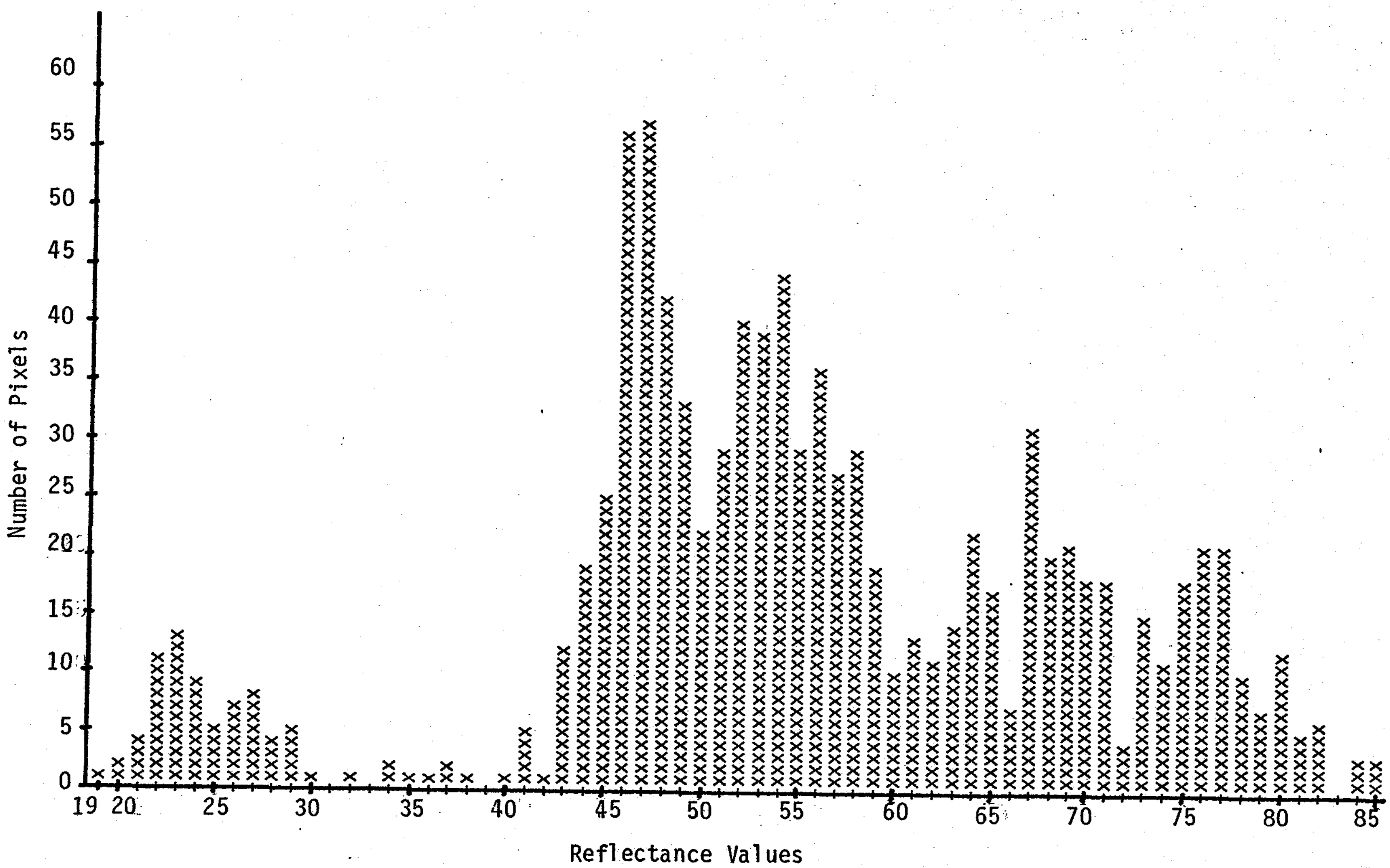


Figure 9e. Histogram representing safflower training site. August 20, 1979 Band 5

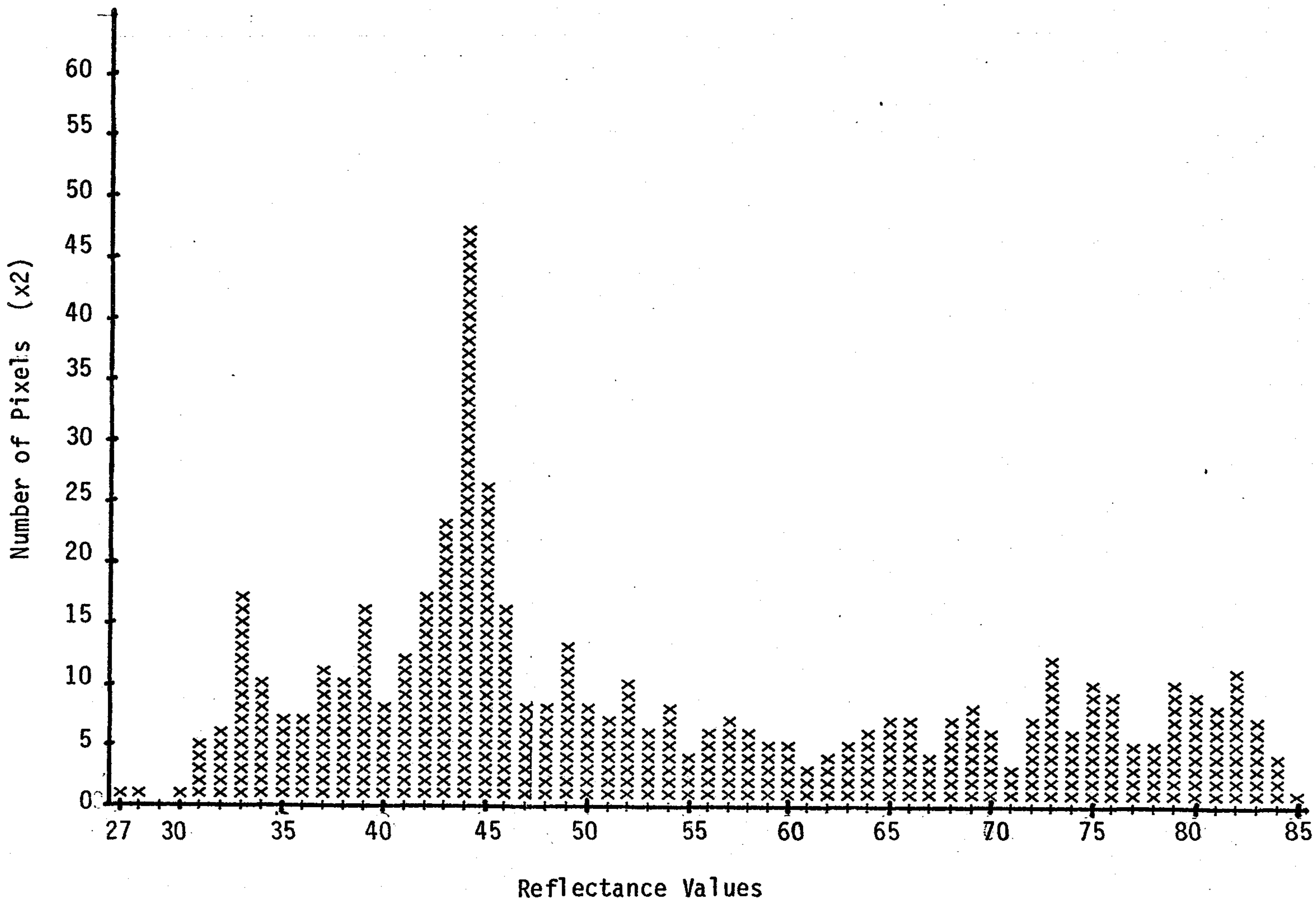


Figure 9f. Histogram representing safflower training site. August 20, 1979 Band 7

Clustering is a procedure in which pixels are grouped within spectral space in such a way that the resulting groups, or clusters, represent the components of an information class (cover type). Figures 10a through 10c demonstrate the clustering procedure, with Figure 10a representing a typical training site in two dimensional space. As the clustering procedure begins, the data is partitioned in groups. A group or cluster mean is established with each iteration of partitioning until all pixels have been assigned to the most appropriate group (Figure 10b). A concentration ellipse plot (Figure 10c) can then be generated to display the appearance of the clusters in two-dimensional space. The clustering algorithm used on the EDITOR software system is a variation of the ISODATA multivariate (Ball & Hall, 1975). This digital analysis technique is very useful when dealing with large, complex data sets because the clustering algorithm determines the spectral classes based on the natural clustering tendencies of the data.

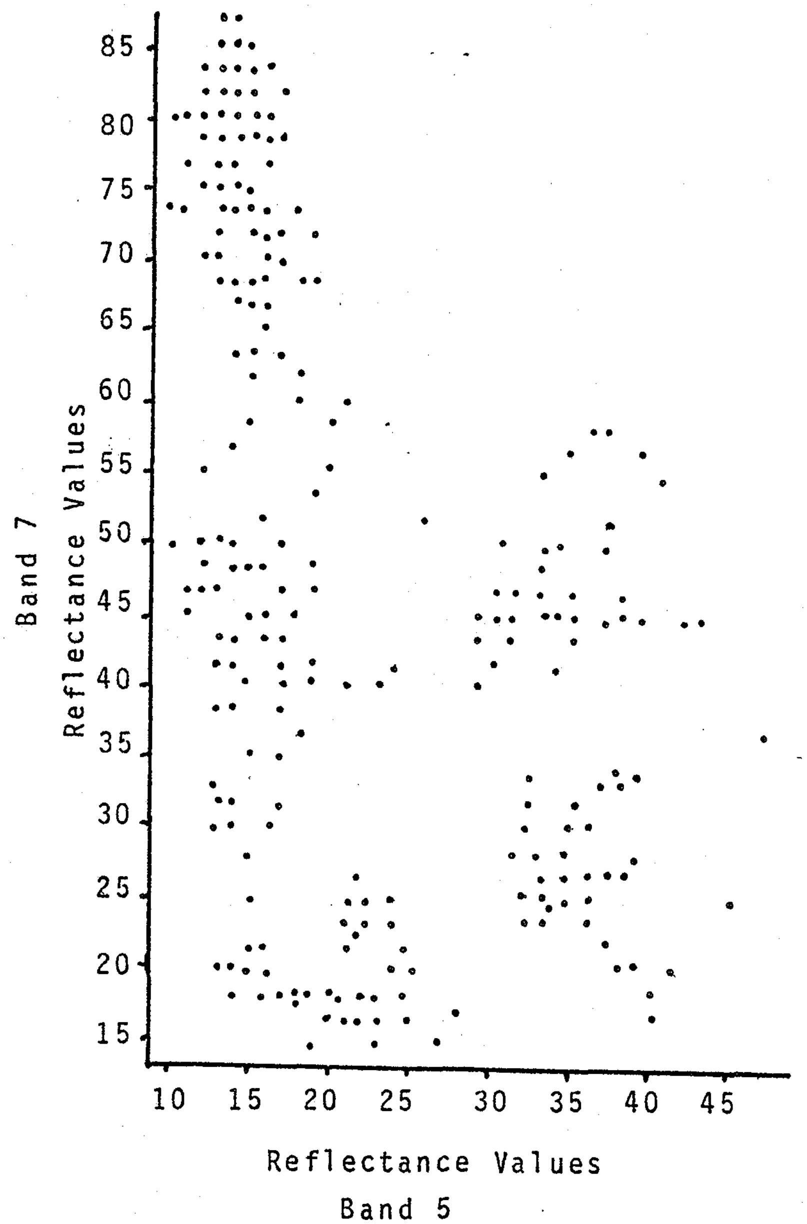


Figure 10a. Scattergram of a typical training site.

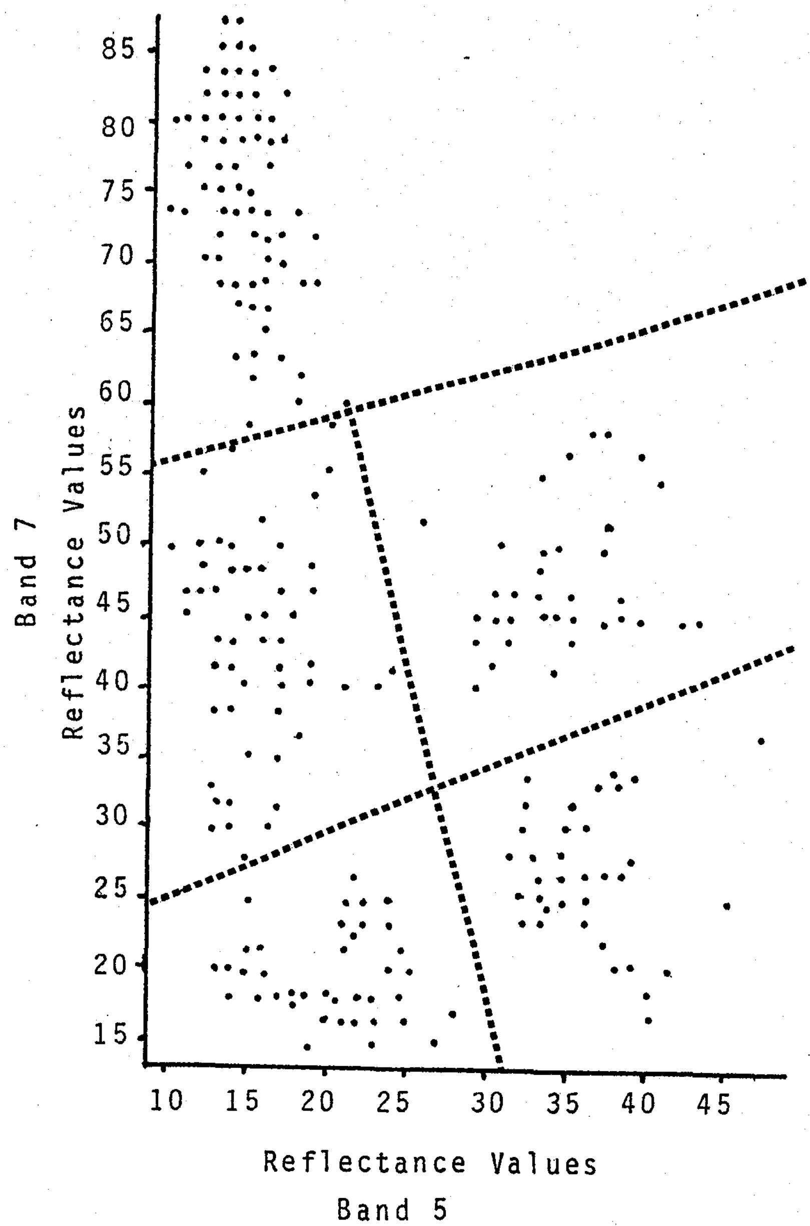


Figure 10b. Partitioning of data accomplished during clustering.

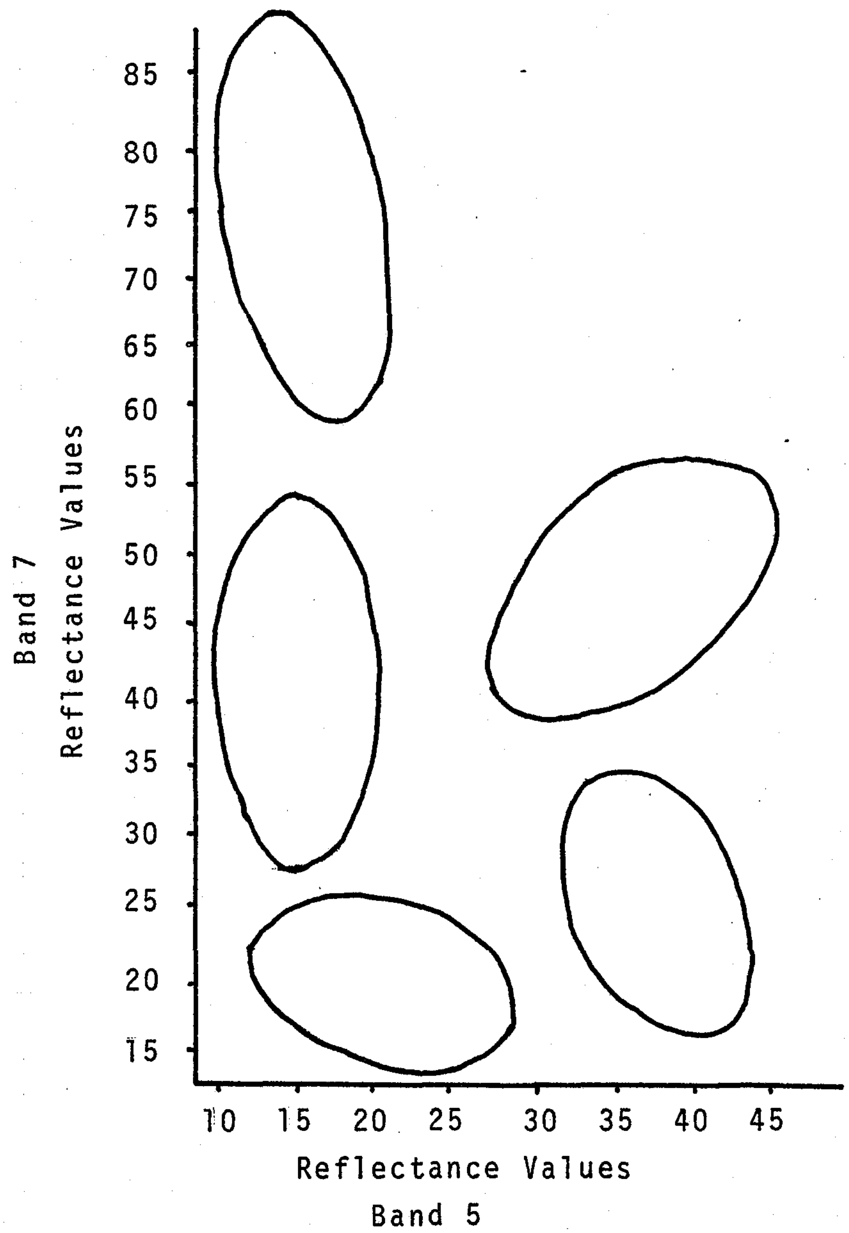


Figure 10c. Concentration ellipse plot for a typical training site after clustering.

For this project, each cover type was clustered individually to evaluate its spectral response characteristics. To initiate the clustering procedure, the analyst determines the number of spectral classes desired. The histograms are examined to identify nodes which are representative of concentrations within the data. For example, using the safflower histograms, seven spectral classes were selected for clustering. Along with the clusters, a set of statistics is also generated for each cluster, defining the components of the spectral signature for safflower. For each cluster a spectral mean, variance, and separability measure is determined. The variance is a measure of the dispersion of a cluster in spectral space. The separability measure used is described by the "Swain-Fu" distance which is a ratio of the distance between two cluster centroids, or means, to the sum of the dispersion of the data for the two clusters (Swain, 1973). This distance is graphically described in Figure 11.

Clusters were considered distinct, or separable, when their separability measure was greater than a specific threshold. Generally, a Swain-Fu separability measure of Ø.75 was considered sufficient for distinguishing different cover types.(3) Clusters with a separability below approximately Ø.55 were considered to be too similar and were either merged, deleted, or reclustered. Table 6 displays the statistics for the initial clustering of

(3) The Ø.75 threshold value is an established convention for four channel single date data sets. The assumption was made that the same threshold could be extended into multi-date analysis.

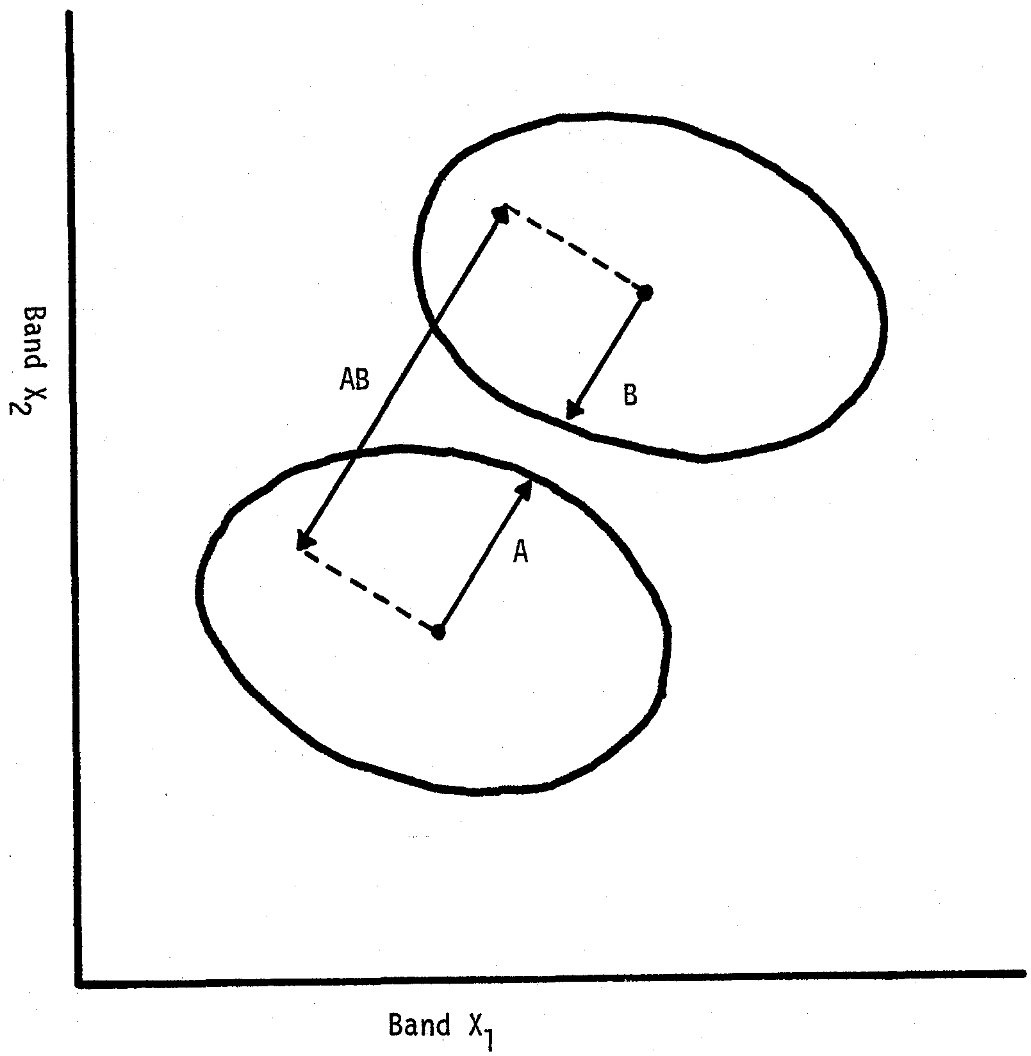


Figure 11. Cluster separability using Swain-Fu distance measurement.

$$\text{Separability} = \frac{AB}{A + B}$$

TABLE 6

Initial Statistics for the Safflower Training Site

SEPARABILITY MATRIX (SWAIN-FU DISTANCE):

CLUSTER#	1	2	3	4	5	6	7
1	1.00	2.00	1.13	3.43	4.61	3.38	3.57
2		1.00	1.72	1.87	3.53	2.63	3.46
3			1.00	1.41	1.57	1.28	1.51
4				1.00	1.65	1.49	2.16
5					1.00	1.54	2.09
6						1.00	1.09
7							1.00

MEANS:

CLUSTER#	CHANNELS 1	2	3	4	5	6
1	56.94	44.39	46.68	36.24	45.40	33.11
2	39.51	57.95	45.27	35.35	25.45	60.84
3	47.47	61.83	40.59	50.11	55.47	51.04
4	43.85	92.79	22.86	63.04	53.69	44.78
5	61.33	78.74	19.34	81.73	52.41	40.80
6	41.41	90.47	21.53	71.35	67.20	71.25
7	65.53	87.30	20.14	80.95	77.11	79.47

VARIANCES:

CLUSTER#	CHANNELS 1	2	3	4	5	6
1	13.32	15.15	10.37	6.85	3.21	4.84
2	17.70	52.00	7.39	14.18	17.51	64.74
3	24.26	41.63	40.25	35.83	89.34	54.03
~~4~~	~~52.19~~	~~40.21~~	~~9.95~~	~~43.99~~	~~13.10~~	~~12.42~~
5	11.75	25.14	3.22	105.70	22.39	17.33
6	36.52	57.77	8.43	95.17	22.01	26.24
7	17.78	26.05	6.89	47.41	12.33	19.05

safflower. The separability matrix in Table 6 displays highly separable clusters, indicating very heterogeneous training sites. The variances were also unusually high for clusters representing the same cover type. This could be due to the multi-date approach in the analysis. In some cases, extremely high variances (greater than 75) were due to pixels included in the training site that formed the histogram "tails". These "tails" could have been miscellaneous features such as dirt roads or bare soil within a training site. It was assumed that the pixels contained in the histogram "tails" were not true representatives of the cover type and added confusion to the spectral signature. Because these pixels tended to be few in number and diffuse in nature, they were grouped into expanded clusters exhibiting high variances. A program on the EDITOR software system was used to remove the histogram "tails" from the training site data. These modified cover types were then clustered again and compared with the original clusters. Because a reduction in variance was noted, all cover type training sites with extraneous pixels were modified and the resulting new clusters were used for further analysis.

