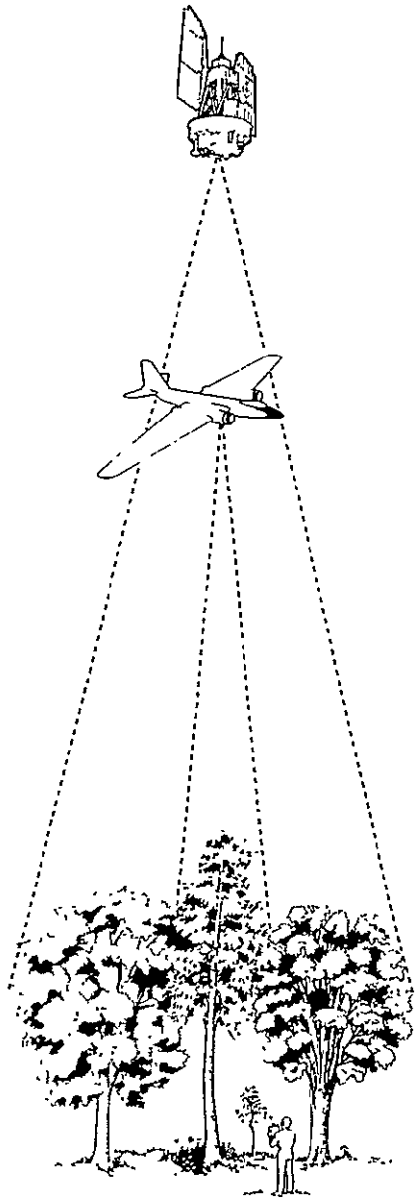
NATIONWIDE FORESTRY APPLICATIONS PROGRAM



TEN-ECOSYSTEM STUDY (TES) SITE VII, WELD COUNTY, COLORADO, FINAL REPORT

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15 Supplementary Notes

16 Abstract

This final report presents the findings and conclusions obtained from automatic data processing analysis of Landsat and photographic data acquired over Site VII of the Ten-Ecosystem Study. This site was selected to be representative of the Grassland Ecosystem.

The analysis of the processing results has led to the following conclusions:

a. The best dates for automatic data processing analysis appear to be in midsummer.

b. The Level II separation of grassland, water, and other is reasonably successful, but the Level III separation of grassland into "cultivated" (growing crops) and weeds does not appear feasible.

c. Low simulated inventory proportions of grassland indicate that the restricted inventory signature is not representative of all grassland classes and cannot be extended with acceptable accuracy.

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PREFACE

The Nationwide Forestry Applications Program was established in 1971 at the Lyndon B. Johnson Space Center of the National Aeronautics and Space Administration to develop and to demonstrate the use of remote sensing technology in performing forestry resources inventories, with particular application to the Forest Service of the U.S. Department of Agriculture. During the 1971-75 time period, many small and localized studies were conducted on the feasibility of using automatic data processing techniques and conventional photointerpretation analysis for forestry applications. The studies were directed primarily toward specific applications for Region VIII of the Forest Service.

The need for extending the technology to intermediate-scale and large-scale applications was reflected in the passage of the Forest and Rangeland Renewable Resources Planning Act of 1974 (Public Law 93-378). In response to some of the research requirements of this act, the Ten-Ecosystem Study was initiated to investigate the feasibility of analyzing forest and grassland ecosystems on a regional scale using automatic data processing techniques. This study analyzes Landsat data, supporting aircraft imagery, and ancillary information to inventory forest, grassland, and water areas by administrative boundaries in 10 broad ecosystems of the United States. For each specific ecosystem, analysis success, problems, and failures are clearly and objectively identified.

The primary objectives of the Ten-Ecosystem Study are:

a. To investigate the feasibility of using the automatic processing of remotely sensed data to inventory forest, grassland, and inland water areas within administrative boundaries for specified ecosystems of the United States

b. To identify automatic data processing analysis problems related to each ecosystem and recommend solutions

c. To define the requirements for an automatic data processing system to perform a nationwide forest and grassland inventory

These objectives will be addressed in the Ten-Ecosystem Study final report to be published after the data for the individual sites have been processed and analyzed.

The current report discusses the analysis of the Weld County, Colorado, site, which was selected to represent the Grassland Ecosystem, specifically the blue grama grass community of the U.S. central Great Plains. This report was prepared by Lockheed Electronics Company, Inc., under Contract NAS 9-15800, Job Order 75-325, Action Document 63-1737-5325-47. It is the final of four reports covering the study conducted at the Weld County, Colorado, site. Distribution of this report has been approved by the supervisor of the Forestry Applications Section and the manager of the Earth Observations Exploratory Studies Department.

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ABBREVIATIONS

ADP	automatic data processing
DAS	Data Analysis Station
ERIPS	Earth Resources Interactive Processing System
Image 100	Interactive Multispectral Image Analysis System, Model 100
JSC	Lyndon B. Johnson Space Center
MSS	multispectral scanner
NASA	National Aeronautics and Space Administration
PCC	percent of correct classification
pixel	picture element
PMIS	Passive Microwave Imaging System
PSU	primary sampling unit
SSU	secondary sampling unit
TES	Ten-Ecosystem Study
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

1. INTRODUCTION

The Ten-Ecosystem Study (TES) was designed to investigate the feasibility of using remote sensing technology to inventory areas of forest and grassland by administrative boundaries in 10 generalized ecosystems of the United States (refs. 1, 2, and 3). The 10 ecosystems are represented in 9 study site locations; 1 site is representative of 2 ecosystems. Another objective of the study was to identify problems associated with individual sites and ecosystems. This report documents the work performed and the results obtained on Site VII, in Weld County, Colorado, which is representative of the Grassland Ecosystem.

The site covers a 360 000-square-hectometer (890 000-acre) area in the northwestern portion of Colorado. Available Landsat data were reviewed and evaluated to determine the two best dates for using automatic data processing (ADP) techniques in performing this study; the June 1974 and November 1974 dates were selected. Field checks were performed in August 1977 using aerial photographs acquired in September 1972.

The data processing consisted of two phases: a type separability study and a simulated inventory study. The separability study was designed to establish the level of classification detail possible using Landsat multispectral scanner (MSS) data. The simulated inventory study was designed to determine how successfully ADP technology can extend limited ground truth for large area inventories. Classification results from the simulated inventory were analyzed to determine feature classification accuracies and to compare feature proportion estimates.

2. PRELIMINARY SITE ANALYSIS AND FAMILIARIZATION

The objectives of the preliminary site analysis and familiarization phases were to select the two best dates available for ADP analysis and to provide familiarity with the study site. This familiarization with the site allowed the scientists to better understand the site characteristics. It also provided knowledge that was beneficial in selecting training fields and in determining the ground-truth data necessary for the evaluation process.

2.1 SITE DESCRIPTION

2.1.1 LOCATION

Site VII is located slightly north of central Weld County, which is in the northeastern portion of the State of Colorado (fig. 2-1). The site covers a 60- by 60-kilometer (37- by 37-mile) area; the following geographic coordinates indicate the approximate location of its four corners:

41°03.5' N., 104°46.5' W.
40°58.5' N., 104°05.0' W.
40°28.5' N., 104°12.5' W.
40°32.0' N., 104°53.0' W.

2.1.2 ECONOMY

The economy of the study area is largely based on cattle grazing and on farming corn, wheat, sugar beets, alfalfa, and sorghum.

2.1.3 CLIMATE

The climate of the area is continental, characterized by low relative humidity, low rainfall, moderately high wind movement, and wide daily variation in temperature. The annual rainfall

varies from 36 to 41 centimeters (14 to 16 inches), and the snowfall ranges from 91 to 102 centimeters (36 to 40 inches) per year. The daytime summer temperatures reach a high of 40° C (104° F), with the normal high being about 28.3° C (83° F). Winter temperatures are as low as -34.4° C (-30° F), with a normal low of -23° C (-10° F). The first frost occurs about September 20, and the last frost takes place about May 25 (ref. 4).

2.1.4 TOPOGRAPHY AND GEOLOGY

The Site VII area is relatively flat. The surface elevation reaches 1843 meters (6045 feet) at the northwestern corner and decreases to about 1397 meters (4581 feet) near the southeastern edge of the site. Considerable erosion has taken place in the northwestern portion, exposing white bluffs which are probably of the White River Formation (refs. 5 and 6). This formation was created by water-laid volcanic ash.[1]

Cenozoic formations covering the northern quarter of the site are made up of sediments that were washed eastward onto the plains from the Rocky Mountains. Most of the Mesozoic formations which underlie the Cenozoic originated as marine sediments deposited in a broad, shallow geosyncline of Upper Cretaceous age. These Cretaceous deposits are exposed in the southern three-quarters of the site.

