REMOTE SENSING APPLICATIONS IN FORESTRY

A report of research performed under the auspices of the

Forestry Remote Sensing Laboratory,
School of Forestry and Conservation
University of California
Berkeley, California

A Coordination Task Carried Out in Cooperation with
The Forest Service, U.S. Department of Agriculture

For

EARTH RESOURCES SURVEY PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA-CR-131580) ANALYSIS OF REMOTE SENSING DATA FOR EVALUATION OF VEGETATION RESOURCES Remote Sensing Applications in Forestry. Annual Progress (California Univ.) 176 p HC $11.00 CSCL 02C G3/13
N73-22336
Unclas
69249

2 (P)

REMOTE SENSING APPLICATIONS IN FORESTRY

STAR

ANALYSIS OF REMOTE SENSING DATA
FOR EVALUATING VEGETATION RESOURCES

by

Forestry Remote Sensing Laboratory
School of Forestry and Conservation
University of California

Annual Progress Report — 30 September, 1970

A report of research performed under the auspices of the

Forestry Remote Sensing Laboratory,
School of Forestry and Conservation
University of California
Berkeley, California
A Coordination Task Carried Out in Cooperation with
The Forest Service, U.S. Department of Agriculture

For

EARTH RESOURCES SURVEY PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ABSTRACT

Work during the current reporting period was centered around (1) completion of a study on the use of remote sensing techniques as an aid to multiple use management, (2) determination of the information transfer at various image resolution levels for wildland areas, and (3) determination of the value of small scale multiband, multidate photography for the analysis of vegetation resources. In addition, a substantial effort was made during the past year to upgrade the automatic image classification and spectral signature acquisition capabilities of the laboratory.

We found that: (1) Remote sensing techniques should be useful in multiple use management to provide a "first-cut" analysis of an area. Frequently, however, the use of these techniques is hampered by the lack of correlation between the multiple use categories (e.g., scenic roadsides) and the physical parameters recognizable on the remote sensing imagery; (2) Imagery with 400-500 feet ground resolvable distance (GRD), such as that expected from ERTS-A, should allow discriminations to be made between woody vegetation, grassland, and water bodies with approximately 80% accuracy. However, if additional information is desired on the detailed species makeup of the woody vegetation, space imagery will have to be supplemented with higher resolution (i.e., 50 feet GRD) aircraft imagery on which individual crowns can be seen; And (3) barley and wheat acreages in Maricopa County, Arizona could be estimated with acceptable accuracies using small scale multiband, multidate photography. Sampling errors for acreages of wheat, barley, small grains (wheat and barley combined), and all cropland were 13%, 11%, 8% and 3% respectively.

ACKNOWLEDGMENTS

This research was performed under the sponsorship and financial assistance of the National Aeronautics and Space Administration for the Earth Resources Survey Program in Agriculture/Forestry, Contract Number R-03-038-002. Appreciation is expressed to Douglas L. Abbott, graduate student in the Department of Electrical Engineering, who designed and implemented the logic interface controller for our CRT storage unit as a project for a Master's degree.

Special thanks are due Dr. Dave Landgrebe and staff of LARS-Purdue for their assistance and cooperation in providing a source program listing of LARSYSAA and a tape of familiar data with which to test our converted LARSYSAA program.

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

Gene A. Thorley
Robert N. Colwell

The recent awareness of problems of pollution and deterioration of environmental quality, coupled with greater recreational use of wildlands places the wildland manager increasingly in the public's view. Accordingly, the wildland manager must be prepared to articulate and defend his management policies, lest he be relieved of these important responsibilities by less qualified, but more vocal groups. To provide the basis for his management policies, the wildland manager must have accurate and timely data about the resources under his purview, as well as data which reflects changes in the amount, distribution and quality of these resources. The objective of the research reported herein is to determine whether modern remote sensing techniques can aid in the acquisition of this resource information by assisting in the inventory and monitoring of wildland resources.

Judging from work which recently has been done by our group and by other NASA-financed investigators under the Earth Resources Survey Program, by far the best way to maintain the necessary surveillance of renewable earth resources and many of the associated environmental factors is by means of photography and related imagery obtained from aircraft and/or spacecraft. Beyond this generalization, however, little has been agreed upon up to the present time. There is great need for developing techniques which will be regarded as optimum for maintaining surveillance of the earth's renewable resources by means of aerial and space imagery. Our experience to date has convenced us of the necessity to use a systems concept and team approach for defining the role of remote sensing in solving problems of interest to the vegetation resource manager. With a view to using a systems approach, our Forestry Remote Sensing Laboratory was reorganized a year ago to include five functional units (see Figure 1.1). These units address themselves to the most important problems which must be solved if a remote sensing system is to be employed successfully for earth resources inventory purposes. The five problem areas investigated under this team concept are as follows:

(1) determination of the feasibility of providing the resource manager with operationally useful information through the use of remote sensing techniques;

(2) definition of the spectral characteristics of wildland resources and the optimum procedures for calibrating the tone and color characteristics of multispectral imagery of those resources;

(3) determination of the extent to which humans can extract useful earth resource information through a study of remote sensing imagery in either original form or when enhanced by various means;

(4) determination of the extent to which automatic data handling and processing equipment can extract useful earth resources information from remote sensing data, and

(5) effective dissemination of remote sensing results through the offering of various kinds of training programs in which the interaction between users and scientists can be emphasized.

The units of our Forestry Remote Sensing Laboratory which are engaged in these five problem areas are respectively, (1) the Operational Feasibility Unit, (2) the Spectral Characteristics Unit, (3) the Image Enhancement and Interpretation Unit, (4) the Automatic Image Classification and Data Processing Unit, and (5) the Training Unit.

Consistent with the organization that has just been described, and mindful of the problems which each of the units of our Forestry Remote Sensing Laboratory seeks to solve, the next five chapters of this report are devoted, respectively, to the activities of these units.

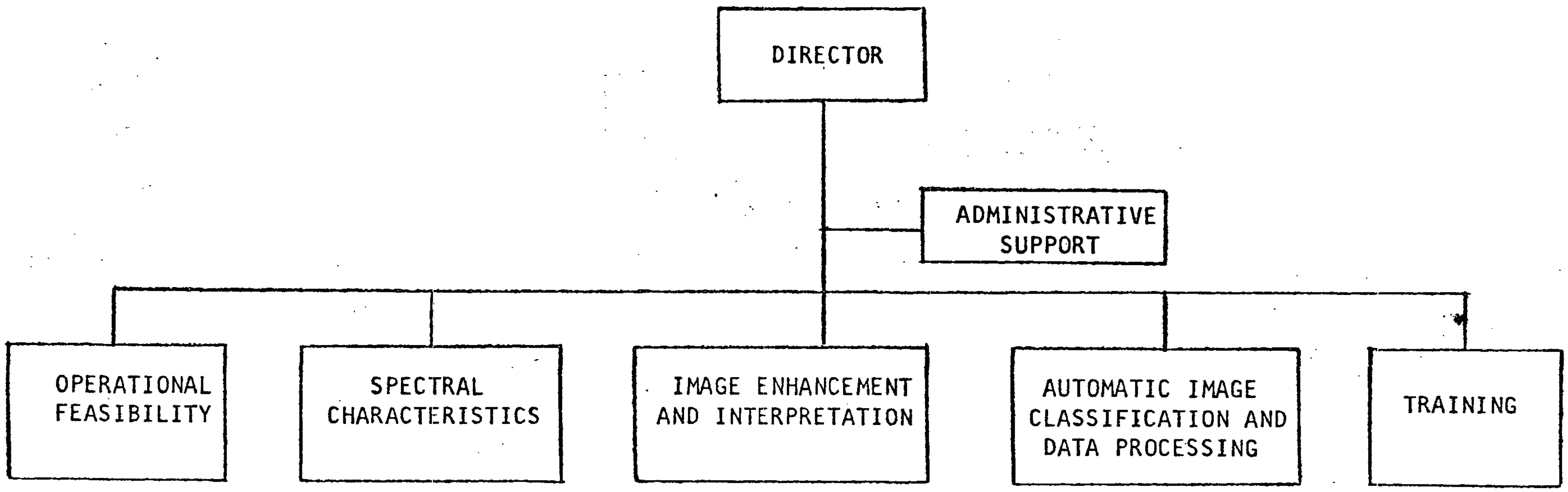


Figure 1.1. Organizational diagram of the Forestry Remote Sensing Laboratory, School of Forestry and Conservation, University of California, Berkeley, California.

CHAPTER 2

OPERATIONAL FEASIBILITY

William C. Draeger

Introduction

Responsibilities of this unit consist primarily of the development of operationally feasible means of using remote sensing capabilities to satisfy information requirements of users concerned with earth resource management. In fulfilling this responsibility the unit provides the link between basic technical studies conducted by other units of the Forestry Remote Sensing Laboratory and elsewhere, and the applications of these techniques to actual earth resource management problems.

Current Research Activities

A. Semi-Operational Agricultural Inventory Using Small Scale Aerial Photography.

A major undertaking of the unit during the past year consisted of cooperation with the Image Interpretation and Enhancement Unit in conducting a semi-operational inventory of small grain crops in Mariposa County, Arizona (NASA Phoenix Test Site, Site #29). Due to the inter-unit nature of this research, the full account is presented in Appendix I of this report.

B. Applications of Remote Sensing in Multiple Use Wildland Management

The introduction and justification for this study, as well as a detailed discussion of multiple-use management information requirements and conventional information-gathering systems appear in the September 1969 Annual Progress

Report of the Forestry Remote Sensing Laboratory. The objective of the study, as stated in the introduction, was to investigate the possible uses of remote sensing data in making "integrated interpretations" of operational wildland management units, in their entirety, and in particular, in multiple-use management planning. It was found that existing multiple-use zoning procedures, as currently carried out by land management agencies, did not lend themselves well to the use of remote sensing techniques. The latter stages of the study, which are presented here, are concerned primarily with the development and evaluation of wildland zoning criteria which would be amenable to the use of aerial photography, while still satisfying the needs of the land manager.

In the interest of brevity, only the portions of the study not included in last year's progress report will be reported here. In addition, numerous photo examples of various multiple use zones which were included in the photo-interpretation keys in the original document have been replaced by a limited number of examples in this report. Complete, fully illustrated copies of the entire multiple-use study are available for interested readers from the author.

I. DEVELOPMENT OF REMOTE SENSING ORIENTED CRITERIA

In view of the difficulties described previously in applying photo interpretation to existing zoning procedures, it was decided that much could be gained by attempting to develop a multiple-use zoning process particularly amenable to the use of aerial photography. Initially, the question arose as to whether any new system should be tied to the zoning concept, or whether some totally different way of integrating potential land uses should be investigated. It was decided, however, that despite its many drawbacks, the concept of wildland zoning probably best meets the needs of those asked to practice multiple use land management in this area now. Perhaps in the future more refined techniques for quantifying benefits derived from various uses and arriving at benefit-cost solutions for land allocation may render the zoning approach obsolete, but at the present time no such practices appear to be fully operational.

A remote sensing oriented system, classifying lands in the Meadow Valley Area should, in all probability, resemble the existing system. The primary difference would be the absence of reliance on an intimate knowledge of the area in question and on criteria that can be gathered only on the ground. In other words, the land classification based on remote sensing should be viewed as an initial broad-scale planning aid, and not as a final map of the type needed for developing plans. It is likely that any operational use of small scale imagery for land planning would utilize interpreters trained in image interpretation and in the general requirements of multiple use planning, but who would not be extremely familiar with each plot of land to be zoned. This would be particularly true of any operation designed to uniformly zone large, widespread wildland areas, and would be even more true if it included areas previously little managed on an intensive basis. At the same time, it is felt that any general mapping system should be designed such that later modification and adjustment would be possible based on on-the-ground checks of areas with specific local requirements, thus providing the needed flexibility to move from the regional planning phase to actual unit management without a total reappraisal being necessary.

Thus the remote sensing oriented zoning system which follows was developed under the following assumptions and constraints:

1. It should provide the general kinds of information necessary for multiple-use planning as practiced by the U. S. Forest Service.

2. It should be amenable to subsequent refinement based on more spe-

cific information that might be obtained either from ground observation or through the use of more sophisticated remote sensing techniques.

3. It should be general enough to apply to rather diverse wildland environments.

4. It was assumed that the identification (not to be confused with the interpretation) of specific wildland conditions is no more limiting than would be encountered using Ektachrome Infrared film at a scale of approximately 1:25,000. The determination of tone signatures and visual appearance of features on aerial images of various types is a separate problem not to be investigated in this study.

5. It was assumed that the interpreters would be reasonably experienced with the image types used, the general ecological relationships encountered in the area, and the broad requirements of the land use planners, but not intimately familiar with the particular area to be zones or specific socio-economic factors which might affect land use decisions.

a) <u>Selection of Zones</u>

Based upon a thorough investigation of the various zoning procedures being followed on the National Forests of Northern California, a compilation of desirable zone categories to be included in the photo interpretation system was prepared. It was felt that the selection was general enough to apply at least to the bulk of the Westside Sierra Subregion, the Northeast Plateau Subregion, and the northern half of the Sequoia Eastside Subregion, as they are designated by the U. S. Forest Service. (See Figure 2.1). The list is in essence, a combination of the zoning systems used by each of the three Subregions, as it was found that some variability existed depending on the vegetation types occurring in each subregion and the date of preparation of the particular set of guidelines.

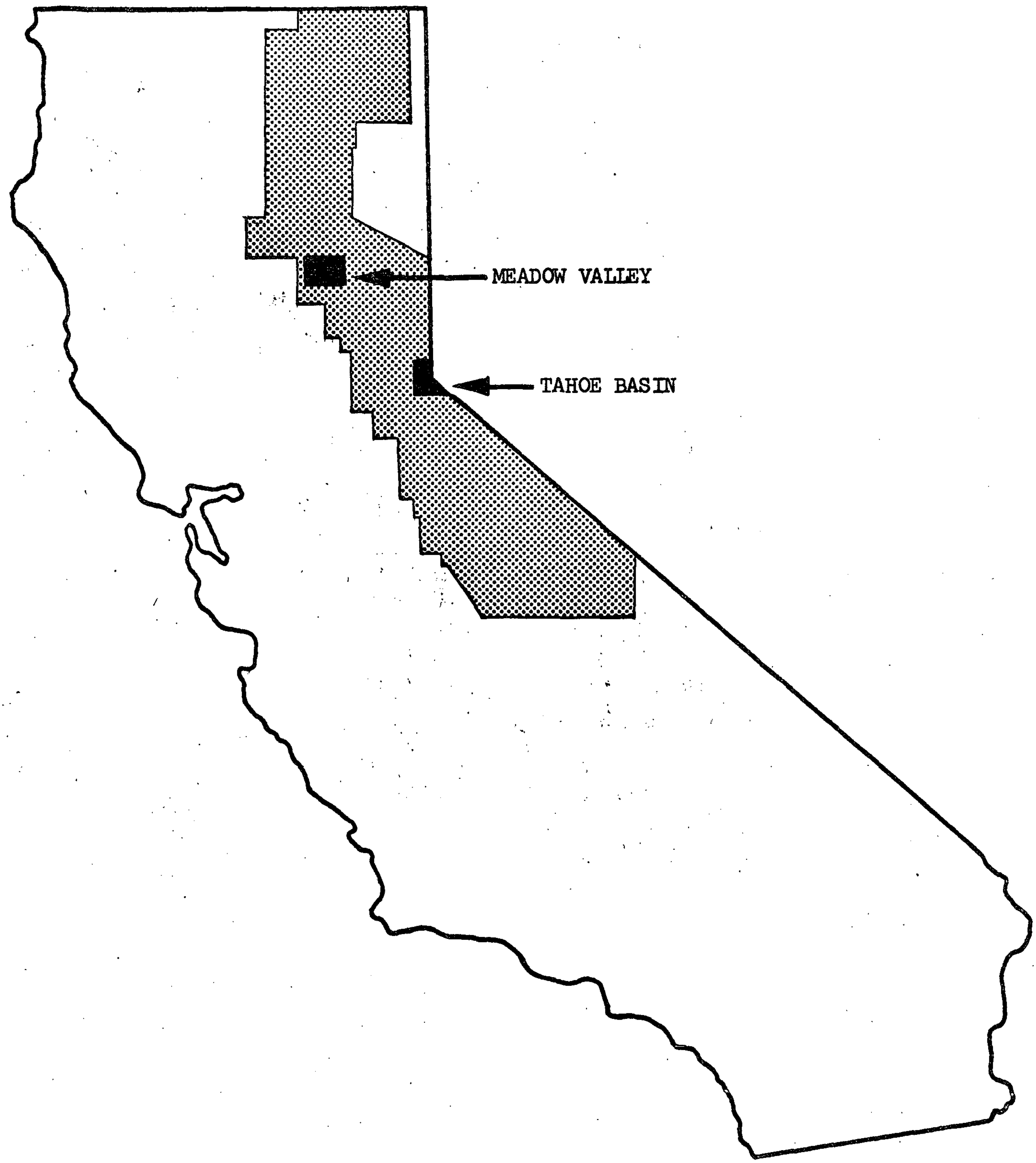


Figure 2.1 The shaded area indicates those portions of the Westside Sierra, Northeast Plateau, and Eastside Subregions for which the zoning criteria described in the text were developed. The two principal areas of study, Meadow Valley and the Tahoe Basin, are also indicated.

For reasons that will become apparent in later sections dealing with the actual mapping procedures to be followed, the zones were lumped into two groups: (1) General Zones, which are based on the broad climatic-vegetation-topography factors prevailing in the area, and (2) Use or Occupancy Zones, which are based on specific characteristics of the local environment likely to influence ultimate use. The determination of the final management to be applied to an area is subtractive in nature. For example, all land classified as Westside Intermediate is subject to the management directives of that zone unless it is specified as constituting a Use or Occupancy Zone, in which case the more restrictive directives will apply.

