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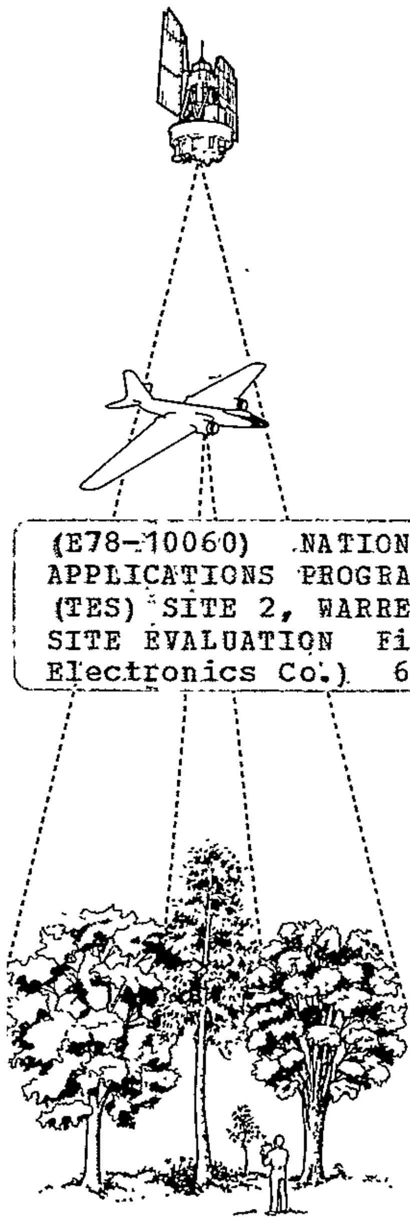

TEN-ECOSYSTEM STUDY (TES) SITE II
WARREN COUNTY, PENNSYLVANIA,
SITE EVALUATION

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FOREST SERVICE
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NOTE: In 1976, the Nationwide Forestry Applications Program was expanded from a Regional project by cooperative agreement between the Forest Service, U. S. Department of Agriculture, and the National Aeronautics and Space Administration (NASA). The Program is designed to sponsor research and development on the application of remote sensing analysis techniques to problems arising from the need to inventory, monitor and manage forests and rangelands, including the assessment of impacts on forest stands from insect and disease damage.

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16 Abstract

This site, representing the Northern Hardwood Ecosystem, was studied to determine the feasibility of using remote sensing technology to inventory forest, rangeland, and inland water areas. A type separability study was performed to determine the level of detail and the corresponding mapping accuracies obtainable by automatic data processing analysis of remotely sensed data. A simulated inventory was conducted to determine how successfully automatic data processing technology can extend limited ground-truth data for large area inventories.

Two data sets (September 1972 and May 1975) were analyzed by means of an interactive computer process utilizing a training field classification approach.

The study determined that hardwood could best be inventoried in May. The acreage estimate was less than 3 percent different from Forest Service estimates.

Classification accuracies indicated that Warren County, Pennsylvania, could be accurately classified using May signatures derived either from the separability study or the simulated inventory.

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PREFACE

To prepare for future nationwide forest and grass renewable resources inventories using automatic data processing remote sensing technology, the National Aeronautics and Space Administration at the Lyndon B. Johnson Space Center and the U.S. Department of Agriculture, Forest Service have categorized the continental United States into ten forest and rangeland ecosystems to conduct a study known as the Ten-Ecosystem Study. The Ten-Ecosystem Study uses Landsat data, supporting aircraft imagery, and ancillary information to perform a forest, rangeland, and inland water inventory of chosen sites within the ten ecosystems.[1]

The primary objectives of the Ten-Ecosystem Study are to

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

b. Identify automatic data processing analysis problems related to each site or ecosystem and recommend solutions

c. Define the requirements for an automatic data processing system to perform a nationwide forest and rangeland inventory

Secondary objectives of the Ten-Ecosystem Study are to

a. Determine the mapping accuracy for Level II features (hardwood, softwood, rangeland, and water) using computer-aided classification

b. Establish the best season for accurately mapping each site or ecosystem

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[1]Only nine different test sites were required because one site was selected to represent two ecosystems.

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c. Provide the Forest Service with findings and conduct evaluation workshops for the purpose of exchanging ideas and receiving Forest Service feedback

This document is the final of four reports covering the study conducted at the Warren County, Pennsylvania, site. It has been concluded that hardwood, softwood, rangeland, and water features can be accurately (86.2 percent ± 5 percent) mapped using Landsat data.

This report was prepared under Contract NAS 9-15200, Job Order 75-325, Action Document 63-1557-5325-18. 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.

Numerous individuals participated in the analysis of the Warren County, Pennsylvania, site. Appreciation is extended to Harold Almond, Larry Hall, Charles Tanner, and James Ward. Additionally, the author wishes to thank all individuals who reviewed and commented upon various drafts of this document for their suggestions and constructive criticisms.

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ABBREVIATIONS

ADP	automatic data processing
CBF	Conotton-Braceville-Fredon
CCG	Cavode-Cookport-Gilpin
CIR	color infrared
CLW	Chagrin-Lobell-Wayland
DAS	Data Analysis Station
DGE	Dekalb-Gilpin-Ernest
EEL	Eric-Ellery-Langford
ERIPS	Earth Resources Interactive Processing System
GCE	Gilpin-Cavode-Ernest
GTS	Gresham-Titusville-Shelmadin
JSC	Lyndon B. Johnson Space Center
Landsat	name given to two satellites which were formerly called Earth Resources Technology Satellites — referred to as Landsat-1 and Landsat-2
MCC	Muck-Caneadea-Canadice
MSS	multispectral scanner
NASA	National Aeronautics and Space Administration
PCC	probability of correct classification
pixel	picture element
PMIS	Passive Microwave Imaging System
PSU	primary sampling unit
rms	root mean square
SSU	secondary sampling unit
TES	Ten-Ecosystem Study

THG	Titusville-Hanover-Gresham
TLG	Titusville-Lordstown-Gresham
USDA	U.S. Department of Agriculture
VMA	Venago-Mardin-Alden
WLC	Wayland-Lobell-Chagrin

1. INTRODUCTION

As part of the Ten-Ecosystem Study (TES), Warren County, Pennsylvania, was selected to represent the Northern Hardwood Ecosystem (Site II). Two studies, a type separability and a simulated inventory, were performed to determine the feasibility of using remote sensing technology to inventory forest, rangeland, and inland water areas. The type separability study was performed to determine the maximum level of detail and corresponding maximum mapping accuracies obtainable using automatic data processing (ADP) analysis of remotely sensed data. In this study, all available ground-truth data and aerial photographs were used to select training fields for the computer-aided classification of the county into hardwood, softwood, rangeland, and water. The simulated inventory study was conducted to determine how successfully ADP technology can extend limited ground-truth data for large area inventories. Only training fields located from aerial photographs within a specified 10-percent area were used to classify the entire county into hardwood, softwood, rangeland, and water in the simulated inventory study.

1.1 SCOPE

In the TES, Landsat multispectral scanner (MSS) data were used as the mapping data base. The TES scientists, aided by Forest Service foresters familiar with the site, used aircraft photographs as the basic source of ground-truth data and analyzed the data by photointerpretation methods. The National Aeronautics and Space Administration (NASA) high-altitude flight color-infrared (CIR) photographs (1:120 000 scale) were used. To aid in the analysis, TES personnel utilized remote sensing application publications, research reports, and personal knowledge from Forest Service contacts.

Each site was to cover one county or 360 000 square hectometers (889 579 acres), whichever figure was smaller. Two Landsat acquisitions [September 1972 (ID 1046-15295) and May 1975 (ID 5018-15101)], representing different data sets, were analyzed for each site. Classification maps of the test sites were statistically evaluated, and acreages were compared to established inventory figures.

The study of Warren County, Pennsylvania, hereafter referred to as Site II, involved three phases. Phase I was the planning and data acquisition phase (ref. 1). Phase II consisted of data compilation, site familiarization, and data processing (refs. 2, 3). This document summarizes Phase II activities and presents the results and conclusions which are most significant as a result of this study. Phase III consists of the final analysis and comparison of all nine sites. This final report will be issued in mid-1978 after the completion of all site analyses.

1.2 ANALYSIS LEVELS

The classification hierarchy investigated during TES is given in table 1-1. In the type separability study, Level II and Level III classification accuracies were investigated. When the Level II accuracy was 90 percent, a Level III classification was attempted. When the Level II accuracy was lower, a Level III classification was not attempted because it was assumed that, at best, the Level III classification would be equal to Level II classification.

1.3 PERFORMANCE CRITERIA

The minimum classification accuracy requirements for Level II analysis were softwood, 90 percent; hardwood, 90 percent; rangeland, 80 percent; and water, 90 percent. Census water and noncensus water were combined in the water category because there is no spectral difference between the two features; therefore, census

TABLE 1-1.— TES ANALYSIS LEVELS

Level I	Level II	Level III
Forest	Softwood	Pine Hemlock
	Hardwood	Maple Oak
Nonforest	Rangeland	
	Other[a]	Cropland Urban
Water	Water	Census water — streams, sloughs, estuaries, and canals wider than 152 meters (500 feet); and lakes, reservoirs, and ponds larger than 16.2 square hectometers (40 acres) in area. Noncensus water — water bodies smaller than 16.2 square hectometers (40 acres) or narrower than 152 meters (500 feet).

[a]In this study, only forest, rangeland, and inland water were classified; the remaining unclassified land was "other" land.

water and noncensus water were treated as the same class in the data processing. During the postprocessing activity, census water was separated from noncensus water based on the size requirements described in table 1-1.