The Cenozoic and Mesozoic formations extend westward to the foot of the Rocky Mountains where they turn upward along the base of the uplift. This occurred in Late Cretaceous and Early Tertiary time (refs. 5 and 6).

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[1]Personal communication by Dr. D. L. Amsbury of the National Aeronautics and Space Administration (NASA), Lyndon B. Johnson Space Center (JSC), Houston, Texas.

2.1.5 SOIL

Surficial deposits in the area include both lacustrine and eolian deposits of Pleistocene age. Clayey residual soils are evident where these deposits are deeply weathered.

The soils which have developed in Weld County are known as mollisols. These grassland soils have an argillaceous horizon and are dark brown to tan, friable, rich in organic material, and very alkaline. During the summer months, they are dry for long periods of time (ref. 6).

2.1.6 VEGETATION

In the southern portion of Weld County, approximately 50 percent of the cropland is irrigated (ref. 7); the primary crops are corn, sugar beets, sorghum, wheat, and alfalfa. Native range and wheat are produced by dryland agriculture in the northern and eastern portions of the study site. All of these grasslands are fenced and used for grazing cattle.

The three important grassland species are blue grama grass (*Bouteloua gracilis*), buffalo grass (*Buchloe daotyloides*), and salt grass (*Distichlis stricta*). Blue grama grass dominates the grassland community, comprising some 80 to 90 percent. In depressions and shallow drainage areas, buffalo grass forms nearly pure mats up to 5 meters (15 feet) in diameter. The only other grass species of significance is salt grass, which forms extensive meadows wherever brackish and wet saline conditions prevail near seepage areas and in large depressions where water does not drain away.

The site has no true shrub community; however, a few small areas are dominated by sage (*Artemisia*), which is a subshrub that reaches a height of 38 centimeters (15 inches). Four-wing salt

bush (*Atriplex canescens*) is found scattered throughout the site, but field surveys and aerial photointerpretation indicate that it does not comprise a significant proportion. Rabbit brush (*Chrysothamnus naseosus*) is occasionally found in fields or by roadsides.

No softwood trees are evident anywhere in the site. The only hardwoods include occasional American elm (*Ulmus americana*) and Chinese elm (*Ulmus parvifolia*), willow (*Salix*), cottonwood (*Populus*), and hackberry (*Celtis*), all planted near homesteads. Occasionally, a solitary cottonwood is found along the major river tributaries in the area.

The site has sustained a great deal of disturbance. Extensive white grub infestations have killed large patches of blue grama grass. It has been replaced by a variety of annual weeds, including pigweed (*Chenopodium leptophyllum*), various species of sage (*Artemisia*), Russian thistle (*Salisola kali*), kochia (*Kochia scoparioides*), and several species of herbaceous salt bush (*Atriplex*). In recently abandoned fields, a similar but more aggressive weed community has developed, including the above-mentioned types plus cheat grass (*Bromus tectorum*) and sunflower (*Helianthus annuus*). The fields in overgrazed areas are frequently dominated by prickly pear (*Opuntia polyacantha*) and some buckwheat (*Eriogonum*). Typically, these fields have only a 20- to 30-percent vegetation cover and would have even lower densities of vegetation were it not for the prickly pear. The only other notable vegetation is yucca (*Yucca glanca*), which colonizes barren, rocky outcroppings.

A few fields have been allowed to recover from overgrazing. Many of these have also been seeded to yield a mix of introduced and native grasses, especially in sandy areas; these grasses include cheat (*Bromus inermis*), hairy grama (*Bouteloua hirsuta*),

western wheat (*Agropyron smithii*), crested wheat (*Agropyron cristatum*), needle (various *Stipa*), redtop (*Agrostis alba*), red three-awn (*Aristida longiseta*), and sand drop seed (*Sporobolus cryptandrus*).

2.2 SITE FAMILIARIZATION

Before the site was visited, a mosaic was made from the color-infrared photographs described in section 2.4.3. The mosaic served as an up-to-date 1:120 000-scale map. It showed many physiographic features and was used as an aid in selecting training fields and field checkpoints and in determining field trip routes. It also proved to be very helpful during the field investigation.

Five TES personnel made the 1-week trip to the site in August 1977. The group included three employees of Lockheed Electronics Company, Inc., a scientist from JSC, and a scientist from the Forest Service of the U.S. Department of Agriculture (USDA). On their arrival in Colorado they met with local personnel of the Forest Service and the USDA Agricultural Research Service to discuss the planned field procedures and methods.

The TES personnel then divided into two teams for the visit to the site; each team was accompanied by an employee of the Agricultural Research Service who had worked extensively at the Pawnee National Grassland. During the trip, these people

a. Familiarized themselves with the general topographic and physiographic characteristics of the site

b. Collected additional pertinent data from Forest Service personnel of the Rocky Mountain Forest and Range Experiment Station

c. Recorded data on field checksheets and obtained individual ground photographs (fig. 2-2) from 78 predetermined field locations

The training fields that were visited were allocated as follows:

Classification	Number of checkpoints
Grassland	60
Hardwood	1
Water	2
Agricultural cropland	15
Total	78

Five additional points were originally chosen but were deleted because of inaccessibility.

The trip provided four major results:

a. The site scientist, the site analyst, and a specialized analyst became familiar with the site. The trip provided them with firsthand knowledge of the study area and also provided a better understanding of the tones and patterns recorded on the color-infrared photographs.

b. Greater accuracy in the selection of training fields was acquired.

c. Photographs were interpreted more accurately.

d. Valuable contacts were made with Forest Service and Agricultural Research Service personnel.

2.3 HIERARCHY OF FEATURES

The basic concept was to interpret aerial photographs of the site to determine all the recognizable classes and to use this

classification hierarchy for comparison with the classes identified from the Landsat imagery. The aerial photographs (see section 2.4.3) were analyzed by several photointerpreters in order to achieve a general concensus of recognizable features.

The following Level III features are a result of both this aerial photograph analysis and field observations.

Level I	Level II	Level III
Forest[2]	Softwood	Not applicable
	Hardwood	Cottonwood
Nonforest	Grassland	Blue grama grass Salt grass Sage Cactus Weeds (overgrazed)
	Cultivated[3]	Not applicable
	Water	Census Noncensus
	Other	Fallow Abandoned

The forest portion of the hierarchy was modified during the processing phase because cottonwood trees were too sparse to form a training field.

[2]There was no forest in this site; therefore, the forest portion of the usual hierarchy was not applicable. Cottonwood trees were observed as ornamental and shade trees around farmhouses only.

[3]For the purposes of this study, the "cultivated" class was treated as a Level II class. Normally, it would be a Level III class.

2.4 DATA UTILIZATION

The data sets used in Phase I, task I.5, and Phase II, task II.1 (ref. 1) are listed, described, and evaluated.

2.4.1 CARTOGRAPHIC DATA

Four different types of maps were used:

a. Army Map Service[4] 1:250 000-scale maps (These maps were used as a reference base for indexing the aerial photographs.)

b. U.S. Geological Survey (USGS) quadrangle sheets at an approximate scale of 1:62 500 (These were used for locating training fields on the ground and familiarizing TES scientists with the site.)

c. Weld County, Colorado, road map at an approximate scale of 1:250 000 (Because all county road numbers are labeled and listed on this map, it was used for navigation while in the field.)

d. Thematic maps portraying specific characteristics such as geology, soil, and vegetation

2.4.2 ANCILLARY DATA

Preparatory research on the site was done on a very general level in the disciplines of soil, climatology, geology, vegetation, and hydrology. The ancillary data used in this study provided limited information.

2.4.3 AERIAL PHOTOGRAPHIC DATA

The primary uses of the aerial photography were:

a. To make land cover classification overlays of the site

b. To familiarize the personnel with the site

[4]Now called the Defense Mapping Agency.

c. To select the checkpoints to be visited in the field

d. To select the training fields to be used in the ADP

e. To assist in the selection and location of training fields on the ground

f. To make a mosaic of the area for aiding navigation and photointerpretation

g. To aid in the evaluation of Landsat data for various dates

Seven aerial photographic frames from Mission 211, flown by NASA in September 1972, covered the study area: frames 180, 101, 99, 158, 160, 85, and 83. The film was color infrared (Kodak 2443) and was processed on 23- by 23-centimeter (9- by 9-inch) transparencies and prints at an approximate scale of 1:120 000. The photographic quality was good and exhibited good contrast between grassland and cultivated areas (figs. 2-2 and 2-3). The contrasting spectral response in grassland areas was generally attributable to differing amounts of exposed soil, which resulted primarily from grazing activities and insufficient precipitation. At two training field locations, grassland had been converted to productive cropland between September 1972 and August 1977. With these exceptions, an acceptable agreement (ref. 2) was found between the photointerpretation classes and the actual classes at points visited in the field.