The following is a list of the zones with accompanying descriptions and appropriate management guidelines. However, two points should first be emphasized: (1) much of this material is not wholly original, but is an amalgamation of descriptions and directives contained in the Forest Service Management Guides for the three subregions mentioned above. Much more detailed management directives can be found in those Guides. (2) Further refinement of the directives for some Use and Occupancy Zones will be held independent of the surrounding General Zone.

1. GENERAL ZONES

A. Valley Front

Description: Generally lower elevation areas below the intermediate zone, and fronting on the Sacramento Valley. Vegetation consists of grass, oak-woodland, or brush, with scattered low-elevation conifers in some localities.

Management: Primary emphasis will be placed on the preservation, maintenance, and improvement of the plant cover so as to furnish optimum conditions for wildlife and livestock grazing. This includes an active awareness of the potential for fires, and both on-site and downstream needs for watershed protection. Recreational use will not be encouraged. Few timber management practices are necessary.

B. Westside Intermediate

Description: Generally heavily timbered areas lying in mid-elevations (range approximately 2000' to 7000') between the Valley Front Zone and the Crest Zone. Vegetation consists primarily of conifers and occasional dense stands of middle elevation brush species.

Management: Primary emphasis is placed on maximum production of forest products on a sustained basis, with current maximum production of water from snowpack in higher elevations. Secondary emphasis is on the maintenance or improvement of forage production for wildlife or livestock on areas unsuited for timber production. Transitory forage types should be utilized in a manner consistent with ultimate timber production. Recreational use will usually be limited to peripheral activities originating in other high recreational use zones.

C. Crest

Description: A high-altitude zone, characterized by rugged peaks, rocky slopes, plateaus, lakes meadows, and sub-alpine tree species.

Management: Primary emphasis is placed on the value of this zone as the principle watershed for most major rivers of the region. Thus activities which adversely affect the quality, timing or quantity of water flowing from the zone will be avoided. The second important use for the zone is mountain type recreation, and the need for such use will be met to the limit of available resources without impairing watershed or scenic values.

D. Eastside Intermediate

Description: A mid-elevation zone lying generally east of the Crest Zone, and bordered to the east by the Basin Front. Vegetation is primarily coniferous, sometimes intermingled with brush and other semi-arid forage species.

Management: Primary emphasis is on maximum production of timber on a sustained basis. Secondary emphasis is on the maintenance of forage values for livestock and wildlife. The arid nature of the zone precludes a high emphasis on watershed management needs.

2. USE OR OCCUPANCY ZONES

1. General Occupancy

Description: All lands which are presently in an "improved" state rather than in the undisturbed wildland state. Includes primarily built-up areas and lands obviously in private commercial agriculture and ranching.

Management: While these lands do not fall under the direct jurisdiction of public wildland management agencies, some adjustments may be necessary in adjacent wildland areas.

2. Streamside

Description: Includes all live streams (including intermittent streams) and associated riparian areas. Also includes a border fringe of vegetation of sufficient width to protect the channel, and scenic canyon walls where applicable.

Management: Objectives are to minimize siltation, channel blockage, channel alteration, and temperature increases. Merchantable trees may be cut within the streamside border on an individual selection basis, but only when such cutting will not adversely affect the stream environment.

3. Water Influence

Description: Areas of varying width along specific streams or lakes which due to their scenic values and/or accessibility promise particularly attractive potential for recreational use. Should include an area large enough to protect the water and near view scenery, as well as provide for necessary recreational developments.

Management: Emphasis is on the preservation of the aesthetic environment, including the quality of the pertinent lakes or streams. Development of recreational facilities as necessary should be undertaken, with appropriate concern given to protection against water pollution, damage to the environment, and protection against fire. Timber cutting should be limited only to high-risk trees and that necessary for construction of roads, campgrounds, and other developments.

4. Travel Influence

Description: Areas of varying width which border main highways and roads. The area should be wide enough to protect the near-view aesthetics.

Management: Timber cutting within this zone will be limited to high-risk trees or those necessary for construction of rights-of-way, scenic overlooks, adequate fire protection breaks, and other necessary developments. Emphasis is on maintaining the natural appearance of the zone.

5. Scenic Roadside

Description: Areas of varying width along secondary roads of particular scenic value. Generally these will be roads providing access to special scenic zones or water influence zones.

Management: The aim will be to remove trees on an individual selection basis while maintaining a near-natural appearance in the roadside strip.

Finally, it was felt that some indication of the dominant cover type would be helpful for planning the ultimate use of each area. Consequently, twelve cover type designations were selected for inclusion in the final zone description code.

b) Zone Description Code

It was anticipated that when zoning maps were finally completed, a simple coding system would be needed which would indicate the zone description assigned to each area. Hence a three-character code was adopted as follows:

B 3 a

- B — General Zone
- 3 — Use or Occupancy Zone (if needed)
- a — Dominant Cover Type

I. General Zones

A. Valley Front
B. Westside Intermediate
C. Crest
D. Eastside Intermediate

II. Use or Occupancy Zones

1. General Occupancy
2. Streamside
3. Water Influence
4. Travel Influence
5. Scenic Roadside
6. No use or occupancy designation

III. Dominant Cover Type

a. Dense mature conifer forest
b. Sparse mature conifer forest
c. Dense young conifer forest
d. Sparse young conifer forest
e. Dense chaparral
f. Sparse chaparral
g. Lush herbaceous vegetation
h. Dry herbaceous vegetation
i. Riparian hardwood vegetation
j. Dry-site hardwood vegetation
k. Semi-arid shrubs
l. Bare rock or soil

Thus the example code, "B 3 a", indicates an area in the Westside Intermediate Zone which, in terms of use or occupancy, is of importance primarily as a Water Influence area, and which has a dominant cover consisting of dense mature conifers. Obviously, if no use or occupancy zones were involved, the code would consist of a code such as "C 6 1," indicating a Crest Zone with predominant bare rock or soil cover.

A source of confusion could arise, however, if when mapping use or occupancy zones, one discovered that more than one designation applied to the same piece of ground. The degree of "restrictiveness" of the management to be applied to the zones helps to remedy this situation -- i.e., if there is a conflict, the more restrictive zoning will apply, as indicated in the following table.

Conflicting Designations	Designation to be used
1,2	1
1,3	1
1,4	1
1,5	1
2,3	3
2,4	4
2,5	2
3,4	3
3,5	3
4,5	4

c) Photo Interpretation Key

A photo interpretation key has been defined as: "reference material designed to facilitate the rapid and accurate identification and determination of the significance of objects and conditions from the analysis of their photo images." (Colwell, 1952) For any system of land classification from aerial photographs to be useful in an operational sense, it must be adequately described in an organized format such that numbers of interpreters of diverse backgrounds and experience can use it with a minimum of training. The preparation of a key or set of instructions for performing a photo interpretation job is an excellent test as to whether the procedure can be expected to work on an operational basis.

It is quite easy to philosophize about a procedure to be followed, but often is quite difficult to compile practical examples.

It has been the experience of the author, and others, that one of the most useful ways to present such information for photo interpretation is in the form of a combination "selective" and "elimination" key. An elimination key provides a step-by-step method of identification; the interpreter proceeds through a series of possible identifications, eliminating all incorrect choices. A selective key illustrates and describes classes of phenomena, and the interpreter chooses that example which most closely matches his unknown.

The photo interpretation guide which follows contains such "elimination-selection" keys. It is presented here as an example of the type of material which could be compiled to aid in multiple use zoning. Some sections consist of word keys based on the appearance, location and associated features of each of the multiple use zones as they appear on small-scale (approximately 1:30,000) Ektachrome Infrared Aero photography. Two problems can arise with such a key, however. First, the description of each feature is of necessity quite brief, and may not present enough information to enable the interpreter to make a final decision with a high degree of confidence. Secondly, it is often difficult, if not impossible, to describe in words the appearance of features on aerial photos in terms with the same meaning for all persons. Consequently, additional sections of the guide consist of actual photo examples of the features and more detailed descriptions of each. Thus the usual interpretation procedure should be for the interpreter to follow the elimination word key until a tentative identification is made, at which time the photos and a more complete description of the tentative choice are checked in the selective section, and either confirm his initial conclusion or discover an error and return to the elimination key and try again.

The following guide, which by its nature contains a fairly limited number of items is most useful for training and instruction purposes, rather than continual use. It is simply an attempt to present material in a well organized, readily accessible manner. After some experience the interpreter will require only infrequent reference to the key in particularly troublesome cases or as a refresher. Furthermore, it must be kept in mind that rarely is a photo interpretation key a total substitute for the use of such thought processes as induction, deduction, and the use of convergence of evidence. Obviously the interpreter who is aware of the basis for the particular mapping system being used and who uses the key only as an aid in addition to his interpretive ability will perform a superior job compared with one who relies wholly on material in the key.

Finally, it will be noticed that the key provides information relative to the identification of the various zones, but only occasionally provides help in the delineation of the actual boundaries of these zones. As discussed earlier, problems of delineation are quite difficult to solve through the use of keys, but rather depend largely upon the experience of the interpreter.

All of the aerial photo examples used in the keys were obtained during the summer months of 1966 and 1967, over the Meadow Valley test site and adjacent areas.

PHOTO INTERPRETATION GUIDE TO MULTIPLE USE ZONING

Film: Infrared Ektachrome
Scale: 1/25,000
Date of Photography: June to September

Section I: Dichotomous Key to General Zones

As a first step in the zoning procedure, all land within the area of interest must be placed into one of the four General Zones. This key is designed to aid in the delineation of boundaries between zones and the identification of those zones. The minimum area within any one zone should be approximately 5000 acres. Therefore, small areas exhibiting characteristics different from their surroundings should be ignored -- areas must be judged on their overall general characteristics. Once a decision has been reached in this key, reference should be made to the Selection Key to verify the results.

A. Generally dense vegetation cover, red or pink in color; occasional areas of dried grass or shrubs, brown in color ------------------ B

AA. Sparse vegetation cover, predominantly grey or light brown in color due to bare rock or soil. Occasional patches of snow. Often with scattered lakes, small patches of vegetation and rugged topography. Elevation usually exceeds 7000'. --------------------------------- Crest

B. Vegetation consists largely of coniferous trees, exhibiting a coarse texture and characteristic pointed crowns. Elevation usually above 2000'. ---------- -- C

BB. Vegetation consists primarily of hardwood trees and chaparrel, billowy or smooth texture and rounded crowns. Often with intermittent cover of brown-colored dried grasses. Topography usually rolling to steep hills, elevations below 2000'. West of the Sierra Crest --- Valley Front

C. Areas uniformly heavily timbered, on the western slopes of the Sierra. Location is immediately east of the Valley Front and west of the Crest or Eastside. Topography moderately hilly to steep elevations generally between 2000' and 8000'. -------------- Westside Intermediate

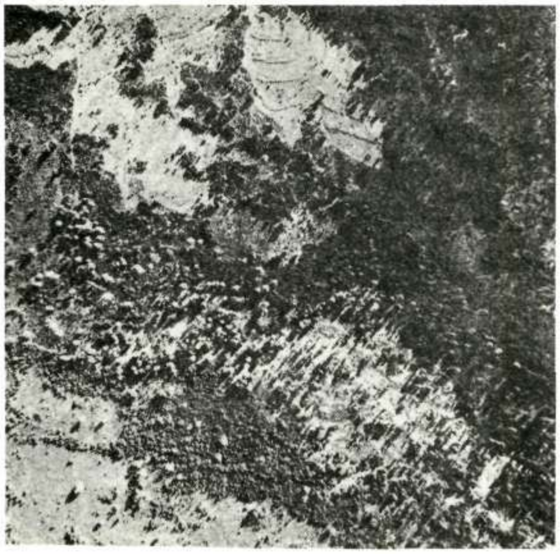
CC. Areas not uniformly timbered, but often with large interspersed flat areas covered with grass or semiarid shrubs. Location is east of the Crest or Westside, and west of the Basin shrub types. Topography moderately steep, but with some large flat areas, elevation between 4000' and 8000'/ ------------------------------ Eastside Intermediate

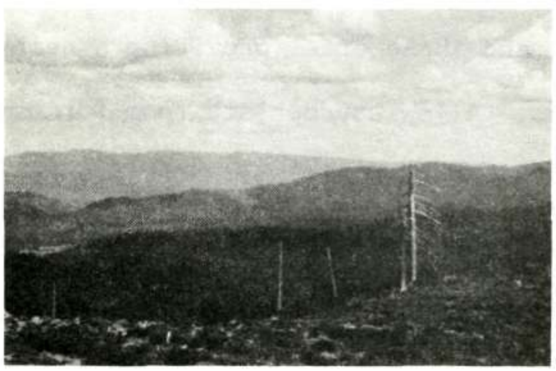
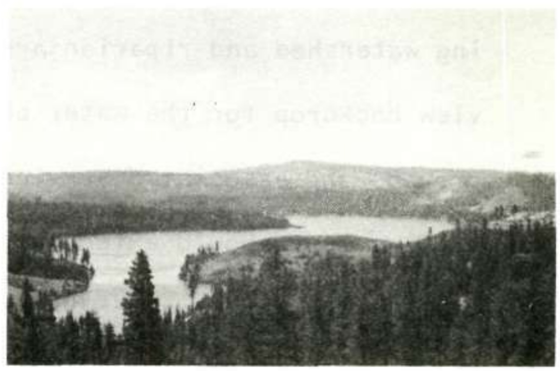
Section II: Selective Key to General Zones

The following pages contain aerial photo examples of each of the four General Zones as they appear on Infrared Ektachrome film. An attempt has been made to illustrate some of the variability that might be expected. In addition to the aerial photographs, Ektachrome ground photos of each of the zones are presented to more clearly indicate the nature of each zones. If, upon study of these illustrations, it appears that an interpretation error has been committed, reference should be made to the word key.

(Note: only one of the examples of a General Zone is included in this progress report.)

Westside Intermediate



Distinguished primarily by the prevalence of extensive stands of coniferous trees, often intermingled with meadows or brushfields.

Section III: Guide to Use and Occupancy Zones

Once the entire area in question has been subdivided into General Zones, Use and Occupancy Zones are to be delineated. In general, only a small proportion of the total area will fall within one of these zones. Minimum required area varies as noted in each zone description. In cases where more than one zone designation might apply to the same parcel of land, refer to the table discussing conflicting designations.

1. Delineate all areas obviously comprising towns or settlements including associated service areas, and commercial agricultural land, i.e., that which is fenced into regular geometric patterns, or with obvious irrigation or cultivation patterns. Minimum area, 40 acres -- General Occupancy
2. Delineate all areas within 200 yeards of all paved highways ---Travel Influence
3. Locate all lakes greater than 10 acres in area, and rivers averaging more than 30 feet in width which appear to possess potential value as recreational sites. Delineate boundaries of the immediately surrounding watershed and riparian areas, and those areas providing a near-view backdrop for the water bodies. Allow appropriate room for campgrounds and associated services. Boundaries will of necessity be subjective, but should extend at least 400 yards from lakes and 200 yards from rivers -- Water Influence
4. Delineate all areas within 200 feet of live streams,[1] including all associated riparian vegetation --------------------------- Streamside

---

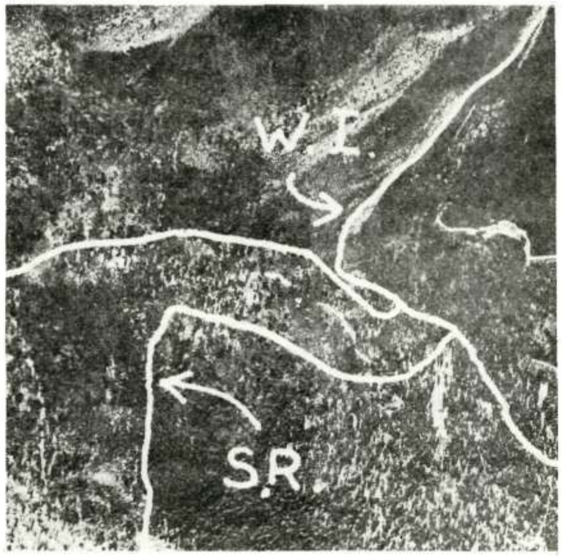
[1] A live stream is one in which water is clearly discernible in the photo, but having an average width of less than 30 feet, thereby differentiating it from a river.

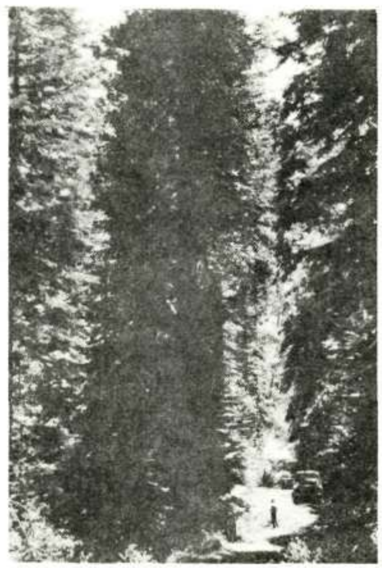
Section IV: Selective Key to Use and Occupancy Zones

The following pages illustrate examples of each of the Use and Occupancy Zones as seen on Infrared Ektachrome aerial photographs, as well as Ektachrome ground photos of such zones. The examples here are not meant to be representative of all variations possible in each category, but are at least indicative of the variability that might be expected.

(Note: Only one of the examples of a Use and Occupancy Zone is included in this progress report.)

Scenic Roadside





Secondary roads which provide access to areas of particular interest should be designated as Scenic Roadside Zones to insure that aesthetic qualities are preserved. The zone should extend at least 200 feet out from the roadway, and further if conditions warrant. In the aerial photograph above, both a Scenic Roadside Zone and the Water Influence Zone which it serves are illustrated.

Section V: Dichotomous Key to Cover Type Designations

As a final step in completing the zone description code, each zone should be typed as to its predominant cover type. Reference should be made to the following dichotomous key. In addition to the cover types which are included in the designations, a number of other features appear in the key which might be of value in the interpretation procedure. (It should be remembered that this key is designed for use with Ektachrome Infrared photographs, with a scale of approximately 1:25,000, obtained during the summer seasonal state.)