2. STUDY SITE DESCRIPTION

Site II is located in the Allegheny Plateau within the Upland Appalachian Plateaus of northern Pennsylvania (ref. 4). Elevations range from approximately 335 to 488 meters (1100 to 1600 feet). Although the plateau was originally flat, the area has been dissected by erosion, resulting in rugged terrain.

The site contains portions of the Allegheny National Forest, private forests, state game lands, croplands, grasslands, and numerous rural communities. The site also includes portions of the Allegheny Reservoir. The Warren County surface area of the Allegheny Reservoir is approximately 2833 square hectometers (7000 acres). Forest totals approximately 196 273 square hectometers (485 000 acres; fig. 2-1, ref. 5). Rangeland occupies approximately 16 228 square hectometers (40 100 acres; ref. 6). Cropland totals approximately 19 627 square hectometers (48 500 acres; ref. 6).

2.1 CLIMATE

The area is cool and humid with a continental plateau climate. Winters are cold and humid, and summers are cool and humid. Average temperatures range from -3° C to 21° C (about 27° F to 69° F). Annual rainfall ranges from approximately 89 to 114 centimeters (approximately 35 to 45 inches) and averages approximately 107 centimeters (42 inches). Snowfall is significant, averaging approximately 137 centimeters (54 inches) a year (ref. 7).

2.2 GEOLOGY

The plateau is composed of crystalline rocks, principally granite, gneiss, and schist, with some shale and siltstone in the northwestern portion. Granite rocks have weathered to coarse, acid

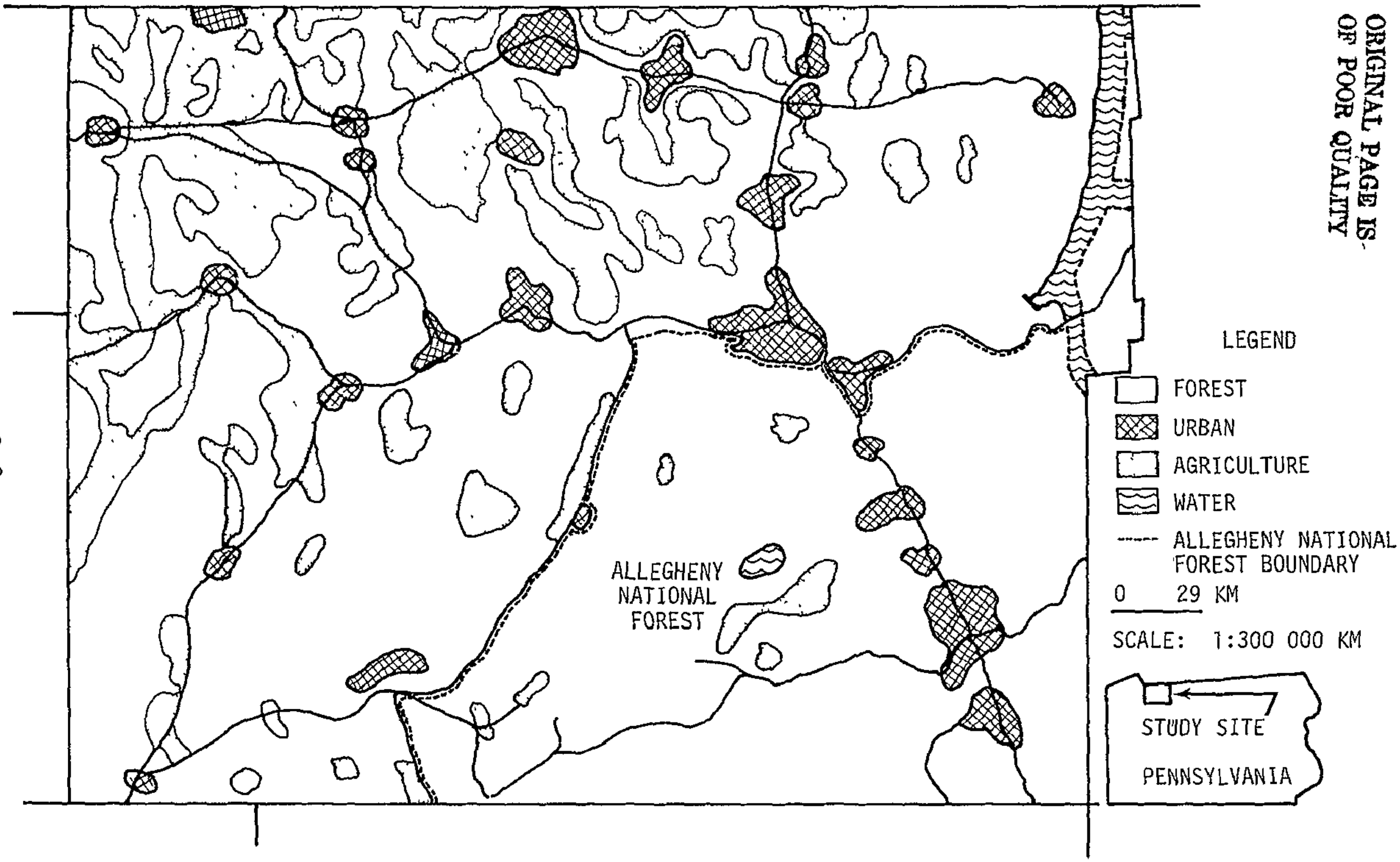

Figure 2-1.- Generalized land use map of Site II (taken from reference 6).

soil with low fertility. Weathering of shale and siltstone has resulted in productive forest soils.

Northern Warren County was glaciated during the Pleistocene age and is covered with glacial till and glacial outwash. However, the glaciers stopped north of the site of the present Allegheny National Forest.

Pleistocene glaciation has greatly changed soil conditions. The manner in which glacial drift was deposited has determined forest site quality. Unsorted drift or till usually found on midslopes of hills and mountains and on mountain tops provides the most productive forest sites. Poorest sites are the sorted or stratified drift found in areas where melted glacial water, streams, ponds, and lakes were located (ref. 8). A significant difference in site quality may occur within short distances.

2.3 SOILS

Site II has been classified into 38 soil types, which are combined into 12 soil associations (ref. 6). A large portion of the county is covered with two nonglaciated soil associations that provide excellent forest sites. The Dekalb-Gilpin-Ernest (DGE) soils, formed from shale, siltstone, and sandstone, occupy 26 percent of the county (table 2-1). These soils occur on steep to very steep areas. The Cavode-Cookport-Gilpin (CCG) soils, also formed from shale, siltstone, and sandstone, are found on the sloping to moderately steep land. This association covers 18 percent of the area.

The glaciated soil associations generally provide fair woodland sites. The Titusville-Hanover-Gresham (THG) soils are silt loam containing a high proportion of coarse fragments. These soils are found on hillsides and gently sloping surfaces and occupy 12 percent of the county. The Titusville-Lordstown-Gresham (TLG)

TABLE 2-1.– AREAS OF SOIL ASSOCIATIONS OF SITE II

Soil associations	Square hectometers (acres)		Percent	Suitability for forest
Conotton-Braceville-Fredon (CBF)	10 117	(25 000)	4.3	Good
Cavode-Cookport-Gilpin (CCG)	42 168	(104 200)	17.9	Excellent
Chagrin-Lobell-Wayland[a] (CLW)	5 665	(14 000)	2.4	Unknown[b]
Dekalb-Gilpin-Ernest (DGE)	61 917	(153 000)	26.3	Excellent
Erie-Ellery-Langford (EEL)	12 262	(30 300)	5.2	Unknown[b]
Gilpin-Cavode-Ernest (GCE)	7 082	(17 500)	3.0	Fair
Gresham-Titusville-Shelmadin (GTS)	16 026	(39 600)	6.8	Good
Muck-Caneadea-Canadice (MCC)	1 659	(4 100)	.7	Unknown[b]
Titusville-Hanover-Gresham (THG)	11 534	(28 500)	4.9	Fair
Titusville-Lordstown-Gresham (TLG)	28 733	(71 000)	12.2	Fair
Venago-Mardin-Alden (VMA)	37 231	(92 000)	15.8	Poor
Wayland-Lobell-Chagrin (WLC)	1 173	(2 900)	.5	Unknown[b]
Total	235 567	582 100	100.0	

[a]Includes 1619 square hectometers (4000 acres) of the Allegheny Reservoir. (The Site II surface area of the Allegheny Reservoir is approximately 2833 square hectometers (7000 acres).

[b]The correlation between these soil associations and forest quality in this site could not be ascertained.

type covers 12 percent of the area. This soil contains very coarse sandstone fragments and is acid, droughty soil not favorable for hardwoods. The Venago-Mardin-Alden (VMA) soils occur on sloping to steep areas. The association covers 16 percent of the county and provides agricultural use.

2.4 VEGETATION

On the Allegheny Plateau, the current forest is the second growth. The original forest was altered by timber cutting and finally devastated by cutting the entire forest. The present timber types were greatly influenced by the regenerative capabilities of each species. The site represents two major forest types: central hardwood and northern hardwood. The central hardwoods are predominantly oak and hickory, and the northern hardwoods are beech and maple.

The present forest consists of maple, beech, and birch; oak and hickory; elm, ash, and maple; aspen and birch; and white pine. Sugar maple (*Acer saccharum*), American beech (*Fagus grandiflora*), and yellow birch (*Betula alleghaniensis*) occupy the majority of the fertile, well-drained soil in the forest. Red oak (*Quercus rubra*), white oak (*Quercus alba*), and hickory (*Carya* species) are typically found on upland sites. Hemlock (*Tsuga-canadensis*) is associated with drainage areas or river bottoms.

The American elm (*Ulmus americana*), black ash (*Fraxinus nigra*), and red maple (*Acer rubrum*) are commonly known as bottomland hardwoods. This group occurs along waterways and in soils with a high water table (ref. 9).