2.4.4 LANDSAT IMAGERY

In accordance with the TES procedures (ref. 2), several areas that were classified manually from the aerial photography were located on the Landsat scene image, enlarged, and also manually interpreted. The Landsat scene interpretations were compared with the aerial photointerpretations to calculate a percent of correct classification (PCC), and the two Landsat scenes with the highest PCC were chosen. The task was simplified in this

case because it was readily apparent that four of the six Landsat frames were so inferior in quality that their PCC's would be below the PCC's of the June and November scenes. Therefore, the PCC's of only the June and November scenes were calculated. The June scene had the highest PCC for Level II features (78.3). A list of the Landsat scenes reviewed and the dates of acquisition follows:

Frame number	Acquisition date	Photograph quality	Status
1798-17142	May 17, 1974	80 percent clouds and haze	Rejected
1586-17091	March 1, 1974	Poor contrast	Rejected
1711-17001	July 4, 1974	Poor contrast	Rejected
1693-17005	June 16, 1974	Good contrast	Accepted
1838-17015	November 8, 1974	Good contrast	Accepted
1514-17110	December 19, 1973	Washed out	Rejected

This Landsat frame evaluation process was used to determine that the June 16, 1974, and November 8, 1974, tapes, which are of excellent quality, would be ordered for the ADP phases. These tapes were also combined to form a temporal data set.

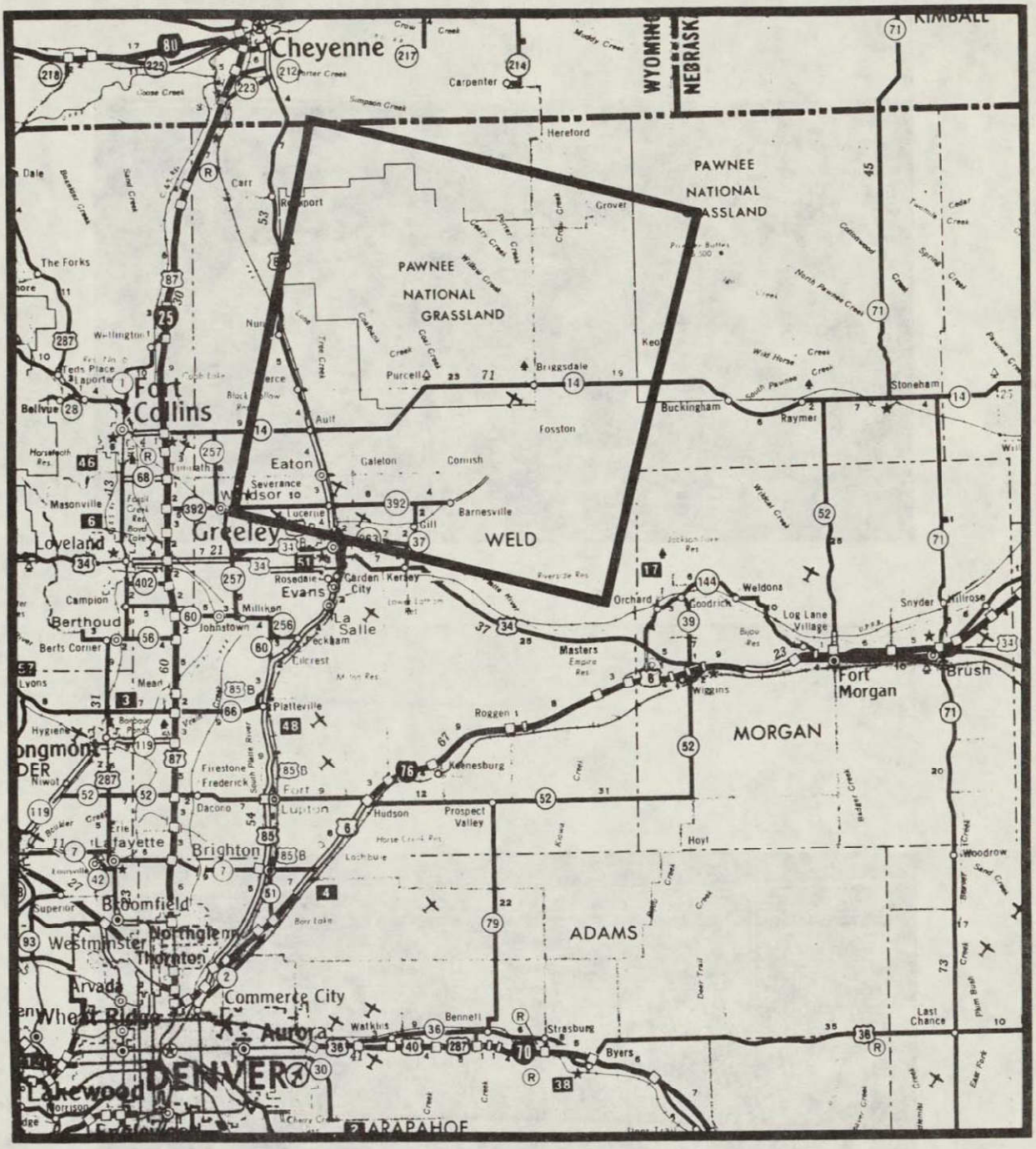


Figure 2-1.– Map showing location of study site.