A. Color red or pink, sometimes mottled with light or dark background -- B

AA. Color not red or pink (usually white, grey, blue, green or black) -- J

B. Texture coarse or medium, readily apparent ------------- C

BB. Texture smooth or fine, not readily apparent ----------- F

C. Crowns of individual trees readily discernible, coarse texture, rounded crowns and conical shadows sometimes apparent ---------- D

CC. Crowns of individual trees bare discernible, fine stippled texture -- E

D. Crown closure greater than 50 percent. Red crowns and black shadows visible, little light-toned soil or rock showing ---------------------- Dense Mature Conifer Forest

DD. Crown closure 5 to 50 percent. Red tree crowns, black shadows and light soil or rock all visible. Background may be pink, due to ground cover--- Sparse Mature Conifer Forest

E. Crown closure greater than 80 percent, entire area evenly stippled, no light soil or rock visible --------- Dense Young Conifer Forest

EE. Crown closure 5 to 80 percent, small red crowns causing stippled appearance against light-colored or pink background ------------------------------------- Sparse Young Conifer Forest

F. Color dark red or brownish red, usually occurring on upland sites -- G

FF. Color bright red or pink, generally occurring on lowland areas or in gullies -- H

G. Smooth textured reddish areas providing almost total cover, less than 20 percent coverage due to bare soil------------- Dense Chaparral

GG. Smooth textured reddish areas intermingled with light-colored rocks or soil, more than 20 percent coverage due to bare soil- Sparse Chaparral

H. Very smooth texture, vegetation occurring on level ground, color bright red ----------------- Lush Herbaceous Vegetation

HH. Billowy texture discernible, color bright red or pink ----- I

I. Vegetation occurring along gullies or streams or other natural drainage areas. Often only small patches, surrounded by other types of vegetation ------------------- Riparian Hardwood Vegetation

II. Vegetation often occurring over widespread areas, usually on relatively dry sites. Common in Valley Front Zone ---- Dry Site Hardwood

J. Features displaying conspicuous linear patterns or shape -- K

JJ. No regular linear patterns apparent ---------------------- M

K. Features linear or sinuous -------------------------------------- L

KK. Features often irregular in shape, light in tone, with narrow parallel bands crossing them --------------------- Windrowed Brushfields

L. Features narrow, often forming a network of large roads -- Roads

LL. Features slightly wider than (L) rarely forming a network, always occurring on flat terrain ------------ Dredge Tailings

M. Features very light in tone ---------------------------------- N

MM. Features dark in tone -- P

N. Areas intense white, usually associated with higher elevations, decreasing in extent during the late spring; non-existent in summer and fall -------------------------- Snow

NN. Areas light grey, tan, blue or yellow -------------------- O

O. Features usually irregular in outline, with some scattered trees or brush, often occurring on uneven terrain ---------- Bare Rock or Soil

OO. Features may be regular or irregular in outline, light brown in color, usually on level terrain, often associated with bright red lush grassland --------------------------- Dry Herbaceous Vegetation

P. Color dark brown, resulting from fine dark stippling against a lighter background. Usually occurring only within the Eastside Intermediate Zone ------- <u>Semi-arid Shrubs</u>

PP. Color black, deep blue, or dark brown. Stippling as above not apparent -- Q

Q. Surfaces perfectly level, little texture apparent ----------------- R

QQ. Surface usually not flat, rough texture apparent --- <u>Bare Rock or Soil</u>

R. Color uniform black or dark blue except for occasional white sun glint ------------------------- <u>Deep Lakes and Ponds</u>

RR. Color uniform black or dark blue except for some red mottling due to aquatic vegetation
--------------------------- <u>Shallow Lakes and Ponds or Marshes</u>

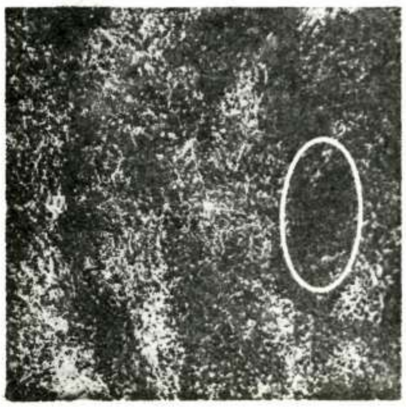
Section VI: Selective Key to Cover Type Designations

The following selective key includes aerial photo examples at various scales, as indicated, and ground photo examples of each of the Cover Type Designations. In most cases both Ektachrome and Infrared Ektachrome ground photo examples are included.

When a designation is being assigned to a zone, only the predominant cover type is included. Thus a subjective evaluation as to the predominant type is necessary.

(Note: Only two examples of Cover Type Designations are included in this progress report.)

Dense Mature Conifer Forest

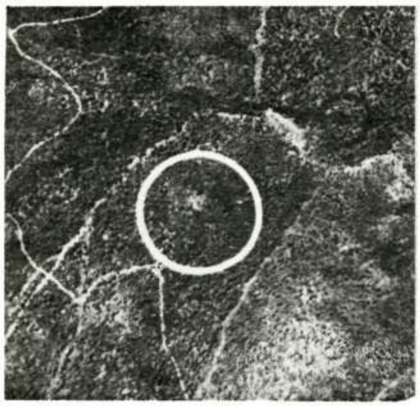


1:25,000

1:20,000

The distinguishing characteristics on the aerial view is the relatively coarse texture wherein individual crowns are visible against a primarily dark background caused by shadows. Occasionally light-colored soil may be visible through openings in the crown canopy. If less than 50% of the area consists of tree crowns, the type should be classified as "sparse mature conifers."

Dry Site Hardwood Vegetation



1:25,000

1:20,000

Color bright red or pink, often with a billowy texture. Generally occurring on well-drained exposed hillsides at lower elevations.

d) Evaluation

The zoning system described above can be evaluated on two bases, namely: (1) the degree to which the system satisfies the user's needs, i.e., the usefulness of the zones as described in terms of multiple use planning, and (2) the facility and accuracy with which the zoning can be performed using aerial photos.

As was discussed in the 1969 progress report, the conducting of a highly quantitative test of the effectiveness of a mapping or interpretation procedure such as the one described here is a nearly impossible task. The principal problem arises from the fact that there exists essentially no basis for a comparison between the mapping done by the experimental method and the "real" or "true" boundaries. In other words, no ground truth exists for use in quantifying the "correctness" of the mapping. The existing multiple-use maps are not appropriate as a reference, since they were produced using an entirely different set of criteria. The only other alternative would be to compare maps produced by the photo interpreter with those produced by a panel of experts, who used both photos and field checking procedures, but this again might not result in an objective evaluation. For this reason, quantitative tests were not made, but rather it was decided to merely subjectively evaluate the multiple use zoning criteria and photo interpretation key. In a way, the preparation of a key or guide to photo interpretation is in itself a good subjective test of the feasibility of performing the interpretation, as nearly all the questions that would arise in the fully operational situation will arise in the process of compiling the key.

In terms of the usefulness of the zoning procedure, it would seem that its primary advantage lies in the fact that a means is provided for rapidly and uniformly classifying large areas of wildlands. In attempting to define the multiple use concept as envisioned by the U. S. Forest Service, the author was continually confused by the multitude of different zoning systems used. It was apparent that even within a Region, which is one of the basic planning units of the Forest Service, many different classification schemes were used. As more and more pressure is brought to bear on the managers of wildland areas to allocate each acre of public land to its "best" use, uniform land evaluation procedures will be needed so that land needs and the resources available can be intelligently balanced over fairly large administrative areas. As was stated earlier, the zoning scheme presented here was not meant to provide the final and absolute land use boundaries, but was meant to provide an initial framework upon which more detailed classifications based on additional information could be built if needed. Finally, it should be kept in mind that the categories or zones discussed specifically in this report are not meant to be applicable to regions other than that for which they were specifically derived.

As to the feasibility of performing the zoning on aerial photography, it seems obvious that both the General Zones and the Cover Type Designations present little problem to the photo interpreter, since both breakdowns depend almost entirely on physical characteristics of the landscape. Consequently, an interpreter, by referring to the photo interpretation guides alone should be able to adequately make the appropriate delineations. This of course is a direct result of the fact that the identification of natural terrain features is quite easy on Infrared Ektachrome photography taken at a scale of 1:30,000. The Use and Occupancy Zones, however, are somewhat more difficult to delineate since they depend to a slightly greater extent on the interpreter's reasoning. As an example, the boundaries of a Water Influence Zone should be such that the watershed and near-view backdrop are protected, and are based on the potential of the site as a recreation area. Here only experience and the intelligence of the interpreter will provide for reasonable delineations, as the requisite information simply cannot be included in a photo interpretation key. However, emphasis should again be placed on the fact that further refinement of the boundaries based on ground checking or additional information is possible, and in fact recommended.

The experience gained through the development of the zoning system presented here suggests several principles to be kept in mind when approaching the problem of photo interpretation for land use planning purposes. The most crucial and difficult step is the definition of the problem, and what one hopes to accomplish through the interpretation, in very precise terms. As can be seen from the example discussed in this study, the final set of interpretation guidelines are a function of the management objectives, and these will, of course, vary greatly depending on the owner or administrator of the land in question. In this study, for example, it was deemed necessary to examine the multiple use concept as practiced by the U. S. Forest Service in some detail so as to ascertain exactly what kinds of data are required by those persons responsible for the actual application of multiple use practices (and hence, those who would use the results of the interpretation and mapping.)

Secondly, the uses and limitations of various remote sensing techniques must be kept in mind, such that, given the objectives of the survey, the proper techniques might be selected. It is desirable to use remote sensing to the greatest extent possible, if appropriate, but inefficiencies can easily arise if operations are attempted which are beyond the capability of the system being employed. For example, in the multiple use mapping case, it was decided that certain determinations as to land use must be left to subsequent on-the-ground evaluations. At the same time, the zoning procedures were set up so as to be as amenable to these subsequent revisions, if needed, as possible.

Finally, the specific procedures to be followed in the photo interpretation process should be presented in as complete and clear a fashion as possible. In most operational cases, the actual image interpretation will be carried out by different persons than those who formulate the procedures. It is easy for one who is quite knowledgeable as to the requirements of the interpretation process and the land involved to carry out interpretation with only a minimum of written instructions. In the case of extensive surveys, however, the interpreters will probably require carefully compiled keys and guides which, if they are not carefully evaluated, can easily lead to confusion on the part of the interpreter. On the other hand, a good photo interpretation key should serve to facilitate the interpretation process without confusion or ambiguity.

II. CONSIDERATION OF THE EFFECTS OF PROBABLE FUTURE DEVELOPMENTS

The investigations reported herein have up to this point dealt entirely with operational image procurement systems. That is, it is possible for any agency or individual to obtain Infrared Ektachrome aerial photography at a scale of 1:30,000 through contracts with private photography firms, and be reasonably assured of prompt and satisfactory delivery. However, much of the research conducted during the last few years in the field of remote sensing has concentrated on various experimental techniques of image acquisition and interpretation. As is true of many experimental systems, speculation as to the future uses has been largely limited to a consideration of the technical feasibility of performing given tasks rather than considering such practical matters as user needs as well.

Thus it seems necessary to include at least a cursory discussion of the role in multiple use management planning which might be played by several of the more widely discussed recent developments in remote sensing techniques. No attempt will be made in this study to provide an exhaustive survey of the characteristics of each system, as much has already been written on these subjects.

a) Small Scale Aerial and Space Photography

The recent advent of very high altitude aircraft and earth orbiting satellites, coupled with very high resolution cameras has made possible the procurement of extremely small scale, high quality photographs. If such factors as focal length and film format are held constant, the net result is much greater areal coverage on each small scale image than on photographs of conventional scale. Among the unique advantages of such small scale imagery are several of interest to the manager of wildland resources:

1. The synoptic view. Probably the most obvious characteristic of small scale imagery is the large area covered by each image, thus enabling any particular feature to be viewed in relation to its surroundings. Often a natural feature which is not readily identified when viewed alone can be identified if it can be related to the surrounding topography. In addition, the synoptic view often enables the interpreter to more fully judge the significance of the various features of interest. Finally, many natural features are of such a large size that they can only be viewed in their entirety from relatively high altitudes.

2. Opportunity for sequential coverage. Often annual, seasonal, or even daily variation in the appearance of a terrain or vegetation type is an aid to its identification, and therefore suggests the desirability of image coverage being obtained at periodic intervals. Theoretically, a satellite in sun-synchronous orbit will pass over any given point of the earth's surface at the same time of day. Thus, with suitable planning and control, any point on the earth's surface can be imaged sequentially as described, with uniform lighting conditions, weather permitting. Furthermore, this capability affords

a chance to obtain imagery of widely spaced points within very short intervals, which is often impossible with conventional aircraft given the usual time, distance, and cost restrictions.

3. Uniformity of the image. In the past, the only available method of examining large areas of land on aerial photos was by means of a photomosaic -- a patchwork of perhaps hundreds of individual photos. Often photos comprising such a mosaic had been obtained at different times of day, at different exposures, or with varying camera orientations. As a result, colors or tones, shadows, weather and ground conditions, and spatial geometry were not constant throughout the mosaic. By means of high-altitude reconnaissance, it is possible to cover vast areas of land with one image, thus providing uniform conditions.

The most obvious factor limiting the usefulness of small scale photography in multiple use planning is the relatively low resolution. While it is possible to obtain fairly high resolution from high altitudes through the use of fine grained films and long focal length lenses, this practice essentially negates many of the advantages of such high-altitude photography. However, even assuming an average ground resolution for natural terrain features of 100 meters, which approximates that of the Apollo 9 photography (see Figure 2.2), it would appear that much can be done in terms of mapping such broad terrain types as are represented by the General Zones discussed earlier in this report. In fact, it could well be that due to the synoptic view afforded by such imagery, this gross mapping could be done better than on photography of a conventional scale. The mapping of more detailed zones, however, could probably be accomplished only to a limited extent on space photography. While certainly features such as large lakes, cities, and some highways can be seen, resolution is generally not good enough to allow the necessary discriminations to be

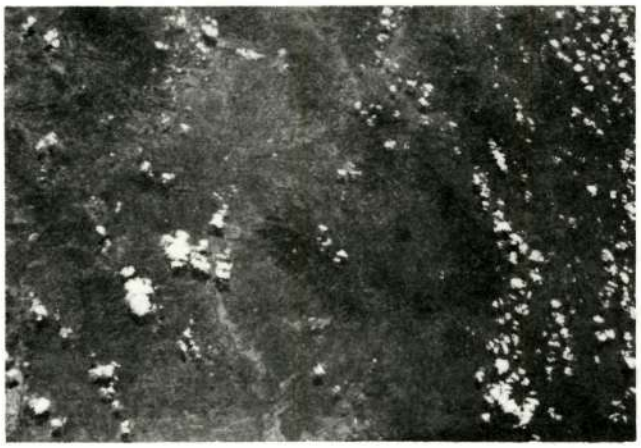


Figure 2.2 Ektachrome photograph of Southeastern Arizona, taken by the Apollo 9 astronauts in March, 1969, from an altitude of over 100 miles. Despite an approximate average ground resolution of no better than about 100 meters, it is entirely possible to delineate broad terrain and vegetation classes with a remarkable degree of accuracy on such photographs. The area covered by the portion of the space photo that is shown here is approximately 60 by 100 miles.

made. The use of high altitude aircraft for such purposes does seem promising. For example, the photograph in Figure 2.3 was taken from an altitude of approximately 60,000 feet, at an original scale of approximately 1:120,000. Obviously many of the discriminations necessary for performing Use and Occupancy zoning and the designation of cover types could be performed on such photography. It should be noted that the original transparency (70 mm format) possessed considerably greater resolution than the print used in the illustration. Thus it would seem that for fairly gross mapping of large areas using the criteria outlined earlier in this report, very small scale photography obtained from high-flying aircraft would be quite satisfactory, but that greater amounts of lower-altitude photography and ground checks would be necessary as the need for more precise and detailed maps arose.

b) Automated Interpretation

A number of systems have recently been developed which are designed to aid the photo interpreter by means of "automatic" computerized feature identification using various types of remote sensing inputs. While the various techniques differ in type of input, method of analysis, and interaction with the human operator, certain generalities can be stated which apply to all. In essence, each system relies on an input of tone values or signal strengths from objects in the area of interest, utilizing one or more portions of the electromagnetic spectrum. These inputs are then "compared" with known "signatures" of terrain types, and tentative identifications are made. In addition, various techniques are used for presenting the output in a pictorial or graphical fashion. Some systems allow for feedback into the decision-making process from a human operator observing the output.