Aspen (*Populus* species) and paper birch (*Betula payrifera*) are invasion species and occur as a result of partial forest destruction or in the conversion of softwood to the northern hardwoods (ref. 10).

3. TECHNICAL APPROACH

3.1 OVERVIEW

The TES project is composed of three phases: Phase I consisted of planning and data acquisition, Phase II was the data reduction, and Phase III is the final intersite and intrasite analysis and reporting of all nine sites. Each phase was divided into tasks (table 3-1), and each task was accomplished in approximately one 6-week period. The tasks were sequential with each feeding into the next.

The final report on Warren County covers task I.5 (preliminary photointerpretation analysis), task II.1 (data compilation and site familiarization), task II.2 (preprocessing), task II.3 (processing), task II.4 (postprocessing), task II.5 (evaluation), and task II.6 (preparation of site report).

Task I.5 (preliminary photointerpretation) involved selecting the two Landsat data sets which provided the highest classification accuracy, familiarizing the site scientists with the area, and selecting training fields to be ground checked.

Task II.1 (data compilation and site familiarization) consisted of a site field trip and an analysis of training fields. Additionally, the accuracy with which training fields could be selected from aerial photography was determined.

Task II.2 (preprocessing) included registering the two Landsat data sets to each other, registering the data to a topographic base map, and superimposing administrative boundaries on the data sets (fig. 3-1).

Task II.3 (processing) involved performing a separability study to evaluate classification accuracies derived from training fields

TABLE 3-1.– TECHNICAL PHASES AND TASKS FOR TES

Phase	Task	
I	I.1	Project planning
	I.2	Technical procedures documentation
	I.3	Technical procedures testing and timing
	I.4	Site selection and acquisition of imagery and ancillary data
	I.5	Preliminary photointerpretation analysis
	I.6	Acquisition of digital data
II	II.1	Data compilation and site familiarization
	II.2	Preprocessing
	II.3	Processing
	II.4	Postprocessing (and outputs production)
	II.5	Evaluation
	II.6	Preparation of site reports
III	III.1	Analysis and project report preparation
	III.2	Evaluation workshops
	III.3	ADP system definition

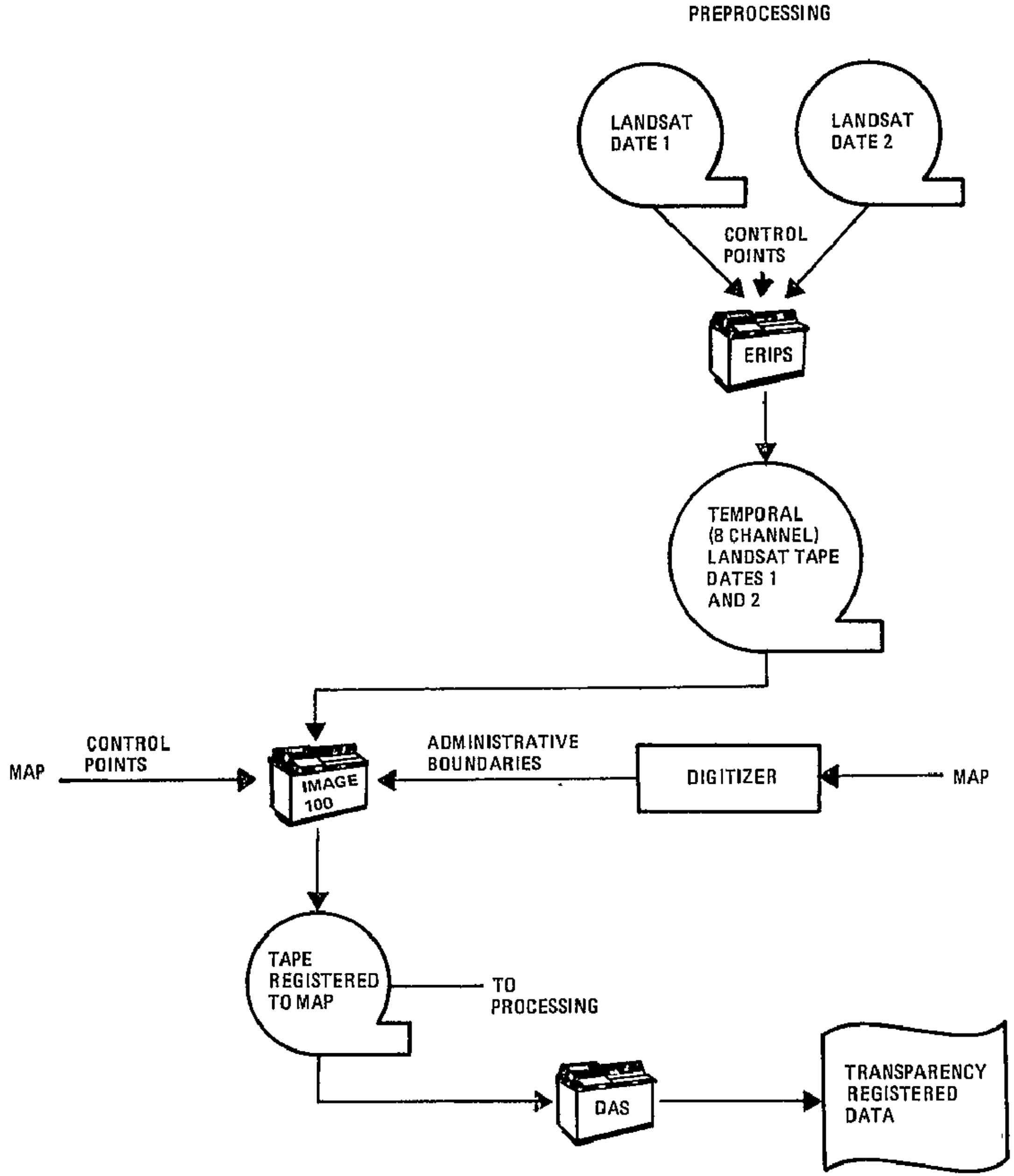

Figure 3-1.— Flow of preprocessing task.

distributed through the county and an inventory study to develop a classification signature based on data within a 10-percent area (fig. 3-2).

Task II.4 (postprocessing) objectives were to refine classification results by eliminating small parcels of land that are smaller than the basic mapping unit [4.04 square hectometers (10 acres) for forest land and grassland, 16.2 square hectometers (40 acres) for census water, and 0.4 square hectometers (1 acre) for non-census water (fig. 3-2)]. Additionally, final classification maps and evaluation products were produced. Classification maps were produced by cartographic compilation not shown on the flow chart.

Task II.5 (evaluation) included determining overall map classification accuracies, acreage proportion estimate accuracies, and accompanying statistical qualifiers. This was accomplished using rigorous evaluation procedures (ref. 11).

Task II.6 (reporting) included preparation of four reports (refs. 1, 2, 3, and this report). Report 1 discusses the site; report 2 cites results obtained from the preprocessing and processing; report 3 details postprocessing and evaluation; and this is report 4, the final report.

A more detailed discussion of the technical approach used in the TES project can be found in reference 11.

3.2 PRELIMINARY SITE ANALYSIS PROCEDURES

3.2.1 IMAGE EVALUATION PROCEDURE

All Landsat data containing less than 10 percent cloud cover over Warren County were evaluated to determine the two best dates for the computer-aided classification. A search of Landsat data acquired over the site produced eight frames. However, only two