2.6.4 Statistics Editing. The process of statistics editing began after each cover type was represented by a set of statistics. The goal of this editing process is to develop a set of statistics that best represent the desired information classes. This is accomplished by comparing the individual statistics and either deleting, merging, or reclustering to obtain spectrally unique clusters. By comparing and analyzing the sets of statistics, a series of combined statistics files were generated, creating a unique set of statistic for each cover type. Statistics combined first were those cover types where confusion, or low separability, was most likely to occur, such as the different orchard classes. Confusion between cover types was defined to exist if the clusters had separabilities of less than 0.75. Resolving this problem included comparing the means, the number of pixels, and the variances of clusters exhibiting low separability. If the variance of one of the conflicting clusters was high (greater than 40)(4) relative to the other cluster, and/or had a small number of pixels, that class was deleted. Many times the deleted cluster within a given cover type was highly separable from the other clusters in that cover type, indicating that the deleted cluster was not actually describing that specific cover type. In certain cases though, the spectral similarity between cover types could not be resolved. For example, this occurred between the garlic and tomato cover types (Table 7). The statistics editing process continued until a master statistics file existed which contained all spectral classes representing the desired cover types (Appendix C).

(4)Variances were unusually high with this data set because of the use of multiple dates. With a four channel single date data set, variances are normally less than 20, and an optimum value is less than 10.

Table 7

Separability Matrix for Garlic and Tomatoes

		Tomatoes 1	Tomatoes 2
Garlic	1	2.03	1.86
	2	1.77	1.20
	3	0.62*	0.89
	4	1.25	0.60*

* spectrally similar clusters

2.6.5 Classification and Evaluation. The classification algorithm used for this project was the Gausian maximum likelihood classifier. Classification involves utilizing the statistics file as a set of spectral samples for defining the information classes. Pixels of unknown cover type are compared to the statistical sample and then "classified" or assigned to the most appropriate information class. The maximum likelihood classifier assumes a normal distribution for all spectral clusters and evaluates both the variance and correlation of each spectral cluster when classifying a pixel. As a pixel is classified, the probability of that pixel belonging to each spectral cluster is calculated and is then assigned to the cluster it most resembles in spectral space (Lillesand and Kiefer, 1979). Although the maximum likelihood classifier is generally more accurate than other classification algorithms, it is a costly and slow procedure to use because of the large number of computations required to clasify each pixel. The final master statistics file and six-channel multi-date data set were used for the classification. Output from this procedure was a sixty-two class categorized image.

Even though a supervised classification approach was used and all spectral classes were assumed to belong to a known cover type, the accuracy of the classification needed to be examined. The IDIMS software system and color display monitor were used for this purpose. As each spectral class was assigned a pseudo color, selected areas where the given class occurred on the classified Landsat image were compared to the DWR ground reference data for accuracy. The areas selected for evaluation were not associated with any of the areas used as training sites. Several problems with the classification were noted and steps to solve these errors were taken. Listed below are the major problems and possible solutions discovered in the first classification.

Problem: Spectral classes labeled as commercial/industrial areas were found throughout the scene. These classes had high reflectance values corresponding to bare soil, grain stubble, and young orchards and vineyards, in addition to commercial/ industrial areas.

Solution: A stratification technique was used to separate the agricultural areas from non-agricultural areas (see "Image Stratification" section).

Problem: Clusters representing the vineyard class and various orchard classes appeared in the residential areas of Fresno. Parks and tree-lined streets have similar spectral response characteristics to the vineyards and orchards, and therefore are misinterpreted by the classifier.

Solution: The same stratification technique mentioned previously was used to separate the agricultural areas from non-agricultural areas.

Problem: Entire fields were misclassified because of the different patterns and stages in growth of certain crops. The misclassification of the crops - young vineyards, young ochards, grain stubble, and burn areas - was due to the lack of training sites selected for digital analysis.

Solution: Coordinates for the misclassified fields were obtained (using the IDIMS color monitor) for histogramming and reclustering procedures, and added to the statistics file.

Problem: Overall, the classification appeared fairly accurate in the southern portion of the scene and less accurate in the northern portion. This phenomenon could have been due to the larger fields in the south and smaller more complex field patterns in the north. Another possibility considered was the variation in soil coloration. The northern portion of the scene was lighter in color than the southern portion, while the Fresno Slough area (central portion) was quite dark in color.

Solution: The Soil Conservation Service (SCS) "Soil Survey of the Eastern Fresno Area" was examined to see if there was a significant change in soil mapping units throughout the study area. After a brief examination, it was determined that there was no significant impact of the soil mapping units on the classification. It was felt that the mapping units (soil series and soil phase levels) were too detailed for extracting the appropriate information and that a generalized map showing soil color changes would have been more beneficial for this problem. Because time did not permit any further investigation, the problem was left to be solved through additional analysis and reclassification.

Problem: Clusters representing the fig class were consistently confused with the native vegetation class, particularly through the Fresno Slough area. It was thought that the original training sites selected were not representative of the cover type.

Solution: Additional fields designated as fig orchards on the DWR ground reference maps were digitized, histogrammed, clustered, and compared to the original training site statistics (very little change was noticed).

As a result of the evaluation of the first classification, a modified statistics file was created, incorporating the changes mentioned above. This new statistics file (85 clusters) was submitted to the CDC-7600 computer with the six channel data set for a second classification. The same procedure was followed as in the first classification to examine the accuracy of the second classification. Selected areas were displayed on the IDIMS color monitor and compared to the DWR ground reference data. In general, the classification had improved over the initial classification, with more accurate spectral signatures developed for figs, vineyards, and grain stubble. In contrast, the dairy/feedlot cover type was very poorly represented in the second classification. The clusters representing the dairy/feedlot category correctly classified the dairy and feedlot areas, but also misclassified areas known to be native vegetation, pasture, alfalfa, corn, vineyards, grain, and cotton. Border pixels representing roads and field boundaries were also misclassified as dairy/feedlot areas. At this point, it was decided to delete two of the three clusters describing the dairy/feedlot class and the remaining cluster, which confused primarily with native vegetation, was labeled as non-cropland. The native vegetation class was also re-labeled as non-cropland because fallow fields were often misclassified as native vegetation and could not be spectrally separated from the native vegetation. These changes were incorporated into the statistics file and preparation for a third and final classification was initiated.

Before the final classification was run, a more detailed evaluation was undertaken. The PGandE ground reference data was used for this evaluation, in the form of thirteen line printer (LP) maps. Each cover type was assigned a symbol and the ground reference maps were printed using the EDITOR software system in such a way that only the digitized fields were displayed, excluding the field boundaries and background information. The same was done for the classified data - the corresponding "windows" were extracted from the classified data and printed in the same manner. An EDITOR program was then run to compare the ground reference and classified data, to determine the accuracy of the classification for each of the thirteen maps. The percentage of pixels correctly classified was given for each cover type, along with a "percent correct" for the entire map. Table 8 shows the variability of the accuracy throughout the transmission line area. (See Figure 12 for map location with respect to transmission lines and study area.)

Table 8

Preliminary Verification Results of the Second Classification Using PGandE Ground Reference Data

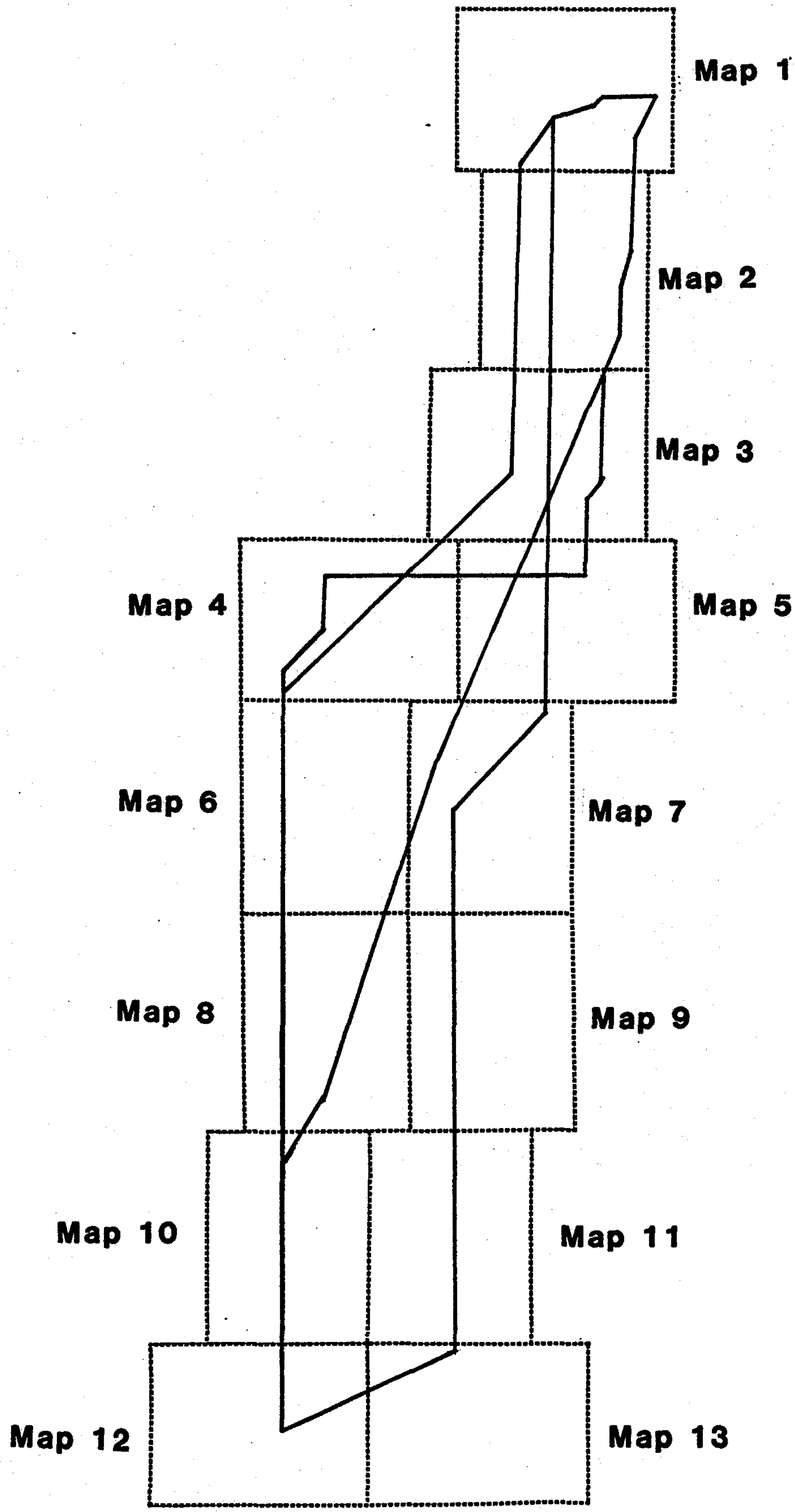
Map Number	Percent Correct
1	63.06
2	71.98
3	52.29
4	42.70
5	54.84
6	47.36
7	67.85
8	70.52
9	85.56
10	71.00
11	97.72
12	72.03
13	94.64

overall percent correct = 67.19

Although it varied between maps, cover types that were consistently misclassified (less than 50% correct) were tomatoes, garlic, peaches, almonds, beans, lettuce, and native vegetation. The peach and almond categories generally confused with native vegetation and pasture, indicating that the satellite sensor was detecting a stronger reflectance from the ground between the rows than from the trees. The various truck crops (tomatoes, garlic, lettuce, and beans) tended to confuse with grain. This could have been due to the double-cropped fields (first planted in grain, then planted in a truck crop) and the Landsat imagery date selections. A problem with the Fresno Slough area appeared again, represented by the lower accuracies for the maps located

Figure 12

Location of PGandE Ground Reference Data in Relation to the Transmission Line Corridors



in the slough (Maps 4-7). Because of time and budget considerations, no efforts were taken to correct these problems. Corrective measures could have included selecting additional training sites in the Slough area and then reclustering, comparison of the PGandE ground reference date to available color infrared photography for evaluating its accuracy, use of the SCS Soil Survey report for stratification purposes, and a closer evaluation of the dates selected for digital analysis.

2.7 Data Post-Processing

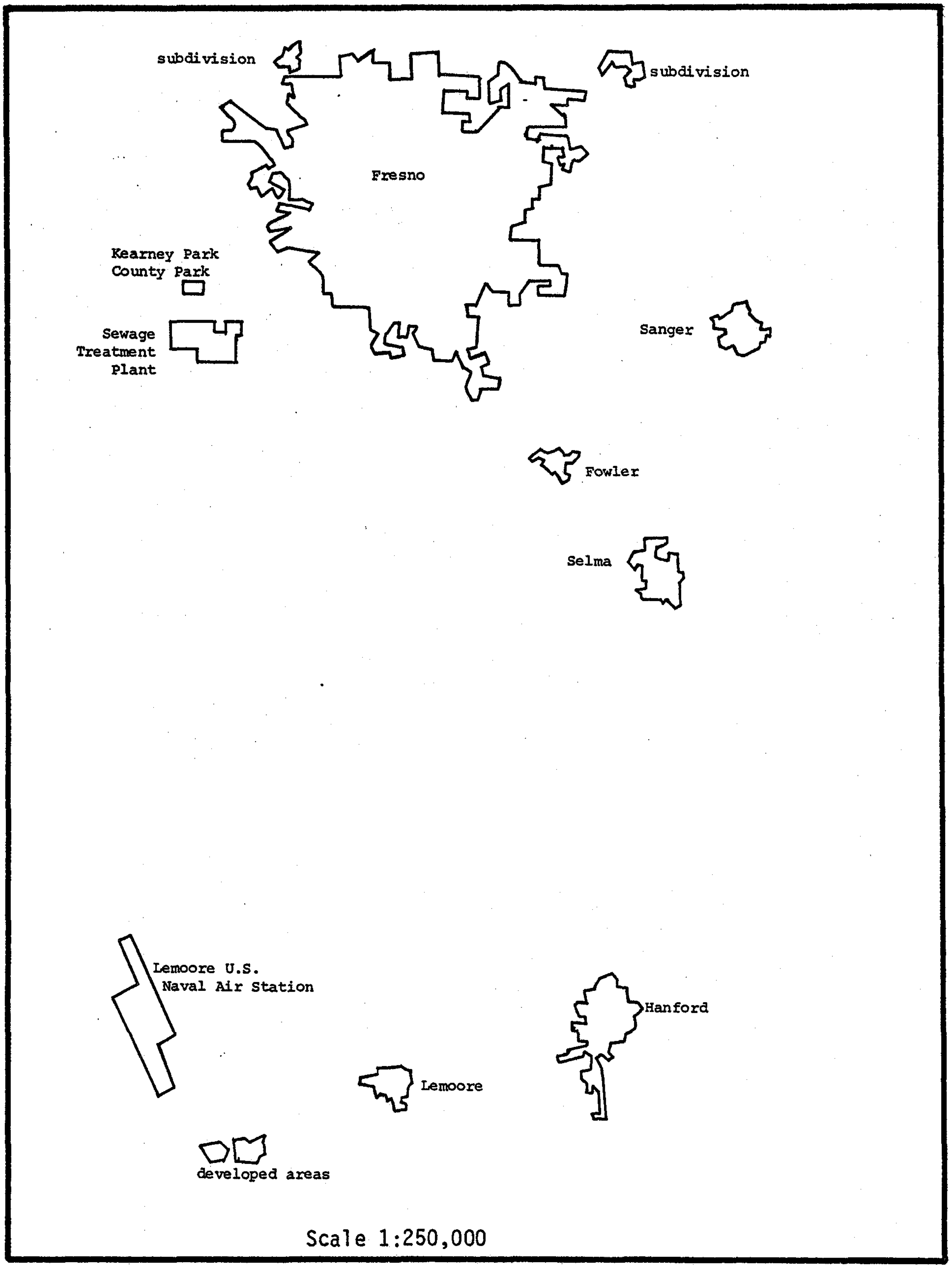
2.7.1 Image Stratification. Stratification is a "post-processing" technique used to separate areas of spectral confusion by physiographic region. Adequate information must be known about the misclassified pixels in order to successfuly stratify an image. The stratification procedure is dependent upon two main factors: 1) ground reference data and/or photography from which proper class identification can be made and, 2) if appropriate, a skilled and experienced photo-interpreter (NASA/Ames, 1981).

Stratification for the Gates to Gregg project was very straightforward because the study area could be divided into three distinct regions - urban areas, agricultural areas, and native vegetation areas. A USGS Land Use Data Analysis (LUDA) map, at a scale of 1:250,000, was used for the urban stratification. The maps were compiled with high altitude aerial photography, using the Level II Land Use and Land Cover classification (Appendix D) (Anderson et al., 1976). Level II categories have a minimum mapping unit of 10 acres for urban areas and water bodies and 40 acres for agricultural areas. Urban areas throughout the study area were color coded on the LUDA map and then digitized (Figure 13). The resulting polygons were used as a "mask" over the classified data, wherein specific mislabled pixels were renamed with a different information class and category number (Appendix E). Each renamed category - commercial/industrial, residential, urban open areas, or native vegetation - was the result of careful photo-interpretation of color infrared aerial photography.

Another stratification was done to separate the Kettleman Hills, a major native vegetation area in the southwestern corner of the study area, from the agricultural area. Instead of digitizing the Kettleman Hills, the IDIMS software system was used to outline the sagebrush vegetation unit (Matyas and Parker, 1980). The orchard and vineyard classes occurring in this area were renamed to woodland/shrub; grain, stubble, and native vegetation classes were renamed to native grasses.

Figure 13

Urban Areas Selected for Image Stratification



2.7.2 Classification Smoothing. "Smoothing" is a technique used to clean up a classified image by reclassifying pixels based on their relationship to adjacent pixels and effectively simulates a ten acre minimum mapping unit by eliminating single occurrences of pixels (cover types). The program operates by scanning the image using a 3 x 3 window, comparing the class number of the central pixel to its eight surrounding neighbors. As the computer counts the number of occurrences of each class within the nine pixel block, a decision is made to either reclassify the central pixel or leave it unchanged, depending on the weighting assigned to the specific class and the central pixel position in the block. For this project, the central pixel position was assigned a weighted value of four, the adjacent pixels were assigned a value of two, and the corner pixels were assigned a value of one. All the class numbers were assigned an equal weight (a value of one), except for the woodland/shrub, native grasses, and water classes, which were assigned a value of 1.5.

The result of this program was a "cleaner-looking" image, with a minimizing of the "salt and pepper" effect caused by single occurrence pixels. After smoothing, the majority of fields appeared as homogeneous entities and the boundaries between fields appeared more distinct.

2.7.3 Registration to the State Plane Grid Coordinate System. As a final post-processing step, the classified image was registered to the State Plane Grid coordinate system. The objective was to create a geographic data base that was compatible with procedures and software systems used by PGandE.

To establish a reference between image line/sample coordinates and State Plane coordinates, a set of control points was selected. (These same points were previously used to correlate the Landsat imagery to the ground. See section 2.5.4 Calibration File Creation.) Two files were created from these points - one with line/sample coordinates and one with State Plane Grid coordinates - and were used to generate a set of coefficients, calculated by a second-order polynomial. The coefficients were then applied to the entire classified image, "mapping" each Landsat pixel (57m x 57m) into each new data base "cell" (200ft x 200ft).