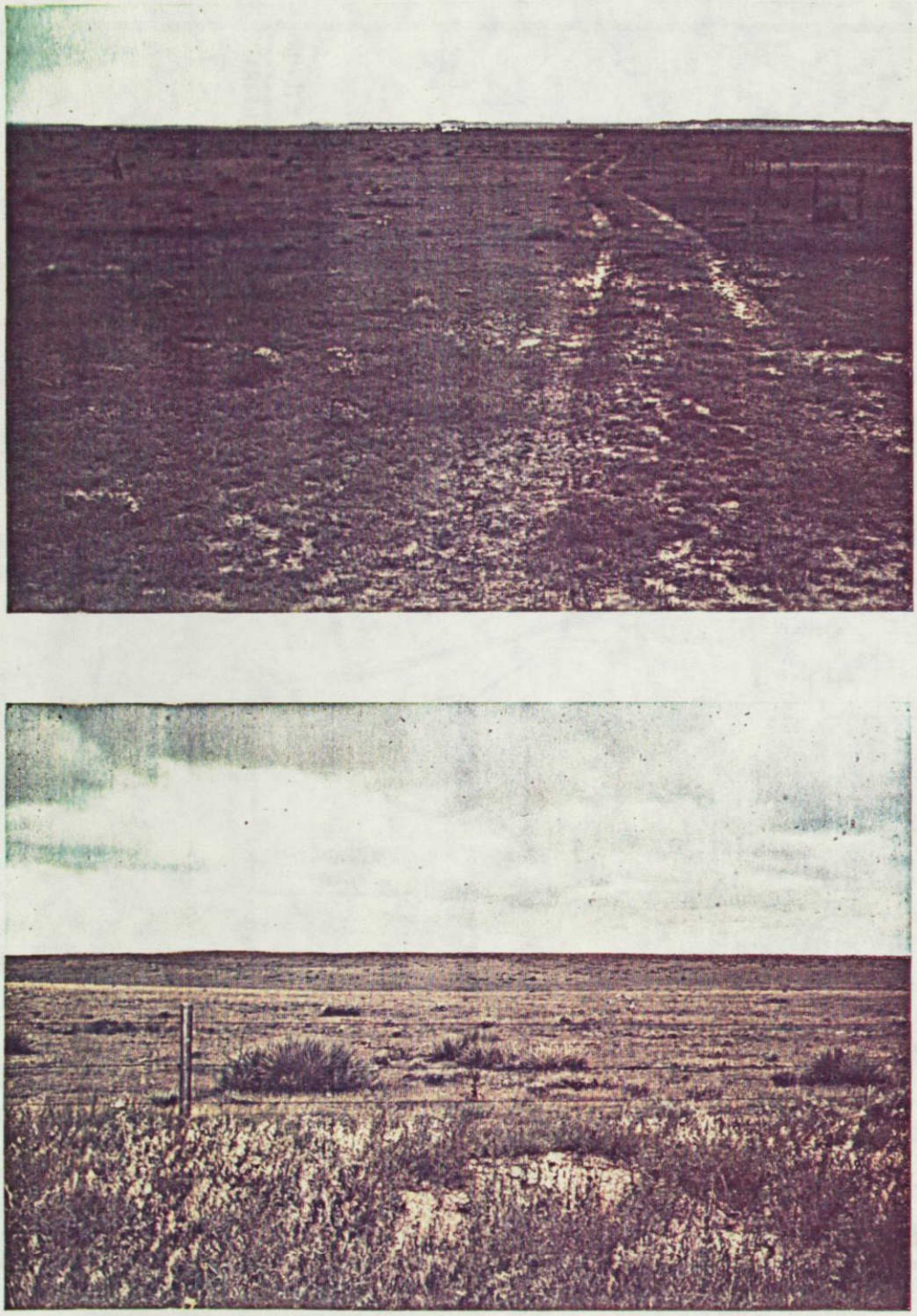


Figure 2-2.– Two scenes that are typical of the study site.

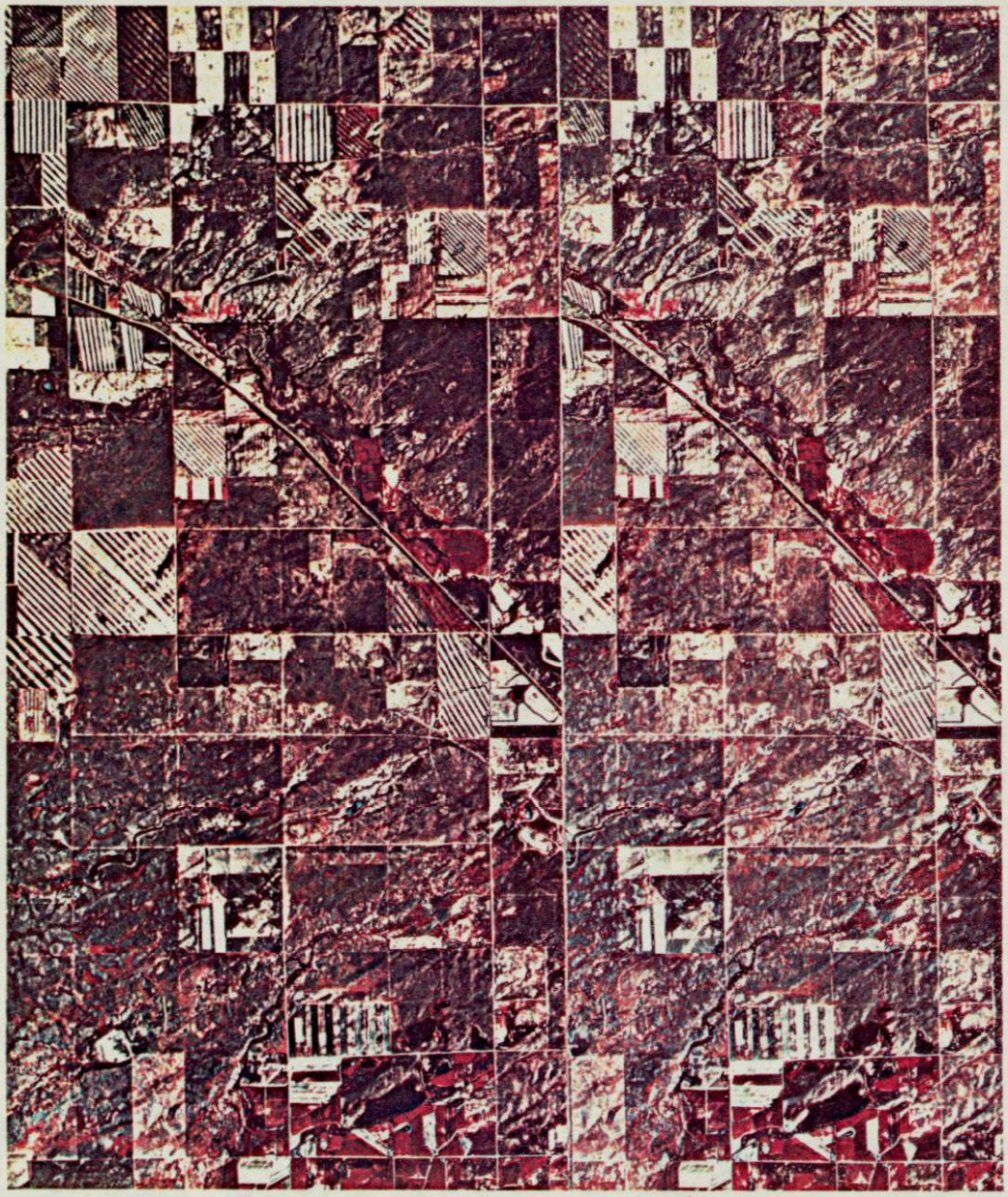


Figure 2-3.— Stereograph of a portion of the study site.

3. PREPROCESSING

The preprocessing consisted of the following activities:

a. Temporal image-to-image registration of Landsat data for two separate dates using the Earth Resources Interactive Processing System (ERIPS)

b. Image-to-ground registration using the Interactive Multispectral Image Analysis System, Model 100 (Image 100)

c. Delineation of training areas on Landsat imagery (ref. 2)

3.1 PROCEDURES

The procedures described in section 4 of reference 2 were followed for the preprocessing task (task II.2) with the following exception: Because the administrative boundary (Pawnee National Grassland) is a series of straight lines, it did not necessitate computer manipulation as in the case of a meandering boundary. Therefore, a manual method was used to superimpose the boundary on the final output map.

3.2 IMAGE-TO-IMAGE REGISTRATION

Registration of the two Landsat data sets was accomplished using the ERIPS image-to-image point-selection method. A root-mean-square error of 1.7 picture elements (pixels) and a residual error of 4 pixels were attained for 25 points. This is in excess of the allowable root-mean-square error of 1.5 (ref. 2).

3.3 IMAGE-TO-GROUND REGISTRATION

Image-to-ground registration was accomplished on the Image 100 using 15 points for the June image and 13 points for the November image. The June image had a root-mean-square line error of 0.7493 pixel and a root-mean-square sample error of 0.9126 pixel.

The November image had a root-mean-square line error of 0.9225 pixel and a root-mean-square sample error of 1.042 pixels. A run of the registration-rotation program produced a rotation factor of 0.0822 for the June image.

3.4 ADMINISTRATIVE BOUNDARY OVERLAY

The administrative boundary will be superimposed manually by a draftsperson-cartographer on the final output map before it is sent for mass printing. The boundary in this case is the border of the Pawnee National Grassland. The 360 000-square-hectometer (890 000-acre) study site covers the western unit of the Pawnee National Grassland, the western edge of the east unit of the Pawnee National Grassland, and portions of private lands that surround the Pawnee National Grassland segments (fig. 2-1).

3.5 FILMING OF STUDY SITE QUADRANTS

Transparencies produced by the Passive Microwave Imaging System (PMIS) Data Analysis Station (DAS) were used primarily in selecting and plotting the training fields to be input on the Image 100 screen. All data sets used the same training fields, and the sets were registered to each other; therefore, only one set of PMIS/DAS transparencies from one Landsat data set was necessary. The four quadrants were filmed from the June data set because it had the best quality (ref. 2). The training fields for Level II processing were selected, in accordance with the TES procedures, by correlating the field observations, aerial photographs, and PMIS/DAS transparencies of the Landsat scene. The sizes of the fields averaged 4.05 square hectometers (10 acres).

4. PROCESSING

4.1 INTRODUCTION

The TES processing procedures (ref. 2) required two studies: a type separability study and a simulated inventory study.

The purpose of the type separability study was to determine the level and accuracy at which the applied TES ADP classification procedures could resolve areal coverage of various vegetative types into the Level II components (softwood, hardwood, grassland, and water). In this study, training signatures were to be derived from such maximum information data as uniformly distributed training fields, ground examination, aerial photographs, and Landsat PMIS/DAS transparencies. A Level III classification of grassland was to be attempted only if its Level II accuracy was at least 80 percent. For other Level II classes that were present, a Level III classification was to be performed only when the accuracy was at least 90 percent.