In assessing the applicability of automated interpretation to multiple use planning, two limitations must be considered. First, in nearly all cases

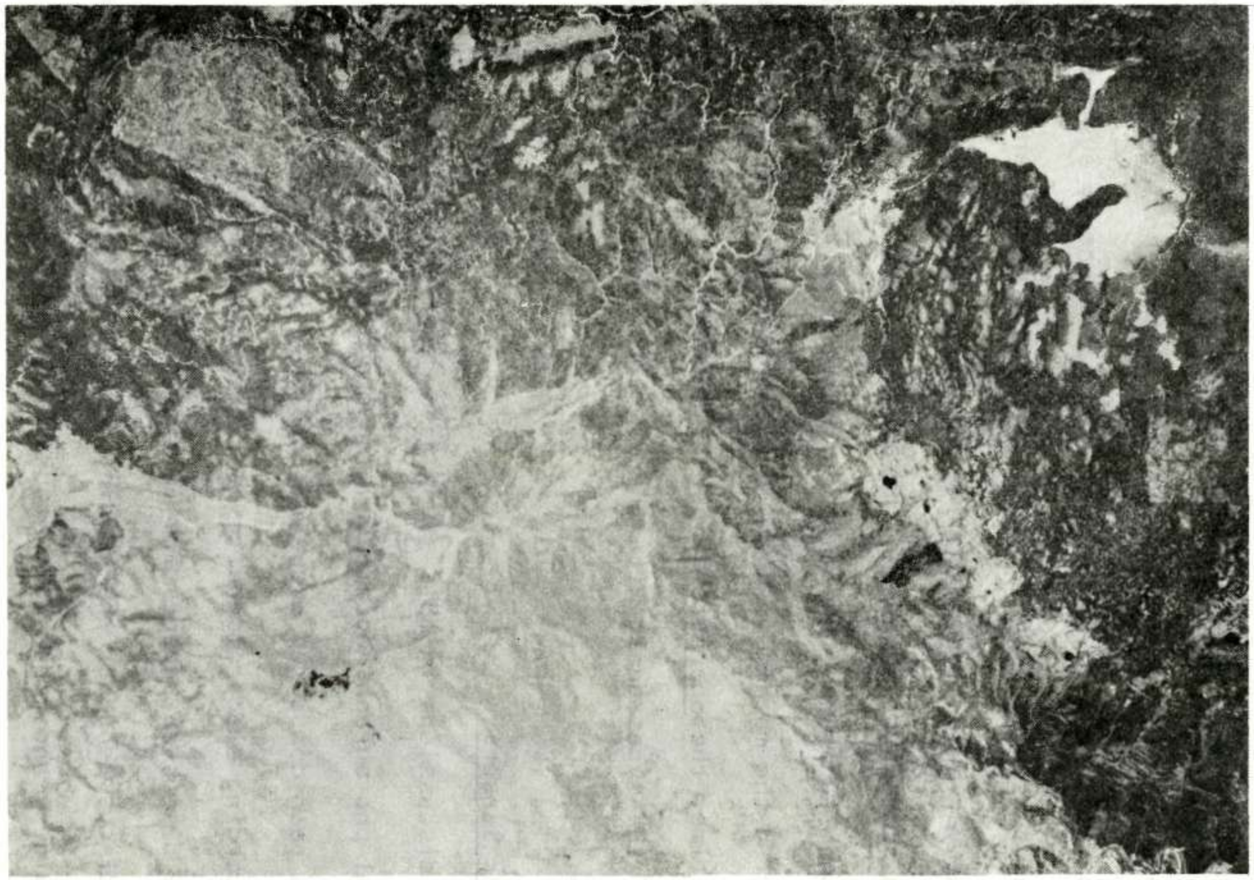


Figure 2.3 Small scale (1:120,000 original scale) Infrared Ektachrome photograph of the Meadow Valley test area. See text for discussion. Date of photography: July 18, 1969.

identification of features depends heavily on the existence of unique tone signatures for natural features as recorded on remote sensing data. Enough apparent contradictions to this assumption have been observed; however, to cause doubt as to the adequacy of present techniques for performing such differentations. Secondly, those systems which seem most applicable to multiple-use mapping depend on some degree of interaction between the operator and the machine, and to date no fully operational and satisfactory systems for accomplishing this have been developed. If satisfactory means can be found for: (1) handling the variable-signature problem, (2) providing for an input to the decision making process of additional parameters relating to the area in question besides tone signatures, and (3) providing for a rapid and efficient interaction of men with the machines, certainly the potential will be encouraging. At the present time, the operational use of automatic techniques for classifying features of the types dealt with in this study does not seem likely for at least 5-10 years.

c) Other Sensors

Earlier discussions in this study have dealt entirely with the interpretation of aerial photographs obtained using conventional cameras. A great deal of research has been conducted recently involving the use of sensors other than cameras for recording electromagnetic radiation from terrain features. Among the more widely discussed sensors are multichannel optical-mechanical scanners, (which will be discussed under the heading of Multiband Sensing) thermal infrared sensing devices, and radar (see Figures 2.4 and 2.5).

Thermal infrared sensors generally utilize radiation at wavelengths of 3 to 14 microns, and record emitted energy which is a function of the temperature and emissivity of the target. Some of the most promising applications to resource management have been in terms of determination of soil moisture and monitoring of water temperature patterns and thermal pollution of water bodies. Application to multiple use mapping would seem to be peripheral in nature -- i.e., in special cases where soil moisture or water temperature is of particular interest, such sensors might provide information which would assist the interpreter in making decisions relative to potential land use.

Radar differs from most other sensors in that rather than depending on the sun as a source of energy, the energy is generated by the instrument itself, in a manner somewhat analogous to a "flash" photograph. Furthermore, radar operates at fairly long wavelengths, typically in the range of from one centimeter to one meter. The primary advantage of radar is that it has essentially an all-weather, day-or-night capability, while its most obvious disadvantage is low resolution. This disadvantage, as compared with other sensors, is minimized if radar is operated from orbital altitudes, since resolution is essentially range-independent for many radar systems, but not for other sensing systems. The most probable way in which radar could be of use in multiple use mapping is in a preliminary mapping of the broad General Zones in areas where, because of illumination or weather conditions, conventional photography is not practical. No definitive tests have been performed to date on the use of radar in mapping natural terrain features, but it would seem that presently unclassified systems are not suitable for detaiied land use mapping in mountainous wildland regions.

d) <u>Multiband Sensing</u>

The term "multiband sensing" refers to the acquiring of data from a number of bands of the electromagnetic spectrum for use in the discrimination or identification of terrain features. This procedure is based on the principle that since all materials vary uniquely in their pattern of reflectance or emission of energy through the electromagnetic spectrum, it is often possible to differentiate between two or more features only through the analysis of

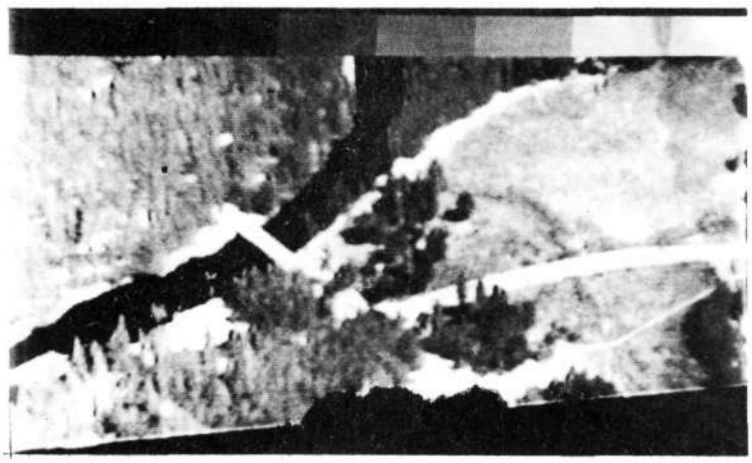


Figure 2.4 A thermal infrared image of a portion of Yosemite Valley, obtained with an instrument operating in the 8-14 micron band, at approximately 10 a.m., in June 1966. The tonal differences in the meadow on the right indicate variable soil moisture conditions which were not apparent on any types of conventional photography

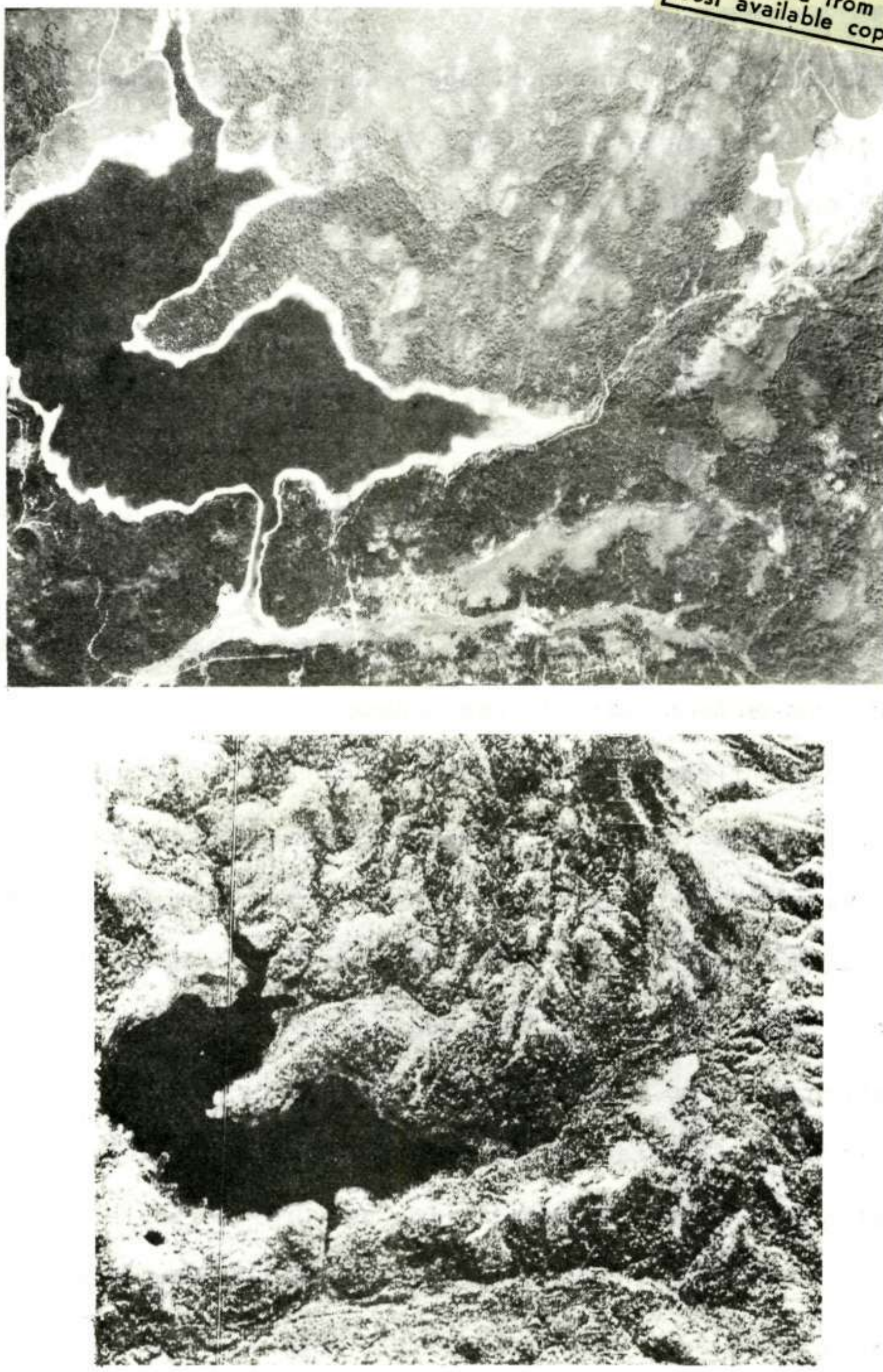


Figure 2.5 A panchromatic photograph, top, and a K-band radar image below, of a portion of the Meadow Valley Test Site. An examination of these images reveals that while gross topography and vegetation differences are discernible on the radar, resolution is such that more detailed discriminations are impossible. Dates of photography for the two images are different, thus precluding comparisons of water level in the reservoir.

several appropriately selected, relatively narrow wavelength intervals rather than only a single wide band.

The acquisition of multiband imagery can be accomplished either through the use of several separate sensing devices, each utilizing a different portion of the spectrum or by specially designed instruments such as multiband cameras or multichannel optical-mechanical scanners which sense simultaneously in several wavelength bands. The multiband data can be analyzed either visually, by an interpreter viewing images separately or recombined into composite images, or by means of automated interpretation, or by some combination of the two.

The real advantage of multiband sensing lies in its ability to facilitate the differentiation of features which are not obviously different when seen in a single broad spectral band. It would seem that, in general, the kinds of data required to perform multiple use management planning using aerial images are such that the identification of terrain features is not the limiting factor. Therefore, in most cases the use of sophisticated multiband sensing devices should not be necessary. (Unless color aerial photography is considered to be a form of multiband sensing, which in a sense it is.) Where multiband procedures could most likely be used in the future is in situations necessitating the classification of large areas of land, and where, for the sake of efficiency, the process must be facilitated to the greatest extent possible. That is, while multiband sensing may not be a necessity for performing the job, it could, when combined with such techniques as additive color enhancement (see Figure 2.6) make the job quicker and easier. For example, the image in Figure 2.6 is, in essence, a color-coded map wherein each color represents a specific cover-type designations. Thus it might be possible to bypass several steps in the conventional process in which the interpreter first inspects the photos, transfers his findings to a map, and the map is color-coded to each type, by producing the "visual

Figure 2.6 A color composite image produced through the simultaneous projection of several black-and-white multiband photographs through colored filters onto a viewing screen. On this photo, bare granite appears pink and vegetation yellow or green. Such a process can, in some cases, greatly facilitate the rapid scanning of many images for the detection of a specific terrain feature. This same area is clearly seen in the lower right quadrant of Figure 2.3.

aid" directly from the multiband imagery by means of color enhancement.

III SUMMARY AND CONCLUSION

The primary objective of this study was to investigate what would seem to be one of the more promising uses for remote sensing data -- namely the use of such data in making integrated interpretations of operational management units, in their entirety. In accordance with that objective, an attempt was made to define the information needs of wildland managers, and to evaluate the ways in which remote sensing data could satisfy those needs.

Initially, it appeared that the role of remote sensing techniques would most appropriately be in amassing numerous bits of data pertaining to the physical resources of an area which would in turn be fed into a complex optimization formula through which optimum uses for each acre of land could be planned. However, when the actual nature of multiple use management as practiced by public land management agencies was carefully investigated, it became apparent that supplementary data necessary for such complex determinations of land use were simply not available. For example, in addition to information pertaining to the physical attributes of the land (much of which is obtainable by remote sensing), data are needed as to the costs and benefits, both tangible and intangible, which would accrue from alternative land uses. Such data often cannot be quantified. Public land managers are officially bound to practice multiple use management, however, which at the present time consists of a consideration of the various possible land uses, plus the practice of "multiple use zoning." This zoning, while varying from location to location, provides a means of breaking large land areas down into units for which certain priorities of land use are specified, based more on common sense and experience than on any particularly complex analytical technique.

It was found that the zoning <u>as currently practiced</u> is not easily accomplished by means of remote sensing. This is due to a variety of factors, but chiefly because the existing system was simply not developed with aerial photo classification in mind. Therefore an attempt was made to establish a system of zoning which would apply to a fairly large area and which would be amenable to the use of aerial photography. A system of zones was decided upon which seemed to provide to a large extent the same information included in the existing system, with certain exceptions wherein some ground checking or supplementary information is necessary. As an example of how training materials for such a photo-based system might be prepared, and as an informal test of the feasibility of performing the zoning on conventional aerial photography, an extensive set of photo interpretation keys and guides was prepared and tested. Finally, several of the more recent developments in the field of remote sensing were discussed in terms of their applicability to multiple use land planning.

In conclusion, it can be stated that, given certain concessions by those persons or agencies responsible for land use allocation, it would seem that remote sensing techniques can at least contribute to the solution of certain planning problems such as multiple use zoning. As is the case in most instances where useful applications for remote sensing techniques are being investigated, the biggest problem encountered in this study was not that of defining the capabilities of remote data gathering systems, but rather of ascertaining precisely what types of data need to be gathered. Only when the land manager can precisely list the information that he needs as an input to his decision making process can the remote sensing specialist adequately assay the potential of his techniques for contributing to the solution of the problem. Once this has been done, it is probable that the full potential of remote sensing could best be realized through modifications of present remote sensing data acquisition systems and analysis techniques based on a cognizance of the application problems in need of solution. Even without such modifications, however, it is apparent from tests reported upon herein that modern remote sensing techniques can be of very great value to those wishing to classify wildland areas into appropriate land use zones, and in making integrated interpretations of operational management units.

Future Research Activities

The activities of the Operational Feasibility Unit during the next funding year will fall into three general categories: (1) cooperation with the Image Interpretation and Enhancement Unit in the continued development of procedures for assessing interpreter performance, (2) the expansion of the agricultural studies reported in Appendix I of this report to new geographical areas, and (3) collaboration with land management and policy-making agencies in the State of California in an attempt to summarize potential uses of ERTS-type data within the state, and define procedures necessary for expediting those uses. Comments about these three proposed areas of emphasis for future research are found in the following paragraphs.

The Forestry Remote Sensing Laboratory has become increasingly involved in quantitative evaluations of the ability of remote sensing systems of various types to aid in the gathering of information relative to particular natural resource problems. For a so-called "quantitative" evaluation to be of greatest use, however, more is required than simply the production of numerical data. In general, the potential ultimate user of remote sensing techniques needs to extrapolate research findings to his particular needs in order to ascertain whether a given procedure should be adopted on an operational basis. Such extrapolations can often be greatly facilitated by researchers if procedures followed during the testing and analysis phase are analogous to those which could be expected to be present in the operational context, and if the specific application being tested is one which fulfills a user requirement.

The successes realized in the inventory of small grain crops in Maricopa

County, Arizona (see Appendix I) have led to a desire to attempt similar surveys on other major crops in the Arizona test site, and in other geographical areas. Consequently, preliminary investigations are being carried out in the Central Valley of California to ascertain such things as relative importance and distribution of crops, general cropping cycles, and the status of already-existing crop inventory programs.

It has become increasingly apparent, as the scheduled launch data for the Earth Resource Technology Satellite draws near, that while there are a number of prospective users of ERTS-type data among the state and federal resource management agencies in California, most if not all of these agencies may not be prepared to utilize this data when it becomes available. We hope to alleviate this problem by surveying prospective data users as to their requirements, advising them as to the technical aspects of the ERTS system and necessary data interpretation, compiling lists of common data acquisition needs among agencies, and helping to establish a coordinated effort within the state in regard to cooperative acquisition, distribution and analysis of ERTS data.

Bibliography

American Society of Photogrammetry. 1960. Manual of photographic interpretation. Banta Co. Menasha, Wisconsin. 868 pp.

Badgley, P. C. and W. L. Vest. 1966. Orbital remote sensing and natural resources. Photogrammetric Engineering 32(5):780-790.

Badgley, P. C., A. P. Colvocoresses and C. D. Centers. 1968. NASA Earth-Sensing Space Experiments. Photogrammetric Engineering 34(2):162-169.