2.8 Accuracy Assessment

The PGandE ground reference data was utilized for the accuracy assessment of the final 27 class, smoothed Landsat classification within the four transmission line corridors. Because the accuracy assessment was performed in the transmission line corridors, a statement about the accuracy of the entire classification could not be made. Normally, a random sample of single points or a random sample stratified by information class is taken to statistically assess the accuracy of a classification. The accuracy assessment is presented in "contingency table" form, comparing, by field, the Landsat classification with the PGandE ground reference data.

In preparation for the accuracy assessment, a comparison was made between the two ground reference data bases - PGandE and DWR. At that time, it was noted that there were several discrepancies between the two sources for field identification. It was decided that for the accuracy assessment, all fields exhibiting differences in identification would be deleted from the assessment.

The first step in the accuracy assessment was to digitize the thirteen PGandE maps. Thirteen "segment files" were generated using the PDP-10/EDITOR system. Then, using these digitized files, corresponding fields from the classified data were extracted. Only fields greater than twenty acres were included in the accuracy test. This was done with the original intention of completing the accuracy assessment on a "per field" basis rather than a "per pixel" basis. The "per field" assessment idea was abandoned when the analysts realized that the digitized fields often contained more than one agricultural field (of the same cover type) and did not represent the intended concept of a field. Typically, a cultivated field will vary in size from 10 to 160 acres, whereas the fields digitized for the accuracy assessment varied in size from 10 to 1,000 acres, including roads and small farmsteads. Therefore, it was decided to perform the analysis on a "per pixel" basis, where the total number of correctly classified pixels was assessed as opposed to the total number of correctly classified fields.

A program on the PDP-10/EDITOR system was then used to aggregate the classified data with the ground reference data. An example of this aggregation is presented in Table 9 (Map 1), where the rows represent the PGandE ground reference data information classes and the columns represent the Landsat classification information classes. The diagonal numbers represent the correctly classified pixels. The remaining column numbers represent errors of commission (classifying a pixel as class A when it is not) and the remaining row numbers represent errors of omission (classifying a pixel as something else when it is really class A). For example, looking at the vineyard class in Table 9 (Map 1), 2,139 pixels were correctly classified, but 23 pixels were classified as vineyards when they were really olives (commission error) and 58 pixels were classified as cotton when they were really vineyards (omission error). Out of a total of 2,744 vineyard pixels (from the ground reference data), 2,139 or 78.0% were correctly classified. Using the table in another manner, the classifier identified 2,352 vineyard pixels, of which 2,139 or 90.0% were correctly classified. There was a 22.0% omission error rate and a 9.1% commission error rate.

For each of the thirteen PGandE ground reference data maps, a contingency table was generated, and the remaining tables can be found in Appendix F. Table 10 summarizes the overall "percent correct" for each of the thirteen maps.

Table 9

CONTINGENCY TABLE FOR ACCURACY ASSESSMENT

MAP 1

LANDSAT CLASSIFICATION

PG&E GROUND REFERENCE DATA	CITRUS	PEACHES	FIGS	OLIVES	ALMONDS	VINEYARDS	COTTON	MELONS	GARLIC	TOMATOES	LETTUCE	BEETS	CARROTS	BEANS	CORN	SAFFLOWER	GRAIN	ALFALFA	PASTURE	NON-CROPLAND	TOTAL	% CORRECT	% OMISSION
CITRUS																					0		
PEACHES																					0		
FIGS			394			24	7							4		9			10	5	453	87.0	13.0
OLIVES	11		18	125		23								4	3					4	188	66.5	33.5
ALMONDS																					0		
VINEYARDS	21	136	25	15	11	2139	58					1	7	11	13	2	57		100	148	2744	78.0	22.0
COTTON						23	51												40	29	143	35.7	64.3
MELONS																					0		
GARLIC																					0		
TOMATOES																					0		
LETTUCE																					0		
BEETS																					0		
CARROTS																					0		
BEANS																					0		
CORN																					0		
SAFFLOWER																					0		
GRAIN	2		18	5	3	42	1						9	11	5	2	25	8	4	26	161	15.5	84.5
ALFALFA						8											8		22	1	39	0	100
PASTURE	1		39	1		16								5					31	17	110	28.2	71.8
NON-CROPLAND	1	1	115	1		77	2		1	12	1		5	23	10		75			181	505	35.8	64.2
TOTAL	36	137	609	147	14	2352	119	0	1	12	1	1	21	58	31	13	165	8	207	411	4343		
% CORRECT	0	0	64.7	85.0	0	90.9	42.9		0	0	0	0	0	0	0	0	15.2	0	15.0	44.0		67.8	
% COMMISSION	100	100	35.3	15.0	100	9.1	57.1		100	100	100	100	100	100	100	100	84.8	100	85.0	56.0			32.2

Table 10

Accuracy Assessment of the Final Classification by Individual Maps

Map Number	Percent Correct
1	67.8
2	80.1
3	58.0
4	4.2
5	46.1
6	73.1
7	57.4
8	89.0
9	95.7
10	85.9
11	98.1
12	76.5
13	95.6

In comparing Table 10 with Table 8 (preliminary verification results) a general improvement in accuracy was noticed, although several maps had drastically reduced accuracy figures. This could be due to the comparison between ground reference data bases during the actual accuracy assessment and not during the preliminary verification. During that comparison process, numerous fields, especially in Map 4, were excluded from evaluation due to discrepancies in field identification. Map 4 is also located in the Fresno Slough, where it was hypothesized that the soil characteristics significantly affected the spectral reflectance values of the various cover types.

After each of the thirteen maps was tabulated, they were summarized into two tables - ungrouped crop types (Table 11) and grouped crop types (Table 12). The overall percent correct for the ungrouped or detailed table was 75.7%, while the more generalized table was 78.7%. Crop types with low omission and commission errors (less than 20%) included vineyards, cotton, and grain. (These crops were consistently identified correctly by Landsat.) Crop types with low commission errors included almonds and tomatoes, and crop types with low omission errors were figs and safflower. Table 13 summarizes the results and problems with this final classification.

Table 11

CONTINGENCY TABLE FOR ACCURACY ASSESSMENT

SUMMARY FOR UNGROUPED CROP TYPES

LANDSAT CLASSIFICATION

PG&E CORRIDOR GROUND REFERENCE DATA

	CITRUS	PEACHES	FIGS	OLIVES	ALMONDS	VINEYARDS	COTTON	MELONS	GARLIC	TOMATOES	LETTUCE	BEETS	CARROTS	BEANS	CORN	SAFFLOWER	GRAIN	ALFALFA	PASTURE	NON-CROPLAND	TOTAL	% CORRECT	% OMISSION
CITRUS																17					17	0	100
PEACHES																					0		
FIGS	1		1291		1	76	7							12		37			22	15	1462	88.3	11.7
OLIVES	11		18	125		23								4	3					4	188	66.5	33.5
ALMONDS	45	1	27	49	354	173	6							9	15	13	7	15	156	275	1145	30.9	69.1
VINEYARDS	70	363	59	101	43	11,822	200		1			10	9	22	295	25	73	118	256	1043	14,510	81.5	18.5
COTTON	16	15	104	12	13	849	20,517	647	36	17	12	164	25	40	81	25	178	273	1023	245	24,292	84.5	15.5
MELONS																					0		
GARLIC									12							4	21			20	57	21.1	78.9
TOMATOES						17	110	57	242	688	17			15	3	6	313	204	4	26	1702	40.4	59.6
LETTUCE																					0		
BEETS						34	121				6	172		1		34		387	100	14	869	19.8	80.2
CARROTS																					0		
BEANS			62			5		18	1				113		16		4	6	154	3	382	0	100
CORN			6			6	35	14						6	30		28	95	85		305	9.8	90.2
SAFFLOWER						6										323	7		11		347	93.1	6.9
GRAIN	4		46	7	7	144	16	8	6	60	68		99	82	11	248	5679	13	66	103	6667	85.2	14.8
ALFALFA	6		9	3	3	253	243	614	26	4		4		6	83	13	85	1572	772	25	3721	42.2	57.8
PASTURE	1		39	1		3	1						1	5	3			18	217	18	307	70.7	29.3
NON-CROPLAND	2	5	218	6		154	31	3	3	12	21		5	27	10		167	4	50	496	1214	40.9	59.1
TOTAL	156	384	1879	304	421	13,565	21,287	1361	327	781	124	350	252	229	550	745	6562	2705	2916	2287	57,185		
% CORRECT	0	0	68.7	41.1	84.1	87.2	96.4	0	3.7	88.1	0	49.1	0	0	5.5	43.4	86.5	58.1	7.4	21.7		75.7	
% COMMISSION	100	100	31.3	58.9	15.9	12.8	3.6	100	96.3	11.9	100	50.9	100	100	94.5	56.6	13.5	41.9	92.6	78.3			24.3

CONTINGENCY TABLE FOR ACCURACY ASSESSMENT
SUMMARY FOR GROUPED CROP TYPES

TABLE 12

LANDSAT CLASSIFICATION

PG&E CORRIDOR GROUND REFERENCE DATA

	ORCHARDS	VINEYARDS	COTTON	TRUCK CROPS	GRAINS	PASTURE	NON-CROPLAND	TOTAL PIXELS	PERCENT CORRECT	PERCENT OMISSION ERROR
ORCHARDS	1,923	272	13	25	92	193	294	2,812	68.4	31.6
VINEYARDS	636	11,822	200	42	393	374	1,043	14,510	81.5	18.5
COTTON	160	849	20,517	941	284	1,296	245	24,292	84.5	15.5
TRUCK CROPS	62	56	231	1,342	401	855	63	3,010	44.6	55.4
GRAINS	70	156	51	343	6,326	270	103	7,319	86.4	13.6
PASTURE	62	256	244	660	184	2,579	43	4,028	64.0	36
NON-CROPLAND	231	154	31	71	177	54	496	1,214	40.9	59.1
TOTAL PIXELS	3,144	13,565	21,287	3,424	7,857	5,621	2,287	57,185		
PERCENT CORRECT	61.2	87.2	96.4	39.2	80.5	45.9	21.7		78.7	
PERCENT COMMISSION ERROR	38.8	12.8	3.6	60.8	19.5	54.1	78.3			21.3

Table 13

Final Classification Results & Problems

Cover Type	Classification Problem	Possible Explanation
Citrus	0% correct	insufficient training sites
Olives	confusion with vineyards	marginal canopy cover; influence of soil reflectance
Almonds	confusion with vineyards, pasture, and non-cropland	marginal canopy cover; influence of soil reflectance; orchard management practices
Vineyards	confusion with non-cropland	influence of soil reflectance; vineyard management practices
Tomatoes	confusion with grain	double cropping
	confusion with garlic, cotton, and alfalfa	??
Garlic	confusion with grain	double cropping
	confusion with non-cropland	??
Beets	confusion with cotton, alfalfa, and pasture	??
Beans	0% correct, classified primarily as carrots and pasture	insufficient training sites
Corn	confusion with pasture and alfalfa	??
Alfalfa	confusion with pasture	spectrally similar
	confusion with melons	??
Pasture	confusion with alfalfa and non-cropland	spectrally similar
Non-cropland	confusion with figs and vineyards	marginal canopy cover; influence of soil reflectance
	confusion with grain	spectrally similar after grain has been cut (stubble)

Even though errors were made in the classification and the sampling was not random, statistical corrections can be made to remove the relative bias, or classification error. This relative bias can then be used to estimate crop percentage acreages for the entire study area by extrapolating the information from the corridors.

In order to estimate crop percentage acreages in the total study area, the assumption was made that the relative bias made by the Landsat classification was constant for each crop type. That is, for each crop type, j, the relative bias was assumed to be the same in the corridors and also in the larger study area. Relative bias can be expressed as:

$$\frac{(\pi j - \hat{P}j)}{\hat{P}j}$$

where $\pi j = \frac{\text{total number of Landsat pixels in a crop type}}{\text{total number of pixels in a corridor}}$

or the Landsat estimated relative area

$\hat{P}j = \frac{\text{total number of ground reference data pixels}}{\text{total number of pixels in a corridor}}$

or the "ground truth" estimated relative area

For example, using Table 12, the Landsat estimated relative area for orchards is .0550 and the "ground truth" estimated relative area is .0492. Therefore, the relative bias for orchards is .1179.

Because the relative bias was assumed constant, the study area relative areas could be estimated from the corridor results. Using the previous example, Landsat estimated that 5.5% of the study area was in orchards and that 4.9% of the study area was in orchards according to the ground reference data. Table 14 summarizes the resulting relative areas for each major crop type.

Table 14

Study Area Relative Areas

	Landsat Estimate % of study area	Ground Reference Data Estimate % of study area
ORCHARDS	5.5	4.9
VINEYARDS	23.7	25.4
COTTON	37.2	42.5
TRUCK CROPS	6.0	5.3
GRAINS	13.7	12.8
PASTURE	9.8	7.0
NON-CROPLAND	4.0	2.1

3.0 FINAL OUTPUT PRODUCTS

At the conclusion of the Landsat digital image processing, various products were generated to illustrate the results of the project. Final classification color photographs and slides were produced for the entire study area, while acreage summaries, by cover type, were obtained for each of the four transmission line corridors. Computer tapes were also provided to PGandE, for future use, containing the final classification and various transmission line corridor files.

The final classification color photographs were produced at a scale of 1:100,000 and covered the entire study area. The four alternate transmission line corridor boundaries were overlaid onto the final classification. For presentation purposes, the information classes described by the classification were grouped in two ways - a generalized (14 classes) and detailed (27 classes) format. Table 15 outlines the specific information classes utilized for each grouping and Figures 14 and 15 represent the photo products. Slides were also produced for each of these groupings. Line printer (LP) maps, at a scale of 1:24,000, were produced for all the USGS 7.5' quadrangles covering the transmission line corridor area (Table 16).

Table 15

Information Classes Utilized for

Final Output Products

Detailed Grouping	Generalized Grouping
Citrus Peaches Figs Olives Almonds	Orchards
Vineyards	Vineyards
Cotton	Cotton
Melons Garlic Tomatoes Lettuce Sugar beets Carrots Beans	Truck Crops
Corn Safflower Grain Burns	Grains
Alfalfa Pasture	Pasture
Non/Cropland	Non/Cropland
Water	Water
Commercial/Industrial	Commercial/Industrial
Residential	Residental
Urban Open Areas	Urban Open Areas
Woodland/Shrub	Woodland/Shrub
Native Grasses	Native Grasses
Corridor Boundary	Corridor Boundary

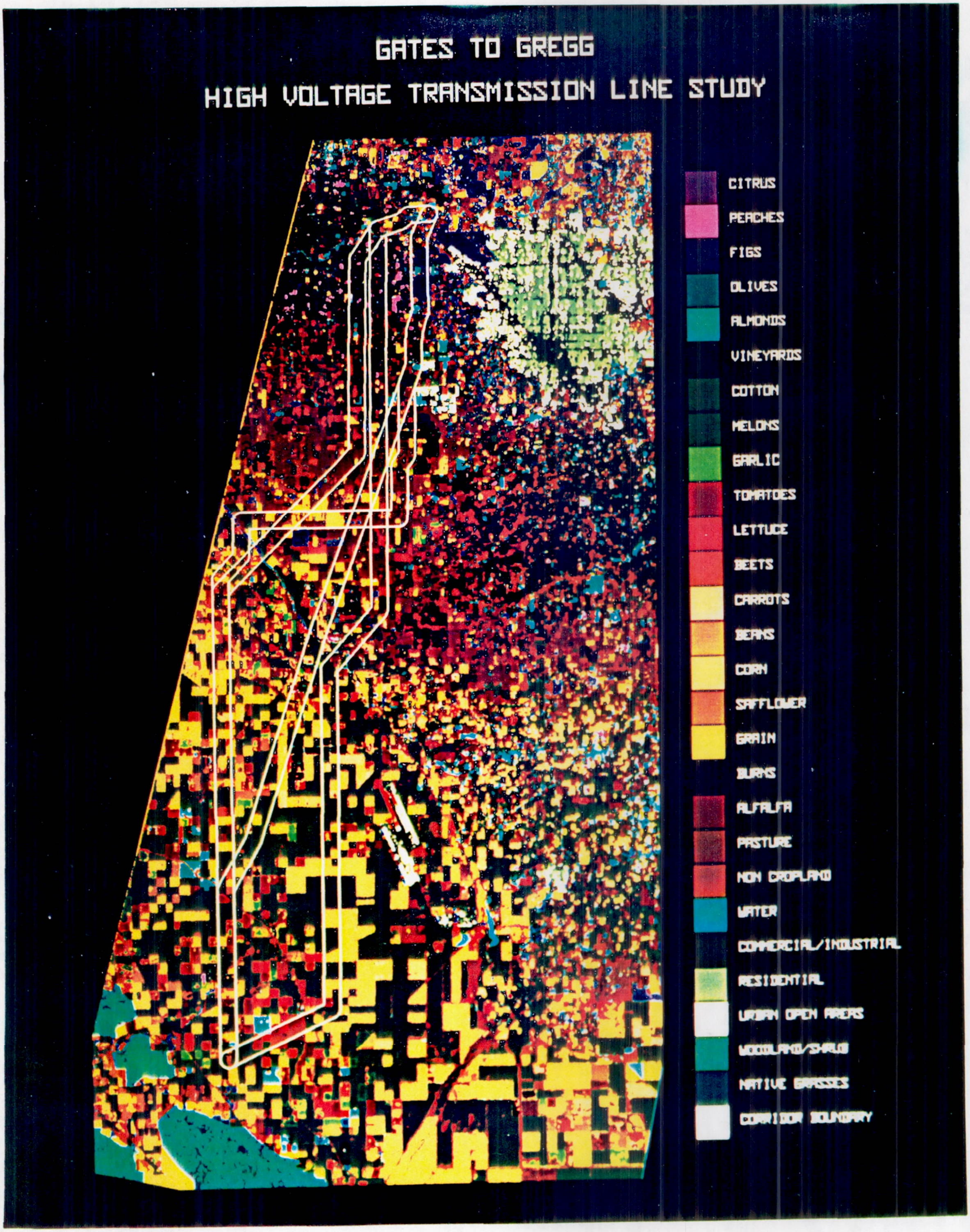


Figure 14. Ungrouped classification photo

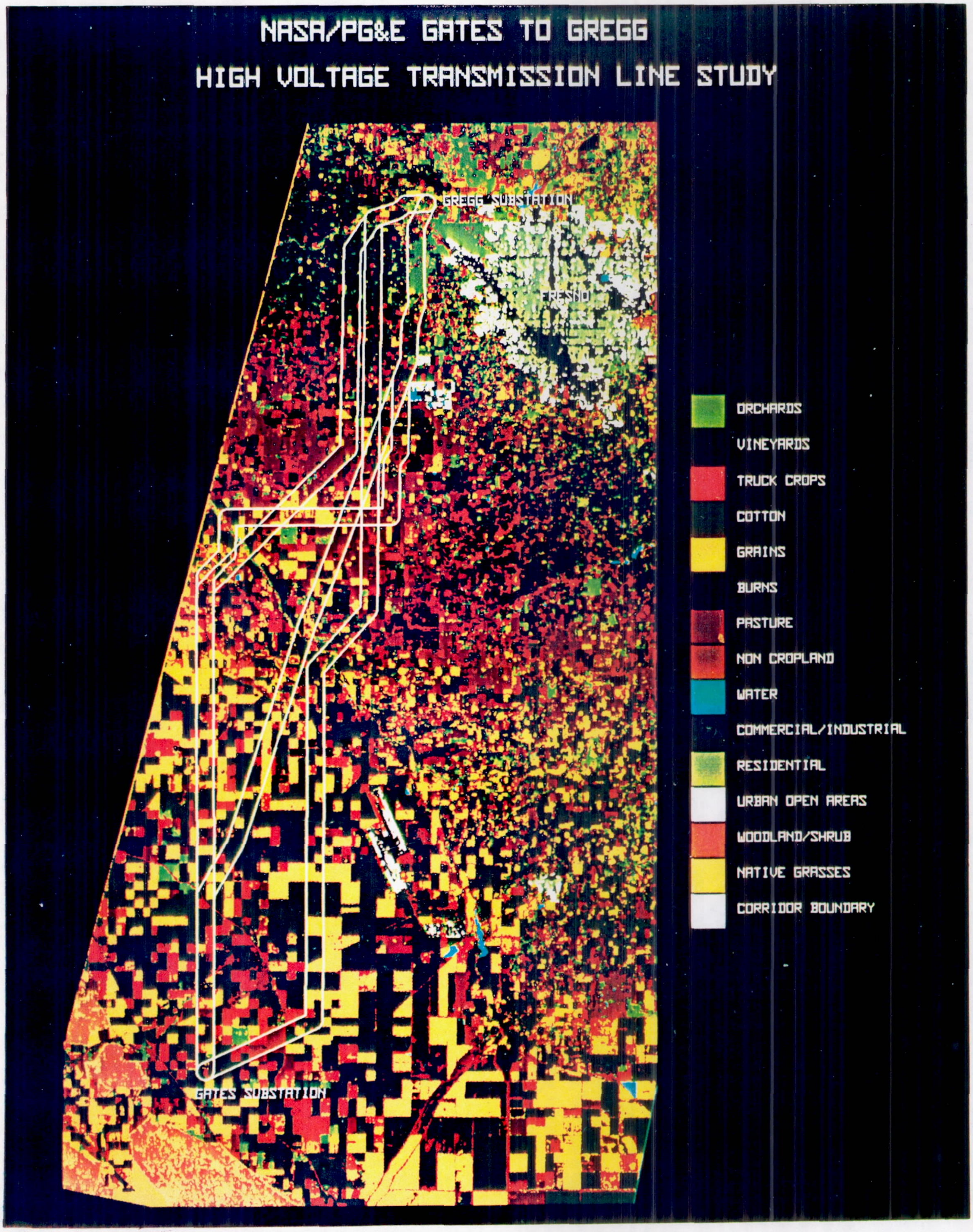


Figure 15. Grouped classification photo

Table 16

USGS 7.5' Quadrangles Covering The Four Transmission Line Corridor Areas

Herndon	Westside
Kerman	Five Points
Kearney	Burrel
San Joaquin	Harris Ranch
Helm	Calflax
Raisin	Guijarral Hills
	Huron

As with the color photographs, the two groupings were also used for the LP maps. Because of software limitations, the generalized version was produced on the HP-3000 Versatec Electrostatic Plotter (IDIMS-ESRI software) and the detailed version was produced on the SEL 32/77 (ILEX software).

A greytone map was generated by the HP-3000 system, whereas the SEL 32/77 system generated an alphanumeric symbol map. In addition to the maps, a separate overlay was generated to show the location of the transmission line centerline and mile wide boundary. Figures 16 and 17 are examples of the line printer maps and overlays produced to coincide with the USGS quadrangles.