The purpose of the simulated inventory was to obtain a similar classification of Level II vegetative and water types over the entire site using signatures extracted from training fields that were selected in an area one-tenth the size of the study site.

The output of the two studies shows the proportions of the Level II features within the study site (table 4-1).

4.2 PROCEDURES

The procedures given in section 5 of reference 2 were followed for the processing task (task II.3) with the following exceptions:

a. The Image 100 was used to digitize the coordinates of the selected training fields.

b. Because there was no forest within this site, a significant area of land was occupied by the "cultivated" and weeds classes. Therefore, the classification hierarchy was designed to use "cultivated" and weeds as Level II features, even though these are normally Level III classes.

4.3 LEVEL II TYPE SEPARABILITY STUDY

The type separability study is divided into three activities:

a. Spectral signature composition

b. Site classification

c. Training field classification accuracy assessment

4.3.1 SPECTRAL SIGNATURE COMPOSITION

The dynamic range of the spectral signature composition was initially set at 128, 128, 128, and 64 for bands 4 through 7, respectively. However, the variance on these training fields proved to be too large, so the range was ultimately reduced to 32, 32, 32, and 16. At this point the variance was acceptable; that is, less than 4.5 (ref. 2).

The June and November signatures for grassland consisted of blue grama grass, salt grass, weeds, shrubs, and cactus. Additional signatures were for water and cultivated lands. In other TES studies, "cultivated" and weeds were not used as separate classes under Level II. However, visual inspection of the aerial photographs of Weld County indicated that about 30 percent of the whole site was being cultivated and that rapidly growing crops were distinct. Also, no hardwood or softwood tree classes were large enough to serve as training fields in the site. Therefore, the "cultivated" and weeds classes were substituted.

The "cultivated" class consisted primarily of corn, wheat; milo, and alfalfa. It was easily separated and had an overall accuracy of 99.4 percent (see table 4-2). The weeds class consisted of the vegetation found in abandoned and fallow fields. This class was not separated until the simulated inventory began; it had a training field accuracy of only 75 percent.

4.3.2 SITE CLASSIFICATION

A maximum likelihood classification program was used to resolve overlapping signatures. The *a priori* input was 5 for "cultivated," 2 for weeds, 59 for grassland, and 1 for water. These numbers were relative weighting factors for the classes and were an estimation based on aerial photointerpretation. They were not necessarily based on a total value of 100. Because the heaviest weight was assigned to grassland, all disputed pixels were assigned to this class. Table 4-3 shows the classification results in area units.

4.3.3 TRAINING FIELD ACCURACIES

The Level II training field accuracies were obtained by dividing the number of correctly classified pixels for each class by the total number of pixels for that class. This procedure was followed for each class. The overall accuracy was obtained by summing all correctly classified pixels and dividing this total by the total number of pixels. The June image, with an overall accuracy of 99.4 percent, was selected for processing (see table 4-2).

4.4 LEVEL III TYPE SEPARABILITY STUDY

The procedures followed for the type separability study for Level III were essentially the same as for the Level II study. The usual categories for classification in the other TES studies were not present because there were no forests in the site.

The Level III classification was performed, and the results indicated that the various grasses were not separable. This was attributed mostly to confusion of spectral signatures between the several types of grasses and weeds.

4.5 SIMULATED INVENTORY STUDY

The procedures for the simulated inventory were in accordance with the TES procedures (ref. 2) except for the hierarchy of features. The 10-percent area was selected in quadrant 2 and was an L-shaped tract along the northern and western lines of the quadrant (fig. 4-1). This area was not visited by any field-investigating team members during the preliminary analysis phase of the study. The training fields were selected for this inventory based on an analysis of aerial photographs, and their boundaries were then overlaid on the PMIS/DAS transparency. From the transparency, the training field boundaries were placed on the Image 100 screen display. The training field accuracies and proportion estimates of the classes are shown in tables 4-1 and 4-2, respectively.

TABLE 4-1.— PROPORTION ESTIMATES FOR THE LEVEL II STUDY

Feature	Separability study			June simulated inventory, proportion
	June, proportion	November, proportion	Temporal, proportion	
Cultivated[a]	0.002	0.034	0.003	0.034
Grassland	.643	.830	.653	.504
Water	.004	.000	.000	.000
Other	.303	.135	.344	.460

TABLE 4-2.— TRAINING FIELD CLASSIFICATION ACCURACIES FOR THE LEVEL II STUDY

Feature	Separability study			June simulated inventory, percent
	June, percent	November, percent	Temporal, percent	
Cultivated[a]	98.5	77.0	97.0	96.0
Grassland	99.8	97.0	99.0	100.0
Water	100.0	96.0	99.0	100.0
Overall accuracy	99.4	90.0	99.0	98.0

[a]For the purposes of this study, the "cultivated" class was treated as a Level II class. Normally, it would be a Level III class.

TABLE 4-3.— CLASSIFICATION RESULTS IN AREA UNITS

Class	Separability study			June simulated inventory
	June	November	Temporal	
Grassland:				
Pixels	648 769	770 807	612 689	472 314
Square hectometers	211 351	311 935	199 597	153 867
Acres	522 259	619 729	493 214	380 213
Water:				
Pixels	354	484	264	120
Square hectometers	115	158	86	39
Acres	285	390	213	97
Cultivated:[a]				
Pixels	1 395	31 811	2 844	31 914
Square hectometers	455	10 363	926	10 397
Acres	1 123	25 608	2 289	25 691
Other:				
Pixels	283 871	125 553	322 382	430 742
Square hectometers	92 477	40 902	105 023	140 324
Acres	228 516	101 070	259 518	346 747
Weeds[a]				
Pixels				1 660
Square hectometers				540
Acres				1 336
Total:				
Pixels	934 389	928 655	938 179	936 750
Square hectometers	304 398	363 358	305 632	305 167
Acres	752 183	746 737	755 234	754 084

[a]For the purposes of this study, the weeds and "cultivated" classes were treated as Level II classes. Normally, these would be Level III classes.

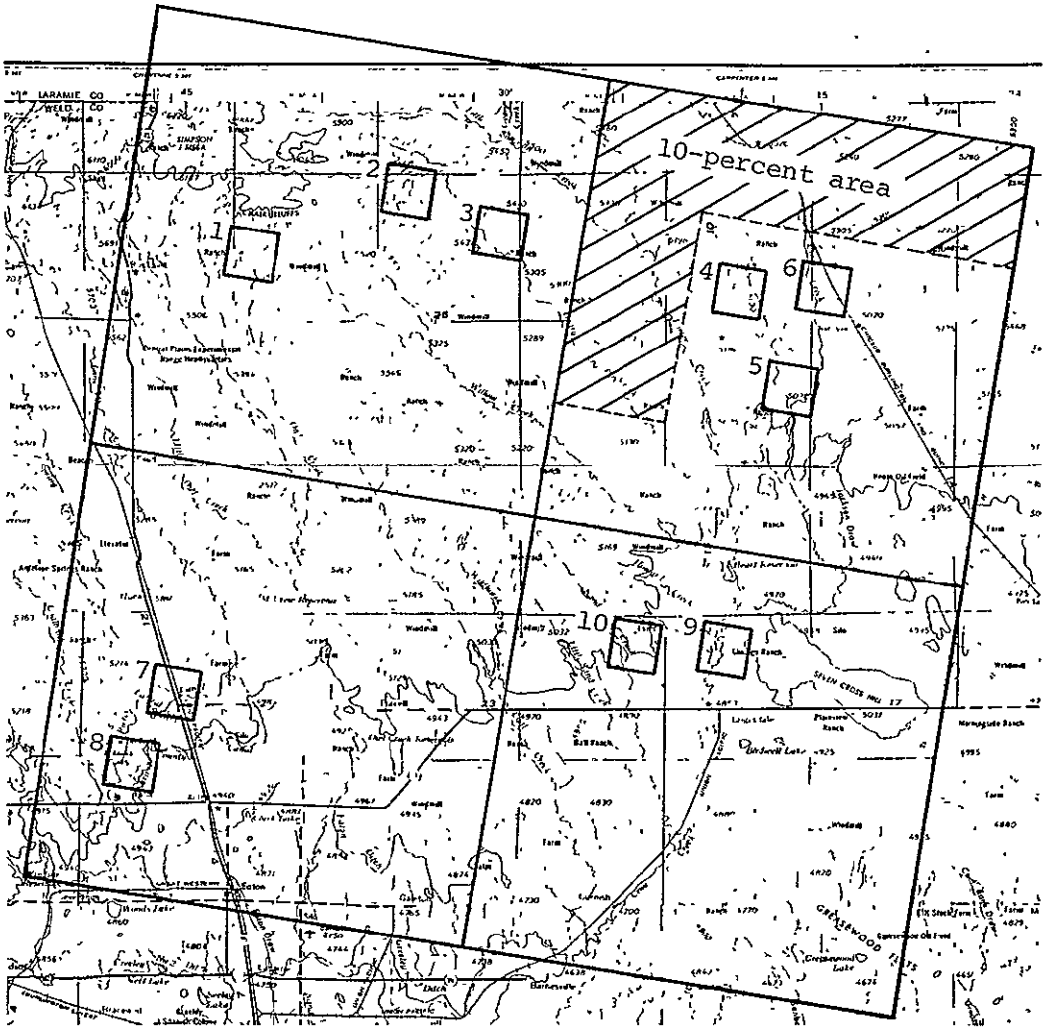


Figure 4-1.— Map of study site showing 10-percent area. [The numbered blocks indicate the location of the primary sampling units (PSU's).]