Belcher, D. S. 1969. Land Use and Natural Resources Inventories. Amer. Astro. Soc. Annual Meeting, Paper AAS69-573.

Benn, B. O. and W. E. Grabau. 1968. Terrain Evaluation as a Function of User Requirements. In Land Evaluation, Macmillan, Melbourne, Australia.

Bock, Peter and J. G. Barmby. 1969. Survey Effectiveness of Spacecraft Remote Sensors. Photogrammetric Engineering 35(8):756-762.

Carneggie, David M. and J. Reppert. 1968. Large Scale 70mm Aerial Color Photography--A Potential Tool for Improving Range Resource Inventories. Proceedings, Annual Meeting American Society of Photogrammetry, March 1968.

Center for Aerial Photographic Studies, Cornell University, 1967. "Potential Benefits to be Derived from Applications of Remote Sensing of Agricultural, Forest and Range Resources." Ithaca, New York.

Center for Aerial Photographic Studies, Cornell University, 1969. "Development of a Land Use Classification System Based on Interpretation of Imagery from the Earth Resources Technology Satellite." Interim Report on Contract Project for the Economic Research Service, USDA.

Choat, G. A. 1957. A selected annotated bibliography of aerial photo interpretation keys to forests and other natural vegetation. Journal of Forestry 55(7):513-515.

Clawson, Marion and C. L. Stewart. 1965. Land Use Information. Resources for the Future, Washington, D. C.

Clawson, Marion and B. Held. 1957. The Federal Lands: Their Use and Management. University of Nebraska Press. 501 pp.

Colwell, R. N. 1952. Report on Commission VII to the International Society of Photogrammetry. Photogrammetric Engineering 18(3) 375-400.

Colwell, R. N. 1964. Potential uses of satellite photography for natural resource surveys. For "Open Space and Peace," Hoover Institution, Stanford, California.

Dana, Samuel T., and Myron Kreuger. 1958. California Lands. American Forestry Association, Washington, D. C. 308 pp.

Doverspike, Flynn and Heller. 1965. Microdensitometer Applied to Land Use Classification. Photogrammetric Engineering 31(2):294-306.

Draeger, W. C. 1968. The Interpretability of High altitude multispectral imagery for the evaluation of wildland resources. Annual Progress Report for the National Aeronautics and Space Administration.

Draeger, W. C. and D. T. Lauer. 1967. Present and future forestry applications of remote sensing from space. AIAA Paper #67-765.

Hegg, Karl M. 1966. A Photo Identification Guide for the Land and Forest Types of Interior Alaska. 55pp. USFS Research Paper NOR-3.

Herrington, R. B. and R. Tocher. 1967. Aerial Photo Techniques for a Recreation Inventory of Mountain Streams and Lakes. USFS Research Paper INT-37.

Hirsch, S. N. 1965. Infrared Line Scanners--A Tool for Remote Sensing of Forested Areas. Proceedings of the Society of American Foresters, Detroit, 1965.

Holter, M. R. 1967. Infrared and Multispectral Sensing. Bioscience 17(6): 376-383. June 1967.

Katz, Amram H. 1960. Observation Satellites: Problems and Prospects. Astronautics, April 1960.

Kuchler, A. W. 1967. Vegetation Mapping. 1967. The Ronald Press, N.Y. 472 pp.

Langley, Philip G. 1965. Automating Aerial Photo Interpretation in Forestry--How It Works and What It Will Do For You. Proceedings of the Society of American Foresters. Detroit, 1965.

Litton, R. Burton. 1968. Forest Landscape Description and Inventories-- A Basis for Land Planning and Design. USFS Research Paper PSW-49.

Martin, Philip L. 1969. Conflict Resolution Through the Multiple-Use Concept in Forest Service Decision Making. Natural Resource Journal 9(2):228-236.

Moore, Richard K. and D. S. Simonett. 1967. Radar Remote Sensing in Biology. Bioscience 17 (6):384-390. June 1967.

McConnell, Grant. 1965. The Multiple-Use Concept in Forest Service Policy. Sierra Club Bulletin 44(7):14-28.

National Aeronautics and Space Administration. 1967. A survey of space applications..."for the benefit of all mankind." Space Applications Program Office, Office of Space Science and Applications. Washington, D. C. NASA SP-142.

Olson, Charles E. 1965. Infrared Sensors and Their Potential Applications to Forestry. Papers of Michigan Academy of Science, Arts and Letters. Vol. L, 1965.

Ory, T. R. 1965. Line Scanning Reconnaissance Systems in Land Utilization and Terrain Studies. 3rd Symposium on Remote Sensing of the Environment.

Sadacca, R. 1963. Human factors in image interpretation. Photogrammetric Engineering. 24(6):978-988.

Starr, Warren A. 1961. Multiple Land Use Management. Natural Resource Journal. 1(2):288-301.

Steiner, D. 1965. Use of Air Photographs for Interpreting and Mapping Rural Land Use in the United States. Photogrammetria 20(2):65-80. April 1965.

Stellingwerf, D. A. 1968. Practical Applications of Aerial Photographs in Forestry and Other Vegetation Studies. International Training Center for Aerial Surveys. ITC Pub. Series B, #46, 47, 48.

U. S. Congress. 1960. Public Law 86-517, Multiple Use Act. 86th Congress, H.R. 10572. June 12, 1960.

USDA, Forest Service. 1954. Field manual, soil-vegetation survey in California. California Forest and Range Experiment Station, Berkeley, California.

USDA, Forest Service, California Region. 1955. Management Direction for the National Forests of Sequoia Eastside Subregion.

USDA, Forest Service, Region 5. 1955. Management Direction for the Northeast Plateau Subregion.

USDA, Forest Service. 1957. Timber Management Handbook, Chapter I, Management Plans.

USDA, Forest Service, Intermountain Region. 1962. Multiple Use Management Plan for National Forest Lands--Lake Tahoe Basin.

USDA, Forest Service. 1962. Multiple Use Management Plan for Quincy Ranger District, Plumas National Forest.

USDA, Forest Service. 1966. "Field Instructions for Integrated Forest Survey-Timber Management Inventories in California." PSW and PNW Forest and Range Experiment Stations and Region 5, Forest Service, San Francisco, California.

USDA, Forest Service. 1967. Forest Service Manual, Region 5 Supplement #31. (Multiple Use Coordination)

White, Gilbert F. 1961. The Choice of Use in Resource Management. Natural Resource Journal 1(1):23-40.

Wilson, Richard C. "Surveys Particularly Applicable to Extensive Forest Areas." Proceedings of Fifth World Forestry Congress, pp. 257-263. The National Publishing Co., Washington, D. C.

Wilson, Richard D. 1967. "Space Photography for Forestry." Photogrammetric Engineering 23(5):483-490.

Zinke, Paul J. 1960. The Soil-Vegetation Survey as a Means of Classifying Land for Multiple Use Forestry. Proceedings 5th World Forestry Congress, Seattle, Washington.

Zivnuska, John A. 1961. The Multiple Problems of Multiple Use. Journal of Forestry 59(8):555-560.

CHAPTER 3

SPECTRAL CHARACTERISTICS

Edwin H. Roberts

Introduction

The basic purpose of the Spectral Characteristics Unit is to investigate and characterize the spectral reflectance properties of natural surfaces. The Unit seeks to determine the parameters of illumination and target features which significantly affect the spectral reflectance as it might be observed by a remote sensing device. The data from these investigations will aid in the determination of (1) spectral regions most useful for discrimination among particular features of interest, (2) the times of year most likely to enhance these discriminations, and (3) analysis methods for interpretation of the resulting imagery.

Current Research Activities

A. Standardization of Spectral Data

Spectral measurements of several common brush species have been taken during the past year and have been shown to correlate well with relative negative densities obtained from multiband aerial photography of these same species as encountered at the NASA Bucks Lake test site. However, because the spectral irradiance of incident illumination was not measured it was necessary to limit the acquisition of spectral measurements to high sun angles on clear days, relying on the assumption that over a short part of the season the illumination at these high sun angles is reasonably constant.

During the field season of this reporting period a spectroradiometer was received which allows meaningful measurements to be made of spectral radiant emittance under various illumination conditions caused by changes in season, time of day, sun angle, and atmospheric conditions. Measuring the spectral irradiance from incident illumination at the same time that spectral radiant emittance from the target is being measured has an important advantage -- it enables an adjustment to be applied to the reflectance data to facilitate a comparison with other adjusted data as if all observations had been acquired under the same illumination conditions. Data were gathered to determine the extent to which this technique permits the standardizing of spectral reflectance measurements obtained under a variety of incident illumination conditions.

The method used in this standardization is shown in the following example. The data were obtained on August 10, 1970 for a mixed grass and clover lawn on the Berkeley campus of the University of California. Table 3-1 lists in columns 2-4 the irradiance, as a function of wavelength, incident on the lawn at three different times during the day. The data from these columns are also presented as a graph in Figure 3-1. For each wavelength the irradiance from the incident illumination at time 1245 has been divided by the irradiance at time 1030 to give a ratio which is shown in column 5. Energy reflected from the lawn at time 1245 is shown in the next column followed by energy reflected at time 1030. For each wavelength the energy reflected at time 1030 has been multiplied by the ratio of energy incident at time 1245 to that incident at time 1030. The product is shown as energy reflected at time 1030 adjusted to time 1245. The reflectance data have been standardized in this case to time 1245.

The spectral radiant emittance was measured for exactly the same patch of lawn in all cases. The instruments were not moved between readings and there is no reason to believe that the spectral reflectance properties of the target materials changed significantly in the short period of time occupied by this experiment. Consequently it can be presumed that any dif-

Wavelength (nanometers)	Incident energy (mw/cm² / nm) at time 1245	Incident energy (mw/cm² / nm) at time 1030	Incident energy (mw/cm² / nm) at time 0950	Ratio incident energy at time 1245/time 1030	Reflected energy (W x 10⁻⁸ /cm² / nm) at time 1245	Reflected energy (W x 10⁻⁸ /cm² / nm) at time 1030	Reflected at time 1030 adjusted to time 1245	Ratio incident energy at time 1245/time 0950	Reflected energy (W x 10⁻⁸ /cm² / nm) at time 0950	Reflected energy at time 0950 adjusted to time 1245
400	65.2	52.2	40.6	1.25	3.8	2.6	3.3	1.61	2.4	3.8
425	82.4	61.8	49.4	1.33	5.4	4.0	5.3	1.67	3.7	6.2
450	120.1	80.4	66.4	1.43	6.8	4.6	6.6	1.81	4.6	8.3
475	133.9	88.8	71.0	1.51	7.5	5.2	7.8	1.89	4.9	9.2
500	134.2	89.6	76.8	1.44	9.3	6.4	9.5	1.75	6.4	11.2
525	136.6	90.5	72.5	1.51	17.9	12.8	19.5	1.88	13.0	24.4
550	138.6	94.5	74.9	1.47	22.8	17.8	26.2	1.85	16.3	30.2
575	112.2	87.3	70.6	1.28	16.6	12.3	15.8	1.59	11.6	18.4
600	133.6	90.2	71.5	1.47	13.1	9.4	13.8	1.87	9.4	17.6
625	127.4	86.9	68.9	1.47	10.4	8.0	11.8	1.85	7.3	13.5
650	129.6	88.0	70.2	1.47	8.1	6.0	8.8	1.85	5.9	10.9
675	121.7	83.6	67.1	1.45	6.7	4.9	7.1	1.81	4.5	8.1
700	117.7	84.1	63.8	1.41	15.8	12.0	16.9	1.84	11.3	20.8
750	101.5	71.4	59.5	1.42	105.0	73.3	97.0	1.70	64.2	112.3
800	103.7	76.4	60.1	1.36	113.2	83.4	113.0	1.72	71.5	123.4
850	84.2	62.9	51.0	1.34	100.3	70.2	94.0	1.65	60.2	99.4
900	67.6	53.4	41.8	1.27	82.0	60.4	76.8	1.62	49.6	80.2
950	48.3	33.8	25.8	1.43	52.0	35.4	50.6	1.87	28.3	53.0
1000	54.7	39.8	31.2	1.37	61.7	44.6	61.0	1.75	37.9	66.4
1050	49.8	37.2	30.0	1.34	62.3	44.2	59.2	1.66	36.7	60.9
1100	38.6	26.7	21.8	1.45	69.2	40.0	58.0	1.77	29.7	52.6

Table 3-1. Tabulated irradiance and ratio values used in standardizing spectral data acquired at three different times as explained in the text.

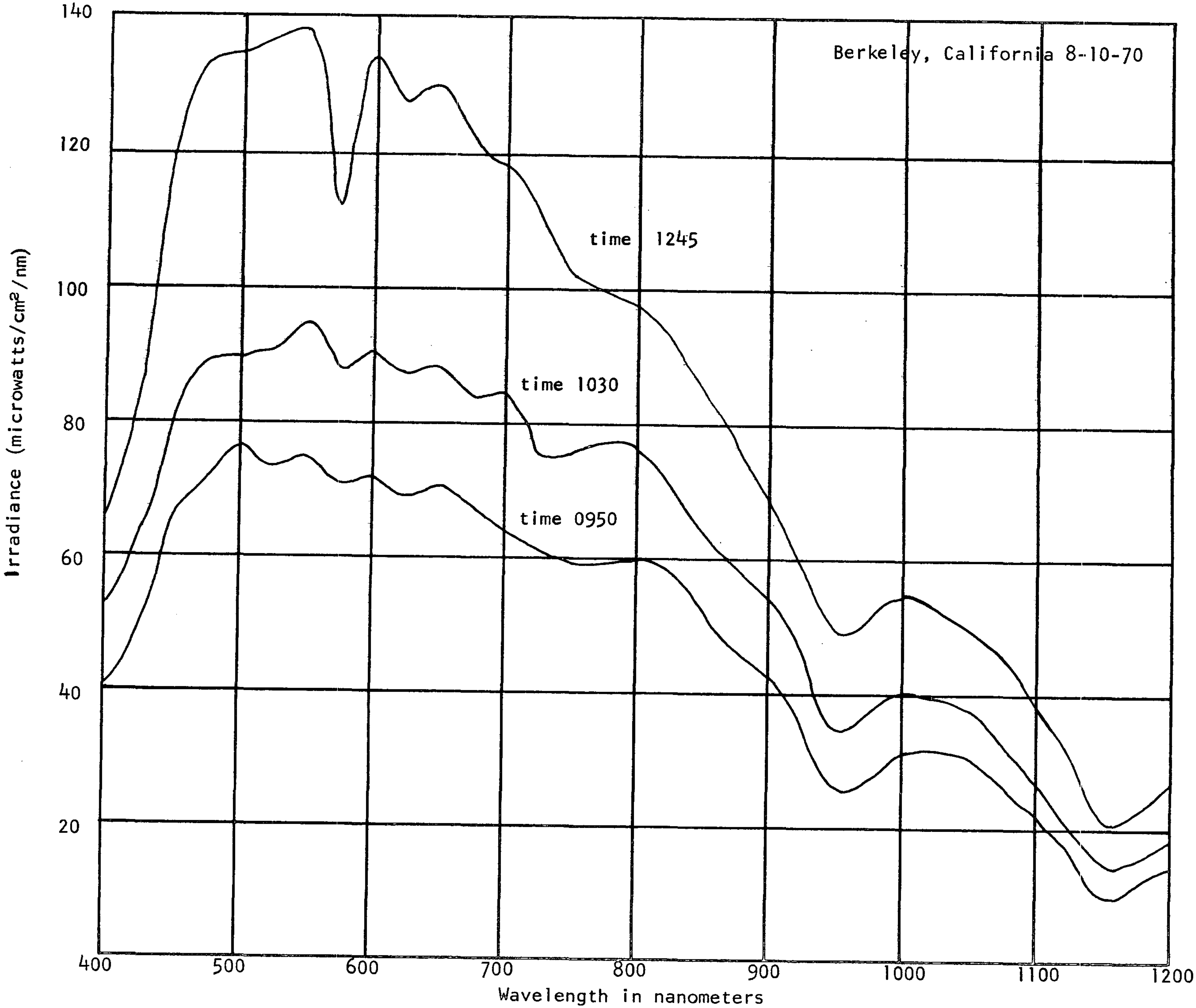


Figure 3-1. Spectral Irradiance incident at three different times of the day.

ferences in the measured spectral radiant emittance are due to (1) changes in the spectral characteristics and/or flux density of the irradiance incident on the lawn or (2) changes in the elevation and azimuth of the main source of the irradiance (the sun). The standardization illustrated here seeks to compensate for changes in the former.

A graph of the adjusted and unadjusted spectral radiant emittance at time 1030 along with that at time 1245 is shown in Figure 3-2. When the curve at time 1030 is compared with the curve at time 1245 (to which the data are being standardized) it can be seen that the adjusted values much more closely approach the values to which they are being standardized than do the unadjusted values. Similar curves for data at time 0950 are shown in Figure 3-3. If a perfect standardization were achieved, the standardized spectral radiant emittance from a given, stable target would be the same no matter what the conditions of illumination.

There will undoubtedly be refinements to the basic method shown here as greater amounts of data become available through use of a data acquisition and analysis system which is briefly described in Section B. It is intended that data will be "standardized" to an arbitrary illumination spectrum which will be approximately an average, clear, midday, summer condition.