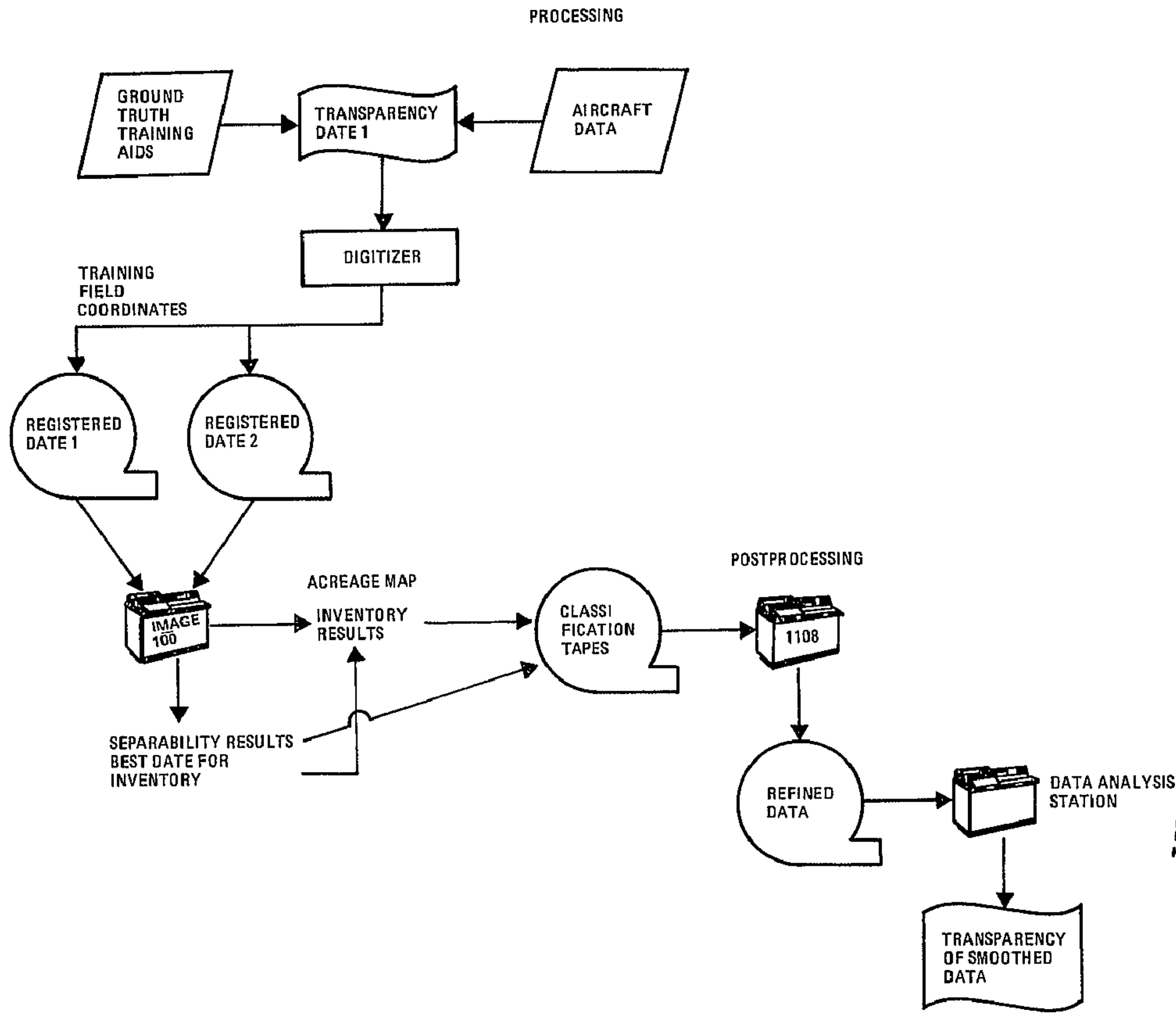

Figure 3-2.— Flow of processing and postprocessing tasks.

dates, September 1972 and May 1975, met the cloud cover requirements. Consequently, these dates were selected as a result of preliminary site analysis.

3.2.2 SITE FAMILIARIZATION PROCEDURE

Site familiarization included photograph evaluation, selection of areas for a field check, and a field trip.

Photographs, at a scale of 1:120 000, covering 90 percent of the Warren County site were examined. Seven classes (hardwood, softwood, rangeland, urban, cultivated, clearcut, and water areas) were differentiated. These classes are delineated on the photographs (fig. 3-3).

Sites to be ground checked were located on the photographs. Ground checkpoints were required to be a minimum of 4.04 square hectometers (10 acres) in size, readily identifiable on maps and photographs, and easily accessible. Since the area was honeycombed with roads, point accessibility was a minor problem.

Based on the apparent homogeneity of the vegetation, it was decided, subjectively, that 55 sample points would represent all classes as well as the diversity within classes. The number of points located for each class was proportionate to the total area of that class in the county. These points were located on the photographs and, later, were field checked.

In order to check the ground points before deciduous leaves turned, the field trip was scheduled for mid-September. At each sample point, the field team observed class characteristics, completed a field check sheet, and photographed the sample point area.

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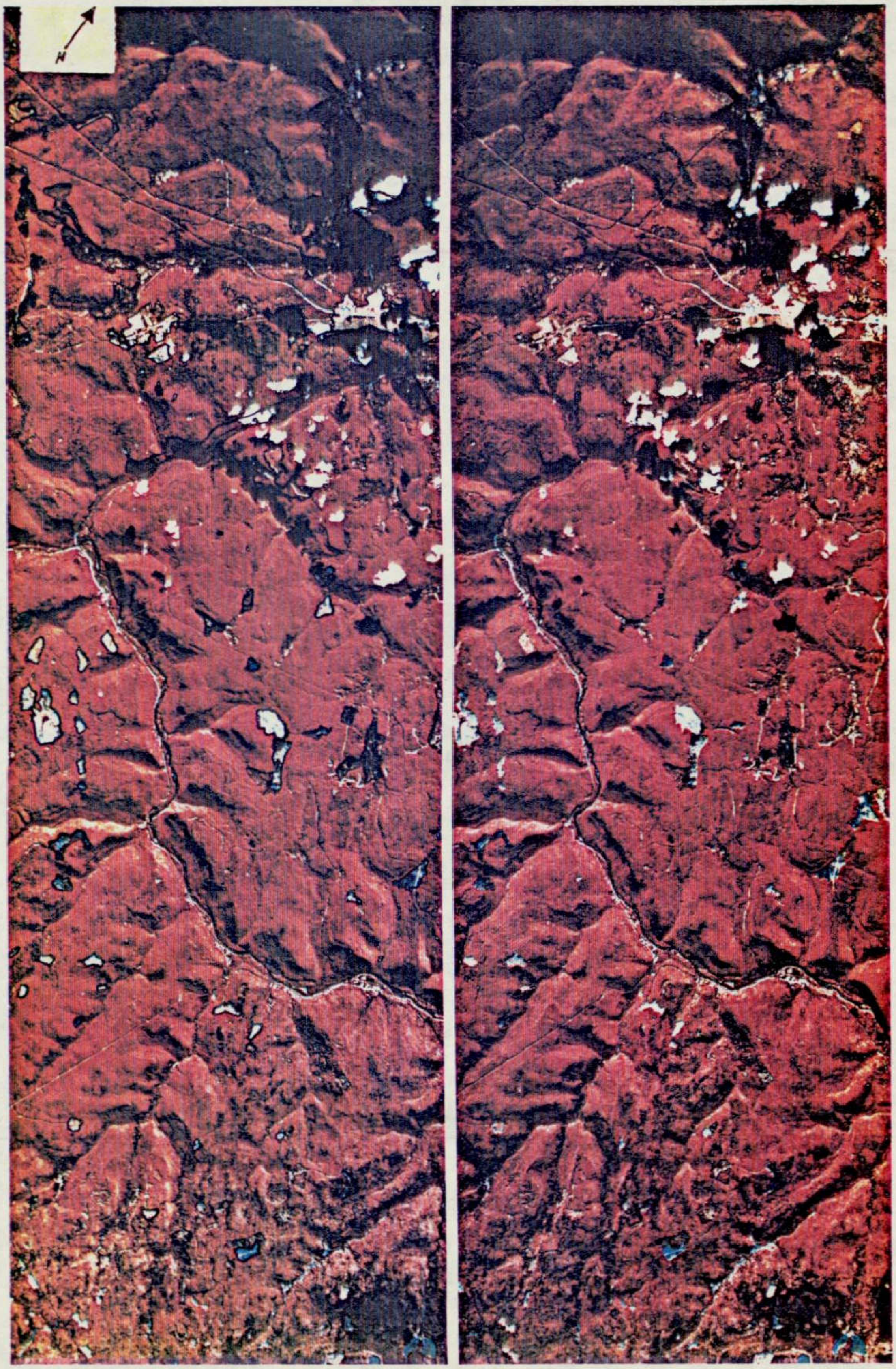

Figure 3-3.— Stereopair of aerial photographs (Mission 160, frames 4513 and 4514).

3.3 PREPROCESSING PROCEDURES

The preprocessing activity involved image-to-image registration of two data sets, registering the data to ground control points, superimposing administrative boundaries on the registered data, filming the registered data, and selecting training fields on the film transparencies.

For image-to-image registration, the second best imagery (acquired in September 1972) was to be registered to the best imagery (acquired in May 1975). A digital tape containing both dates was to be produced.

For the image-to-ground registration, the May data set was registered to ground control points derived from a topographic map (1:500 000 scale). A linear regression was used to calculate the parameters to be used in a registration program. The regression analysis can be visualized as the control point's Landsat location plotted along the X-axis (horizontal) of a graph and the control point's map location plotted along the Y-axis (vertical). For a more detailed explanation, see reference 12.

A line of best fit (least-square line) was calculated mathematically. This is the straight line that is closest to all data points. The line can be said to represent the expected value of any combination of Landsat and map values.

A root-mean-square (rms) error was calculated from the regression. The rms error is an indication of how accurately the control points were located. For example, an rms error of 3.0 picture elements [(pixels) 240 meters] would show that the control point had 240 meters of horizontal displacement from image to map.

During the registration process, each pixel was rotated horizontally, and the original rectangular pixel was represented as a square pixel.

To rotate the image, a rotation factor was calculated. This factor was used to rotate the satellite data, line by line, so that it attained an east-west orientation corresponding to a topographic map.

The Landsat pixel is not square. In order to overlay a pixel on a ground map, the pixel must be squared. To obtain a square pixel, approximately every third line was duplicated. For example, 350 Landsat lines were displayed as 485 lines. The acreage of the new pixel was calculated (appendix A) and used to determine acreage estimates.

The Landsat image of the Warren County study site was 970 pixels by 970 lines. The Interactive Multispectral Image Analysis System, model 100 (IMAGE 100), which was to be used in processing the data, had a maximum data set size of 512 by 512 pixels. Since the procedures specified that every pixel was to be classified, it was necessary to divide the registered data into four quadrants, each containing 485 by 485 pixels (fig. 3-4).

The Warren County boundary was superimposed on the data sets by digitizing the county boundary and registering the boundary to the Landsat data. The registration process utilized the previously referenced linear regression.