5. POSTPROCESSING

The postprocessing activity consisted of refining and reformatting the classifications that resulted from the processing phase in order to produce final output products in the form of color films, transparencies, photographic prints, offset prints, and alphanumeric printouts of the classifications. These were used in the evaluation phase.

5.1 PROCEDURES

The procedures given in section 6.3 of reference 2 were followed for the postprocessing task (task II.4).

5.2 FALSE-COLOR FILMING

Two sets of color positive transparencies were made on the PMIS/DAS. Each set consisted of four frames, and each frame represented a fourth of the study site. The data from the separability study and the simulated inventory classification tapes were used for this step in the process.

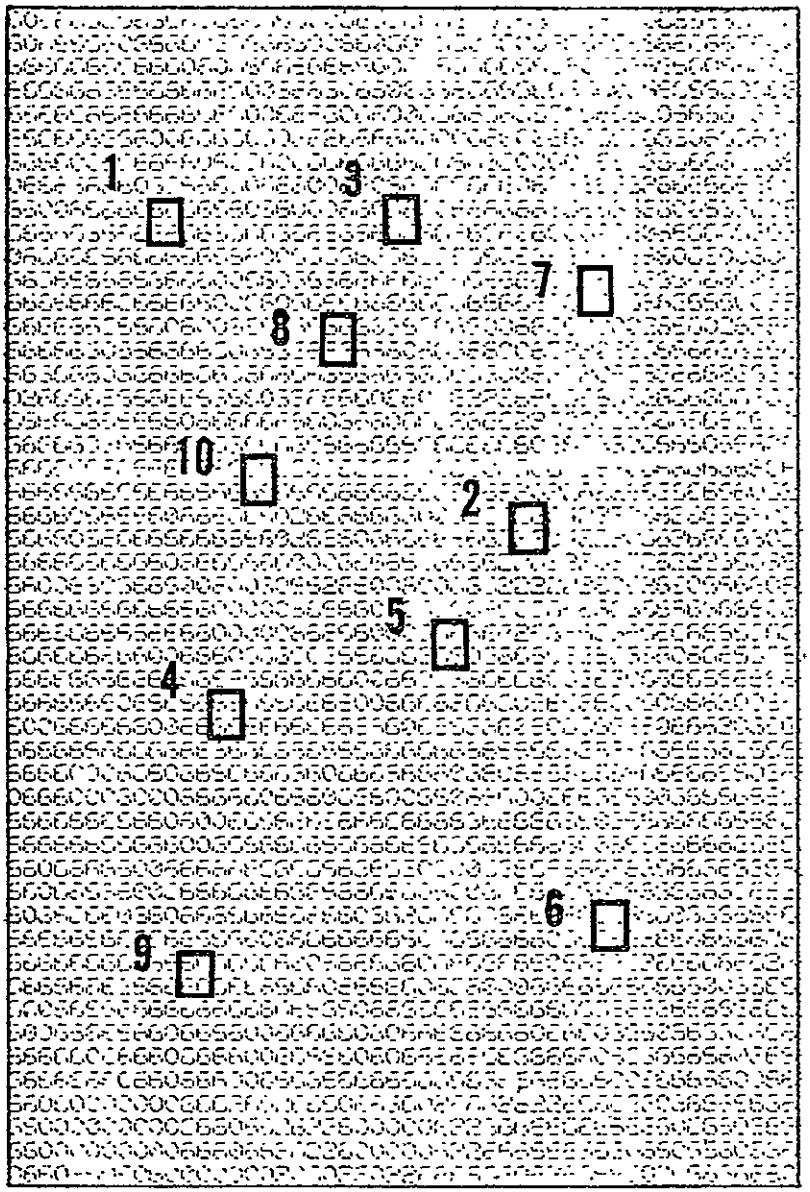
5.3 SAMPLE UNIT LOCATIONS

The PSU's (see fig. 4-1) and secondary sampling units (SSU's) were located for the purpose of evaluating and determining classification accuracy. The 10 randomly selected PSU's, each 50 by 50 pixels in size, were located on an alphanumeric printout, the PMIS/DAS transparencies, and the aerial photographs. The 10 SSU's, each 2 by 2 pixels in size, were then randomly placed within each PSU (fig. 5-1).

5.4 FINAL OUTPUT PRODUCT

The simulated inventory output computer tape that contained the Image 100 classifications of all four segments was taken to a

private subcontractor who will prepare the final product: a color-coded classification map of grassland, "cultivated," water, and other. The map will be produced by a hardware and software system that uses a laser light source and precision optical and mechanical components to produce hardcopy displays from digital tapes.



Legend:

6 — Grassland
0 — Other
□ — SSU

Figure 5-1.— Alphanumeric printout of a 50- by 50-pixel PSU showing location of SSU's. (Any symbol can be designated to represent a particular class.)

6. EVALUATION

The evaluation task was performed to determine the accuracy of the classification map. A statistical sampling technique of the inventory classification and analyses of the aerial photographs were used to estimate the overall PCC and its confidence interval, the class proportions, and the average error proportions. Ten 50- by 50-pixel PSU's, each containing ten 2- by 2-pixel SSU's, were randomly selected from the classification map. These were compared with the SSU's on the interpreted aerial photographs, which were assumed to represent the actual ground features in this study. A regression estimate of the relationship between the photograph sample estimate and the inventory sample estimate was also calculated. It was applied to the inventory proportions for the purpose of adjusting these proportions to account for inventory classification bias.

6.1 PROCEDURES

The procedures given in section 7.3 of reference 2 were followed for the evaluation task (task II.5).

6.2 ACCURACY

Table 6-1 contains an estimate of the overall PCC and its confidence interval for the 10 PSU's. The class proportions in the PSU's are summarized in table 6-2. Table 6-3 summarizes the class proportion errors. The regression estimates of the class proportion and associated precision are found in table 6-4.

TABLE 6-1.— ESTIMATED PCC AND CONFIDENCE INTERVAL AT 90-PERCENT CONFIDENCE LEVEL FOR 10 PSU'S

Inventory sample size	PCC	Half-confidence interval, $\Delta_{.9}$	PCC $\pm \Delta_{.9}$
10 PSU's	73%	4.7%	68.3% to 77.7%

TABLE 6-2.— SUMMARY OF CLASS PROPORTIONS IN PSU'S

PSU number	Cultivated		Weeds		Grassland		Water		Other	
	p_i	$\hat{p}_i$	p_i	$\hat{p}_i$	p_i	$\hat{p}_i$	p_i	$\hat{p}_i$	p_i	$\hat{p}_i$
1	0.000	0.000	0.000	0.000	1.000	0.750	0.000	0.000	0.000	0.250
2	0.000	0.000	0.000	0.000	0.600	0.750	0.000	0.000	0.400	0.250
3	0.000	0.000	0.000	0.000	0.480	0.525	0.000	0.000	0.520	0.475
4	0.210	0.025	0.000	0.000	0.150	0.200	0.000	0.000	0.640	0.775
5	0.000	0.025	0.000	0.000	0.470	0.675	0.000	0.000	0.530	0.300
6	0.000	0.000	0.000	0.000	0.300	0.525	0.000	0.000	0.700	0.475
7	0.000	0.050	0.000	0.000	0.200	0.225	0.000	0.000	0.800	0.725
8	0.300	0.125	0.000	0.000	0.000	0.025	0.000	0.000	0.700	0.850
9	0.000	0.000	0.180	0.000	0.570	0.875	0.000	0.000	0.250	0.125
10	0.000	0.000	0.090	0.000	0.630	0.875	0.000	0.000	0.280	0.125

Definitions:

p_i = photograph sample for i*th* PSU

$\hat{p}_i$ = ADP sample for i*th* PSU

TABLE 6-3.— SUMMARY OF CLASS PROPORTION ERRORS

Class	Inventory class proportion, $\hat{p}$	Photograph class proportion, p	Average error, B	Standard deviation of error, S_B	Half-confidence interval, $\Delta_{.9}$	Confidence interval, B ± Δ	Percent relative error, RB
Cultivated	0.022	0.050	0.028	0.025	0.047	(-0.019, 0.075)	56
Weeds	0	.027	.027	.019	.035	(-.008, .062)	100
Grassland	.543	.441	-.102	.050	.091	(-.193, -.011)	23.13
Water[a]							
Other	.435	.482	.047	.052	.096	(-.049, .143)	9.75

[a]There were no significant water bodies in this site.