B. Spectral Acquisition System

There are many external factors in addition to the spectral intensity of the illuminant that can affect the measurement of the spectral reflectance of a surface or complex of surfaces in the direction of the detector. Chief among these are the angular parameters including solar altitude and azimuth in relation to the azimuth and vertical angle of the detector system. In order to quantify the affects of these geometrical relationships on the measurements of spectral reflectance from natural surfaces it is necessary to be able to characterize the spectral signature and the variability of the signature of

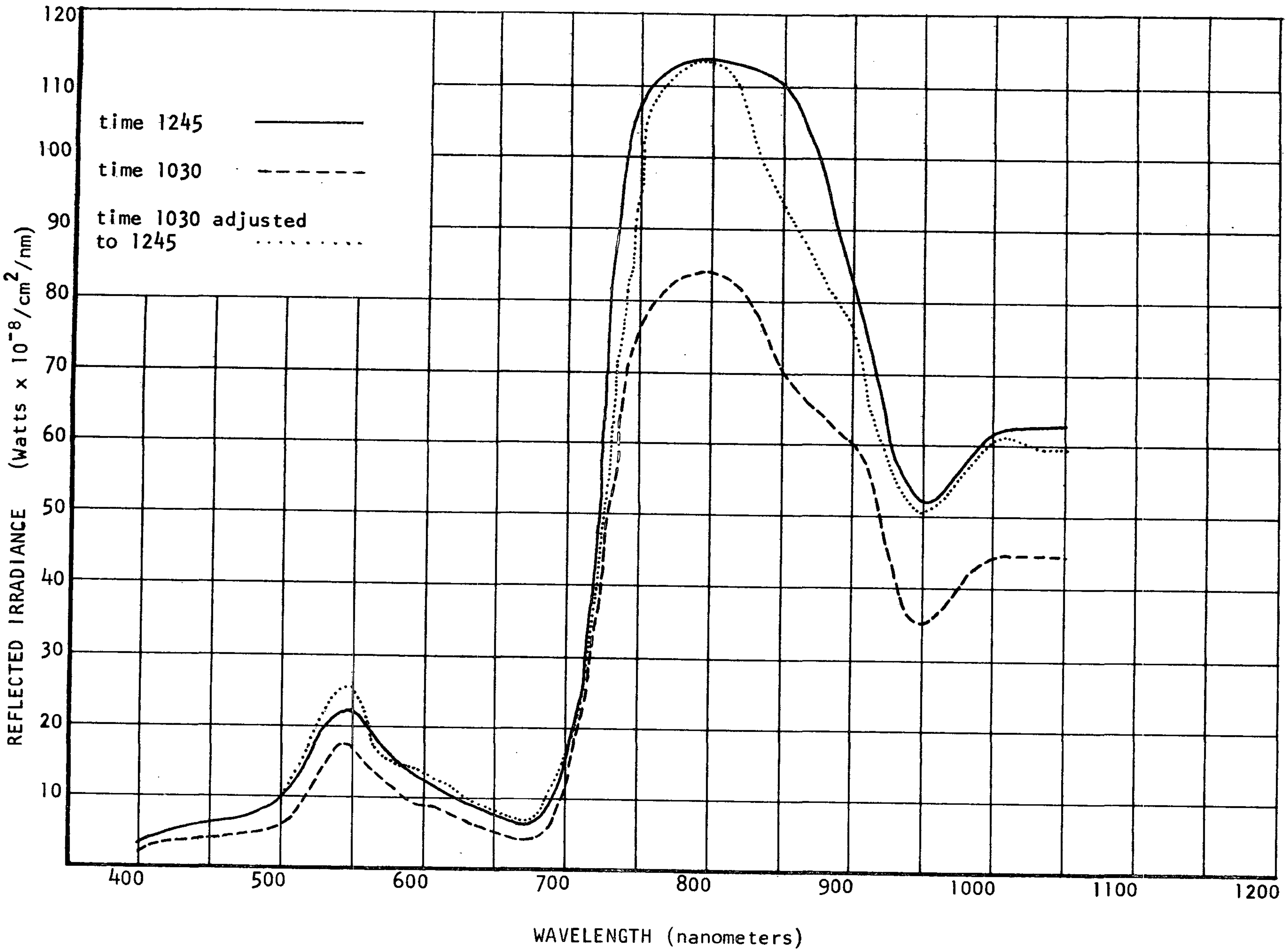


Figure 3-2. Comparison of unadjusted and adjusted spectral radiant emittance data. See text for explanation.

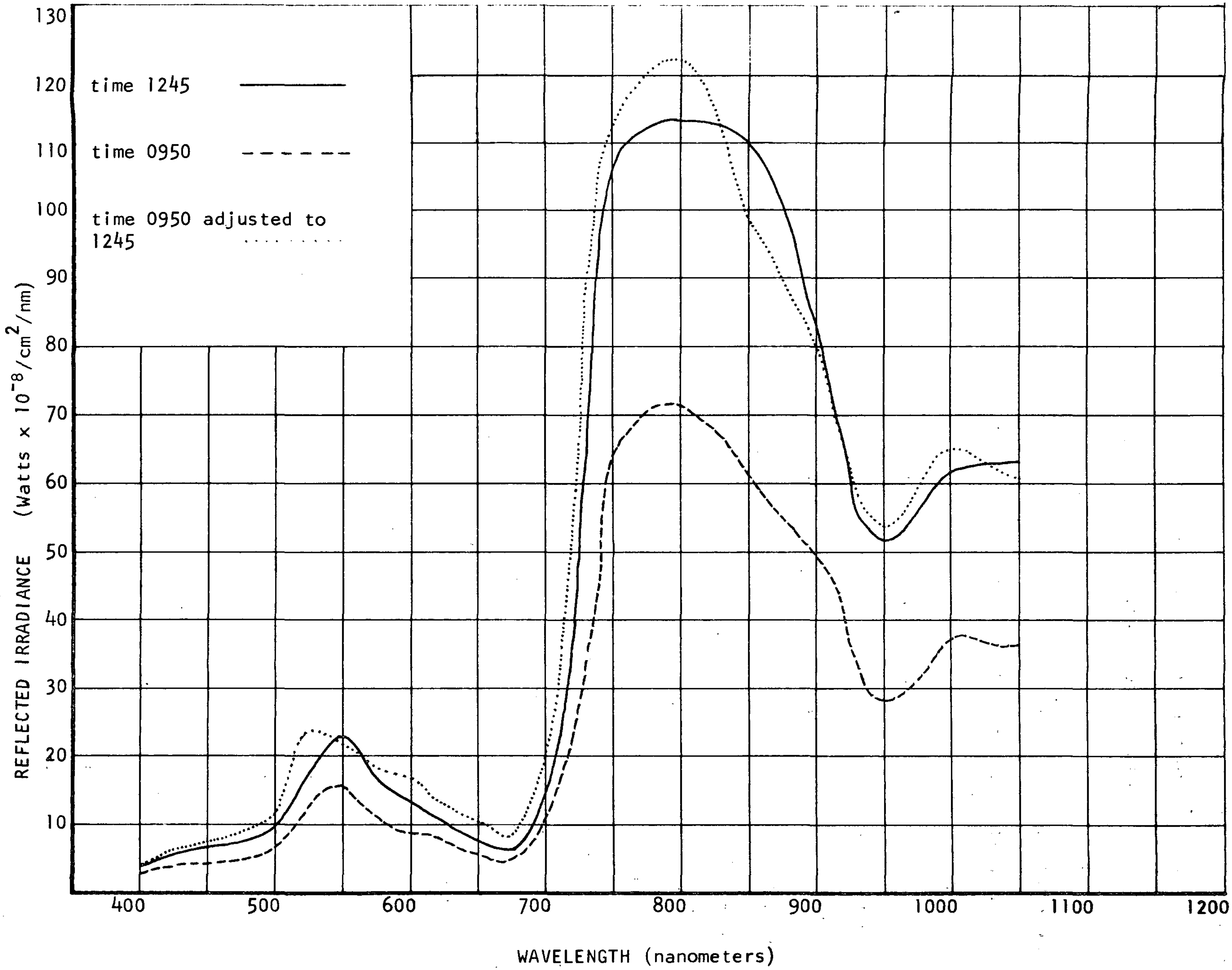


Figure 3-3. Comparison of unadjusted and adjusted spectral radiant emittance data. See text for explanation.

that surface for some fixed geometry. Then, holding all angles but one fixed, the spectral signature of the surface can be characterized for changes in one of the angles. In order to accomplish such measurements without allowing the sun angles, for example, to change appreciably, the measurements must be made quickly and repetitively.

A data acquisition system is being assembled here at the FRSL which will not only allow more rapid spectral signature measurement, but will also provide data output which can be put directly into the ADP Unit mini-computer for rapid and effective analysis. The system utilizes our present equipment and includes modifications to this equipment and the addition of other data transfer and storage units. The entire system is designed to be completely field portable and operable from a battery power supply. It retains the flexibility to be used as a system or to be broken down so that individual units can be used to perform other laboratory or field functions if necessary.

The system, which is shown as a functional block diagram in Figure 3-4, consists primarily of a spectroradiometer which measures irradiance at a cosine corrected diffuser plate illuminated by incident sunlight and skylight. The instrument measures over the range 380 nm - 1350 nm and can be automatically scanned through this range by a drive motor. The analog voltage from this spectroradiometer is passed through an FM adapter which converts the voltage input to a frequency output. The frequency output is recorded by an audio tape recorder. The stored data are played back through a frequency discriminator which converts frequency to voltage. The voltage output is entered into a computer through an analog to digital converter.

A second set of spectroradiometers operating over the range 350 nm - 1200 nm is used to measure the spectral reflectance of surfaces. The analog voltage from the spectroradiometers is passed through a digital voltmeter with BCD output, thence into an incremental digital tape recorder. The

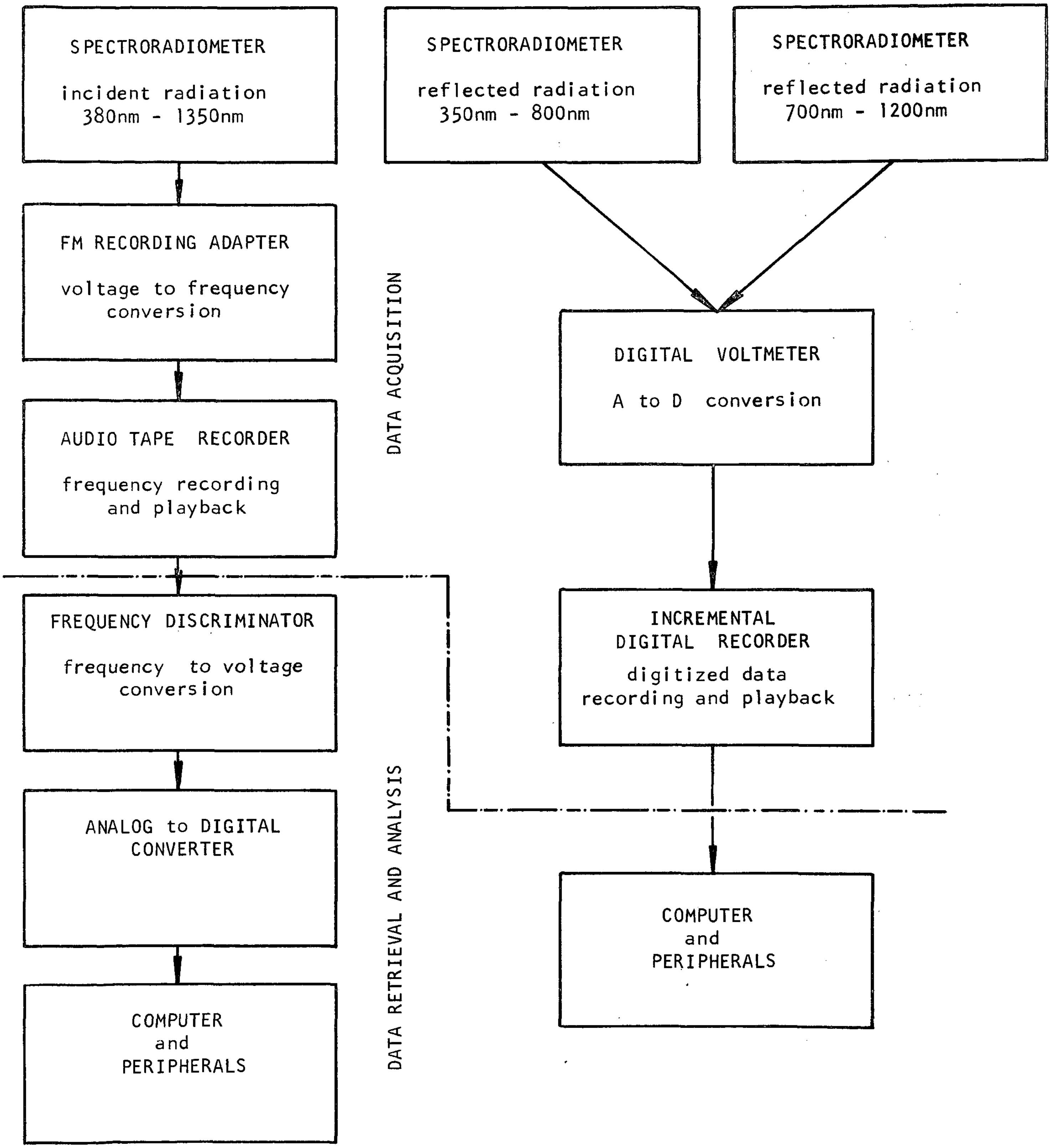


Figure 3-4. Functional block diagram of the FRSL computer compatible, field portable system for acquiring and recording incident and reflected spectral radiation in the range 350 nm - 1350 nm.

recorded data can be input directly into a computer.

The completed spectral acquisition system and data analysis procedures will be reported in detail in future reports.

C. Calibration of Spectral Filters

Spectral transmission measurements were made for filters being used on the FRSL optical image combiner. The gelatine absorption filters presently being used deteriorate over time due to the strong light from the projection lamps. An example of the change in spectral transmission of a deteriorated filter is shown in Figure 3-4. The transmission characteristics are being monitored over time in order to insure that the filters are replaced when either their density or spectral transmission characteristics shift significantly.

The FRSL optical image combiner is also being calibrated with respect to the light output from each projector. Anti-vignetting filters are being made to correct for intensity fall-off of axis on the rear projection screen. The resulting evenness of screen illumination will be measured.

D. Measurement of Stressed Pines

During the spring of 1970 a severe attack of bark beetles killed a large number of Monterey pines (Pinus radiata) in the watershed surrounding the San Pablo Reservoir NASA test site. In order to supply information for assessing the damage and predicting the probable spread of the infestation, the Image Interpretation and Enhancement Unit required input as to the spectral bands most likely to give maximum contrast between healthy and dead or dying trees.

Spectral measurements were made in the field for green-healthy, green-infested, chartreuse, and sorrel pines. The graphed spectral responses from these measurements are shown in Figure 3-5. The results aided in determining the optimum film-filter combinations for use in the overflight.

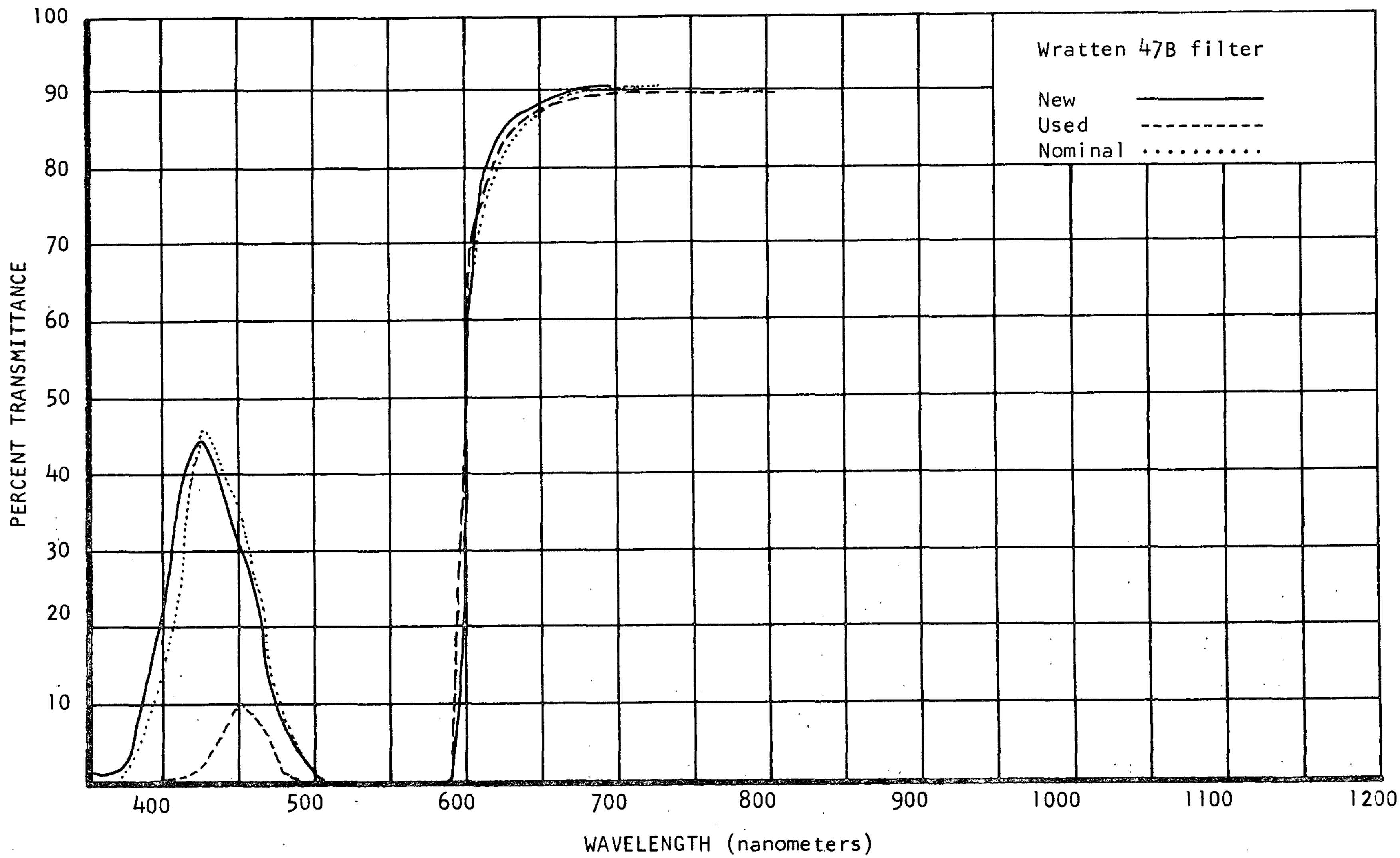


Figure 3-4. Measured spectral transmission of an unused gelatin absorption filter and one which had been used an extended period of time on the color enhancement projection system along with the nominal value for such a filter.