3.4 PROCESSING PROCEDURES

3.4.1 TYPE SEPARABILITY STUDY PROCEDURE

Two ADP studies were conducted for Site II. A type separability study was designed to evaluate classification accuracies derived

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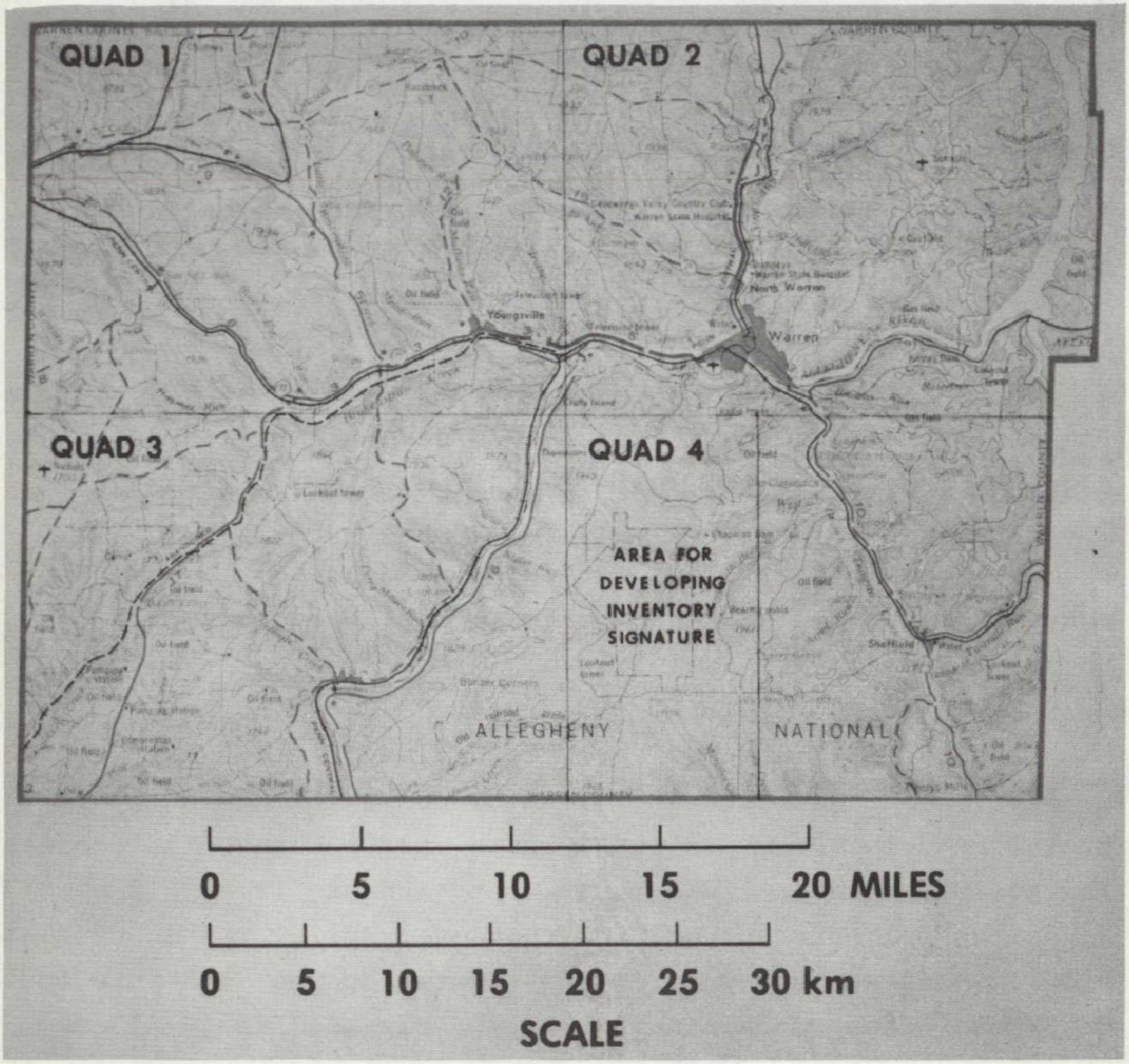

Figure 3-4.— Topographic map of Warren County, Pennsylvania, showing four quadrants and inventory area of the study site.

from the September Landsat data using supplemental aircraft photographs. As specified in the procedures, no ground checks were performed in order to determine if accurate classification maps could be produced from training fields selected solely from aerial photographs. Area estimates were determined by the following formula:

$$A = \text{number of pixels} \times \text{square hectometers/pixel area}$$

An additional inventory was performed using the May data set. The same training fields were used to produce the signatures. Reasons for the additional analysis are given in sections 6.2 and 7.2.

3.5 EVALUATION PROCEDURES

Before an analyst can place confidence in the classification map produced by using these processing procedures (ref. 9), it is necessary to evaluate the classification accuracy of the map. Since the cost of checking 100 percent of the map would be prohibitive even if it were possible, an efficient evaluation method is required. As specified in the TES analysis procedures (ref. 11) the ad hoc evaluation procedure was undertaken.

The probability of correct classification (PCC) with corresponding confidence intervals and proportion errors for each class were calculated. Additionally, a paired t-test was performed. The PCC is an estimated accuracy based on the mean of accuracies from several primary sampling units (PSU's). These PSU's (50 by 50 pixels) on the classification map are compared to aerial photographs and are scored as either correct or incorrect.

A confidence interval is the range in which the true accuracy is found at a prescribed confidence level. For TES, a 90-percent confidence level was selected (ref. 11). For example, using a confidence interval of 83 to 93 percent with the 90-percent confidence level, the analyst would be confident that the classification map was 83 to 93 percent correct 90 percent of the time.

A paired t-test was used to determine if the difference between the PCC's for the separability and the inventory classification was significant. The null hypothesis tested was that the difference was insignificant, that is, $(PCC_i - PCC_s) - 0 = 0$. As in the confidence interval determination, a level of significance ($\alpha = 0.05$) was selected for TES. Based on the number of degrees of freedom (number of PSU's - 1) and the level of significance, a t-value was calculated. (For details on calculating t-values, see reference 12.) For example, with 11 degrees of freedom and $\alpha = 0.05$, the t-value equals 2.20.

The calculated t-value was compared to the table t-value. If the calculated value was greater than the table value, the difference between the PCC's for the separability and the inventory classification was significant at $\alpha = 0.05$. If the value was less, the difference was insignificant and can be said to be attributed to chance.

Initially, 10 randomly selected PSU's were evaluated. The PSU's were selected on the classification map and located on corresponding aerial photographs. A linear regression registration program was used to determine the PSU location on the photographs.

In each PSU, 10 secondary sampling units [(SSU's) 2 by 2 pixels] were randomly selected. The computer classification of the SSU's was compared to the photointerpreted classification from the same area on the aerial photographs. The SSU classification accuracies were summed to determine the PCC and class proportions for each PSU.

TES procedures state that no fewer than 10 and no more than 25 PSU's should be evaluated. The criterion for determining the number of PSU's to evaluate was the delta, the half-range confidence interval. The delta was used to calculate the range of the confidence interval symmetric to the PCC. For example, the PCC was the mean of the confidence interval. If the PCC equals 87.5 percent and delta is 0.049, the confidence interval is (87.5 - 4.9, 87.5 + 4.9). (For details on calculating the delta, see reference 12.) A delta less than 0.05 was acceptable.

The class proportion (p), the estimated proportion ($\hat{p}$), the error of estimate (B), and the confidence interval of the error at a 90-percent confidence level were calculated. The class proportion was obtained by a manual interpretation of the designated PSU on aerial photographs. The estimated proportion was obtained from the computer classification. The error of estimate was obtained using the following formula (ref. 11):

$$B = \frac{1}{n} \sum (p_i - \hat{p}_i)$$

where

n = the number of PSU's

p = the class proportion

$\hat{p}$ = the estimated class proportion

$i = 1, 2, 3, \cdots, n$

The confidence interval of the error at $\Delta 0.9$ equals the range $B - \Delta$ and $B + \Delta$. To test the significance in the difference between p versus $\hat{p}$, the confidence interval was evaluated.

If the interval contains both a negative and a positive number, the difference is considered insignificantly different from zero, and the area measurements are accurate. If the interval contains two negative or two positive numbers, the difference is considered significantly different from zero, and the area measurements are not accurate. This is equivalent to testing the hypothesis H: $\mathrm{Avg}(p_i - \hat{p}_i) = 0$.

3.6 ADDITIONAL ANALYSIS

The study site was classified and evaluated using the hardwood, softwood, rangeland, and water signatures derived from the separability study. This effort, which was not required by the TES investigation plan, was performed; and the results are given in section 4.3.1.

An additional inventory was performed using the May Landsat data. In order to compare the results of both data sets, September and May, the same fields were used in each case. The results were evaluated and are reported in section 4.4.

4. ANALYSIS RESULTS

4.1 PRELIMINARY SITE ANALYSIS RESULTS

Only two Landsat data sets, acquired in September 1972 and May 1975, met the cloud cover requirements. Consequently, these acquisitions were selected for preliminary site analysis. Because hardwood areas were easier to delineate on the May data set than on the September data set, the May data set was determined to be the best.

Ground checks verified that the sample points represented species differences within the hardwood, softwood, and cultivated areas (figs. 4-1, 4-2). Of the 30 hardwood points visited, 21 (70 percent) were beech and maple, 5 (17 percent) were oak and hickory, and 4 (13 percent) were aspen and associated species. Within the softwood points, 5 (75 percent) were pine, 1 (12.5 percent) was spruce, and 1 (12.5 percent) was tamarack. Of the 6 cultivated sites, 2 (33.3 percent) were corn; 2 (33.3 percent) were grass; and, at the time of the ground check, the remaining 2 were weeds.

The accuracy of the image photointerpretation checked against the actual ground observations verified that the photointerpreter incorrectly classified one softwood point as hardwood and classified two weedy areas as cultivated. The class accuracies were as follows: hardwood, 100 percent; softwood, 88 percent; urban, 100 percent; cultivated, 67 percent; water, 100 percent; and cut, 100 percent. Overall accuracy was 95 percent.