FIGURE 16

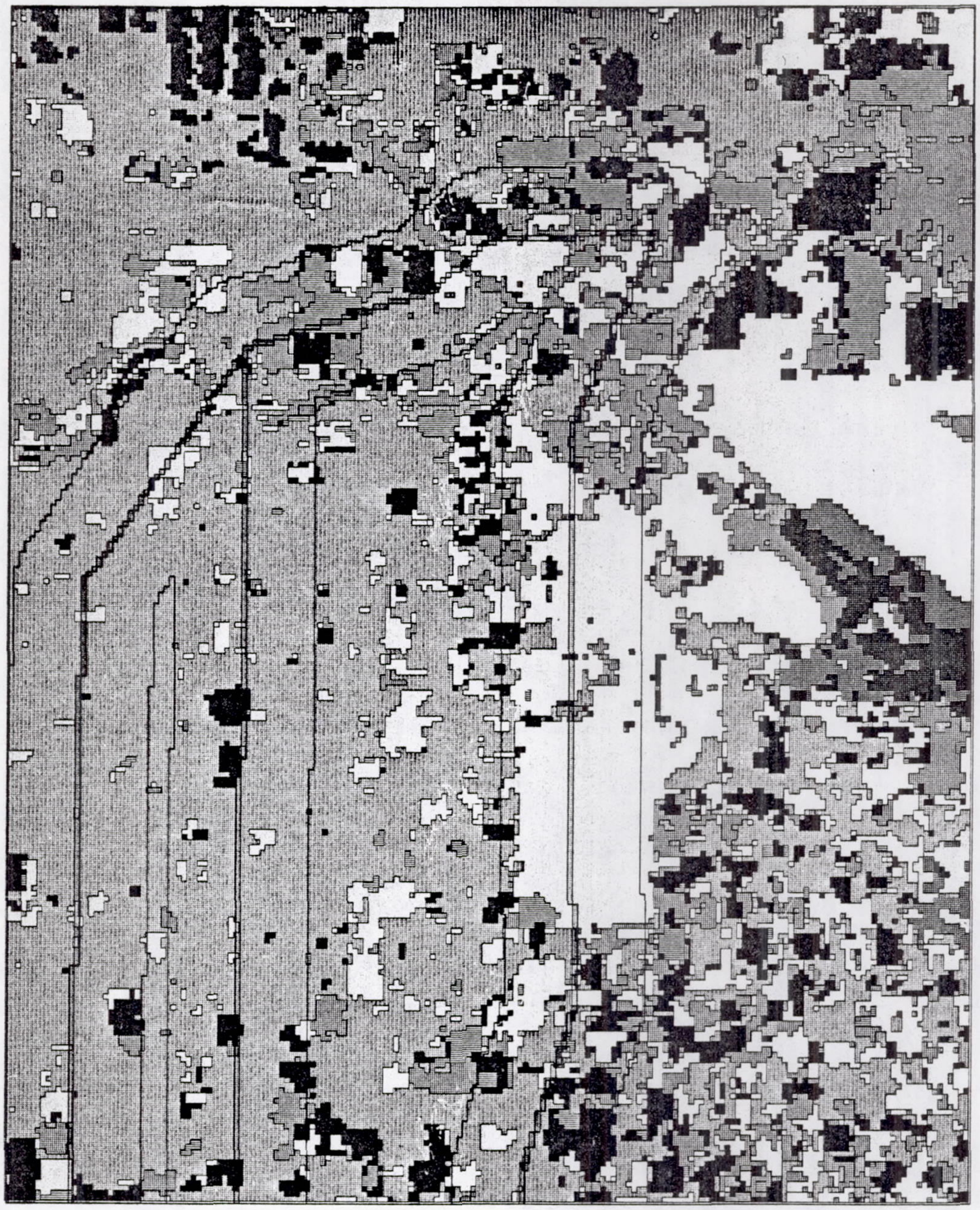
E - CITRUS	I - CARROTS	2 - ALFALFA
J - PEACHES	T - TOMATOES	P - PASTURE
+ - FIGS	B - BEANS	O - NON CROPLAND
8 - OLIVES	C - COTTON	W - WATER
A - ALMONDS	7 - LETTUCE	$ - COMMERCIAL/INDUSTRIAL
* - VINEYARDS	# - GRAIN	R - RESIDENTIAL
M - MELONS	S - SAFFLOWER	X - URBAN OPEN SPACES
Y - GARLIC	K - CORN	7 - WOODLAND/SHRUB
= - SUGAR BEETS	/ - BURNS	> - NATIVE GRASSES

▦ CORRIDOR CENTERLINE
⊓ 1 MILE CORRIDOR BOUNDARY

1/24,000 SCALE
1 PIXEL = 200 X 200 FEET

HERNDON QUADRANGLE

FIGURE 17



- ORCHARDS
- VINEYARDS
- TRUCK CROPS
- COTTON
- GRAINS
- PASTURE
- BURNS
- NON CROPLAND
- WATER
- COMMERCIAL/INDUSTRIAL
- RESIDENTIAL
- URBAN OPEN AREAS
- CORRIDOR CENTERLINE
- 1 MILE CORRIDOR BOUNDARY

1/24,000 SCALE

1 PIXEL = 200 X 200 FEET

A factor in the final transmission line route selection process is the cost of crossing over specific agricultural crops. Crops, such as tomatoes and rice, are more expensive to cross due to crop market value and management practices.

Crop acreage summaries for each of the four corridors provided the necessary information for dealing with this factor. Each corridor was grouped into two parts - the 200 foot wide centerline and the entire mile wide corridor. Acreages were computed for each crop type found within these two sections (Tables 17 through 20).

Computer tapes were also provided to PGandE. The tape contents (compatible with ESRI single - variable file format) included the final classification, the four transmission line corridors, corridor boundary masks, and control files for the various ESRI programs used.

Table 17

ACREAGE SUMMARY FOR CORRIDOR A

Cover Type	Corridor Centerline		Mile Wide Corridor	
	Acres	% of Total	Acres	% of Total
Citrus	5	0.4	145	0.4
Peaches	18	1.5	166	0.5
Figs	6	0.4	425	1.2
Olives	8	0.7	240	0.7
Almonds	14	1.1	255	0.7
Vineyards	246	19.9	7,747	21.4
Melons	0	0	143	0.4
Garlic	3	0.2	204	0.6
Sugar beets	34	2.7	609	1.7
Carrots	10	0.8	516	1.4
Tomatoes	20	1.6	881	2.4
Beans	6	0.4	270	0.7
Lettuce	51	4.2	1,097	3.0
Grain	153	12.4	4,631	12.8
Burn	6	27.5	53	0.1
Cotton	341	0.4	8,534	23.6
Safflower	8	0.7	674	1.9
Alfalfa	95	7.7	2,888	8.0
Pasture	112	9.1	3,511	9.7
Corn	26	2.1	343	0.9
Non/cropland	75	6.1	2,759	7.6
Water	0	0	15	0
Commercial/ Industrial	0	0	0	0
Residential	0	0	0	0
Urban Open Areas	0	0	0	0
Woodland/Shrub	0	0	0	0
Native Grasses	0	0	0	0
Total	1,237		36,106	

Table 18

ACREAGE SUMMARY FOR CORRIDOR B

Cover Type	Corridor Centerline		Mile Wide Corridor	
	Acres	% of Total	Acres	% of Total
Citrus	5	0.4	107	0.3
Peaches	16	1.2	166	0.4
Figs	6	0.5	430	1.2
Olives	9	0.7	272	0.7
Almonds	4	25.0	135	0.4
Vineyards	328	0.3	8,637	23.3
Melons	0	0	4	0
Garlic	0	30.0	69	0.2
Sugar beets	12	0	413	1.1
Carrots	27	0.8	404	1.1
Tomatoes	14	9.1	544	1.5
Beans	7	0.6	168	0.5
Lettuce	11	0.9	386	1.0
Grain	119	2.0	3,939	10.6
Burn	8	1.1	287	0.8
Cotton	393	0.6	11,864	32.0
Safflower	3	0.2	162	0.4
Alfalfa	56	4.3	1,838	5.0
Pasture	142	10.9	3,475	9.4
Corn	27	2.0	496	1.3
Non/cropland	124	9.5	3,261	8.8
Water	0	0	11	0
Commercial/ Industrial	0	0	0	0
Residential	0	0	0	0
Urban Open Areas	0	0	0	0
Woodland/Shrub	0	0	0	0
Native Grasses	0	0	0	0
Total	1,311		37,068	

Table 19

ACREAGE SUMMARY FOR CORRIDOR C

Cover Type	Corridor Centerline		Mile Wide Corridor	
	Acres	% of Total	Acres	% of Total
Citrus	6	0.5	160	0.5
Peaches	2	0.2	151	0.4
Figs	75	6.4	1,952	5.8
Olives	15	1.2	201	0.6
Almonds	7	0.6	438	1.3
Vineyards	166	14.1	4,722	14.0
Melons	2	0.2	206	0.6
Garlic	1	0.1	181	0.5
Sugar beets	6	0.5	141	0.4
Carrots	11	0.9	389	1.2
Tomatoes	29	2.4	839	2.5
Beans	8	0.7	308	0.9
Lettuce	15	1.2	299	0.9
Grain	128	10.8	3,253	9.6
Burn	0	0	115	0.3
Cotton	375	31.8	10,597	31.4
Safflower	32	2.7	855	2.5
Alfalfa	88	7.5	1,965	5.8
Pasture	94	8.0	3,395	10.1
Corn	29	2.5	872	2.6
Non/cropland	91	7.7	2,693	8.0
Water	0	0	13	0
Commercial/ Industrial	0	0	3	0
Residential	0	0	8	0
Urban Open Areas	0	0	15	0
Woodland/Shrub	0	0	0	0
Native Grasses	0	0	0	0
Total	1,180		33,771	

Table 20

ACREAGE SUMMARY FOR CORRIDOR D

Cover Type	Corridor Centerline		Mile Wide Corridor	
	Acres	% of Total	Acres	% of Total
Citrus	3	0.2	134	0.3
Peaches	3	0.2	106	0.3
Figs	76	5.4	1,976	5.1
Olives	11	0.8	196	0.5
Almonds	7	0.5	357	0.9
Vineyards	186	13.3	4,863	12.5
Melons	1	0.1	161	0.4
Garlic	10	0.7	281	0.7
Sugar beets	17	1.2	392	1.0
Carrots	19	1.4	589	1.5
Tomatoes	13	0.9	968	2.5
Beans	17	1.2	338	0.9
Lettuce	49	3.5	990	2.6
Grain	193	13.8	5,381	13.9
Burn	5	0.3	37	0.1
Cotton	391	27.9	9,986	25.7
Safflower	12	0.9	809	2.1
Alfalfa	110	7.9	2,905	7.5
Pasture	154	11.0	4,825	12.4
Corn	14	1.0	339	0.9
Non/cropland	110	7.9	3,062	7.9
Water	0	0	24	0.1
Commercial/ Industrial	0	0	28	0.1
Residential	0	0	21	0.1
Urban Open Areas	0	0	24	0.1
Woodland/Shrub	0	0	0	0
Native Grasses	0	0	0	0
Total	1,401		38,792	

4.0 COST ESTIMATION

The use of Landsat digital data for large area resource inventories can provide reliable information on a cost effective basis. The approximated costs encountered in this project are presented in Table 21. The costs are estimated for various reasons, including subsidized computer systems and agency training workshops. A number of computer systems used throughout the project are subsidized by Ames Research Center and computer usage is not charged to each project. Subsequently, the computer costs were estimated based on information from commercially available systems. During a demonstration project, there are many tasks that would not necessarily be duplicated in an operational mode. For example, training workshops and demonstrations for PGandE personnel were intensive and thorough, affecting the "Staff Support" cost estimate.

One way to evaluate the cost effectiveness of Landsat digital data is to determine the cost of the project for a unit of area. Cost figures for the Gates to Gregg study area, encompassing 1,287,052 acres, was .09/acre, or 54.70/square mile. These relatively high figures are due to the techniques used during the project - a supervised classification approach - and the nature of the project itself - a demonstration/agency training project.

Table 21

Project Costs

Data Acquisition	3,000
Staff Support	45,000
Project Coordination	20,000
Computer Costs	17,000
Output Products	10,000
Field Work/Travel	5,000
NASA Overhead	10,000
Total	110,000

5.0 OPERATIONAL ALTERNATIVES

The following section is an brief evaluation of PGandE's operational alternatives at the present time, written by Mr. Greg Thornbury, PGandE Project Coordinator for the Gates to Gregg project.

The only operational alternative now available to PGandE is to employ the knowledge and experience of private contractors in the business of providing Landsat services. Information from the current project will allow PGandE to prepare well defined requests for proposals, evaluate contractor bids and monitor contract performance.

To support a successful Landsat-based informatin system at PGandE, four criteria must be met:

1. Applications staff with a thorough understanding of the uses and limitations of Landsat data.
2. Appropriate hardware and software with an experienced technical support staff.
3. Staff trained and experienced in the use of a Landsat-based software system.
4. Projects of suitable frequency where Landsat technology can pay for itself and allow staff to remain current in their knowledge.

While criteria one was met as a result of this project and PGandE can easily meet criteria two with present computer facilities, the remaining criteria cannot be met.

Participation in this project has produced three PGandE individuals with a thorough understanding of the uses and limitations of Landsat satellite data. PGandE has the technical support staff and the computer facitilites with adequate capacity to support a Landsat- based system. Any system installed would be housed on an IBM 3033 mainframe computer available to the Land Department. In the future, it may be feasible to integrate a Landsat-based system on the Land Department's Computer Aided Land Mapping System. This is a minicomputer based system using a Digital Equipment Corporation PDP 11/44 computer.

However, to justify staff trained and experienced in operating a Landsat-based software system (criteria three), a reasonably large number of projects would have to be started each year. Because of the stressed financial position of PGandE, a greatly reduced level of transmission line projects are anticipated for the next several years. Rather than maintain an underused technical staff to work on infrequent transmission line projects it would be more desireable to contract this work to outside vendors for those projects where Landsat data would provide cost savings and better information.

6.0 SUMMARY

The results of this demonstration project have shown that the use of Landsat digital data for land use/land cover inventories can be very useful in the planning and routing of transmission lines. Previously, PGandE could not economically obtain land use information over large study areas; but with the implementation of remote sensing techniques, large area inventories could become more feasible and cost effective. This would allow for a more complete transmission line route evaluation by PGandE, with regard to agricultural impacts.

Of the five primary project objectives, only one was met by Ames Research Center - the identification of agricultural land uses within the Gates to Gregg transmission line study area. A multi-date supervised analysis approach was used to develop an agricultural land use/land cover map for the study area. From this classified data, specific areas (the four corridors) were analyzed in detail to evaluate the accuracy of Landsat. Several specific crops were very accurately identified by Landsat (greater than 80% correct) and they included cotton, grain, and vineyards. Overall, the Landsat classification accuracy was 75%.

To visually display the results of the project, maps at various scales were generated. Black and white line printer maps at 1:24,000 scale were created for field use and color 1:100,000 and 1:250,000 scale maps were produced for presentation and display purposes. Acreage totals for each major crop type were also generated to summarize the crops grown within each of the four corridors.

The remaining objectives - the identification of the most desirable and economic route, the potential uses of this information for other projects, and the evaluation of a Landsat-based system for in-house use - can now be attained by PGandE with the results of this project.

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APPENDIX A

FLIGHT SUMMARY REPORT

Flight No: 79-076

Date: 14 June 1979

FSR No: 1282

Julian Date: 165

Sensor Package: Dual RC-10
Aerosol Particulate Sampler (APS)

Aircraft No: 4

Purpose of Flight: #0666R Support
Requestor: Lumb/Bauer
#0047 Support
Requestor: Ferry

Area(s) Covered: Central California

SENSOR DATA

Accession No:	02770	02771	---
Sensor ID No:	031	033	024
Sensor Type:	RC-10	RC-10	APS
Focal Length:	6" 153.05mm	6" 153.17mm	---
Film Type:	High Definition Aerochrome Infrared, SO-127	Panatomic-X, 3400	---
Filtration:	CC .10B + 2.2AV	Wratten 12 + 2.2AV	---
Spectral Band:	510-900nm	510-700nm	---
f Stop:	4.0	5.6	---
Shutter Speed:	1/175	1/225	---
No. of Frames:	210	210	---
% Overlap:	60	60	---
Quality:	Excellent	Excellent	---
Remarks:	---	---	Non-imaging sensor

FLIGHT SUMMARY

79-076

This flight was flown in support of Flight Requests #0666R (Lumb/Bauer, NASA/ARC) and #0047 (Ferry, NASA/ARC) under the FY 1979 Airborne Instrumentation Research Program (AIRP) plan. Photography was acquired over agricultural regions of central California (see Track Map). Aerosol Particulate Sampler (APS) data was collected throughout the flight but is not indicated on the track map.

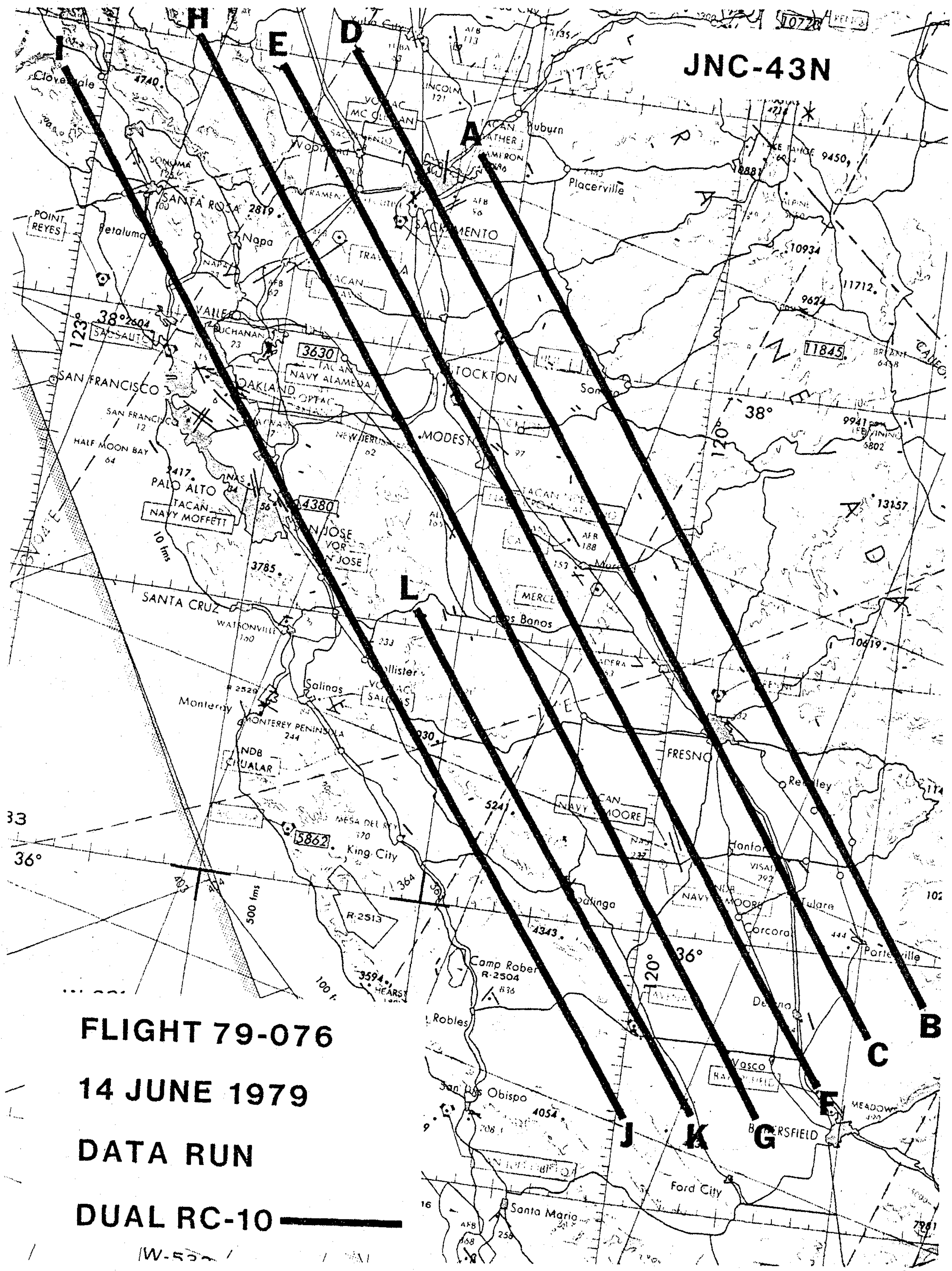
The weather was clear over the entire area. However, some minor smoke was encountered along the first three data lines from agricultural burns and grass fires. The photography is of excellent quality with no camera or processing malfunctions noted.

The APS has been developed and is operated by Dr. Guy Ferry of the NASA-Ames Research Center Atmospheric Experiments Branch. The sampler is a non-imaging sensor designed to gather high altitude dust particles for laboratory research.