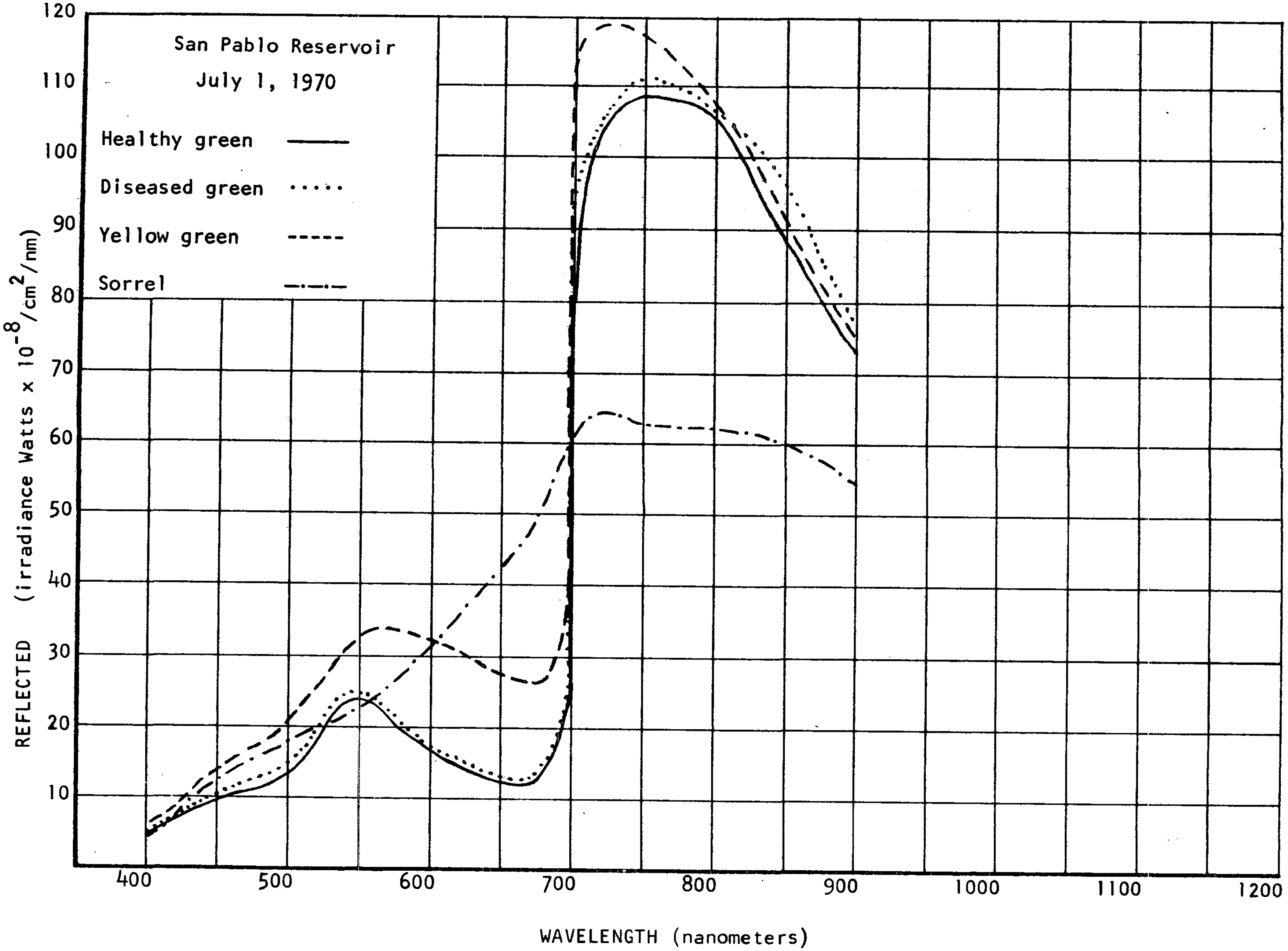


Figure 3-7. Spectral radiation reflected from healthy Monterey pine (*Pinus radiata*) foliage and foliage from trees affected to varying degrees from infestations of *Dendroctonus valens* bark beetles.

Future Research Activities

The main thrust of research within the Spectral Characteristics Unit for the next reporting period will be acquisition and analysis of spectral data from a limited number of natural surfaces including soil and vegetation. An intensive investigation is planned on the effects of angular parameters on the spectral reflectance from natural surfaces. Improvement in methodology for the measurement of this reflectance also will be sought. It is probable that a great deal of this work will be done on agricultural crops because of the relative uniformity of surface, and ease of access. Studies of more complex natural surfaces which are more difficult of access and instrumentation will be deferred until our analyses of the more simple surfaces have indicated the importance of various angular parameters.

It is anticipated that procurement and fabrication of the instrumentation discussed earlier will be completed by the end of 1970 and that instrument calibration and software development will be far enough advanced to allow field testing by early spring of 1971. We are hopeful of following the phenological changes of some local natural vegetation at the San Pablo NASA test site through the 1971 season if early field testing discloses no major problems.

Spectral data collected through this field season will form the beginning of a data bank comprised of "standardized" reflectance data which can be directly cross compared. Comparison with the more extensive laboratory acquired spectral data being deposited in the data bank at the University of Michigan also is contemplated. The digitized data will be stored on magnetic tape and should eventually be retrievable in a variety of print-out or display modes.

CHAPTER 4

IMAGE INTERPRETATION AND ENHANCEMENT

Donald T. Lauer
Randolph R. Thaman

Introduction

The basic function of the Image Interpretation and Enhancement Unit is to develop methodology for extracting useful resource information from remote sensing imagery -- using human photo interpreters. This effort requires a thorough understanding of the components of the image interpretation process. Evaluations are continually being made of the following factors that relate directly to the perception and interpretation of imagery: (1) sensitivity characteristics of the film-filter combination or other detector; (2) exposure and processing; (3) season of year; (4) time of day; (5) atmospheric effects; (6) image scale; (7) resolution characteristics of the imaging system; (8) image motion; (9) stereoscopic parallax; (10) visual and mental acuity of the interpreter; (11) interpretation equipment and techniques, and (12) training aids. Obviously, certain combinations of these factors would better allow an interpreter to perform an interpretation task better than other combinations. Consequently, one of the primary objectives of the Image Interpretation and Enhancement Unit is to define, to the best of our ability, the optimum combination of factors needed to solve specific problems with the aid of remote sensing.

Current Research Activities

The work performed during the past year at the Phoenix Test Site (NASA Test Site #29) clearly illustrates the approach used for deriving a method by which an agricultural crop survey can be made. In this case, the objective was to inventory, by means of remote sensing, the acreage of all cereal grains (i.e., wheat and barley) found in Maricopa County, Arizona. A full account of this research is documented in Appendix I of this report. Note, however, that prior to implementing this type of semi-operational survey, certain quantitative techniques were applied in an attempt to select the proper inputs to the interpretation system. For example, (1) thorough interpretation testing led to the selection of a particular film-filter type deemed best for discriminating wheat from barley and wheat-barley from all other crops, (2) optimum photographic dates on which these crop discriminations could best be made were selected using the crop calendar concept, (3) rigorous testing and screening of interpreters led to the selection of three highly skilled and motivated persons who then performed the interpretation, and (4) ground truth data collection, compilation and analysis procedures were developed that were compatible with a sampling scheme using ratio estimators. In addition, the photos used during this survey were selected on the basis that they were obtained with the NASA RB57F aircraft (1) at midday (high sun angle) assuring minimum shadow density, (2) with a six-inch focal length Wild RC8 metric camera providing large format, high quality imagery, (3) at maximum flying altitude (approximately 60,000 feet above mean sea level) simulating, insofar as possible, spaceborne photography, and (4) with no stereo overlap -- stereo parallax will have negligible influence on the interpretability of satellite photography taken of agricultural areas.

Concurrent with the Arizona flights, the RB57F aircraft obtained photo coverage of one additional semi-arid agricultural area located in the southwestern United States -- the Imperial Valley. Flights occurred throughout 1969 and 1970 at monthly intervals with the last flight being made on June 16, 1970. Ground truth operations similar to those at Phoenix were conducted during each of these overflights. These ground data as well as the airborne imagery are being retained on file for future study with the anticipation that the analysis techniques currently being developed at Phoenix can eventually be tested within this adjacent and analogous agricultural environment.

In addition to the extensive amount of work being done in the two agricultural areas, Maricopa County and Imperial Valley, significant progress has been made in developing remote sensing techniques applied to the forest or wildland environment. The remainder of this chapter will present the results derived from two separate studies, each illustrating a useful technique applicable to a particular problem.

Both of the following studies have been geared towards determining the information content on imagery obtainable from orbiting spacecraft. Since, however, spaceborne data have yet to be procured over the forestry test sites located in the upper latitudes of the United States, this work was done on small and intermediate scale aerial photography. Nevertheless, the subject matter in each case (i.e., image resolution and additive color image enhancement) relates directly to the ultimate usefulness of spacecraft imagery.

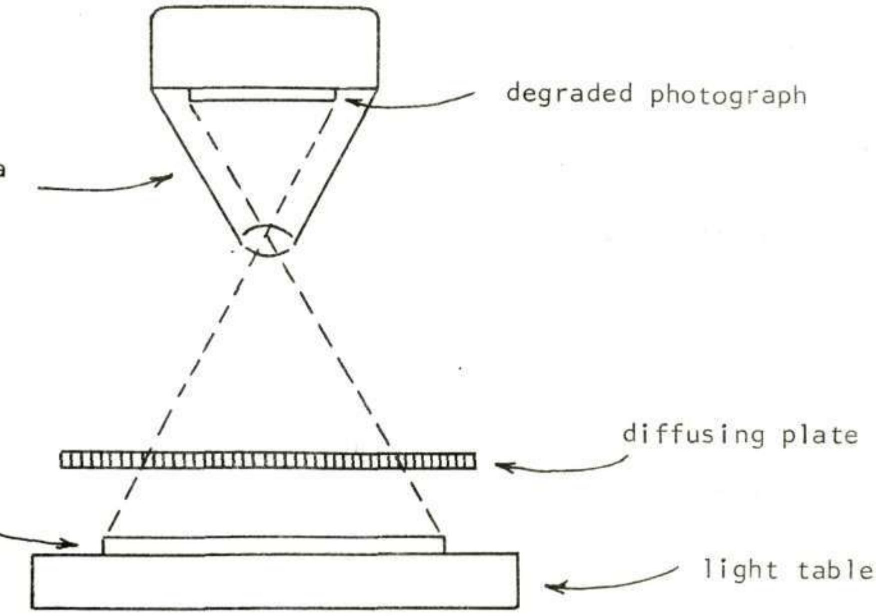
A. Vegetation/Terrain Classification -- on Degraded Imagery

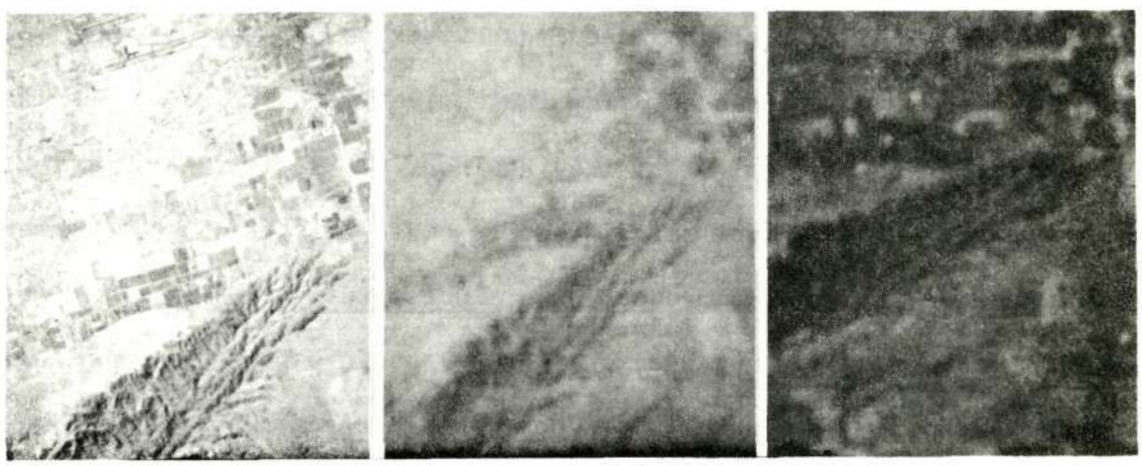
The objective of this study is to determine the information content of simulated space photos as a function of various levels of image resolution. The experiment was performed using a series of images taken of the San Pablo Reservoir Test Site (NASA Test Site #48), each purposely degraded optically to a different level of ground resolvable distance (GRD). This research seeks to answer two questions. First, given low resolution ERTS data within the next few years, how well can a skilled image analyst identify the major vegetation-terrain types found to occur within the chaparral-hardwood-grassland cover type of California? Second, if certain vegetation/terrain types cannot be consistently identified on simulated low resolution imagery, what level of image resolution is required that would allow a skilled interpreter to discriminate between various types?

Until the recent series of Gemini and Apollo photographic experiments, remote sensing research regarding application of spaceborne imagery to earth science problems was based mainly on an analysis of airborne imagery. These studies, combined with conjectured reasoning, have led to a wide variety of opinions as to the usefulness of satellite imagery. Fortunately, the recently procured space photos are providing authentic data from which definitive experimental results can be derived. Experiments to date, however, suffer from two limitations: (1) existing and available spaceborne imagery as obtained by the Mercury, Gemini and Apollo astronauts give coverage only of the lower latitudes of the United States -- due to the contraints of the orbital path -- thereby limiting the kinds of resource phenomena that might be studied, and (2) each study, to our knowledge, has simply sought to determine what kinds of useful information might be extracted from space photos with only minimal consideration to the informational requirements of users. The work reported herein not only applies to a resource inventory problem indigenous to the mid-latitude western United States but also approaches the resource inventory problem from a user's standpoint, i.e., given a particular problem, what kinds of spaceborne imagery (in this case, what level of resolution) is required so that useful information can be extracted from the imagery.

Probably the most common method of simulating synoptic view space photography is to prepare an uncontrolled photo mosaic from conventional vertical aerial photos of a large area and then reproduce the mosaic on a single sheet of film. Low resolution is obtained by greatly reducing photographic scale. Photographic tone, however, is disrupted throughout the final image due to haloing and fall-off common to each photo within the mosaic. This causes tonal mismatches in the mosaic that are easily confused with tonal differences between resource features. Since image tone or color, as opposed to image detail or stereo parallax, is the primary criterion used by the image analyst when interpreting low resolution space photos, a photo mosaic reduced in scale does not provide a realistic simulation of a space photo. Another method that is sometimes used is to enlarge or reduce the photo, as desired, with a projector that is purposely "out of focus" to the extent necessary to produce the desired image degradation. The problem which arises from this method is that linear features such as roads or boundaries between different vegetation types, because they are out of focus, become displaced or spread out and if defocused enough will become double images taking up a greater areal extent on the resultant degraded image than they do on the original. To overcome such problems a technique has been developed for degrading aerial photography in such a way that image sharpness can be manipulated while image color or tone remains nearly unaltered. The technique entails reproducing an original high-altitude, small scale photograph with a flat diffusing plate of frosted acetate placed at various positions between the original photo and the copy camera (see Figure 4.1). In this manner, natural terrain features up to several hundred feet in size can be made to disappear or reappear on the copy photograph depending upon the distance between the acetate plate and the original photo. The scale of the copy photo is a function of copy camera focal length and distance from the copy camera lens to the original photo.

In this case, a single Ekta Aero Infrared photograph taken of the San Pablo Reservoir Test Site from an altitude of 15,000 feet above terrain by the NASA Convair 240 on June 1, 1968 was chosen for detailed analysis. More





GRD:	10-20'	200-300' (degraded)	200-300'
Scale:	1/300,000	1/300,000	1/300,000
Film Type:	Ekta Aero Infrared	Ekta Aero Infrared	Ekta Aero Infrared
Flight Altitude:	60,000' AMS	60,000'AMS	125 NM
Vehicle:	NASA RB57F	NASA RB57F	Apollo 9
Date:	March 8, 1969	March 8, 1969	March 8, 1969

Figure 4.1. The three photos shown here are of the multidisciplinary test site at Phoenix, Arizona (NASA Test Site #29). In order to simulate low resolution space photography, high altitude small scale aerial photography was photographed through a diffusing screen made of frosted acetate. By degrading image sharpness without grossly affecting image tone or color, photography can be analyzed that exhibits 200-300 foot GRD, similar to the quality of existing Apollo and Gemini photography. In addition, by shifting the position of the diffusing screen, a photograph can be made with nearly any GRD desirable. (The differences in color balance between the RB57F and Apollo photos are due primarily to the exposure and processing of the original photography and not to the degradation process.)

than 50 photo reproductions were made of this image, each time slightly changing the position of the diffusing screen thereby spanning the range of GRD from a few feet, as seen on the original photo, to several hundred feet on the most degraded image. Objects of known size seen on different backgrounds were examined on each image. In this way a resolution value in terms of ground resolvable distance was assigned to each image. A respesentative value was assigned to both high contrast features (e.g., dark toned tree crowns on a light toned grass background) and to low contrast features (e.g., dark toned tree crowns on a dark toned brush background). For testing purposes, five images ultimately were selected, each representing a distinct level or range of image resolution which was quite different from all others (see Figures 4.2, 4.3, 4.4, 4.5 and 4.6).