4.2 PREPROCESSING RESULTS

After selecting control points and performing a linear regression, the resulting rms error was 2.4 pixels. Points were added and deleted until nine points remained. However, the rms error remained 2.4. Consequently, an image-to-image registration was not successfully met for the TES criteria. Sufficient control

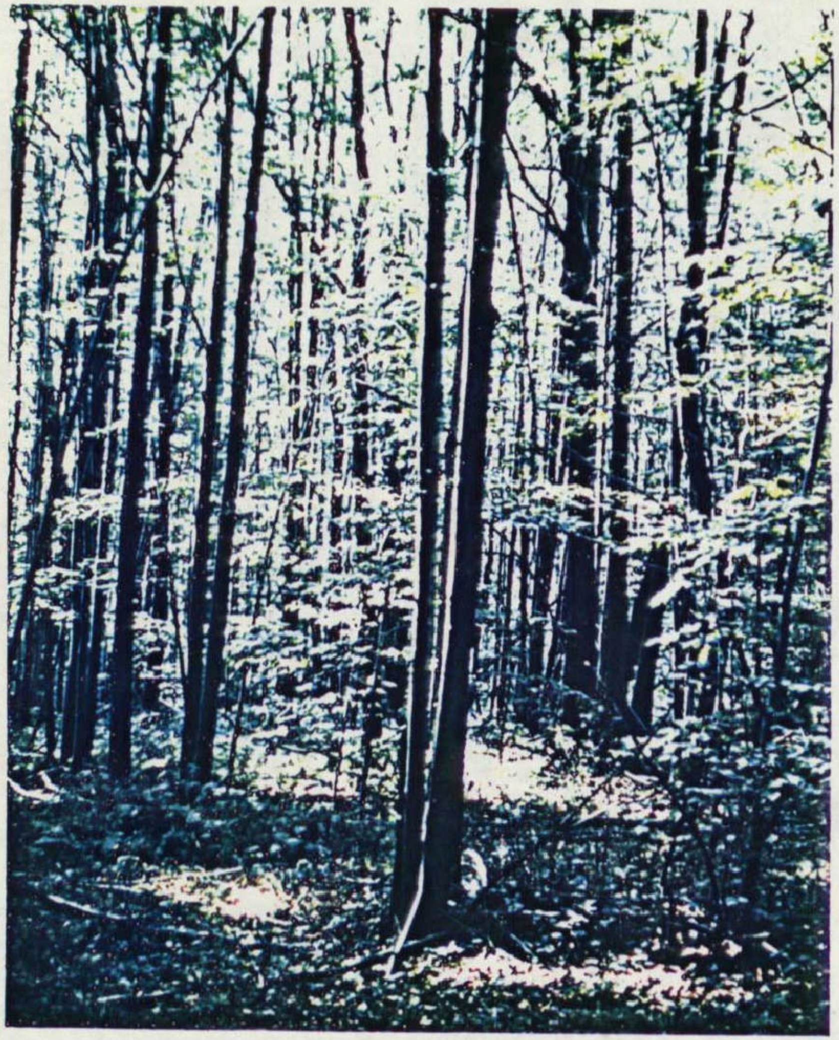

Figure 4-1.- Photograph of hardwood stand consisting of maple and beech.

Figure 4-2.- Photograph of softwood stand consisting of tamarack.

TABLE 4-1.— TRAINING FIELD ACCURACIES FOR THE MAY SEPARABILITY STUDY

Pixels per class	Class	Classified pixels				Accuracy[a]
		Softwood	Hardwood	Range- land	Water	
55	Softwood	24	31			43.6
263	Hardwood		263			100
56	Rangeland		1	55		98.2
80	Water				80	100

[a]Overall accuracy $= \frac{\text{number of correctly classified pixels}}{\text{total number of pixels}} \times 100$

$= \frac{422}{454} \times 100$

$= 93\%$

TABLE 4-2.— TRAINING FIELD ACCURACIES FOR THE SEPTEMBER SEPARABILITY STUDY

Pixels per class	Class	Classified pixels				Accuracy[a]
		Softwood	Hardwood	Range- land	Water	
20	Softwood	16	4			80
168	Hardwood		168			100
36	Rangeland		2	34		94.4
56	Water				56	100

[a]Overall accuracy $= \frac{\text{number of correctly classified pixels}}{\text{total number of pixels}} \times 100$

$= \frac{274}{280} \times 100$

$= 97.9\%$

TABLE 4-3.— SUMMARY OF AREA OBTAINED USING THE SEPARABILITY AND THE INVENTORY SIGNATURES FOR THE MAY DATA SET

Area	Computer classification, May separability results (a)	Differs from Forest Service survey figures, percent	Computer classification, May inventory results (a)	Differs from Forest Service survey figures, percent	Forest Service survey figures[b] (a)
County	237 789 (587 589)	0.89	237 789 (587 589)	0.89	235 689 (582 400)
Hardwood	176 878 (437 075)	-5.43	71 922 (424 829)	-8.1	187 046 (462 200)
Softwood	1 759 (4 346)	81.19	385 (951)	95.88	9 348 (23 100)
Rangeland	7 031 (17 374)		5 316 (13 136)		
Water	2 862 (7 072)		2 512 (6 207)		

[a]Area given in square hectometers followed by acreage in parentheses.

[b]Forest Service survey figures taken from reference 5.

The softwood estimate was 81.19 percent lower, and the hardwood estimate was 5.43 percent lower than the survey estimates.

A Level III classification of hardwood as maple and oak was performed on the four segments of Site II. Training field accuracies were 83.6 percent for maple and 50.0 percent for oak. However, the resulting map did not show maple or oak in minimum areas of 4.04 square hectometers (10 acres), but rather the maple and oak classifications were intermixed. Classified areas smaller than 4.04 square hectometers (10 acres) would be eliminated in post-processing. Consequently, final classification maps were not made.

Assuming that the acquisition date with the higher training field accuracies was the best date for an inventory study, September was selected for the inventory.

4.3.2 INVENTORY RESULTS

Training field accuracies were as follows:

Class	September data set, percent	May data set, percent
Softwood	81.2	90.0
Hardwood	100.0	100.0
Rangeland	81.1	87.5
Water	100.0	100.0

The September data set inventory acreage estimates were 96.9 percent lower for softwood and 61.9 percent lower for hardwood when compared with Forest Service survey figures. For a discussion of these results, see section 6.2.

The May data set inventory estimates (table 4-3) were 8.1 percent lower for hardwood and 95.88 percent lower for softwood when compared to Forest Service survey figures.

4.4 EVALUATION RESULTS

4.4.1 PCC RESULTS

Sixteen PSU's were evaluated to reach a delta of 0.049. The PCC and confidence interval for the May separability and inventory studies and for the September inventory study are shown in table 4-4.

TABLE 4-4.— PCC AND CONFIDENCE LEVEL FOR TWO CLASSIFICATION METHODS DERIVED FOR SITE II

Classification method	PCC, percent	90-percent confidence interval	Δ
May separability study	85.6	80.7 to 90.5	±4.9
May inventory study	86.6	80.8 to 92.4	±5.8
September inventory study	51.7	43 to 60.2	±8.6

For the September inventory study, the PCC was 52 percent. The PCC's for both the May separability study and the May inventory study are very similar.

The PCC's for the May separability study and the May inventory study were 86 and 87 percent, respectively. The confidence interval was approximately ±5 to ±6 percent at a 90-percent confidence level. The true PCC fell within this 10- to 12-percent confidence level 90 percent of the time. Results from the paired t-test showed the calculated t-value (0.4656) was less than the tabulated t-value (1.697) at a 95-percent level of significance for 30 degrees of freedom.

4.4.2 CLASS PROPORTION RESULTS

Evaluation of the error and the confidence interval for each class in the May separability study showed class proportions could be estimated for all classes with insignificant errors (table 4-5). For the May inventory study, classes hardwood and other could be accurately estimated. No water was found in the PSU's.

The hardwood acreage estimation determined from the proportion ($\hat{p}$) and the Forest Service survey acreage estimates are summarized in table 4-6. Estimated proportions for hardwood vary from 77 to 77.3 percent for the May inventory and separability studies, respectively. The proportion estimated for the September inventory study was 48.8 percent. The Forest Service survey proportion (p_t) was 79.4 percent for hardwood.

Except for the September proportion, all proportions produced estimates which were less than 3 percent different from the Forest Service survey estimate (table 4-6).

Although a sampling error for the estimates of forest type throughout the state was calculated for the Forest Service survey, no error estimate is available on a county basis. (See appendix B for the Forest Service survey sampling procedure.) The statewide error estimate for softwood is 12 percent; and the hardwood error ranges from 3 to 11 percent, depending on the timber type.

By applying the estimated proportion derived during evaluation to the county acreage, hardwood estimates were produced that are slightly lower than Forest Service survey estimates (2.65 percent for the May separability study and 2.98 percent for the May inventory study).

4.5 OUTPUT PRODUCTS

Output products included final classification maps and refined classification maps.

TABLE 4-5.– SUMMARY OF CLASS PROPORTION ERRORS

Class	May separability study				May inventory study			
	Estimated class proportion, $\hat{p}$	Error, B	Confidence interval, $\Delta 0.9$	Significance of error	Estimated class proportion, $\hat{p}$	Error, B	Confidence interval, $\Delta 0.9$	Significance of error
Hardwood	0.773	0.005	-0.018, 0.029	None	0.770	0.009	-0.003, 0.029	None
Softwood	.005	.010	-.006, .026	None	.002	.013	-.002, .028	None
Rangeland	.016	-.004	-.011, .003	None	.014	-.003	-.012, .006	None
Water								
Other	.206	-.011	-.034, .012	None	.214	-.019	-.050, .013	None

TABLE 4-6.– HARDWOOD AREA DETERMINED FROM PROPORTION ESTIMATES FOR SITE II

Condition	May		September inventory	Forest Service survey figures (a)
	Separability	Inventory		
Hardwood	$\hat{p}(0.773)$[b]	$\hat{p}(0.77)$[b]	$\hat{p}(0.488)$[b]	$p(0.794)$[c]
Area, square hectometers (acres)	182 188 (450 196)	181 480 (448 447)	115 016 (284 211)	187 046 (462 200)
Differs from Forest Service survey area, %	-2.60	-2.98	-51.20	0

[a]From reference 5.