TABLE 6-4.— REGRESSION ESTIMATES OF CLASS PROPORTION AND ASSOCIATED PRECISION

Class	Simulated inventory proportion, p_{inv}	Regression equation, $<> = mp_{inv} + b$	Regression estimate of proportion, $\langle p/p_{inv} \rangle$[a]	Coefficient of determination, r^2	Variance of the estimate, $s^2_{<>}$	Half-confidence interval, $\Delta_{.9}$	Percent relative variation, $100\Delta/<>$
Cultivated	0.034069	2.185153 × 0.034069 + 0.001834 = 0.0762799	0.076280	0.632257	0.000483	0.040283	52.81
Grassland	0.504205	0.819351 × 0.504205 - 0.004498 = 0.4086228	0.408623	0.726602	0.002318	0.088256	21.60
Other	0.459826	0.732494 × 0.459826 + 0.163366 = 0.5001866	0.500186	0.628223	0.002329	0.088461	17.69

[a]The conditional expectation of p, given p_{inv}.

7. DIRECT RESOURCE UTILIZATION

Direct resources for this study included (1) manpower, (2) machine and equipment time, and (3) site data such as Landsat imagery, aerial photographs, and ancillary information.

Throughout the study, records were kept on the man-hours and machine time expended. These are listed in table 7-1. Table 7-2 shows a breakdown of the hourly costs for machine time and manpower, including the costs of transportation, food, and lodging for the five people who visited the site. Incidental costs for such items as six color-composite Landsat frames, Landsat scenes in the form of computer-compatible tapes, and color-infrared aerial photographs from Mission 211 (flown in September 1972) are not itemized. A comparison of the total costs with the total land area shows that the direct costs amounted to 23.7 cents per square hectometer (9.6 cents per acre).

Work performed at similar future sites and in a production mode would be considerably less expensive because the analysts would be familiar with site and system characteristics. The cost analysis would still fluctuate because of increased machine and labor costs resulting from inflation, but this could be overcome on the projected cost estimates by applying a percentage factor to the basic costs.

TABLE 7-1.– RESOURCES UTILIZED FOR SITE PROCESSING

Task	Man-hours	Actual machine hours					
		Image 100 interactive analysis	ERIPS registration	Univac 1110 product merge and cleanup	PMIS/DAS image composition	Dell Foster digitizing	Bausch & Lomb zoom transfer scope
Preliminary image analysis	160						
Site analysis (including trip)	250						
Preprocessing	180	47	9		6	6	
Processing	350	130			3		
Postprocessing	119	10		3.5	8.5	15	
Evaluation	226					17	24
Reporting	443						
Total	1728	187	9	3.5	17.5	38	24

TABLE 7-2.— DIRECT COSTS FOR MACHINE TIME AND MAN-HOURS

Item	Cost per hour	Hours	Total cost
Machine:			
Image 100	$300.00	187.0	$56 100.00
ERIPS	300.00	9.0	2 700.00
Univac 1110	300.00	3.5	1 050.00
PMIS/DAS	100.00	17.5	1 750.00
Dell Foster	15.00	38.0	570.00
Total machine cost			$62 170.00
Man-hours	$ 12.43	1728.0	$21 479.04
Trip expenses			$ 1 907.33
Total direct cost[a]			$85 556.37

[a]Total area in square hectometers = 360 000
Total area in acres = 890 000
Cost per square hectometer = $0.237
Cost per acre = $0.096

8. ANALYSIS OF RESULTS

The results of the proportion estimates obtained during this site study (figs. 8-1 and 8-2) are analyzed and evaluated in this section. These estimates are described according to their line numbers in the figures, as follows:

Line number	Description	Use
1	Separability proportion estimates of the given class for the three dates and the ADP simulated inventory estimate	Visual comparison of the three separability estimates and the simulated inventory estimate
2	ADP simulated inventory sample estimate and its 90-percent confidence interval	Comparison of the results of the simulated inventory sample estimate with both the simulated inventory estimate and the separability estimate of the same date; comparison of the position of the line 1 elements with the line 2 confidence interval
3	Aerial photograph sample estimate and its 90-percent confidence interval	Comparison of the results of the aerial photograph sampled estimate with the elements of lines 1 and 2; visual representation of its confidence interval; representation of the regression transformation between the line 2 and line 3 sample estimates by an arrow labeled R

Line number	Description	Use
4	ADP simulated inventory estimate	Application of the regression transformation (R) to the inventory proportion
5	Regression estimate,[5] its 90-percent confidence interval, and the corresponding separability estimate	The *a priori* expected regression transformation, based on the assumed maximum information status of the separability estimate, represented by a dashed-line arrow between the simulated inventory estimate (line 4) and the separability estimate for the same date (line 5)

8.1 ESTIMATES OF "CULTIVATED" AREA

The proportion estimates of the "cultivated" area (fig. 8-1) for the June simulated inventory and November separability classifications are both 0.034 and appear to agree with the proportion evident from a visual inspection of aerial photography. The June and temporal separability estimates are 0.001 and 0.003, respectively; however, these estimates are probably too low to be realistic. The training field accuracies indicate that the June data set is the best overall, in spite of the low proportion estimate for "cultivated."

[5]The application of the regression transformation (R) to the simulated inventory estimate gives the regression estimate, which is the conditional estimate of the mean of all aerial photograph sample estimates, given the simulated inventory proportion.

8.2 ESTIMATES OF GRASSLAND AREA

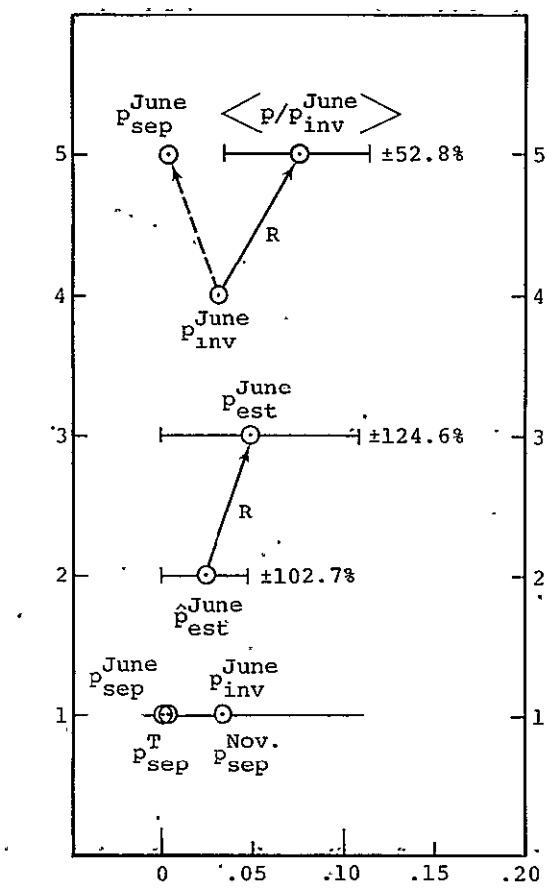
The temporal and June separability proportions are similar for the grassland classification, while the June simulated inventory and November separability classifications are at opposite ends of the scale (see fig. 8-2). The temporal data set indicates that the proportion of grassland in the site is 0.65, while the June separability data set shows a proportion of 0.69. A visual inspection of an aircraft imagery mosaic of the whole site indicates that both of these estimates are reasonable. However, the photograph sample estimate agrees more closely with the June simulated inventory proportion estimate, which is only 0.5.