FLIGHT LINE DATA

FLIGHT NO. 79-076

	Check Points	Frame Numbers	Time (GMT–hr, min, sec) START	Time (GMT–hr, min, sec) END	Altitude, MSL feet/meters	Cloud Cover/Remarks
RC-10 #031	A-B	6465-6497	17:49:46	18:19:57	65,000/19800	Smoke, frs. 6479-6485
	C-D	6498-6534	18:23:38	18:57:36	"	Smoke, frs. 6532-6534
	E-F	6535-6574	19:01:08	19:38:02	"	Smoke, frs. 6537-6540
	G-H	6575-6615	19:41:05	20:18:58	"	Clear
	I-J	6616-6656	20:25:42	21:04:07	"	"
	K-L	6657-6674	21:07:32	21:23:10	"	"
RC-10 #033	A-B	1044-1076	17:49:15	18:19:31	65,000/19800	Smoke, frs. 1058-1064
	C-D	1077-1113	18:23:12	18:57:12	"	Smoke, frs. 1111-1113
	E-F	1114-1153	19:00:44	19:37:39	"	Smoke, frs. 1116-1119
	G-H	1154-1194	19:40:42	20:18:36	"	Clear
	I-J	1195-1235	20:25:20	21:03:45	"	"
	K-L	1236-1253	21:07:11	21:22:49	"	"
APS	---	---------	17:48:00	21:18:00	65,000/19800	APS #1 exposed near checkpoint "A" and sealed near checkpoint "L"


JNC-43N
A
B
C
D
E
F
G
H
I
J
K
L
FLIGHT 79-076
14 JUNE 1979
DATA RUN
DUAL RC-10
SACRAMENTO
STOCKTON
MODESTO
SAN FRANCISCO
OAKLAND
PALO ALTO
SAN JOSE
SANTA CRUZ
Monterey
Salinas
Hollister
King City
Los Banos
FRESNO
Hanford
Tulare
Corcoran
Porterville
Delano
Vasco
BAKERSFIELD
Ford City
Santa Maria
San Luis Obispo
Paso Robles
Coalinga
Placerville
Auburn
Santa Rosa
Petaluma
Napa
Cloverdale
POINT REYES
HALF MOON BAY
Watsonville
Reedley
38°
36°
120°
123°

Appendix B

Training Site Field Sizes

Information Class	Training Site #	Digitized Size (Acres)
Citrus	13	159.3
Peaches	2	83.5
	6	47.8
	6	22.7
Figs	6	972.6
	6	37.8
Olives	11	113.6
Almonds	1	158.7
	1	36.9
	2	28.4
	2	32.8
	5	139.9
	5	41.9
	5	170.3
	6	6.2
	6	2.3
	7	17.9
	13	63.1
Vineyards	1	22.2
	1	36.5
	1	74.7
	1	20.4
	1	1773.1
	2	17.5
	2	37.5
	2	14.2
	2	19.4
	2	17.4
	2	16.4
	2	10.1
	2	39.5
	2	8.1
	2	4227.0
	2	10.7
	2	6.5
	2	20.3
	2	11.1
	2	5.9
	4	410.7
	4	43.0
	6	2.5

Information Class	Training Site #	Digitized Size (Acres)
Vineyards (cont.)	6	678.5
	6	895.1
	8	174.3
	14	53.0
Melons	1	22.3
	8	168.7
	10	420.3
	10	104.9
	10	254.0
	11	320.6
	11	38.6
	11	163.3
Garlic	12	160.8
	12	324.5
	14	38.4
Sugar beets	1	39.4
	3	192.4
	3	392.4
Carrots	4	110.8
Tomatoes	7	10.7
	8	1065.2
	8	88.3
	12	81.6
	12	325.4
	13	99.6
	14	332.2
	14	152.6
Beans	2	18.3
	10	240.7
	13	155.8
Lettuce	8	353.2
	12	36.4
	12	1086.5
	12	319.8
	12	159.6
	14	324.2
	14	165.4
Grain	1	40.2
	3	984.4
	3	33.4
	3	430.7
	3	156.3
	4	91.4

Information Class	Training Site #	Digitized Size (Acres)
Grain (cont.)	5	128.4
	5	297.7
	7	6.2
	8	176.1
	8	129.4
	9	939.9
	9	3.5
	9	1.2
	9	4.7
	9	477.0
	9	567.8
	9	53.9
	9	110.9
	9	24.7
	10	410.9
	11	108.5
	11	653.5
	11	316.3
	11	320.0
	12	56.1
	13	328.3
	14	1028.2
	14	851.4
	14	47.0
	14	157.1
	14	133.4
	14	504.2
	15	1329.0
	15	156.1
	15	550.1
Cotton	1	54.3
	1	159.0
	1	313.6
	1	117.3
	2	47.5
	2	13.1
	2	279.7
	2	14.9
	2	67.7
	2	97.7
	2	20.5
	2	41.0
	2	27.8
	2	25.6
	3	300.5
	3	159.1
	3	213.8
	3	81.4
	3	25.3
	4	492.1

Information Class	Training Site #	Digitized Size (Acres)
Cotton (cont.)	4	80.4
	4	16.9
	4	31.5
	4	41.2
	4	18.3
	5	789.4
	5	317.2
	5	434.7
	7	128.4
	7	50.3
	7	24.2
	7	7.4
	7	19.6
	7	20.8
	8	1044.1
	8	48.2
	8	1573.6
	8	284.4
	8	187.0
	9	25.9
	9	313.4
	9	87.9
	9	35.8
	9	221.6
	9	122.8
	9	258.1
	9	346.9
	9	110.0
	9	147.7
	10	3878.6
	11	314.5
	11	316.3
	11	590.5
	11	330.7
	11	1039.8
	12	24.5
	12	554.5
	12	157.7
	13	190.7
	13	1280.2
	14	1209.1
	14	2496.7
	14	46.3
	14	1151.9
	14	41.3
	14	275.6
	14	477.2
	14	31.7
	15	444.9
	15	4082.6

Information Class	Training Site #	Digitized Size (Acres)
Safflower	2	35.0
	5	338.4
	8	425.2
	8	207.3
	9	98.0
	9	50.6
	9	160.3
	9	273.8
	9	107.6
	12	49.4
Alfalfa	1	55.8
	1	129.4
	1	47.1
	1	183.9
	1	162.3
	2	36.6
	2	98.9
	2	39.2
	2	26.4
	2	15.2
	3	21.9
	4	40.2
	4	143.1
	4	146.8
	4	51.5
	4	202.9
	4	125.4
	5	165.6
	7	35.7
	7	60.3
	7	17.8
	7	9.0
	11	160.4
	11	329.7
Pasture	1	10.3
	1	16.7
	4	10.1
	4	5.1
	4	126.8
	4	119.9
	4	57.6
	6	20.9
	6	3.7
	6	2.2
	7	21.9
	7	38.8
	7	17.6
	7	7.0
	7	18.1

Information Class	Training Site #	Digitized Size (Acres)
Pasture (cont.)	7	4.1
	7	93.5
	7	38.5
Corn	1	19.8
	1	52.4
	1	48.9
	1	77.6
	2	23.2
	4	38.5
	4	40.4
	4	41.1
	4	36.6
	7	79.8
	7	18.7
	7	310.9
	10	300.9
Native Vegetation	1	37.0
	1	22.0
	2	4.7
	2	3.4
	2	1.9
	2	26.0
	2	3.8
	6	9.3
	6	18.5
	7	19.5
	7	14.9
	7	29.1
	7	28.4
	7	12.8
	8	2.9
	9	79.8
	9	9.2
	9	11.3
	9	21.9
	9	92.2
	10	7.5
	12	6.3
	13	36.9
	14	3.3
	14	13.4
Dairies	1	17.9
	1	52.5
	7	10.2
	7	11.1

Information Class	Training Site #	Digitized Size (Acres)
Feedlots	2	7.4
	4	17.3
	4	26.2
	7	21.8
Farmsteads	1	2.3
	1	1.3
	1	6.1
	2	3.4
	2	3.6
	4	9.4
	6	15.3
	6	2.3
	7	3.5
	7	3.1
	7	4.9
	7	5.1
	7	6.8
	8	4.8
	9	6.7
	9	6.2
	10	5.7
	11	5.4
	12	13.2
	12	5.3
	13	12.3
	13	2.1
	14	7.9
	14	12.5
	14	8.8
	14	3.3
	14	4.4
	14	12.0
Urban Areas	2	5.0
	2	16.3
	2	4.7
	2	12.8
	2	10.1
	5	22.5
	5	5.3
	6	4.7
	6	10.7
	6	5.5
	7	4.7
	7	11.0
	7	4.4
	8	13.9
	8	36.8
	10	10.0
	10	7.2

Information Class	Training Site #	Digitized Size (Acres)
Urban Areas (cont.)	1Ø	2Ø.9
	12	58.1
	14	6.9

APPENDIX C

Final* Classification Statistics

Cover Type	Cluster No.	Number of Points
Citrus	1	71
"	2	77
Peaches	3	24
"	4	18
Figs	5	317
"	6	394
"	7	563
"	8	379
Grapes	9	592
"	A (10)	523
"	B (11)	131
"	C (12)	98
"	D (13)	75
"	E (14)	272
"	F (15)	710
"	G (16)	870
Olives	H (17)	162
"	I (18)	84
Almonds	J (19)	192
"	K (20)	152
Melons	L (21)	474
"	M (22)	487
"	N (23)	115
"	O (24)	87
"	P (25)	106
Cotton	Q (26)	46
"	R (27)	45
Garlic	S (28)	125
"	T (29)	338
"	U (30)	374
"	V (31)	155
Lettuce	W (32)	250
"	X (33)	377
"	Y (34)	182
Lettuce/Grain	Z (35)	59
"	a (36)	82
Garlic/Grain	b (37)	57
"	c (38)	64
"	d (39)	81
Corn/Grain	e (40)	97
Grain	f (41)	2654
"	g (42)	947
Burn	h (43)	84
"	i (44)	99
"	j (45)	127
"	k (46)	25

* Used for third classification.

Cover Type	Cluster No.	Number of Points
Grain stubble	l (47)	328
"	m (48)	126
"	n (49)	473
Sugar beets	o (50)	117
"	p (51)	113
"	q (52)	86
Carrots	r (53)	37
"	s (54)	21
"	t (55)	28
Tomatoes	u (56)	420
"	v (57)	679
Beans	w (58)	131
"	x (59)	106
Safflower	y (60)	183
"	z (61)	78
"	! (62)	112
"	$ (63)	139
"	# (64)	148
"	" (65)	111
Alfalfa	% (66)	149
"	& (67)	177
"	' (68)	92
"	((69)	298
"	) (70)	246
"	* (71)	333
Pasture	+ (72)	62
"	, (73)	82
Cotton	- (74)	3509
"	/ (75)	5284
Corn	: (76)	58
"	; (77)	116
"	< (78)	129
"	= (79)	142
Native vegetation	> (80)	14
"	@ (81)	63
"	[(82)	91
"	\ (83)	242
"	] (84)	231
Dairy/feedlot	^ (85)	304
Water	_ (86)	50
"	` (87)	50
"	{ (88)	52

CLUSTER MEAN REFLECTANCE VALUES

	CHANNELS					
	JULY		MAY		AUGUST	
CLUSTER#	1	2	3	4	5	6
1	29.83	67.39	31.27	59.82	26.44	47.56
2	38.48	68.30	39.29	56.43	34.06	44.94
3	27.29	60.62	37.17	52.71	22.29	59.25
4	30.78	53.67	44.17	50.33	32.28	53.94
5	67.68	72.12	45.91	50.06	57.73	56.46
6	55.12	63.55	41.60	47.91	47.56	49.90
7	62.04	69.65	43.59	48.83	49.73	51.35
8	62.01	66.18	45.38	48.34	56.04	53.56
9	44.24	72.45	31.78	33.22	32.50	50.56
A	35.43	60.51	53.59	56.29	30.88	56.39
B	23.34	95.34	40.88	49.53	25.59	67.28
C	63.17	58.27	55.95	51.49	48.79	45.04
D	69.79	60.19	58.43	47.51	64.83	52.99
E	36.11	72.28	41.76	49.73	29.19	61.97
F	41.42	65.60	42.89	48.52	40.03	54.50
G	46.30	68.50	46.85	53.06	42.19	53.94
H	23.72	59.66	23.42	47.06	21.40	46.50
I	41.37	58.51	38.45	48.54	35.63	45.06
J	23.79	61.05	22.65	58.21	23.56	48.72
K	28.57	56.99	27.25	55.32	29.86	47.57
L	29.45	86.83	46.81	37.17	47.47	37.14
M	25.32	99.17	47.14	36.77	46.53	37.01
N	29.36	91.11	44.09	34.48	42.97	33.94
O	28.69	96.95	56.67	45.63	56.46	44.41
P	28.66	100.20	59.17	46.59	66.16	51.15
Q	39.17	74.26	46.22	36.96	20.24	70.17
R	25.89	68.98	46.20	37.11	19.24	84.67
S	23.91	74.65	31.90	34.70	62.50	54.01
T	26.76	88.01	29.85	50.02	61.49	52.89
U	30.45	81.79	42.65	37.93	53.93	40.98
V	39.41	92.90	39.48	54.15	53.75	41.26
W	68.66	57.34	27.06	80.23	36.10	26.88
X	62.80	51.63	48.36	79.47	47.20	34.60
Y	62.18	50.72	36.23	94.97	34.49	24.18
Z	66.02	54.64	19.49	71.83	40.44	29.75
a	68.56	56.18	19.65	70.77	56.21	41.44
b	30.25	88.68	33.68	24.35	41.58	40.98
c	24.91	102.70	33.37	23.48	40.73	41.05
d	24.19	82.12	41.70	47.43	57.70	51.86
e	56.24	45.76	25.89	55.70	25.51	36.70
f	67.36	69.25	20.47	79.10	56.03	42.34
g	111.41	111.03	22.21	72.07	57.67	44.03
h	~~20.44~~	~~16.01~~	~~19.19~~	~~73.25~~	~~37.89~~	~~29.08~~
i	25.64	21.03	22.76	60.40	38.35	28.41
j	18.68	12.89	20.43	65.74	46.81	35.39
k	20.80	16.24	18.48	73.16	48.52	43.16
l	91.59	91.45	47.45	64.37	63.52	51.31

	CHANNELS					
	JULY		MAY		AUGUST	
CLUSTER#	1	2	3	4	5	6
m	83.23	68.49	71.21	61.29	75.25	56.36
n	87.02	79.02	38.51	58.39	94.54	71.04
o	27.92	92.13	27.43	53.37	29.06	58.61
p	24.46	104.32	38.37	45.63	26.87	62.20
q	30.15	92.58	57.74	60.14	23.40	75.17
r	45.24	40.22	26.32	62.51	34.27	66.89
s	70.24	60.67	27.24	61.05	33.86	50.48
t	94.39	80.75	26.11	62.18	40.68	36.43
u	32.15	80.95	40.57	39.04	42.25	33.67
v	35.76	94.11	42.22	46.95	48.38	39.17
w	62.21	52.85	18.21	77.27	35.89	52.18
x	45.62	68.93	42.32	52.60	51.80	46.83
y	31.64	83.26	46.70	43.07	51.19	59.97
z	31.72	90.12	29.81	50.91	78.46	78.29
!	78.33	85.32	19.69	72.06	60.85	45.91
$	43.85	92.79	22.86	63.04	53.69	44.78
#	41.41	90.47	21.53	71.35	67.20	71.25
"	65.53	87.30	20.14	80.95	77.11	79.47
%	37.24	62.99	42.23	36.23	40.15	42.07
&	25.71	83.62	41.13	38.69	28.59	52.84
'	21.84	102.49	40.78	41.89	22.30	72.80
(	29.82	72.23	20.29	96.31	19.65	72.98
)	19.19	96.81	20.84	96.57	37.92	52.99
*	19.92	95.89	19.80	99.76	17.73	82.84
+	37.00	78.32	37.19	63.87	29.79	60.18
,	27.20	84.68	26.12	76.72	23.49	63.95
-	40.25	56.95	46.01	35.83	24.76	63.92
/	30.19	84.60	48.40	38.61	19.63	87.87
:	39.40	33.59	21.00	51.07	23.95	44.31
;	41.79	35.95	19.67	58.99	20.86	50.50
<	23.71	73.00	42.35	41.66	24.03	44.59
=	49.27	51.84	21.46	67.18	21.66	54.37
>	56.43	48.64	52.43	43.64	18.07	8.36
@	44.57	42.79	40.32	37.14	38.51	33.29
[	57.73	50.89	49.49	40.95	50.04	40.93
\	43.56	34.64	42.83	31.68	37.20	25.69
]	65.27	51.35	58.74	44.70	55.71	39.77
^	78.12	72.79	70.50	63.62	66.69	58.45
_	14.34	5.60	17.56	6.46	15.28	5.40
`	23.54	8.78	26.54	10.18	18.64	4.48
{	19.67	13.19	23.56	12.42	26.77	18.19

CLUSTER VARIANCES

	CHANNELS					
	JULY		MAY		AUGUST	
CLUSTER#	1	2	3	4	5	6
1	9.00	3.96	7.63	7.09	7.68	1.65
2	8.02	19.50	12.21	19.43	5.90	3.32
3	17.43	13.90	36.49	17.00	5.43	13.07
4	12.18	7.88	9.44	14.00	31.04	3.23
5	8.82	8.20	6.88	5.50	9.96	5.08
6	9.82	14.71	7.07	5.65	10.84	4.67
7	8.36	5.92	5.70	5.45	5.94	4.41
8	8.39	6.86	6.11	5.20	7.66	5.45
9	29.97	29.96	15.13	21.72	29.33	23.87
A	16.39	18.60	35.25	13.37	25.83	41.81
B	9.76	25.33	3.02	3.74	8.67	8.20
C	13.09	8.73	11.57	8.54	10.64	5.79
D	7.01	4.83	9.65	13.98	8.09	3.01
E	18.68	24.97	20.35	16.04	20.47	23.79
F	10.39	16.77	10.70	11.51	11.17	9.31
G	10.45	14.40	9.11	11.87	7.54	10.33
H	11.58	4.61	5.90	6.77	6.64	3.47
I	13.08	2.61	14.73	3.26	10.96	1.67
J	7.72	8.37	5.33	9.83	7.65	5.09
K	11.77	19.59	6.61	14.83	17.18	5.92
L	6.84	16.87	4.32	3.47	6.47	8.92
M	2.86	15.51	5.68	4.65	5.75	6.79
N	3.69	12.42	21.20	18.76	1.22	1.39
O	5.01	17.46	9.20	4.65	7.04	4.80
P	4.04	25.34	3.46	2.11	4.99	3.39
Q	12.06	9.00	2.22	1.33	1.96	12.86
R	2.69	17.07	3.39	1.87	2.28	23.18
S	5.40	29.12	14.41	11.05	5.77	3.57
T	9.28	32.20	12.03	16.40	13.18	7.68
U	9.54	37.35	18.50	15.01	35.13	18.87
V	4.84	9.86	23.89	21.83	30.77	13.84
W	8.88	6.16	11.50	33.59	15.35	14.34
X	24.05	13.36	27.92	25.66	18.38	11.54
Y	19.43	9.22	13.56	47.89	23.75	16.22
Z	1.78	1.68	4.81	8.59	11.73	10.43
a	3.80	3.02	2.75	11.56	14.31	7.29
b	6.01	24.11	7.29	6.84	11.14	9.59
c	3.17	18.02	4.02	2.60	4.39	6.59
d	10.43	37.61	13.49	6.72	9.96	14.59
e	10.83	7.47	11.39	42.25	27.59	15.17
f	24.56	53.08	9.38	28.81	17.51	10.97
g	26.87	29.17	8.53	32.23	22.42	22.00
h	11.00	13.63	1.99	10.58	14.96	5.38
i	13.36	16.09	3.12	6.55	3.05	2.88
j	3.43	3.86	1.49	4.23	3.90	1.91
k	4.50	4.69	1.84	9.06	9.68	6.56
l	30.85	30.16	57.90	16.37	16.88	15.34

	CHANNELS					
	JULY		MAY		AUGUST	
CLUSTER#	1	2	3	4	5	6
m	26.80	20.70	40.31	9.60	59.39	28.89
n	90.63	45.25	38.43	34.96	29.30	12.09
o	2.36	18.61	7.68	14.99	3.68	13.67
p	10.05	22.09	3.50	6.91	1.76	21.81
q	10.08	47.89	12.92	5.98	6.03	26.43
r	26.24	33.17	5.61	7.26	27.65	125.82
s	27.09	24.13	2.69	6.85	11.93	64.86
t	21.43	7.68	8.99	2.37	5.26	16.70
u	40.56	29.49	8.51	39.79	8.63	7.70
v	28.43	25.45	32.95	17.08	13.36	16.35
w	12.09	11.42	8.12	9.87	5.94	11.93
x	27.57	25.51	5.76	10.26	9.04	2.35
y	6.42	15.50	9.48	14.55	31.80	7.04
z	9.06	9.77	11.04	15.56	24.93	19.33
!	10.40	9.81	4.76	7.90	3.90	1.99
$	52.19	40.21	9.95	43.99	13.10	12.42
#	36.52	57.77	8.43	95.17	22.01	26.24
"	17.78	26.05	6.89	47.41	12.33	19.05
%	19.10	36.16	6.87	5.16	11.54	18.23
&	10.09	52.38	32.45	28.77	36.41	41.07
'	4.64	43.02	35.89	35.92	21.82	53.92
(	60.24	50.39	4.87	27.47	8.40	63.66
)	18.67	52.44	7.03	33.36	73.25	23.08
*	7.47	74.36	2.64	16.42	5.23	68.50
+	33.80	48.09	32.72	47.95	16.50	32.31
,	10.38	35.03	10.58	27.44	13.44	29.38
-	35.93	37.57	13.75	14.93	23.50	41.08
/	22.65	27.14	9.74	6.77	1.93	17.01
:	7.37	6.11	0.84	7.12	9.91	13.80
;	14.24	8.31	3.77	9.19	3.72	4.79
<	49.66	28.81	21.32	32.66	7.58	14.20
=	43.31	26.18	13.29	39.44	13.73	22.89
>	28.57	10.71	29.03	15.32	28.23	30.40
@	22.76	11.36	11.74	5.32	36.51	18.21
[	23.18	19.45	22.01	12.01	34.15	33.20
\	22.59	25.29	18.80	21.91	20.30	18.65
]	36.50	33.03	35.91	24.45	33.15	21.49
^	42.60	22.61	50.34	20.41	35.28	15.25
_	8.68	18.94	4.66	6.78	12.61	23.35
`	11.64	21.44	13.15	14.31	5.05	7.40
{	26.19	26.20	18.53	19.03	22.81	15.22

SEPARABILITY MATRIX (SWAIN-FU DISTANCE)

CLUSTER NUMBER

CLUSTER#	1	2	3	4	5	6	7	8
1	1.00	0.78	2.19	2.58	3.28	2.20	2.70	3.30
2		1.00	2.28	1.95	2.74	1.65	2.14	2.59
3			1.00	1.09	4.04	2.95	3.47	3.97
4				1.00	3.13	2.10	2.72	2.73
5					1.00	0.99	0.62	0.48
6						1.00	0.54	0.70
7							1.00	0.51
8								1.00