[b]$\hat{p}$ = estimated class proportion.

[c]p = true class proportion.

After classifying the Landsat data for the Warren County test site as hardwood, softwood, rangeland, water, and other, classification tapes were produced. These tapes were the basis for both the final map products and the evaluation products.

Map products included film transparencies of each segment produced from the May inventory study (fig. 4-3).

To refine classification maps, the GETMIX/CLEAN program (ref. 11), which eliminates classified areas less than 10 pixels in size from the map, was run on the four May inventory classifications (fig. 4-4). The program reassigns areas smaller than 10 pixels, except for water, to the class surrounding them. The smallest mapping unit for water was 1 pixel [0.325 square hectometers (0.802 acre)]. During the same computer run, water was separated into census and noncensus water. Census water [water bodies larger than 16.2 square hectometers (40 acres)] was differentiated from noncensus water [water bodies 0.404 to 16.2 square hectometers (1 to 40 acres) in size].

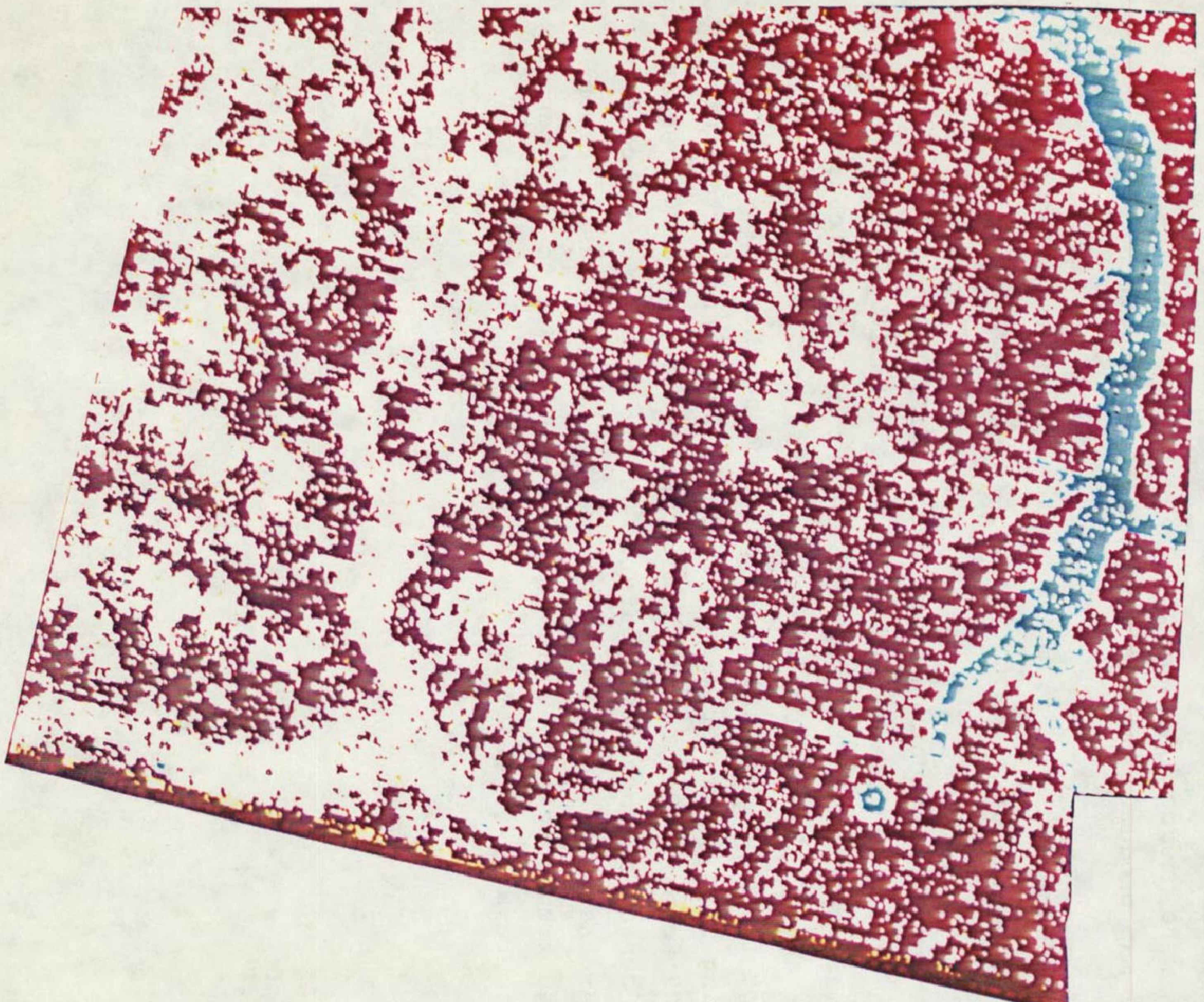

Figure 4-3.- Classification of segment 2 using May inventory signatures.

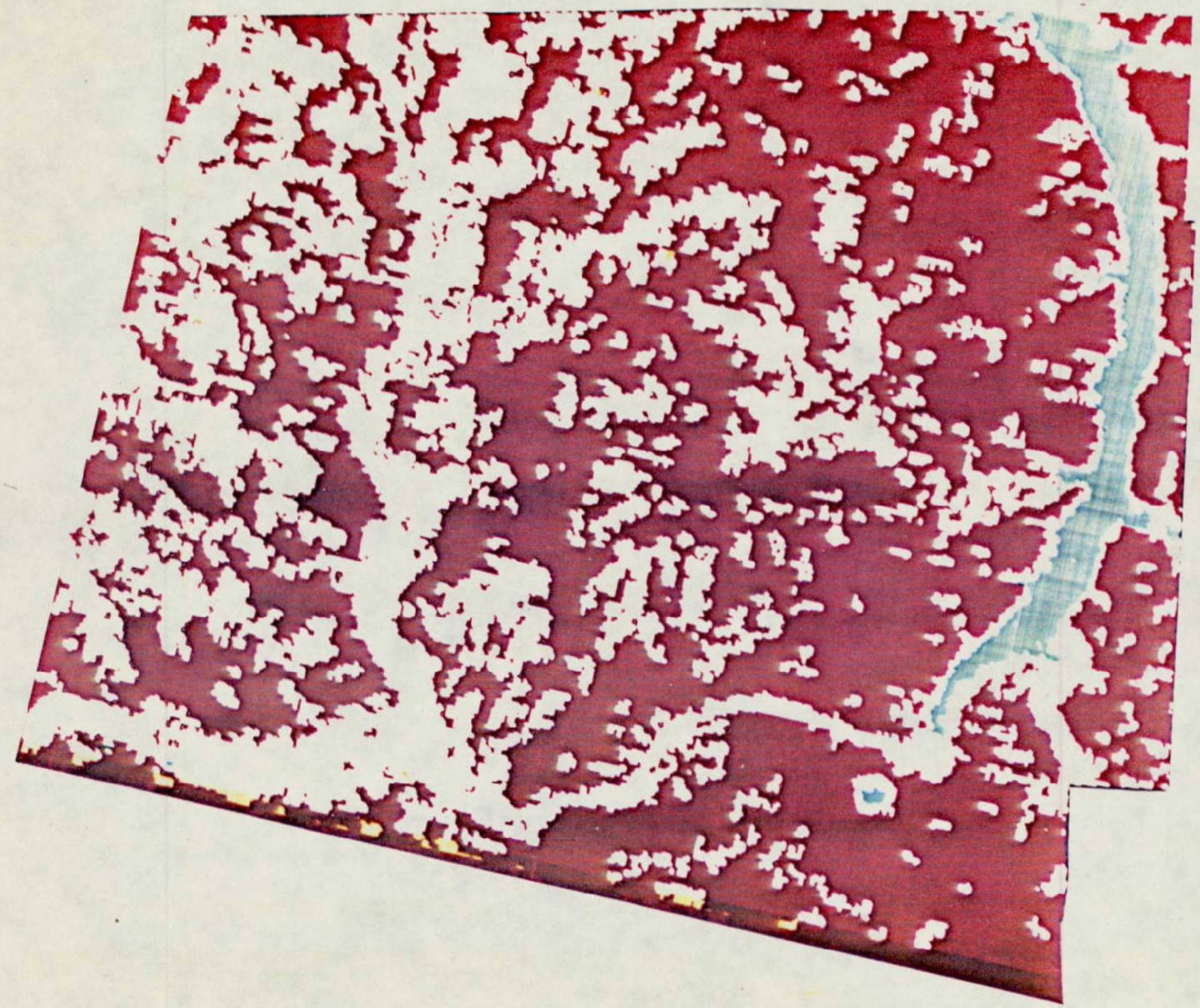

Figure 4-4.— Classification of segment 2 using May inventory signatures after applying the GETMIX/CLEAN algorithm.