These differences could have been caused by cultivation practices and growth rates that varied with the year, season, and/or month. The aerial photography was taken in September 1972, the June and November Landsat data were acquired in 1974, and the field investigation was made in 1977. Therefore, it is possible that some fields could have changed character twice or more from 1972 to 1977. Conceivably, a field that was blue grama grass in 1972 could now be fallow after cultivation or could now be sage after abandonment. A difference in the field character in the aerial photography, Landsat scene, and/or field interpretation could result in a classification error. This, in turn, could affect the ADP interpretation, especially when the evaluation is determined by the random sampling method.

Similar or overlapping signatures for different field characteristics could also cause the discrepancy in the proportion estimates. For instance, some sage, although it is a shrub, has a signature similar to or overlapping the signatures for grasses, abandoned fields, and fallow fields.

8.3 ESTIMATES OF WATER AREA

This site is within the U.S. central Great Plains. The only sources of water in the area are one river, several creeks, intermittent streams and gullies, and one reservoir. As a result, the random sampling method of evaluation failed to pick up any significant water bodies, and no water estimate could be made.



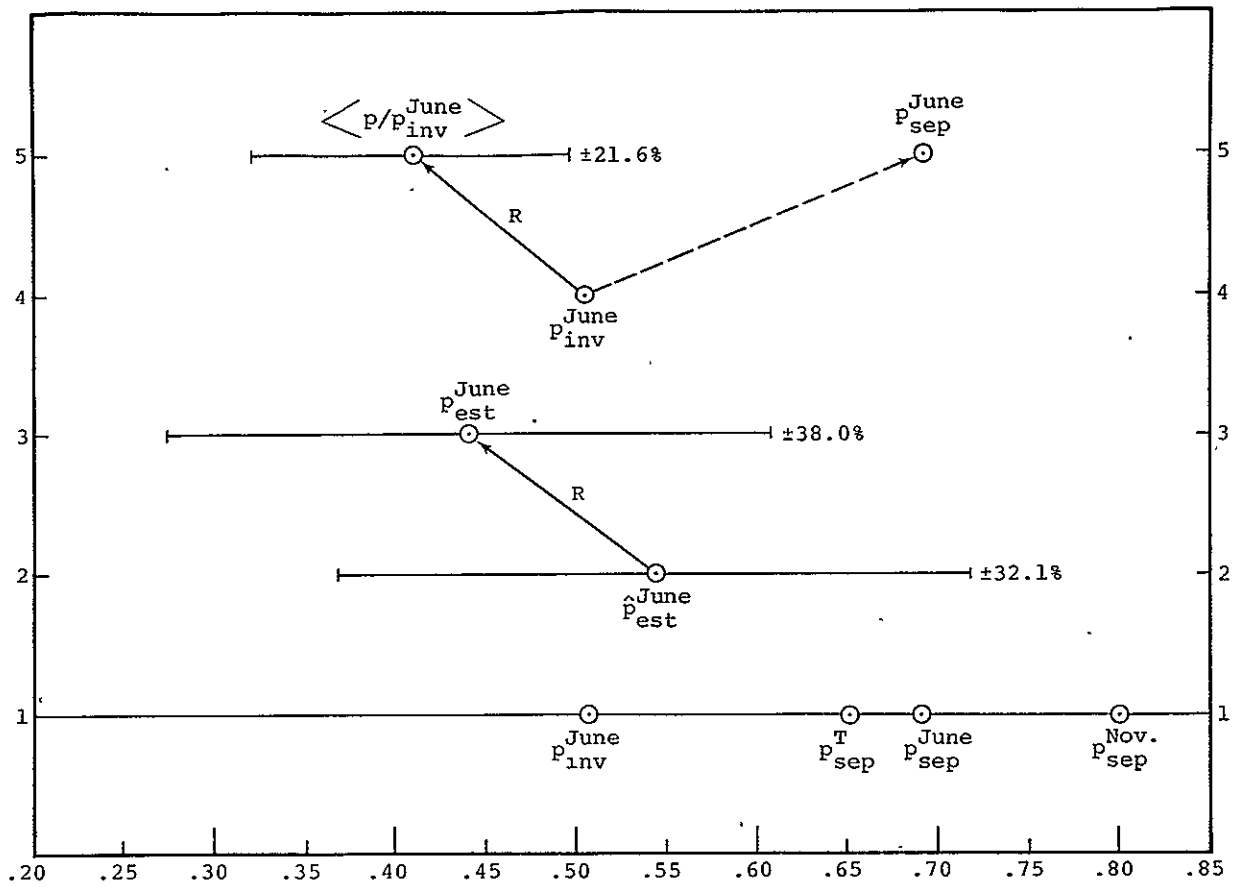
Legend:

p — proportion estimate
$\hat{p}$ — simulated inventory proportion
est — statistical estimate
inv — inventory
sep — separability
R — regression transformation
T — temporal
⟶ — actual transformation
⇢ — expected transformation

Line number:

1 — ADP inventory and separability estimates
2 — simulated inventory estimate from 10 samples
3 — aerial photointerpretation estimate from 10 samples
4 — simulated inventory
5 — regression estimate

Figure 8-1.— Proportion estimates for "cultivated."



Legend:

p — proportion estimate
$\hat{p}$ — simulated inventory proportion
est — statistical estimate
inv — inventory
sep — separability
R — regression transformation
T — temporal
⟶ — actual transformation
⇢ — expected transformation

Line number:

1 — ADP inventory and separability estimates
2 — simulated inventory estimate from 10 samples
3 — aerial photointerpretation estimate from 10 samples
4 — simulated inventory
5 — regression estimate

Figure 8-2.— Proportion estimates for grassland.

9. CONCLUSIONS

9.1 OPTIMAL DATE

Although six Landsat data sets covering the site were available, only the data for June 1974 and November 1974 were of acceptable quality. Consequently, these two data sets, representing the summer growing season and the postharvest fall season, were used for the analysis.

The June 1974 date was selected as optimal because the June training field accuracies were higher than the November accuracies. In the June data, the natural range grasslands were separable from cultivated grasses or crops. In contrast, there was considerable confusion between the postharvest cultivated lands and the natural range grasslands in the November data.

9.2 TYPE MAPPING ACCURACIES

A comparison of the Level II photointerpretation results with the ground data collected on the site familiarization trip to Weld County indicated that the accuracy of the Level II photointerpretation was very high. Therefore, the aerial photography was considered acceptable for use in selecting the training fields.

In the type separability study, the training field accuracies showed good separation into the Level II features (cultivated, grassland, and water) with the exception of the November data for "cultivated," which had an accuracy of only 77 percent. This may have resulted from the use of the same training fields for the "cultivated" class for both dates: in June the crops were growing, while in November the same land was often bare or fallow. The June separability data had the highest overall training field accuracy, 99.4 percent.

An evaluation of the simulated inventory study results indicated that the overall map accuracy was 73 percent ± 4.7 percent at the 90-percent confidence level and that the derived regression transformations were ineffective in adjusting the simulated inventory Level II class proportions. It was also apparent that the signatures developed from training fields selected from 10 percent of the site were not representative of the Level II classes and, therefore, were not extendable.

9.3 SPECIFIC SITE PROBLEMS

Two problems were encountered during the Weld County study. First, it was difficult to locate control points on the Landsat data to be used for registration purposes. Some of the cultivated fields were 0.4 square hectometer (10 acres) and under, and exact registration is very important when the area to be classified is small.

Another more obvious problem became evident during the classification of cultivated fields. During the summer when crops were growing, some areas had an extremely different spectral signature from the same areas in the fall postharvest season. In addition, crop rotation, which is practiced by the local farmers, often caused the spectral response of the same area during the same season to change from one year to the next. At two training field locations, grassland had been converted to productive cropland between September 1972, when the photography was taken, and August 1977, the date of the field trip.

9.4 FEASIBILITY OF USING ADP REMOTE SENSING FOR LARGE AREA GRASSLAND INVENTORIES

The total direct cost of analyzing the Level II features in Weld County was 23.7 cents per square hectometer (9.6 cents per acre). This included the costs of the separability study, other developmental studies, and report writing. For an inventory of grassland

only, with a predetermined set of operating procedures, the cost would be greatly reduced and would be feasible for large area inventories.

Landsat data would be very helpful in monitoring the change of grassland into cultivated fields, determining the drought condition of the grassland, and producing a gross estimate of crop yield.

10. REFERENCES

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