CLUSTER NUMBER

CLUSTER#	9	A	B	C	D	E	F	G
1	1.94	1.57	3.70	2.99	4.26	1.80	1.82	1.78
2	1.40	1.10	2.46	2.42	3.69	1.22	1.28	1.24
3	1.59	0.71	2.33	3.65	5.21	0.91	1.65	2.19
4	1.53	0.60	2.52	2.55	3.62	1.16	0.99	1.42
5	1.69	2.11	4.16	1.58	1.44	2.22	1.78	1.56
6	1.16	1.58	2.60	1.33	1.63	1.51	1.01	0.83
7	1.38	1.83	3.16	1.39	1.74	1.77	1.38	1.09
8	1.52	1.91	3.56	1.20	1.39	2.00	1.49	1.28
9	1.00	1.29	1.94	2.04	2.45	1.07	0.80	1.09
A		1.00	1.92	1.86	2.60	0.69	0.75	0.87
B			1.00	3.69	5.20	1.01	1.50	1.69
C				1.00	1.10	2.15	1.87	1.46
D					1.00	3.03	2.48	2.22
E						1.00	0.65	0.83
F							1.00	0.48
G								1.00

CLUSTER NUMBER

CLUSTER#	H	I	J	K	L	M	N	O
1	1.38	1.65	1.01	0.88	4.16	5.07	4.91	4.55
2	1.64	0.94	1.71	1.19	2.40	2.85	2.76	2.51
3	1.46	2.24	1.60	1.51	4.55	4.86	5.17	4.78
4	2.65	1.94	2.40	1.74	4.49	4.92	5.96	4.39
5	3.33	2.11	3.58	2.62	3.57	5.03	5.47	4.28
6	2.24	1.14	2.60	1.87	3.03	4.14	4.35	3.09
7	2.94	1.73	3.20	2.33	3.13	4.41	4.59	3.49
8	3.24	1.85	3.75	2.67	3.24	4.62	5.12	3.69
9	1.65	1.12	1.87	1.37	2.38	2.98	3.02	2.94
A	1.57	1.11	1.85	1.45	2.38	2.80	2.77	2.43
B	3.90	2.66	3.65	2.75	3.45	3.61	4.64	3.29
C	3.07	1.37	3.66	2.73	3.83	5.38	5.22	4.04
D	4.19	2.42	4.99	3.77	4.05	5.81	6.59	4.85
E	1.88	1.33	1.87	1.39	2.14	2.43	2.69	2.22
F	1.96	0.97	2.20	1.51	2.55	3.06	3.46	2.53
G	2.43	1.30	2.48	1.79	2.70	3.30	3.63	2.58
H	1.00	1.06	0.77	0.83	4.76	5.44	5.54	5.30
I		1.00	1.69	1.12	3.47	4.30	4.27	3.51
J			1.00	0.61	5.03	5.67	5.57	5.65
K				1.00	3.81	4.34	4.29	4.25
L					1.00	0.58	0.62	1.12
M						1.00	0.80	0.95
N							1.00	1.97
O								1.00

CLUSTER NUMBER

CLUSTER#	P	Q	R	S	T	U	V	W
1	5.19	6.02	5.63	3.49	3.17	3.62	4.13	5.17
2	3.35	4.54	4.51	2.96	2.46	2.44	2.51	3.56
3	5.88	2.64	2.82	4.83	4.92	5.30	6.09	5.08
4	4.81	3.02	3.48	3.32	3.47	4.42	5.09	4.92
5	4.91	5.30	6.34	3.78	3.55	3.31	3.35	3.14
6	4.19	4.16	4.83	2.98	2.60	2.78	2.81	3.18
7	4.35	4.55	5.47	3.18	2.85	2.90	2.86	3.20
8	4.46	4.67	5.49	3.27	3.11	2.92	3.02	2.97
9	3.86	1.83	2.41	2.32	2.23	2.69	2.68	3.55
A	2.97	1.91	2.10	2.60	2.69	2.44	2.71	3.36
B	4.18	2.29	2.30	3.79	3.40	3.76	3.04	6.37
C	4.87	4.98	5.86	4.05	3.78	3.43	3.60	2.43
D	5.08	6.66	7.61	4.65	4.54	3.74	3.84	3.07
E	2.88	1.39	1.58	2.23	2.07	2.18	1.96	3.56
F	3.24	2.43	2.91	2.23	2.25	2.53	2.85	3.78
G	3.49	2.77	3.31	2.68	2.52	2.72	2.85	3.31
H	5.88	4.42	4.04	3.69	3.42	4.31	4.79	4.54
I	4.54	3.62	3.82	2.70	2.63	3.07	3.95	3.43
J	6.26	4.08	4.18	3.58	3.33	4.51	4.68	4.31
K	4.71	3.00	3.47	2.54	2.33	3.29	3.37	3.27
L	1.74	3.92	4.48	2.65	2.41	0.52	2.33	7.15
M	1.80	4.26	4.69	2.92	2.61	0.77	2.62	8.77
N	3.47	5.15	5.57	4.08	3.16	0.79	2.82	7.78
O	0.90	4.76	5.44	3.11	2.49	0.99	2.30	8.11
P	1.00	6.02	6.72	2.84	2.60	1.37	2.66	8.94
Q		1.00	1.33	5.71	5.60	5.49	6.13	6.69
R			1.00	6.63	6.58	6.17	6.65	7.15
S				1.00	0.89	1.55	2.60	5.26
T					1.00	1.69	1.52	3.98
U						1.00	1.76	5.40
V							1.00	5.31
W								1.00

CLUSTER NUMBER

CLUSTER#	X	Y	Z	a	b	c	d	e
1	4.81	6.29	6.28	6.00	4.18	5.71	3.22	4.19
2	3.12	4.33	3.81	4.23	2.65	3.45	2.30	2.23
3	5.60	6.38	6.89	7.44	4.09	5.06	4.33	3.83
4	4.63	5.88	6.84	6.58	4.26	5.55	3.06	4.21
5	2.94	3.82	4.50	4.29	4.30	6.14	3.83	3.00
6	3.03	3.95	4.04	4.25	3.43	5.08	2.57	2.71
7	3.00	3.97	4.43	4.43	3.83	5.40	2.98	3.00
8	2.61	3.48	4.01	4.02	3.82	5.72	3.26	3.00
9	3.01	4.24	4.12	3.83	1.92	2.79	1.88	2.92
A	3.11	4.06	3.89	4.28	2.59	3.32	2.03	2.51
B	5.32	7.52	6.95	6.70	3.52	4.19	2.42	5.25
C	2.11	2.58	3.30	3.52	4.52	6.58	4.11	2.45
D	2.26	2.87	4.65	4.45	4.81	7.30	4.94	3.34
E	3.05	4.19	4.10	4.03	2.26	2.86	1.74	2.97
F	3.31	4.40	4.52	4.62	2.41	3.52	1.77	2.98
G	2.81	3.80	3.86	3.96	2.78	3.98	2.23	3.06
H	3.88	5.18	6.04	5.66	4.28	5.61	4.07	3.59
I	3.17	4.20	4.19	4.20	3.39	4.89	2.42	2.72
J	4.43	4.95	5.44	5.24	4.36	5.61	4.22	3.55
K	3.24	3.64	4.06	3.80	3.36	4.33	3.01	2.77
L	4.86	6.84	7.45	7.13	1.22	1.69	2.05	5.55
M	5.87	8.23	9.15	8.63	1.20	1.38	2.32	6.93
N	5.26	7.30	8.27	8.48	1.01	1.45	3.26	6.30
O	5.36	7.77	8.21	7.59	1.94	2.56	2.35	5.53
P	5.84	8.14	9.54	8.82	2.47	3.79	2.42	6.93
Q	7.91	9.52	8.90	9.36	3.65	4.19	3.51	5.48
R	8.49	9.91	9.18	9.78	4.31	4.63	4.54	5.50
S	3.90	5.14	5.45	5.09	2.22	3.56	1.23	4.47
T	3.15	3.86	4.09	4.19	2.24	2.95	0.91	3.48
U	3.67	5.31	5.46	5.08	1.17	1.84	1.38	4.49
V	3.73	5.11	5.44	5.20	2.74	3.49	2.19	4.88
W	1.09	1.02	0.95	1.52	7.54	9.75	5.85	1.38
X	1.00	0.85	1.57	1.70	5.32	7.01	4.43	2.36
Y		1.00	2.21	2.50	7.50	9.63	5.80	2.44
Z			1.00	0.95	8.06	10.35	5.81	1.47
a				1.00	7.50	9.97	5.77	1.95
b					1.00	0.60	2.12	5.78
c						1.00	3.22	7.72
d							1.00	4.43
e								1.00

CLUSTER #	f	g	h	i	j	k	l	m
	CLUSTER NUMBER							
1	3.88	5.26	5.62	4.98	6.63	5.91	3.53	3.70
2	2.87	4.32	4.61	3.91	5.44	4.80	3.04	3.28
3	5.36	6.56	5.30	4.92	6.41	6.21	4.49	5.42
4	4.39	6.14	4.96	4.62	4.93	4.41	3.70	4.14
5	2.83	3.35	4.78	4.32	5.86	5.29	1.43	1.92
6	2.84	3.74	4.39	3.75	5.22	4.76	1.92	2.30
7	2.87	3.73	4.80	4.22	6.04	5.44	1.74	2.26
8	2.72	3.42	4.79	4.23	5.85	5.33	1.57	2.09
9	3.02	3.95	3.51	3.02	3.64	3.65	2.40	2.94
A	3.43	4.48	3.92	3.29	4.27	4.11	2.80	2.86
B	5.07	6.75	7.53	6.28	7.92	7.51	4.66	5.82
C	2.60	4.02	4.87	3.83	5.60	5.41	1.80	1.45
D	3.21	4.13	6.08	5.31	6.98	6.46	1.64	1.32
E	3.27	4.45	4.22	3.66	4.64	4.50	2.79	3.47
F	3.35	4.43	4.33	3.69	4.95	4.57	2.66	3.08
G	2.91	4.17	4.27	3.75	4.93	4.42	2.45	2.83
H	4.02	6.11	5.14	4.63	6.40	6.01	3.86	4.23
I	3.07	4.84	4.27	3.77	5.48	4.83	2.91	2.83
J	3.73	5.50	3.99	3.50	4.56	4.45	3.91	4.48
K	2.71	4.35	2.68	2.42	2.96	2.91	3.01	3.58
L	4.40	5.52	7.82	5.94	8.07	7.80	4.59	4.78
M	5.01	6.60	9.11	6.98	9.23	8.82	5.94	6.13
N	4.77	6.34	9.15	7.05	10.05	9.35	5.78	6.74
O	5.06	6.39	9.14	7.07	9.46	8.92	5.59	5.41
P	5.51	6.70	9.14	7.13	9.20	8.91	5.94	5.49
Q	6.91	7.55	7.82	7.14	9.15	9.19	5.35	7.27
R	7.65	9.05	7.80	6.62	8.92	9.29	6.42	8.61
S	3.17	4.84	6.26	4.97	6.51	5.71	4.19	5.20
T	2.63	4.56	5.11	4.14	5.26	4.78	3.97	4.64
U	3.48	4.77	6.30	4.74	6.33	6.13	3.97	4.25
V	3.09	4.89	6.98	5.59	7.89	7.40	4.07	4.05
W	1.29	3.07	3.11	2.73	4.47	3.87	2.90	2.85
X	1.62	3.15	3.02	2.76	3.63	3.50	2.37	1.81
Y	1.88	3.71	3.16	3.06	4.04	3.57	3.42	2.92
Z	1.28	3.82	4.03	3.26	6.54	5.70	3.99	4.04
a	0.86	3.27	3.83	3.79	6.03	5.46	3.27	3.49
b	4.26	6.27	7.91	6.30	8.39	7.40	5.19	5.63
c	5.08	7.36	9.96	7.82	10.42	9.49	6.60	7.64
d	3.75	5.39	6.82	5.26	7.24	6.79	4.70	5.45
e	2.02	3.88	2.81	2.53	3.32	3.13	3.26	3.23
f	1.00	1.74	2.24	2.24	2.94	2.88	2.07	2.68
g		1.00	4.43	4.11	5.68	5.35	1.51	3.61
h			1.00	0.98	1.07	1.20	4.42	4.22
i				1.00	1.37	1.86	3.93	3.95
j					1.00	1.16	5.29	4.62
k						1.00	5.09	4.31
l							1.00	1.16
m								1.00

CLUSTER NUMBER

CLUSTER #	n	o	p	q	r	s	t	u
1	3.96	2.41	3.46	3.33	3.76	5.60	5.39	2.91
2	3.42	1.98	2.90	2.69	2.83	4.08	4.35	1.77
3	4.95	2.27	2.75	2.30	2.94	5.68	5.53	3.65
4	3.99	2.40	3.37	2.83	3.47	7.63	5.90	3.68
5	1.85	4.98	5.36	3.86	2.56	3.60	3.47	2.79
6	2.38	2.99	3.85	3.19	2.32	3.91	3.67	2.21
7	2.26	3.82	4.38	3.37	2.37	3.78	3.79	2.35
8	1.91	4.64	4.94	3.65	2.70	4.13	3.43	2.53
9	2.56	1.83	1.85	2.32	3.25	3.84	3.95	2.05
A	3.00	2.03	2.54	1.48	2.20	3.62	3.87	1.89
B	5.01	1.54	0.82	1.68	4.44	6.49	7.41	3.18
C	2.15	5.54	6.18	3.40	3.51	4.14	3.61	2.67
D	1.81	6.97	7.32	4.67	4.03	4.07	3.96	3.38
E	3.31	1.25	1.49	1.41	2.32	3.56	4.19	1.93
F	2.79	1.87	2.39	2.14	2.60	4.24	4.37	2.10
G	2.74	2.18	2.69	1.97	2.51	4.04	4.08	2.13
H	4.00	3.13	3.78	3.84	4.26	5.39	5.72	3.43
I	3.11	2.54	3.55	3.26	2.94	4.23	4.54	2.43
J	3.97	2.57	3.45	3.57	3.33	5.09	5.30	3.48
K	3.14	1.84	2.69	3.12	2.66	3.88	4.14	2.71
L	3.50	3.01	3.19	4.03	5.34	7.82	8.00	0.71
M	4.06	3.16	3.05	4.08	5.94	9.86	10.78	1.05
N	4.48	2.90	3.44	4.73	6.63	9.83	10.05	0.72
O	3.54	4.11	3.82	4.01	4.92	7.86	9.70	1.50
P	3.43	5.47	5.22	5.26	5.62	10.35	11.39	2.27
Q	5.88	3.02	2.21	2.76	4.72	8.14	6.81	3.70
R	7.01	2.70	2.43	2.48	4.73	8.68	7.73	4.07
S	2.92	3.94	4.68	5.39	4.80	6.14	6.74	2.03
T	2.66	3.55	4.31	5.07	4.03	4.88	5.93	1.77
U	2.87	3.72	4.35	4.98	5.09	6.72	6.38	0.62
V	2.84	3.91	4.57	4.39	4.83	6.98	7.39	1.25
W	2.79	6.06	7.38	5.29	2.66	2.27	2.44	3.24
X	2.16	5.58	7.07	4.39	4.41	4.66	2.53	2.30
Y	2.99	6.48	8.29	5.87	4.55	4.67	3.45	3.38
Z	3.50	6.27	7.54	5.95	2.24	1.64	3.76	3.57
a	2.34	6.47	7.58	6.30	2.34	2.45	3.40	3.69
b	3.85	2.70	2.70	3.93	5.54	8.39	9.70	1.11
c	4.67	3.03	3.01	4.45	7.45	11.16	12.10	1.48
d	2.97	3.19	2.94	3.73	4.63	6.46	7.40	1.46
e	3.11	5.30	5.85	4.73	1.40	1.41	3.06	3.57
f	1.95	4.35	5.22	4.93	2.60	2.65	1.98	2.64
g	2.14	7.01	7.11	6.49	3.66	3.44	2.28	3.77
h	3.56	6.33	6.91	6.68	1.80	3.28	5.02	5.10
i	3.84	5.28	5.90	5.89	2.24	3.48	4.40	3.98
j	4.04	7.22	7.94	7.89	2.23	4.29	6.95	5.33
k	3.62	6.60	7.49	7.45	2.01	3.70	6.22	5.19
l	1.44	4.97	5.56	4.19	3.38	3.63	2.35	3.02
m	1.13	6.37	7.25	4.80	5.12	4.58	3.36	3.75
n	1.00	4.83	5.14	4.86	3.13	3.02	2.84	3.06
o		1.00	1.29	2.50	3.49	7.40	9.26	2.05
p			1.00	2.00	4.37	7.29	9.11	2.63
q				1.00	3.70	6.24	7.11	3.53
r					1.00	1.19	2.51	4.33
s						1.00	1.63	4.81
t							1.00	4.07
u								1.00

CLUSTER#	CLUSTER NUMBER v	w	x	y	z	!	$	#
1	2.90	3.46	2.01	2.34	4.33	5.18	3.30	2.90
2	1.74	2.48	1.51	1.85	3.29	3.78	2.35	2.83
3	3.80	3.96	3.25	2.70	5.68	6.77	4.08	3.95
4	~~3.62~~	~~4.17~~	~~1.89~~	~~2.44~~	~~5.30~~	~~5.37~~	~~3.45~~	~~3.56~~
5	2.51	3.05	1.88	3.26	3.37	3.19	2.68	2.75
6	1.96	2.77	0.89	2.32	2.65	3.16	2.02	2.41
7	2.06	2.87	1.22	2.70	2.86	3.14	2.18	2.49
8	2.24	3.11	1.46	2.71	2.72	2.97	2.50	2.67
9	2.13	3.31	1.38	1.76	2.30	3.83	1.68	2.21
A	2.10	3.08	1.50	1.56	3.12	3.80	2.61	3.06
B	2.55	4.65	2.21	1.43	3.84	6.29	2.22	3.40
C	2.51	2.89	1.71	3.49	3.41	3.11	3.86	3.66
D	3.05	3.35	2.42	3.99	3.76	4.01	4.45	4.12
E	1.70	2.83	1.37	1.23	2.65	3.73	1.72	2.48
F	2.03	2.94	1.11	1.31	2.45	3.86	2.03	2.48
G	1.99	2.69	1.03	1.58	2.44	3.36	2.15	2.54
H	3.47	3.79	2.49	3.25	4.80	6.01	3.76	3.20
I	2.62	2.88	1.45	2.14	3.77	4.09	2.90	2.94
J	3.41	3.24	2.77	3.01	4.53	5.29	3.50	2.77
K	2.69	2.54	1.90	2.30	3.54	3.75	2.42	2.13
L	0.86	4.96	1.89	1.89	3.00	6.18	3.17	3.45
M	0.81	5.79	2.26	2.15	3.56	7.53	3.73	3.60
N	0.98	5.70	2.74	3.64	4.41	7.55	3.44	3.85
O	0.89	5.18	1.64	2.01	3.18	6.86	4.29	4.14
P	1.48	5.83	2.14	2.00	3.16	7.60	4.99	4.44
Q	4.10	5.54	4.06	2.68	5.38	8.20	3.08	5.05
R	4.42	5.88	4.81	3.66	6.79	9.24	3.91	5.53
S	1.86	4.06	1.99	1.96	2.42	4.70	1.94	1.95
T	1.20	3.25	1.57	1.77	1.62	4.05	1.25	1.64
U	0.89	4.16	1.28	2.11	2.45	4.74	2.38	2.86
V	0.60	4.14	1.45	2.79	2.78	4.57	1.74	2.50
W	3.53	2.08	3.49	4.89	5.10	3.15	4.66	2.74
X	3.09	2.82	2.65	3.87	4.18	2.74	4.14	3.61
Y	4.37	3.33	3.86	4.76	5.38	4.06	5.50	3.43
Z	3.48	2.04	3.54	5.00	5.43	3.87	4.53	2.66
a	3.21	2.28	2.96	4.66	4.91	2.64	3.58	2.03
b	1.59	5.36	2.32	2.01	3.20	7.28	2.58	2.88
c	1.97	6.68	3.17	3.34	5.17	9.10	3.72	3.45
d	1.34	4.27	1.25	1.02	1.89	5.11	2.12	2.59
e	3.34	1.31	2.72	3.81	4.80	3.63	4.54	3.21
f	2.30	2.14	2.21	3.51	3.35	0.78	1.77	1.53
g	3.87	3.86	3.73	5.54	5.39	1.51	3.15	2.97
h	6.39	3.23	4.57	5.48	8.78	4.35	6.70	3.56
i	5.08	2.87	3.83	4.74	7.66	4.17	5.23	3.33
j	6.83	3.76	4.98	6.30	10.44	5.98	7.58	3.97
k	6.27	3.77	4.35	5.41	8.60	5.56	7.13	3.47
l	3.13	3.30	2.31	4.08	4.17	1.86	2.99	2.45
m	3.35	3.50	2.65	4.70	4.27	3.33	4.23	3.62
n	2.72	3.45	2.54	3.03	2.57	2.45	2.49	1.95
o	2.34	3.65	2.84	2.21	3.57	6.63	2.22	2.95
p	2.90	4.65	3.32	2.09	4.51	6.96	2.55	3.33
q	3.30	4.35	3.26	2.54	4.69	5.60	2.91	4.20
r	3.62	1.90	2.55	3.59	4.74	2.96	3.88	2.86
s	3.39	1.59	2.84	5.60	5.28	3.71	3.87	3.68
t	3.77	3.36	3.83	7.31	7.91	2.64	3.37	3.79
u	0.70	3.56	1.48	2.09	2.67	3.57	1.81	2.63
v	1.00	2.80	1.18	1.82	2.13	2.78	1.34	1.79
w		1.00	2.23	3.32	4.52	3.54	3.52	2.59
x			1.00	1.51	2.48	2.89	1.91	2.53
y				1.00	1.60	4.84	2.19	2.12
z					1.00	5.33	2.85	1.08
!						1.00	1.48	2.11
$							1.00	1.49
#								1.00