TABLE 5-1.— RESOURCE UTILIZATION

[Machine-hours and man-hours]

System	Preliminary site analysis	Preprocessing		Processing		Postprocessing		Evaluation		Reporting	
		Estimated	Used	Estimated	Used	Estimated	Used	Estimated	Used	Estimated	Used
IMAGE 100		21	24	40	20	17	12				
PMIS DAS		6	18		6	18	6				
ERIPS		8	15								
Dell Foster		10	10		4						
Zoom transferscope						20	10		16		
UNIVAC 1110						2	2				
Man-hours	260	120	150	120	125	200	60		164	480	600

TABLE 5-2.– SITE II ESTIMATED COST PER ACRE

System	Cost/hour, dollars	Total hours	Cost, dollars	Cost/square hectometer based on 380 931 square hectometers, cents
IMAGE 100	300	56	16 800	4.41
ERIPS	300	15	4 500	1.18
UNIVAC	300	15	4 500	1.18
PMIS DAS	100	30	3 000	.78
Dell Foster	15	24	360	.09
Man-hours	[a]8.75	1195	10 460	2.74
Overhead	[a]3.68	1195	4 400	1.15
Travel			592	.15
				[b]11.68

[a]Rate approximations were obtained informally from government sources.

[b]An average cost of 11.68 cents/square hectometer (4.72 cents/acre) was estimated.

6. DISCUSSION OF RESULTS

Because some unexpected results occurred in Site II, the following section discusses these results and postulates possible reasons for the results.

6.1 PREPROCESSING

A poor image-to-image registration resulted from lack of control points. Because Warren County is a heavily forested area, permanent landmarks such as road intersections of distinct topographic or vegetative features such as field boundaries or stream junctions could not be located on the Landsat scenes for use as control points. Since control points could not be identified, it is not surprising that image-to-image registration was poor. In fact, poor registration can be expected in any area where control points cannot be readily identified.

6.2 PROCESSING

Although contrast between vegetation cover types was low in both the May and September data sets, vegetative types were more difficult to visually distinguish on the September data set. Only a subset of the May training fields could be located on the September data set.

Because vegetation boundaries were not distinct, the sizes of some hardwood and grass training fields were slightly decreased to stay within the vegetation type and avoid boundary pixels. Boundary pixels contained both hardwood and grass or hardwood and softwood. Some of the softwood and water training fields could not be located. A few of the distinct softwood training fields on the May data set were not distinct on the September data set. In fact, using these fields, known hardwood fields were erroneously classified as softwood. Consequently, these fields were omitted.

In the case of the water, the single largest water feature is the Allegheny Reservoir. In May 1975, it was filled with water; in September 1972, it was only partially filled with water. Some training fields that represented water in 1975 were over vegetation in 1972. These fields were omitted.

As previously mentioned, overall training field accuracies were high for each date (section 4.3.1). Based on the higher September accuracy for the September data (97.9 percent versus 93 percent), it was chosen as the better date for an inventory. When the September data were classified using both the inventory signature and the separability signature, acreage estimates were low. Considering the high training field accuracy, this result was surprising. However, training field accuracies measure only the accuracy of the pixels within the field and give no indication of the number of training fields needed to classify every pixel in the site correctly. The implication from the poor results is that an insufficient number of fields were selected to account for the diversity within the classes. In other words, the hardwood signature was too narrow because selected training fields did not cover all possible hardwood signatures.

The reason the hardwood signatures varied from place to place can only be speculated. One explanation could be differing atmospheric conditions across the county. Looking down through a haze tends to make the features' boundaries less distinct. Additionally, since haze density varies, the same feature would look slightly different under each haze density. Unless all haze hardwood combinations were included, some hardwood would not be classified as hardwood. In order to make appropriate changes to the data to correct for haze, the scientist must realize haze is present before data processing begins. After data processing is complete, it is too late for atmospheric corrections to the data. Warren County does have frequent haze.

In fact, 3 of the 4 days spent in Warren County on the site trip were very hazy.

6.3 EVALUATION

When comparing softwood acreage estimates with historical estimates, it is important to keep in mind that softwood is a minor feature, less than 4 percent of the county. The softwood acreage estimates were 81 to 96 percent lower than Forest Service survey estimates. Although the difference is large, it must be remembered that the 96-percent difference is only for 4 percent of the total area. Both the Forest Service and TES procedures place emphasis on the majority features and expect a larger error in a minor feature than in a major one.

In the procedures used for Site II, less emphasis was placed on minor features. The number of site fields selected were proportionate to the proportion of that feature in the county. Consequently, fewer softwood areas were checked in the field and fewer softwood training fields were selected. If all features had been considered equally, more softwood, grass, and water areas would have been field checked. Bearing in mind the constraint that field checks were limited to 5 days with 4 scientists, the total number of points checked would remain constant. However, fewer hardwood sites could be visited, which would probably result in a poorer hardwood classification. If minor and major features are equally important, additional procedures must be developed.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

The Warren County, Pennsylvania, study addressed two of the TES primary objectives.

a. It was determined that remote sensing technology could be used to inventory forest, grass, and inland water areas within a county boundary for the Northern Hardwood Ecosystem (section 4.3).

b. A problem specific to the study site was the difficulty in locating ground control points for use in registration. The area was heavily forested, and control points were difficult to locate on the Landsat scenes (section 4.2).

Achieving the third objective of defining the requirements of an ADP system to perform a nationwide forest and grass inventory will require information from all sites. As a result of this study, no specific system requirements have been defined.

Secondary objectives were addressed as follows.

a. Based on the level of significance of the classification error (table 4-5), it was concluded that computer classification of timber types could be accurately produced for Level II features, hardwood, softwood, grass, and water (section 4.3.1).

b. Computer classification of timber types could not be accurately produced for Level III hardwood features, maple and oak (section 4.3.1).

c. Based on the successful classification of the May data set, late spring was determined to be the better date for inventory (section 4.1).

d. This final report documents findings for the Northern Hardwood Ecosystem. An evaluation workshop was held to discuss TES results with Forest Service personnel in September 1977.

Additional conclusions were obtained from the study.

a. After verifying training field accuracies with ground checks, it was determined that training fields could be accurately selected from aerial photography. For this site, a field trip was not mandatory to select training fields (section 4.1).

b. Using the May data set, Warren County could be accurately classified using either signatures derived from training fields distributed through the county or from training fields restricted to 10 percent of the area (sections 4.3.1 and 4.3.2).

7.2 ASSESSMENT OF TECHNICAL PROCEDURES AND SYSTEM REQUIREMENTS

The procedures used for processing Site II were adequate for correctly classifying hardwood, softwood, grass, and water and in determining acreage estimates for each feature. However, the method to determine the best date for the inventory gave ambiguous results. As a result, additional analysis, which could have been avoided if the best inventory date had been selected initially, was necessary.

7.3 ASSESSMENT OF ANALYSIS PROBLEMS RELATED TO SITE ECOLOGY

A temporal registration could not be achieved because the same control points could not be located on both data sets. Site II is heavily forested, and very few permanent features, such as road intersections, can be located on the Landsat scenes. In areas without many visible permanent landmarks, another registration method that does not rely on visible surface features is necessary.

7.4 RECOMMENDATIONS

Because signatures developed from training fields within a 10-percent area were representative of the county, it is recommended that a study be conducted to determine the areal distance that the signatures will extend.

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APPENDIX A

CALCULATIONS FOR LANDSAT PIXEL SIZE AND RESAMPLED PIXEL SIZE

APPENDIX A

CALCULATIONS FOR LANDSAT PIXEL SIZE AND RESAMPLED PIXEL SIZE

The Jacobi equation (ref. 13) was used to calculate the Landsat pixel size.

$$\text{Landsat pixel size} = |AE - BD|(\text{photoscale} \times 10^2)^2(\text{conversion factor})$$

where

A,B,D,E = coefficients generated by the least-squares analysis

photoscale = scale of the topographic transparency

$$\text{conversion factor} = \frac{1}{(3 \times 12)^2(4840)}$$

Therefore,

$$\begin{aligned}\text{Landsat pixel size} &= |(0.90 \times 10^{-5})(1.61 \times 10^{-5}) \\ &\quad - (-6.14 \times 10^{-5})(4.40 \times 10^{-5})| \\ &\quad \times (491\ 600 \times 10^2)^2\left[\frac{1}{(3 \times 12)^2(4840)}\right] \\ &= |-1.305 \times 10^{-10} - (-2.7016 \times 10^9)| \\ &\quad \times [2.46 \times 10^{11}(10^4)]\left(\frac{1}{6\ 272\ 640}\right) \\ &= |2.56655 \times 10^{-9}(2.46 \times 10^{15})\left(\frac{1}{6\ 272\ 640}\right) \\ &= 2.83 \times 10^{-9}(3.98556 \times 10^8) \\ &= 1.091 \text{ acres/pixel}\end{aligned}$$

The Landsat pixel is not square. In order to overlay a pixel on a ground map, the pixel must be squared. To square the pixel, approximately every third line was duplicated. The new pixel area is calculated as follows.

$$\text{New pixel size} = \frac{\text{Landsat acres/pixel}}{\text{GY}}$$

$$= \frac{1.091}{1.36}$$

$$= 0.802 \text{ acre/pixel}$$

GY was calculated during the least-squares regression.

APPENDIX B

FOREST SURVEY ACREAGE ESTIMATION PROCEDURES

APPENDIX B

FOREST SURVEY ACREAGE ESTIMATION PROCEDURES

The Forest Service survey estimates are obtained from tabulations based on a sampling procedure (ref. 5). For sampling purposes, Pennsylvania was stratified into six geographic units. Aerial photographs were used to locate 5117 ground plots. More than half the plots (2998) fall within the Allegheny National Forest, a 1.1 million square hectometer (2.6 million acre) area; 456 plots were taken on state forest land; and the remainder were other land.

Although the size of the plot was not specified, plots are generally less than 0.404 square hectometers (1 acre). Within a ground plot, trees are tallied by species, and the volume per tree is calculated. Additionally, parameters are measured to estimate volume cut, mortality, and net annual growth. Measurements obtained in the field are used to estimate timber type acreage for the state. Documentation of the method to produce acreage has not been discovered by the author.

Because every tree is not measured in a sampling strategy, some error occurs in the estimates produced.