CLUSTER NUMBER

CLUSTER#	▪	%	&	'	(	)	*	+
1	4.51	2.34	2.97	3.30	2.18	1.99	3.04	0.91
2	3.65	1.46	2.04	2.77	2.47	2.10	3.51	0.84
3	5.57	2.66	1.95	2.19	2.57	2.51	3.25	1.14
4	4.85	2.37	1.87	2.48	3.38	2.84	4.38	1.26
5	2.82	2.79	4.22	4.83	3.94	3.66	5.96	2.11
6	2.65	2.11	3.02	3.60	3.26	2.86	4.51	1.33
7	2.72	2.45	3.57	4.18	3.45	3.20	5.04	1.63
8	2.71	2.41	3.64	4.22	4.11	3.46	6.00	2.00
9	3.07	1.14	1.51	1.92	3.02	2.72	3.97	1.13
A	3.68	1.47	1.28	1.83	3.20	2.97	4.02	0.93
B	5.38	1.99	1.23	0.75	3.35	2.71	4.12	1.05
C	3.41	2.59	3.81	4.82	4.12	3.79	6.06	2.10
D	3.93	3.06	4.65	5.50	4.99	4.38	7.26	2.84
E	3.44	1.44	1.17	1.41	2.52	2.23	3.29	0.56
F	3.11	1.34	1.63	2.09	2.90	2.54	3.80	0.87
G	2.98	1.67	1.95	2.30	2.80	2.45	3.49	0.88
H	4.99	2.69	2.82	2.92	2.70	2.47	3.19	1.46
I	3.58	1.76	2.21	2.98	3.10	2.85	4.66	1.14
J	4.54	3.28	3.11	3.22	1.98	1.99	2.52	1.29
K	3.41	2.39	2.27	2.62	2.03	1.92	2.83	1.04
L	3.63	1.28	1.29	1.73	4.58	3.58	5.79	2.14
M	4.06	1.83	1.46	1.66	4.77	3.73	5.82	2.38
N	4.22	1.73	1.49	1.92	4.76	3.76	6.06	2.42
O	4.49	2.05	1.68	1.98	5.38	4.13	6.54	2.35
P	4.86	2.56	2.30	2.62	6.04	4.28	7.21	2.85
Q	6.68	2.08	1.63	2.06	4.44	3.73	6.11	1.51
R	7.68	2.34	1.61	1.69	4.08	3.79	5.45	2.03
S	2.71	2.16	2.26	3.24	4.40	2.66	5.56	2.36
T	2.52	2.35	2.81	3.46	4.07	2.12	5.19	2.11
U	2.96	1.32	1.69	2.32	4.42	3.14	5.82	2.16
V	2.96	2.92	3.36	3.41	4.17	2.54	5.52	2.16
W	3.36	5.17	6.34	6.60	2.44	3.51	5.68	2.35
X	3.78	4.03	5.01	5.67	4.14	3.52	6.23	2.37
Y	4.30	5.31	6.59	6.90	3.30	3.46	5.91	2.75
Z	3.72	6.23	7.21	7.24	3.20	3.88	6.55	2.28
a	2.94	6.10	7.27	7.29	4.43	3.99	7.35	2.52
b	4.05	1.61	1.50	1.65	4.38	3.71	5.57	2.15
c	5.08	2.28	1.78	1.67	4.92	4.09	6.05	2.64
d	3.20	1.58	1.62	2.33	4.29	2.71	5.31	1.93
e	3.50	3.99	4.71	5.16	2.79	3.33	5.03	1.81
f	2.17	3.89	4.93	5.54	3.66	2.77	5.68	2.14
g	2.84	5.21	6.80	7.75	5.04	4.89	8.21	3.89
h	4.90	5.77	6.07	6.46	3.09	3.86	4.95	3.23
i	4.93	4.61	4.90	5.30	3.02	3.47	4.52	2.78
j	6.03	6.61	6.45	7.18	3.85	4.13	5.91	3.76
k	5.43	5.88	6.10	7.07	4.00	3.73	5.84	3.63
l	2.41	3.44	4.80	5.47	4.17	3.90	6.04	2.71
m	3.07	3.79	5.09	5.96	5.40	3.94	7.14	3.15
n	2.23	3.25	4.19	5.01	5.14	3.26	6.56	3.12
o	4.98	2.30	1.34	1.63	2.23	1.99	2.72	0.92
p	5.22	2.06	1.03	0.72	3.14	2.56	3.56	1.36
q	5.16	2.65	1.63	1.14	3.88	3.33	4.43	1.07
r	3.24	4.19	4.20	4.25	2.21	2.65	3.54	1.79
s	3.58	6.85	7.59	7.45	3.20	4.36	7.41	1.97
t	4.16	6.62	8.50	9.14	4.34	5.91	9.48	3.50
u	2.97	1.04	1.21	1.89	3.57	2.69	4.55	1.75
v	2.28	1.70	1.94	2.25	3.25	2.36	4.02	1.71
w	3.37	4.13	4.68	4.74	2.21	2.91	4.10	1.52
x	2.78	1.69	2.10	2.94	3.27	2.40	4.56	1.43
y	3.05	1.53	1.23	1.36	3.09	2.45	3.77	1.31
z	2.15	3.14	2.93	3.70	5.01	2.44	5.29	2.49

CLUSTER NUMBER

CLUSTER#	"	%	&	'	(	)	*	+
!	2.77	5.24	6.83	7.12	4.89	4.09	7.59	2.86
$	2.16	2.38	2.03	2.76	3.60	2.14	4.27	1.56
#	1.09	3.07	3.13	3.45	3.30	1.55	3.84	2.05
"	1.00	3.48	4.67	5.30	4.89	3.32	6.01	2.81
%		1.00	0.75	1.52	3.94	3.36	5.28	1.54
&			1.00	0.69	3.50	2.89	4.25	1.22
'				1.00	3.17	2.88	3.79	1.37
(					1.00	1.18	0.70	1.49
)						~~1.00~~	~~1.38~~	~~1.27~~
*							1.00	1.90
+								1.00

CLUSTER NUMBER

CLUSTER#	,	-	/	:	;	<	=	>
1	1.38	3.30	5.69	5.30	4.69	1.17	1.29	7.50
2	1.68	2.38	4.71	2.73	2.82	1.17	1.49	5.75
3	1.64	1.47	3.07	4.17	3.68	1.03	1.35	5.01
4	2.23	1.51	3.96	5.35	4.37	1.82	2.24	6.58
5	3.35	2.24	5.85	4.46	4.18	3.27	2.69	3.94
6	2.42	1.80	4.77	4.14	3.76	2.29	2.24	3.72
7	2.81	1.92	5.06	4.69	4.08	2.61	2.43	3.92
8	3.33	1.99	5.30	5.02	4.61	3.01	2.86	3.32
9	2.21	1.17	2.28	3.41	3.53	1.00	1.78	2.88
A	2.00	1.16	2.16	2.91	2.71	1.17	1.90	2.91
B	2.12	1.78	2.18	6.00	5.84	2.16	2.55	7.56
C	3.42	1.74	5.47	4.52	4.26	3.09	2.97	2.29
D	4.24	2.49	7.30	5.82	5.23	4.28	3.56	2.90
E	1.52	1.05	1.73	3.29	3.07	1.16	1.47	4.10
F	1.95	1.33	3.02	3.91	3.59	1.57	1.84	3.82
G	1.83	1.52	3.14	4.43	3.87	1.83	2.08	3.80
H	1.88	2.57	4.51	4.19	4.10	1.56	1.55	5.66
I	2.40	1.85	4.36	4.26	3.58	1.44	1.70	4.91
J	1.38	2.65	4.45	3.71	3.59	1.53	1.23	5.42
K	1.48	2.05	3.71	2.82	2.75	1.30	1.17	4.85
L	3.58	2.05	4.32	7.06	6.83	2.17	2.92	4.76
M	3.81	2.40	4.26	7.98	7.78	2.30	3.22	6.25
N	3.91	2.40	5.19	8.02	7.81	2.07	3.07	7.16
O	3.82	2.65	5.23	7.11	6.72	3.01	3.40	6.11
P	4.31	3.16	6.55	8.06	7.76	3.83	3.99	6.65
Q	2.82	0.82	1.05	7.33	6.44	1.85	2.56	5.43
R	2.98	1.11	0.75	5.97	5.94	2.23	2.54	6.90
S	3.44	2.93	6.31	5.37	5.53	3.25	3.02	5.08
T	2.99	3.22	6.30	4.44	4.72	3.08	2.55	4.87
U	3.53	2.46	6.09	6.06	6.13	2.70	2.82	3.90
V	3.08	3.11	6.55	7.23	6.88	3.11	2.88	4.51
W	4.00	3.81	6.87	3.37	3.47	3.80	1.99	3.33
X	3.61	3.77	7.44	4.86	4.89	3.58	3.44	2.88
Y	3.97	5.09	8.87	4.99	5.16	4.31	3.26	2.74
Z	4.42	4.86	8.41	4.14	4.12	3.81	2.02	4.54
a	4.57	4.94	9.02	3.64	4.57	3.92	2.66	5.75
b	3.63	1.94	3.69	6.41	6.37	1.84	2.84	5.10
c	4.19	2.37	3.81	8.42	8.40	2.24	3.53	7.57
d	3.18	2.22	4.10	6.29	6.16	2.59	2.78	4.36
e	3.37	2.82	5.55	1.36	1.38	2.72	1.13	3.06
f	3.50	4.19	7.13	3.31	3.84	3.14	2.32	4.70
g	5.55	4.56	7.43	4.76	4.96	4.38	3.97	5.92

CLUSTER NUMBER

CLUSTER#	,	-	/	:	;	<	=	>
h	3.76	4.67	7.96	3.14	3.54	4.32	3.37	5.74
i	3.39	4.10	7.12	2.74	3.29	3.84	3.19	4.62
j	4.53	5.01	9.04	3.19	3.87	4.93	3.90	5.86
k	4.42	5.16	9.08	3.62	4.63	4.45	4.07	6.31
l	3.80	2.84	5.64	4.44	4.54	3.53	3.32	3.86
m	4.18	3.20	7.80	5.10	5.23	4.51	4.01	2.33
n	4.05	3.41	6.79	3.75	4.51	3.78	3.51	3.89
o	1.34	2.20	2.78	5.44	5.00	1.68	2.10	8.23
p	2.12	1.90	1.79	6.01	5.85	1.78	2.79	7.94
q	2.26	1.96	1.77	5.44	5.01	2.23	2.89	5.22
r	2.42	2.81	4.53	1.98	1.93	2.41	1.22	3.94
s	4.49	3.91	7.11	2.57	1.77	2.66	1.44	7.66
t	6.11	3.58	6.88	4.20	3.76	4.13	2.57	7.22
u	2.85	1.95	4.24	4.97	5.05	1.57	2.32	3.21
v	2.45	2.26	4.51	4.90	4.65	2.08	2.25	3.45
w	2.75	3.73	5.35	2.44	2.38	2.46	1.12	6.98
x	2.41	2.00	5.03	3.80	3.48	2.20	2.05	4.93
y	2.09	1.84	3.30	4.80	4.31	2.18	2.18	4.93
z	3.24	3.64	6.18	7.24	7.31	3.66	3.67	4.85
!	4.63	4.59	8.25	4.96	5.53	4.01	3.24	7.38
$	2.43	2.51	3.64	6.17	6.00	2.11	2.56	6.31
#	2.36	3.49	5.31	3.83	4.12	3.01	2.62	5.16
"	3.76	4.27	7.16	4.66	5.54	3.97	3.47	5.51
%	3.03	1.02	2.62	5.39	4.88	1.20	2.38	3.56
&	2.45	1.15	1.63	4.71	4.92	0.89	2.12	3.51
'	2.23	1.75	1.22	4.72	4.87	1.35	2.75	5.67
(	1.02	3.39	4.01	3.12	2.68	2.35	1.40	6.78
)	0.91	3.04	3.77	3.48	3.14	2.26	1.77	5.15
*	1.24	4.44	5.30	4.41	3.97	3.09	2.56	8.65
+	0.73	1.30	1.80	2.28	2.14	1.03	1.03	3.81
,	1.00	2.35	2.79	3.06	2.76	1.71	1.49	5.36
-		1.00	1.38	3.76	3.33	1.21	1.79	3.31
/			1.00	6.51	6.18	2.47	2.95	6.23
:				1.00	0.65	2.88	1.59	6.34
;					1.00	2.60	1.15	7.65
<						1.00	1.36	4.49
=							1.00	4.67
>								1.00

CLUSTER NUMBER

CLUSTER#	@	[	\	]	^	_	`	{
1	3.41	2.90	2.52	2.44	2.20	5.89	5.09	6.57
2	1.93	2.01	1.85	1.92	1.94	4.88	4.08	4.48
3	3.26	2.70	2.41	2.95	2.72	4.96	5.07	5.37
4	3.13	1.84	2.34	2.05	2.31	5.87	5.57	5.90
5	2.54	1.56	2.28	1.29	1.03	6.13	5.13	4.31
6	1.91	1.06	1.70	1.10	1.26	5.32	4.38	3.99
7	2.39	1.35	2.03	1.19	1.23	6.12	4.96	4.47
8	2.22	1.22	2.02	1.10	1.09	6.11	4.99	4.20
9	1.75	1.40	1.71	1.77	1.87	3.28	3.25	3.32
A	2.11	1.63	1.87	1.88	1.71	4.11	3.86	3.93
B	3.96	2.60	3.45	3.15	3.23	6.41	6.53	8.11
C	1.39	0.73	1.33	0.72	0.95	4.50	3.60	2.82
D	2.08	1.15	2.10	0.83	0.88	6.78	5.33	3.63
E	2.41	1.71	2.11	2.10	1.90	4.33	4.36	4.42
F	1.89	1.30	1.67	1.64	1.60	4.44	3.92	4.22
G	2.16	1.21	1.75	1.39	1.40	5.15	4.30	4.65
H	2.33	2.36	2.03	2.31	2.44	4.76	4.36	5.64
I	2.31	1.54	1.73	1.40	1.71	5.80	4.77	5.39
J	3.00	3.28	2.30	2.79	2.63	4.98	4.37	5.19
K	2.44	2.53	1.97	2.24	2.20	4.47	3.96	4.40

CLUSTER NUMBER

CLUSTER#	@	[	\	]	^	_	`	{
L	2.92	2.42	2.73	2.81	3.37	5.07	4.74	5.45
M	4.08	3.52	3.67	3.83	4.34	5.96	5.67	6.48
N	3.58	3.19	3.58	3.50	4.53	6.65	6.47	7.49
O	4.04	2.91	4.05	3.30	3.78	7.32	7.06	8.11
P	4.35	3.26	4.12	3.63	3.86	7.06	6.98	7.29
Q	4.04	2.51	3.38	4.13	3.65	6.10	6.94	6.55
R	3.70	2.83	3.32	4.79	4.64	6.05	6.78	6.25
S	2.87	2.27	2.95	2.96	3.19	5.23	5.50	5.63
T	2.92	2.52	3.10	3.02	3.20	5.48	5.39	5.84
U	2.42	2.14	2.53	2.61	2.95	4.52	4.44	4.59
V	3.67	2.54	3.59	2.72	3.07	6.52	5.98	7.32
W	3.23	2.81	3.06	2.48	2.71	6.38	5.52	5.11
X	2.69	2.16	2.33	1.68	1.97	5.43	4.56	4.02
Y	3.27	2.58	2.89	2.19	2.91	6.68	5.67	5.25
Z	4.51	3.46	3.94	3.14	3.66	10.25	8.32	7.77
a	4.65	4.15	3.97	3.21	3.33	8.86	7.49	6.89
b	3.23	2.66	2.94	2.97	3.85	5.29	5.09	6.48
c	4.42	3.90	3.80	4.15	5.21	6.73	6.44	7.87
d	2.41	2.26	2.60	3.06	3.34	6.02	5.63	6.80
e	1.70	2.22	1.53	2.05	2.60	5.23	4.28	3.73
f	3.15	3.03	2.98	2.65	2.72	5.14	4.67	4.29
g	4.46	4.02	4.24	3.11	3.58	6.96	6.17	5.56
h	4.12	4.48	3.46	4.01	4.33	5.41	5.16	4.75
i	3.11	3.35	2.58	3.09	3.63	5.65	5.04	4.47
j	4.60	4.70	3.52	4.02	4.66	6.47	6.14	5.38
~~k~~	~~4.69~~	~~4.92~~	~~3.78~~	~~4.10~~	~~4.65~~	~~6.06~~	~~5.97~~	~~5.24~~
l	2.72	2.03	2.62	1.46	1.16	5.25	4.54	3.85
m	2.62	1.82	2.41	1.08	0.51	6.52	5.18	3.93
n	3.06	2.35	3.08	1.76	1.49	5.75	5.41	4.17
o	3.51	3.53	2.84	3.64	3.35	6.30	5.46	7.73
p	4.28	3.69	3.41	4.33	4.08	5.83	5.42	7.04
q	4.12	2.77	3.33	3.24	2.69	5.82	5.98	6.81
r	3.52	2.89	2.95	2.80	3.55	7.42	6.68	5.94
s	5.12	4.57	3.73	2.95	2.86	9.16	7.72	6.52
t	5.10	4.42	4.73	2.94	3.10	10.45	8.69	7.02
u	2.00	1.85	2.01	2.16	2.72	3.86	3.54	3.85
v	2.87	2.01	2.87	2.15	2.59	5.12	4.72	5.57
w	3.76	3.28	3.28	2.59	2.86	7.16	6.39	5.58
x	2.32	1.38	2.29	1.55	1.64	5.72	4.89	4.97
y	3.05	2.06	2.81	2.59	2.76	5.57	5.31	6.58
z	4.21	2.52	4.07	2.80	3.08	7.14	7.48	8.72

CLUSTER#	@	[	\	]	^	_	`	{
!	4.45	3.44	4.19	2.90	3.33	9.41	8.00	7.45
$	3.41	2.92	3.41	3.13	3.40	6.45	5.69	6.52
#	3.20	3.07	2.99	2.89	3.01	5.13	4.66	4.87
"	3.56	3.30	3.23	2.82	3.21	6.75	5.78	5.78
%	1.37	1.29	1.35	1.65	2.24	4.10	3.54	4.09
&	1.94	2.32	1.79	2.73	2.99	4.35	4.11	4.92
'	3.34	3.06	2.79	3.76	3.55	4.08	3.96	4.44
(	3.79	4.01	3.04	3.46	3.71	5.81	5.29	5.32
)	3.50	3.52	3.30	3.36	3.53	5.52	4.83	5.54
*	5.36	5.55	3.85	4.61	4.40	6.13	5.60	6.47
+	1.91	1.87	1.71	1.94	1.78	3.66	3.30	3.53
,	3.29	3.23	2.60	2.86	2.60	4.79	4.32	5.02
-	1.74	1.13	1.80	1.77	2.14	3.68	3.85	3.19
/	4.88	3.11	4.10	4.83	4.21	5.57	6.38	5.99
:	3.76	3.97	2.77	3.14	3.63	4.65	4.18	3.53
;	3.64	3.79	3.01	3.21	3.66	6.37	6.15	4.71
<	2.38	2.26	2.18	2.53	2.65	4.09	3.91	4.52
=	2.77	2.91	2.48	2.57	2.75	5.17	4.74	4.35
>	1.61	1.74	2.12	1.81	2.51	5.24	4.21	3.14
@	1.00	0.72	0.60	0.91	1.95	3.72	2.92	2.20
[		1.00	0.93	0.41	1.30	3.82	3.04	2.22
\			1.00	0.93	1.84	2.12	1.52	1.22
]				1.00	1.00	3.20	2.54	2.04
^					1.00	4.41	3.74	2.98
_						1.00	0.80	0.81
`							1.00	1.25
{								1.00

Appendix D

USGS Land Use and Land Cover Classification Scheme
Level I and Level II

1 URBAN OR BUILT UP LAND

- 11 Residential
- 12 Comercial and Services
- 13 Industrial
- 14 Transportation, Communications and Utilities
- 15 Industrial and Commerical Complexes
- 16 Mixed Urban or Built-Up Land
- 17 Other Urban or Built-Up Land

2 AGRICULTURAL LAND

- 21 Cropland and Pasture
- 22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
- 23 Confined Feeding Operations
- 24 Other Agricultural Land

3 RANGELAND

- 31 Herbaceous Rangeland
- 32 Shrub and Brush Rangeland
- 33 Mixed Rangeland

4 FOREST LAND

- 41 Deciduous Forest Land
- 42 Evergreen Forest Land
- 43 Mixed Forest Land

5 WATER

- 51 Streams and Canals
- 52 Lakes
- 53 Resevoirs
- 54 Bays and Estuaries

6 WETLAND

- 61 Forested Wetland
- 62 Non-Forested Wetland

7 BARREN LAND

71 Dry Salt Flats
72 Beaches
73 Sandy Areas Other than Beaches
74 Bare Exposed Rock
75 Strip Mines, Quarries, and Gravel Pits
76 Transitional Areas
77 Mixed Barren Land

8 TUNDRA

81 Shrub and Brush Tundra
82 Herbaceous Tundra
83 Bare Ground Tundra
84 Wet Tundra
85 Mixed Tundra

9 PERENNIAL SNOWFIELDS AND ICE

91 Perennial Snowfields
92 Glaciers

Appendix E

Renaming Second Classification Categories for Urban Stratification

Before Stratification		After Stratification	
Class Number#	Information Class	Class Number#	Information Class
1,2	Citrus	33	residential
3,4	Peaches	-	(no change)*
5,6	Figs	34	native vegetation
7,8	Olives	33	residential
9,10	Almonds	33	residential
11,12	Melons	-	(no change)*
13,14,45,46	Cotton	-	(no change)*
15,16	Garlic	-	(no change)*
17,18,19	Lettuce	-	(no change)*
20,21,22,23 24,40,47,48	Grain	-	(no change)*
25,26,27	Carrots	-	(no change)*
28,29	Tomatoes	34	native vegetation
30,31	Bean	34	native vegetation
32,33,34	Safflower	-	(no change)*
35,36,37	Alfalfa	-	(no change)*
38,39	Pasture	35	urban open areas
41,42,43,44	Vineyards	33	residential
49,50,51,52	Corn	35	urban open areas
53,54	Native vegetation	36	commercial/ industrial
55,56,57	Water	-	(no change)*
58,59,60,61	Burns	-	(no change)*
62,63,64	Melons (reclustered)	-	(no change)*
65,66	Garlic (reclustered)	-	(no change)*
67,68,69	Alfalfa (reclustered)	-	urban open areas
70,71,72	Safflower (reclustered)	-	(no change)*
73,74,75,76	Sugar beets (reclustered)	-	(no change)*
77,78,79	Native vegetation (reclustered)	36	commercial/ industrial
80,81	Young vineyards	34	native vegetation
82,83,84,85	Grain stubble	34	native vegetation

* Note: These categories were not changed because they were not present within the urban areas.

APPENDIX F

Accuracy Assessment Contingency Tables

Maps 1 through 13

CONTINGENCY TABLE FOR ACCURACY ASSESSMENT

MAP 1

LANDSAT CLASSIFICATION

PG&E GROUND REFERENCE DATA

	CITRUS	PEACHES	FIGS	OLIVES	ALMONDS	VINEYARDS	COTTON	MELONS	GARLIC	TOMATOES	LETTUCE	BEETS	CARROTS	BEANS	CORN	SAFFLOWER	GRAIN	ALFALFA	PASTURE	NON-CROPLAND	TOTAL	% CORRECT	% OMISSION
CITRUS																					0		
PEACHES																					0		
FIGS			394			24	7							4		9			10	5	453	87.0	13.0
OLIVES	11		18	125		23								4	3					4	188	66.5	33.5
ALMONDS																					0		
VINEYARDS	21	136	25	15	11	2139	58					1	7	11	13	2	57		100	148	2744	78.0	22.0
COTTON						23	51												40	29	143	35.7	64.3
MELONS																					0		
GARLIC																					0		
TOMATOES																					0		
LETTUCE																					0		
BEETS																					0		
CARROTS																					0		
BEANS																					0		
CORN																					0		
SAFFLOWER																					0		
GRAIN	2		18	5	3	42	1						9	11	5	2	25	8	4	26	161	15.5	84.5
ALFALFA						8											8		22	1	39	0	100
PASTURE	1		39	1		16								5					31	17	110	28.2	71.8
NON-CROPLAND	1	1	115	1		77	2		1	12	1		5	23	10		75			181	505	35.8	64.2
TOTAL	36	137	609	147	14	2352	119	0	1	12	1	1	21	58	31	13	165	8	207	411	4343		
% CORRECT	0	0	64.7	85.0	0	90.9	42.9		0	0	0	0	0	0	0	0	15.2	0	15.0	44.0		67.8	
% COMMISSION	100	100	35.3	15.0	100	9.1	57.1		100	100	100	100	100	100	100	100	84.8	100	85.0	56.0			32.2

CONTINGENCY TABLE FOR ACCURACY ASSESSMENT

MAP 2

LANDSAT CLASSIFICATION

PG&E CORRIDOR GROUND REFERENCE DATA

	CITRUS	PEACHES	FIGS	OLIVES	ALMONDS	VINEYARDS	COTTON	MELONS	GARLIC	TOMATOES	LETTUCE	BEETS	CARROTS	BEANS	CORN	SAFFLOWER	GRAIN	ALFALFA	PASTURE	NON-CROPLAND	TOTAL	% CORRECT	% OMISSION
CITRUS																					0		
PEACHES																					0		
FIGS	1		897		1	52								8		28			12	10	1009	88.9	11.1
OLIVES																					0		
ALMONDS	45		27	48	332	130	5							7	12			4	143	34	787	42.4	57.6
VINEYARDS	10	189	13	23	27	6598	22					2	2	1	26	6		28	143	186	7276	90.7	9.3
COTTON						185	199					95	1					3	189	4	676	29.4	70.6
MELONS																					0		
GARLIC																					0		
TOMATOES																					0		
LETTUCE																					0		
BEETS																					0		
CARROTS																					0		
BEANS																					0		
CORN						6									13			35	3		57	22.8	77.2
SAFFLOWER																					0		
GRAIN																					0		
ALFALFA	6				2	27	1		3	4		3		5	9			224	223		507	44.2	55.8
PASTURE																					0		
NON-CROPLAND																					0		
TOTAL	62	189	937	71	362	6998	227	0	3	4	0	100	3	21	60	34	0	294	713	234	10,312		
% CORRECT	0	0	95.7	0	91.7	94.3	87.7		0	0		0	0	0	21.7	0		76.2	0	0		80.1	
% COMMISSION	100	100	4.3	100	8.3	5.7	12.3		100	100		100	100	100	78.3	100		23.8	100	100			19.9

CONTINGENCY TABLE FOR ACCURACY ASSESSMENT

MAP 3

LANDSAT CLASSIFICATION

PG&E CORRIDOR GROUND REFERENCE DATA

	CITRUS	PEACHES	FIGS	OLIVES	ALMONDS	VINEYARDS	COTTON	MELONS	GARLIC	TOMATOES	LETTUCE	BEETS	CARROTS	BEANS	CORN	SAFFLOWER	GRAIN	ALFALFA	PASTURE	NON-CROPLAND	TOTAL	% CORRECT	% OMISSION
CITRUS																					0		
PEACHES																					0		
FIGS																					0		
OLIVES																					0		
ALMONDS						38								2		13	7	11	13	241	325	0	100
VINEYARDS	2	1	1		5	1300	25					7		5	27	17	8	5	20	311	1734	75.0	25.0
COTTON						102	54					43			3			4	193	12	411	13.1	86.9
MELONS																					0		
GARLIC																					0		
TOMATOES																					0		
LETTUCE																					0		
BEETS																					0		
CARROTS																					0		
BEANS																					0		
CORN														6	17			56	76		155	11.0	89.0
SAFFLOWER																					0		
GRAIN						1										5	87		2	10	105	82.9	17.1
ALFALFA						1												391	33	2	427	91.6	8.4
PASTURE							1										18	17	142		178	79.8	20.2
NON-CROPLAND			60			34					8						4	4	9	32	151	21.2	78.8
TOTAL	2	1	61	0	5	1476	80	0	0	0	8	50	0	13	47	35	124	488	488	608	3486		
% CORRECT	0	0	0		0	88.1	67.5				0	0		0	36.2	0	70.1	80.1	29.1	5.3		58.0	
% COMMISSION	100	100	100		100	11.9	32.5				100	100		100	63.8	100	29.9	19.9	70.9	94.7			42.0

CONTINGENCY TABLE FOR ACCURACY ASSESSMENT

MAP 4

LANDSAT CLASSIFICATION

PG&E CORRIDOR GROUND REFERENCE DATA

	CITRUS	PEACHES	FIGS	OLIVES	ALMONDS	VINEYARDS	COTTON	MELONS	GARLIC	TOMATOES	LETTUCE	BEETS	CARROTS	BEANS	CORN	SAFFLOWER	GRAIN	ALFALFA	PASTURE	NON-CROPLAND	TOTAL	% CORRECT	% OMISSION
CITRUS																					0		
PEACHES																					0		
FIGS																					0		
OLIVES																					0		
ALMONDS																					0		
VINEYARDS																					0		
COTTON			86			15		644	6								128				879	0	100
MELONS																					0		
GARLIC																					0		
TOMATOES						4		7	38		17				3		299				368	0	100
LETTUCE																					0		
BEETS																					0		
CARROTS																					0		
BEANS			62					18	1						1		4				86	0	100
CORN			6					14									28				48	0	100
SAFFLOWER																					0		
GRAIN	1		4			50		8	5						1		99				168	58.9	41.1
ALFALFA			6	3		79		614	10						14		66				792	0	100
PASTURE																					0		
NON-CROPLAND		1	2	3		2		3	2								1				14	0	100
TOTAL	1	1	166	6	0	150	0	1308	62	0	17	0	0	0	19	0	625	0	0	0	2355		
% CORRECT	0	0	0	0		0		0	0		0				0		15.8					4.2	
% COMMISSION	100	100	100	100		100		100	100		100				100		84.2						95.8

CONTINGENCY TABLE FOR ACCURACY ASSESSMENT

MAP 5

LANDSAT CLASSIFICATION

PG&E CORRIDOR GROUND REFERENCE DATA

	CITRUS	PEACHES	FIGS	OLIVES	ALMONDS	VINEYARDS	COTTON	MELONS	GARLIC	TOMATOES	LETTUCE	BEETS	CARROTS	BEANS	CORN	SAFFLOWER	GRAIN	ALFALFA	PASTURE	NON-CROPLAND	TOTAL	% CORRECT	% OMISSION
CITRUS																					0		
PEACHES																					0		
FIGS																					0		
OLIVES																					0		
ALMONDS																					0		
VINEYARDS																				16	16		
COTTON						147	25	1				26						4	243	24	470	5.3	94.7
MELONS																					0		
GARLIC									12							4				20	36	33.3	66.7
TOMATOES																					0		
LETTUCE																					0		
BEETS																					0		
CARROTS																					0		
BEANS						5							113		15			6	154	3	296	0	100
CORN																					0		
SAFFLOWER																					0		
GRAIN						1			21							7	644	10		13	696	92.5	7.5
ALFALFA			3			4										13		330	356	9	715	46.1	53.9
PASTURE																					0		
NON-CROPLAND						2											1		9	43	55	78.2	21.8
TOTAL	0	0	3	0	0	159	25	1	33	0	0	26	113	0	15	24	645	350	762	128	2284		
% CORRECT			0			0	100	0	36.4			0	0		0	0	99.8	94.3	0	33.6		46.1	
% COMMISSION			100			100	0	100	63.6			100	100		100	100	0.2	5.7	100	66.4			53.9

CONTINGENCY TABLE FOR ACCURACY ASSESSMENT

MAP 6

LANDSAT CLASSIFICATION

PG&E CORRIDOR GROUND REFERENCE DATA

	CITRUS	PEACHES	FIGS	OLIVES	ALMONDS	VINEYARDS	COTTON	MELONS	GARLIC	TOMATOES	LETTUCE	BEETS	CARROTS	BEANS	CORN	SAFFLOWER	GRAIN	ALFALFA	PASTURE	NON-CROPLAND	TOTAL	% CORRECT	% OMISSION
CITRUS																					0		
PEACHES																					0		
FIGS																					0		
OLIVES																					0		
ALMONDS																					0		
VINEYARDS	37	36	14	42		1415	31								161		7	20	13	403	2179	64.9	35.1
COTTON	9	4	6	8	10	158	2863		9	10			2		36			30	56	37	3238	88.4	11.6
MELONS																					0		
GARLIC																					0		
TOMATOES																					0		
LETTUCE																					0		
BEETS						2	1					34						4	26		67	50.7	49.3
CARROTS																					0		
BEANS																					0		
CORN							35													2	37	0	100
SAFFLOWER																					0		
GRAIN			12	2		1	1			1				2		1	341		3	12	376	90.7	9.3
ALFALFA					1	102	239		13						58			295	102	13	823	35.8	64.2
PASTURE						3							1		3				44	1	52	84.6	15.4
NON-CROPLAND	1	3	41	2		26													1	35	109	32.1	67.9
TOTAL	47	43	73	54	11	1707	3170	0	22	11	0	34	3	2	258	1	348	349	245	503	6881		
% CORRECT	0	0	0	0	0	82.9	90.3		0	0		100	0	0	0	0	98.0	84.5	18.0	7.0		73.1	
% COMMISSION	100	100	100	100	100	17.1	9.7		100	100		0	100	100	100	100	2.0	15.5	82.0	93.0			26.9

CONTINGENCY TABLE FOR ACCURACY ASSESSMENT

MAP 7

LANDSAT CLASSIFICATION

PG&E CORRIDOR GROUND REFERENCE DATA

	CITRUS	PEACHES	FIGS	OLIVES	ALMONDS	VINEYARDS	COTTON	MELONS	GARLIC	TOMATOES	LETTUCE	BEETS	CARROTS	BEANS	CORN	SAFFLOWER	GRAIN	ALFALFA	PASTURE	NON-CROPLAND	TOTAL	% CORRECT	% OMISSION
CITRUS																					0		
PEACHES																					0		
FIGS																					0		
OLIVES																					0		
ALMONDS																					0		
VINEYARDS																					0		
COTTON	3	6	1	1	2	27	1219		1		9		16	1	32	1	2	21	34	14	1390	87.7	12.3
MELONS																					0		
GARLIC																					0		
TOMATOES						4	118	1	63	181				1		1	12	85	3		469	38.6	61.4
LETTUCE																					0		
BEETS						29					6	2		1		34		383	74	14	543	0	100
CARROTS																					0		
BEANS																					0		
CORN																					0		
SAFFLOWER																					0		
GRAIN			3		2	14	9			31	25		68	9	1	213	508	8	19	17	927	54.8	45.2
ALFALFA																					0		
PASTURE																					0		
NON-CROPLAND																					0		
TOTAL	3	6	4	1	4	74	1346	1	64	212	40	2	84	12	33	249	522	497	130	45	3329		
% CORRECT	0	0	0	0	0	0	90.6	0	0	85.4	0	100	0	0	0	0	97.3	0	0	0		57.4	
% COMMISSION	100	100	100	100	100	100	9.4	100	100	14.6	100	0	100	100	100	100	2.7	100	100	100			42.6

CONTINGENCY TABLE FOR ACCURACY ASSESSMENT

MAP 8

LANDSAT CLASSIFICATION

PG&E CORRIDOR GROUND REFERENCE DATA

	CITRUS	PEACHES	FIGS	OLIVES	ALMONDS	VINEYARDS	COTTON	MELONS	GARLIC	TOMATOES	LETTUCE	BEETS	CARROTS	BEANS	CORN	SAFFLOWER	GRAIN	ALFALFA	PASTURE	NON-CROPLAND	TOTAL	% CORRECT	% OMISSION
CITRUS																					0		
PEACHES																					0		
FIGS																					0		
OLIVES																					0		
ALMONDS																					0		
VINEYARDS																					0,		
COTTON	2	1	8	2		112	2916	2		2		5			1	1	5	48	52	5	3162	92.2	7.8
MELONS																					0		
GARLIC																					0		
TOMATOES									73	60		13				4	2				152	39.5	60.5
LETTUCE																					0		
BEETS						3	2					136									141	96.4	3.6
CARROTS																					0		
BEANS																					0		
CORN																					0		
SAFFLOWER																					0		
GRAIN			7			22	1				38	44				1	995	1	29	16	1154	86.2	13.8
ALFALFA						1	3					1			2			306	36		349	87.7	12.3
PASTURE																					0		
NON-CROPLAND																					0		
TOTAL	2	1	15	2	0	138	2922	2	73	62	38	199	0	0	3	6	1002	355	117	21	4958		
% CORRECT	0	0	0	0		0	99.8	0	0	96.8	0	68.3			0	0	99.3	86.2	0	0		89.0	
% COMMISSION	100	100	100	100		100	0.2	100	100	3.2	100	31.7			100	100	0.7	13.8	100	100			11.0

CONTINGENCY TABLE FOR ACCURACY ASSESSMENT

MAP 9

LANDSAT CLASSIFICATION

PG&E CORRIDOR GROUND REFERENCE DATA

	CITRUS	PEACHES	FIGS	OLIVES	ALMONDS	VINEYARDS	COTTON	MELONS	GARLIC	TOMATOES	LETTUCE	BEETS	CARROTS	BEANS	CORN	SAFFLOWER	GRAIN	ALFALFA	PASTURE	NON-CROPLAND	TOTAL	% CORRECT	% OMISSION
CITRUS																					0		
PEACHES																					0		
FIGS																					0		
OLIVES																					0		
ALMONDS																					0		
VINEYARDS																					0		
COTTON		3	2			30	3577						3	3	3			12	34	19	3686	97.0	3.0
MELONS																					0		
GARLIC																					0		
TOMATOES																					0		
LETTUCE																					0		
BEETS																					0		
CARROTS																					0		
BEANS																					0		
CORN																					0		
SAFFLOWER																					0		
GRAIN	1		1		2	10	4		1	17			20	10	2	6	912	4	11	2	1003	90.9	9.1
ALFALFA																					0		
PASTURE																					0		
NON-CROPLAND																					0		
TOTAL	1	3	3	0	2	40	3581	0	1	17	0	0	23	13	5	6	912	16	45	21	4689		
% CORRECT	0	0	0		0	0	99.9		0	0			0	0	0	0	100	0	0	0		95.7	4.3
% COMMISSION	100	100	100		100	100	0.1		100	100			100	100	100	100	0	100	100	100			

CONTINGENCY TABLE FOR ACCURACY ASSESSMENT

MAP 10

LANDSAT CLASSIFICATION

[illegible] CORRIDOR GROUND REFERENCE DATA

	CITRUS	PEACHES	FIGS	OLIVES	ALMONDS	VINEYARDS	COTTON	MELONS	GARLIC	TOMATOES	LETTUCE	BEETS	CARROTS	BEANS	CORN	SAFFLOWER	GRAIN	ALFALFA	PASTURE	NON-CROPLAND	TOTAL	% CORRECT	% OMISSION
CITRUS																					0		
PEACHES																					0		
FIGS																					0		
OLIVES																					0		
ALMONDS																					0		
VINEYARDS				2		190	19							1	36			9	1	7	265	71.7	28.3
COTTON	1					62	2720		2					6	7	3		79	93	48	3021	90.0	10.0
MELONS																					0		
GARLIC																					0		
TOMATOES						4	35	45	3	275				1				67		26	456	60.3	39.7
LETTUCE																					0		
BEETS																					0		
CARROTS																					0		
BEANS																					0		
CORN																					0		
SAFFLOWER						6										323	7		11		347	93.1	6.9
GRAIN																					0		
ALFALFA																					0		
PASTURE																					0		
NON-CROPLAND						11	10													151	172	87.8	12.2
TOTAL	1	0	0	2	0	273	2784	45	5	275	0	0	0	8	43	326	7	155	105	232	4261		
% CORRECT	0			0		69.6	97.7	0	0	100				0	0	99.1	0	0	0	65.1		85.9	
% COMMISSION	100			100		30.4	2.3	100	100	0				100	100	0.9	100	100	100	34.9			14.1

CONTINGENCY TABLE FOR ACCURACY ASSESSMENT

MAP 11

LANDSAT CLASSIFICATION

PG&E CORRIDOR GROUND REFERENCE DATA

	CITRUS	PEACHES	FIGS	OLIVES	ALMONDS	VINEYARDS	COTTON	MELONS	GARLIC	TOMATOES	LETTUCE	BEETS	CARROTS	BEANS	CORN	SAFFLOWER	GRAIN	ALFALFA	PASTURE	NON-CROPLAND	TOTAL	% CORRECT	% OMISSION
CITRUS																					0		
PEACHES																					0		
FIGS																					0		
OLIVES																					0		
ALMONDS																					0		
VINEYARDS																					0		
COTTON				1		15	3552						2	4				1	43	3	3621	98.1	1.9
MELONS																					0		
GARLIC																					0		
TOMATOES										127								4			131	96.9	3.1
LETTUCE																					0		
BEETS																					0		
CARROTS																					0		
BEANS																					0		
CORN																					0		
SAFFLOWER																					0		
GRAIN						4				10	1		2	5		10	1851			4	1887	98.1	1.9
ALFALFA																					0		
PASTURE																					0		
NON-CROPLAND																					0		
TOTAL	0	0	0	1	0	19	3552	0	0	137	1	0	4	9	0	10	1851	5	43	7	5639		
% CORRECT				0		0	100			92.7	0		0	0		0	100	0	0	0		98.1	
% COMMISSION				100		100	0			7.3	100		100	100		100	0	100	100	100			1.9

CONTINGENCY TABLE FOR ACCURACY ASSESSMENT

MAP 12

LANDSAT CLASSIFICATION

PG&E CORRIDOR GROUND REFERENCE DATA

	CITRUS	PEACHES	FIGS	OLIVES	ALMONDS	VINEYARDS	COTTON	MELONS	GARLIC	TOMATOES	LETTUCE	BEETS	CARROTS	BEANS	CORN	SAFFLOWER	GRAIN	ALFALFA	PASTURE	NON-CROPLAND	TOTAL	% CORRECT	% OMISSION
CITRUS																							
PEACHES																					0		
FIGS																					0		
OLIVES																					0		
ALMONDS		1		1	22	5	1								3						33	66.7	33.3
VINEYARDS		1		19		180	45		1					4	32			49	1	3	335	53.7	46.3
COTTON	1	1	1		1	21	2128		7	2	3		1		1	18	43	67	40	13	2348	90.6	9.4
MELONS																					0		
GARLIC																					0		
TOMATOES						5	75	4	65	31				21		1		47	1		250	12.4	87.6
LETTUCE																					0		
BEETS																					0		
CARROTS																					0		
BEANS																					0		
CORN																					0		
SAFFLOWER																					0		
GRAIN																					0		
ALFALFA																					0		
PASTURE																					0		
NON-CROPLAND							19				12			3			74		11		119	0	100
TOTAL	1	3	1	20	23	211	2268	4	73	33	15	0	1	28	36	19	117	163	53	16	3085		
% CORRECT	0	0	0	0	95.7	85.3	93.8	0	0	93.9	0		0	0	0	0	0	0	0	0		76.5	
% COMMISSION	100	100	100	100	4.3	14.7	6.2	100	100	6.1	100		100	100	100	100	100	100	100	100			23.5

CONTINGENCY TABLE FOR ACCURACY ASSESSMENT

MAP 13

LANDSAT CLASSIFICATION

PG&E CORRIDOR GROUND REFERENCE DATA

	CITRUS	PEACHES	FIGS	OLIVES	ALMONDS	VINEYARDS	COTTON	MELONS	GARLIC	TOMATOES	LETTUCE	BEETS	CARROTS	BEANS	CORN	SAFFLOWER	GRAIN	ALFALFA	PASTURE	NON-CROPLAND	TOTAL	% CORRECT	% OMISSION
CITRUS																					0		
PEACHES																					0		
FIGS																					0		
OLIVES																					0		
ALMONDS																					0		
VINEYARDS																					0		
COTTON						19	1213			1						2		8	10	1	1254	96.7	3.3
MELONS																					0		
GARLIC																					0		
TOMATOES										14								1			15	93.3	6.7
LETTUCE																					0		
BEETS																					0		
CARROTS																					0		
BEANS																					0		
CORN																					0		
SAFFLOWER																					0		
GRAIN			1							1	1			1	2	3	217			3	229	94.8	5.2
ALFALFA																					0		
PASTURE																					0		
NON-CROPLAND						1											12			22	35	62.9	37.1
TOTAL	0	0	1	0	0	20	1213	0	0	16	1	0	0	1	2	5	229	9	10	26	1533		
% CORRECT			0			0	100			87.5	0			0	0	0	94.8	0	0	84.6		95.6	
% COMMISSION			100			100	0			12.5	100			100	100	100	5.3	100	100	15.4			4.4

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16. Abstract

The Gates to Gregg High Voltage Transmission Line Project was a cooperative effort between NASA/Ames Research Center and Pacific Gas and Electric Company to demonstrate and assess the utility of Landsat data in the planning of transmission line routes. Landsat digital data and image processing techniques, specifically a multi-date supervised classification approach, were used to develop a land cover map for an agricultural area near Fresno, California. Twenty-six land cover classes were identified, of which twenty classes were agricultural crops. High classification accuracies (greater than 80%) were attained for several classes, including cotton, grain, and vineyards. The primary products generated at the conclusion of the project were 1:24,000, 1:100,000 and 1:250,000 scale maps of the classification and acreage summaries for all land cover classes within four alternate transmission line routes.

17. Key Words (Suggested by Author(s)): Landsat; Agricultural Inventory; Transmission Line; Siting; California

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