Tests were conducted using these five images to determine their information content in terms of portraying identifiable tonal and/or textural signatures for various terrain and vegetation types (i.e., Monterey pine <u>Pinus radiata</u>; blue gum eucalyptus, <u>Eucalyptus globulus</u>; mixed hardwoods -- oak, bay, madrone, buckeye; chaparral -- coyote brush, poison oak; annual grasslands -- wild oats, soft chess, brome, ryegrass, fescue; water bodies -- reservoirs, lakes, ponds; and non-vegetated areas). A group of 15 highly skilled photo interpreters was drawn from the pool of personnel working at the Forestry Remote Sensing Laboratory. These individuals were divided into five groups of 3 interpreters per group and each group analyzed a single image on which 100 randomly chosen points of known identity were to be identified. Consequently, three sets of data were generated for each image yet each interpreter analyzed only one image.

Prior to analyzing each of the test images the photo interpreters were trained in such a way as not to bias the test results. A photo interpretation key plus accompanying aids were carefully prepared in which the identifying characteristics of each vegetation/terrain type were presented in (1) a summary table, (2) a dichotomous word description and (3) selective photo illustrations. The several photo examples appearing in the key were selected from an adjacent but analogous area and enough examples were made of each type to show the range in tone or color variability exhibited by each type.

Interpretation results for the various images appear in tables below the corresponding images in Figures 4.2 through 4.6. These tables show the cumulative results of the three interpreters (data along rows for each type) along with the actual ground truth (data down the columns). For example, consider the case of chaparral in Figure 4.2. First reading down the column marked (C), out of a total of 48 plots known to be chaparral, 41 were correctly identified, however, 5 were called mixed hardwoods and 2 non-vegetated, resulting in an omission error equal to 7. Reading across the row marked (C), out of a total of 59 plots called chaparral by the interpreter, 41 were correctly identified, however, 7 mixed hardwoods plots, 8 grassland plots and 3 non-vegetated plots were incorrectly identified as chaparral, resulting in a commission error equal to 18. Hence, of 48 chaparral plots, 41 were correctly identified yielding a percent correct rating of 86%. Percent commission error for chaparral is computed by dividing the number of chararral commission errors made by the interpreter, 18, by the total number of plots called chaparral, 59; i.e., 33%. Interpretation results, expressed in percent, are presented in tabular form in Tables 4-II and 4-III and graphically in Figures 4.7, 4.8, 4.9 and 4.10.

IMAGE I: GROUND RESOLVABLE DISTANCE = 5-10 FEET

		GROUND TRUTH							TOT. SEEN BY P.I.	COM. ERROR
		MP	E	MH	C	G	W	N		
PHOTO INTERPRETER'S RESULTS	MP	**27**	1						28	1
	E		**11**						11	0
	MH			**77**	5				82	5
	C			7	**41**	8		3	59	18
	G					**67**		3	70	3
	W						**30**		30	0
	N				2			**18**	20	2
TOTAL PLOTS		27	12	84	48	75	30	24		
OMIS-SION		0	1	7	7	8	0	6		

Figure 4.2. Three photo interpreters working with the above image produced the cumulative results shown here. A total of 100 randomly distributed points of known identity were used in this interpretation test. The numbers in the body of the array of results indicate the total number of plots identified by all interpreters. The numbers in the bold-faced diagonal row of boxes indicate the number of plots identified correctly.

IMAGE 2: GROUND RESOLVABLE DISTANCE = 50-100 FEET

PHOTO INTERPRETER'S RESULTS	GROUND TRUTH							TOT. SEEN BY P.I.	COM. ERROR
	MP	E	MH	C	G	W	N		
MP	**25**	5	9	10				49	24
E		**6**						6	0
MH	2		**53**	17	2			74	21
C		1	20	**20**	12			53	33
G			2		**60**		3	65	5
W						**28**	3	31	3
N				1	1	2	**18**	22	4
TOTAL PLOTS	27	12	84	48	75	30	24		
OMIS - SION	2	6	31	28	15	2	6		

Figure 4.3. Three photo interpreters working with the above image produced the cumulative results shown here. A total of 100 randomly distributed points of known identity were used in this interpretation test. The numbers in the body of the array of results indicate the total number of plots identified by all interpreters. The numbers in the bold-faced diagonal row of boxes indicate the number of plots identified correctly.

IMAGE 3: GROUND RESOLVABLE DISTANCE = 100-200 FEET

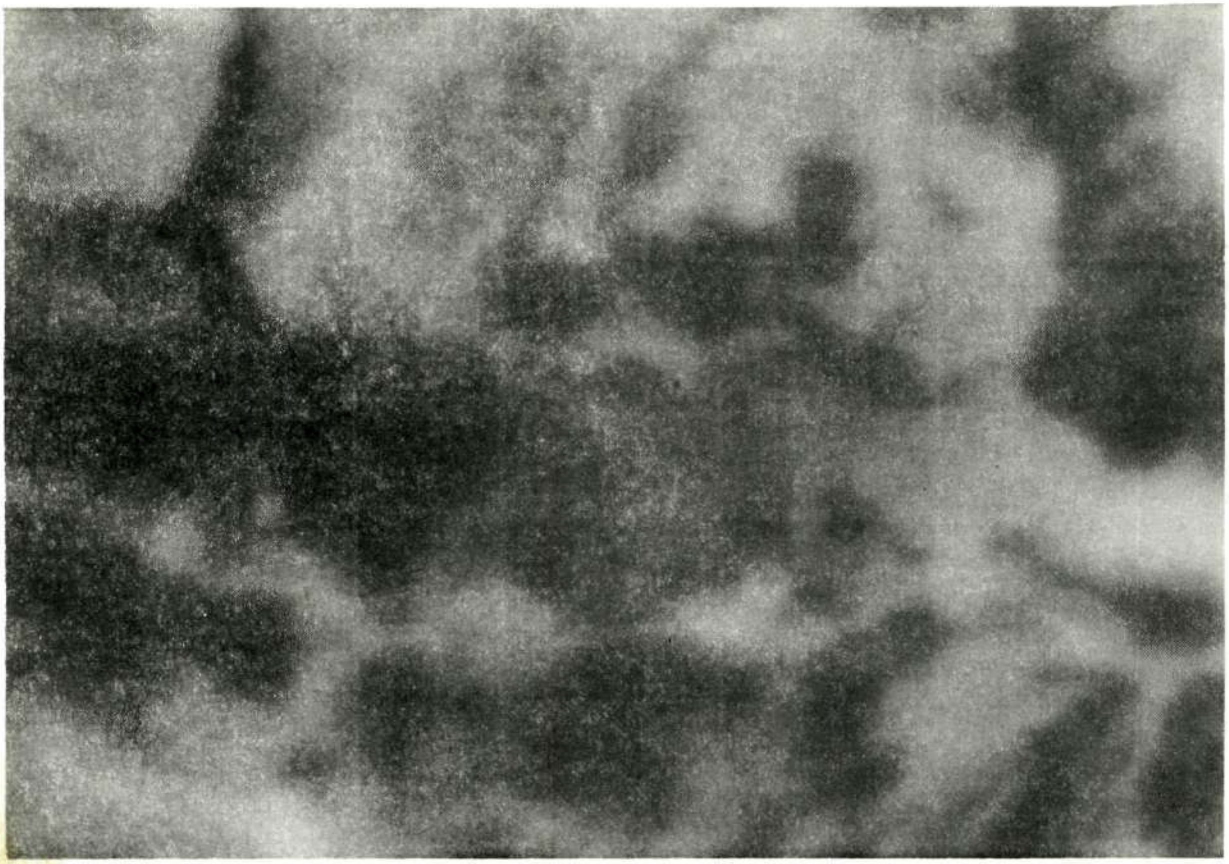


PHOTO INTERPRETER'S RESULTS		GROUND TRUTH							TOT. SEEN BY P.I.	COM. ERROR
		MP	E	MH	C	G	W	N		
	MP	21	1	10	4				36	15
	E		9	1	2				12	3
	MH	3	1	39	16	3			62	23
	C	3	1	27	22	14			67	45
	G			4	2	57	3	8	74	17
	W					0	27	2	29	2
	N			3	2	1		14	20	6
TOTAL PLOTS		27	12	84	48	75	30	24		
OMISSION		6	3	45	26	18	3	10		

Figure 4.4. Three photo interpreters working with the above image produced the cumulative results shown here. A total of 100 randomly distributed points of known identity were used in this interpretation test. The numbers in the body of the array of results indicate the total number of plots identified by all interpreters. The numbers in the bold-faced diagonal row of boxes indicate the number of plots identified correctly.

IMAGE 4: GROUND RESOLVABLE DISTANCE = 200-300 FEET

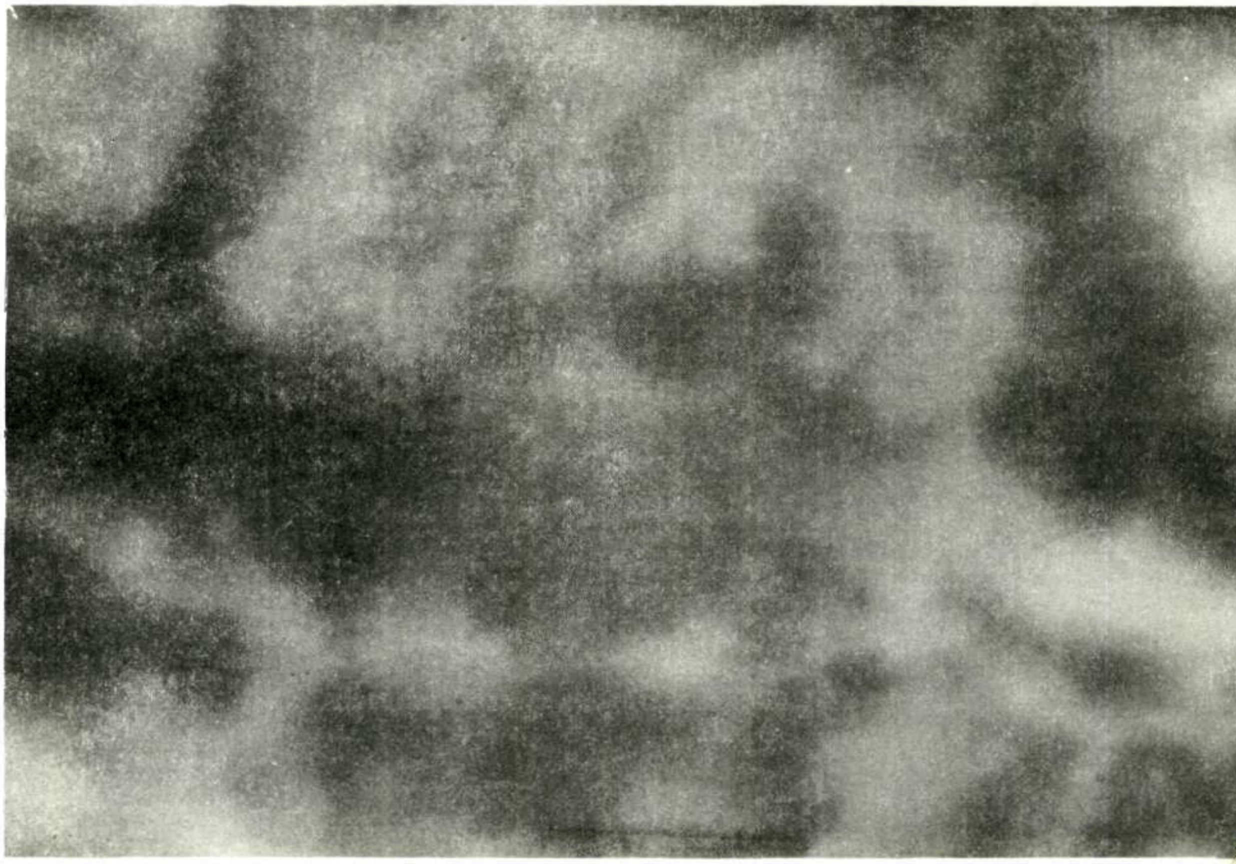


PHOTO INTERPRETER'S RESULTS		GROUND TRUTH							TOT. SEEN BY P.I.	COM. ERROR
		MP	E	MH	C	G	W	N		
	MP	**14**	3	13	7	2			39	25
	E	3	**6**	3	4		2		18	12
	MH			**22**	11	2			35	13
	C	7	2	38	**22**	16		3	88	66
	G	3		7	3	**52**	3	6	74	22
	W						**25**		25	0
	N		1	1	1	3		**15**	21	6
TOTAL PLOTS		27	12	84	48	75	30	24		
OMISSION		13	6	62	26	23	5	9		

Figure 4.5. Three photo interpreters working with the above image produced the cumulative results shown here. A total of 100 randomly distributed points of known identity were used in this interpretation test. The numbers in the body of the array of results indicate the total number of plots identified by all interpreters. The numbers in the bold-faced diagonal row of boxes indicate the number of plots identified correctly.

IMAGE 5: GROUND RESOLVABLE DISTANCE = 300-500 FEET

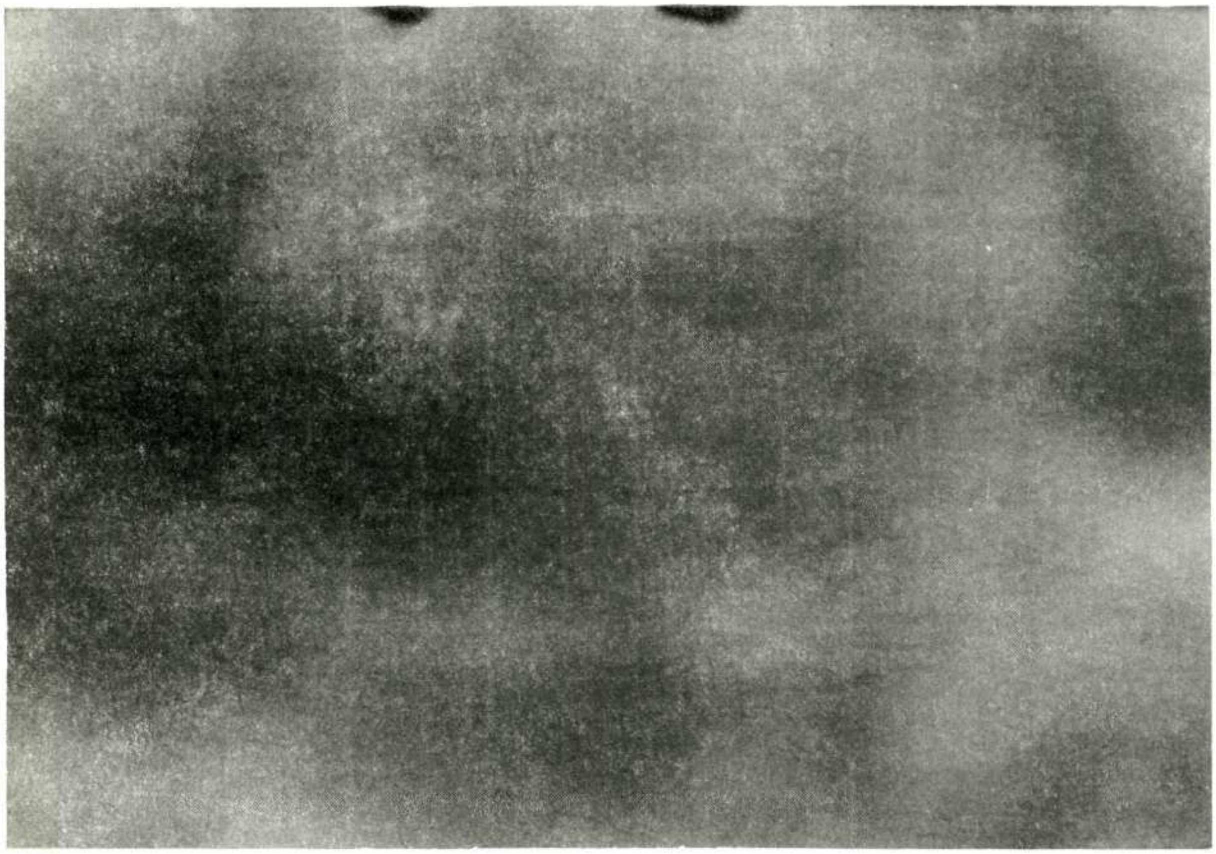


PHOTO INTERPRETER'S RESULTS	GROUND TRUTH: MP	E	MH	C	G	W	N	TOT. SEEN BY P.I.	COM. ERROR
MP	**9**	3	11	4	4			31	22
E	5	**8**	5	6				24	16
MH	2		**18**	15	6			41	23
C	2	1	34	**14**	23			74	60
G	2		14	6	**33**	3	11	69	36
W	2					**25**		27	2
N	5		2	3	9	2	**13**	34	21
TOTAL PLOTS	27	12	84	48	75	30	24		
OMISSION	18	4	66	34	42	5	11		

Figure 4.6. Three photo interpreters working with the above image produced the cumulative results shown here. A total of 100 randomly distributed points of known identity were used in this interpretation test. The numbers in the body of the array of results indicate the total number of plots identified by all interpreters. The numbers in the bold-faced diagonal row of boxes indicate the number of plots identified correctly.

TABLE 4-1. GROUND TRUTH KEY FOR OVERLAY IN FIGURE 4.2

1. G	21. C	41. G	61. G	81. G
2. MP	22. MP	42. W	62. N	82. G
3. C	23. G	43. MH	63. C	83. MH
4. MH	24. G	44. G	64. W	84. MH
5. MH	25. G.	45. G	65. W	85. C
6. MH	26. C	46. MH	66. W	86. G
7. C	27. N	47. C	67. N	87. C
8. C	28. W	48. C	68. W	88. MP
9. C	29. MP	49. C	69. MP	89. MH
10. G	30. MP	50. G	70. N	90. MH
11. G	31. MP	51. G	71. MP	91. G
12. G	32. MH	52. MH	72. G	92. MH
13. MH	33. E	53. G	73. E	93. MH
14. G	34. W	54. MH	74. G	94. MH
15. G	35. MH	55. MH	75. W	95. C
16. G	36. C	56. MH	76. MH	96. G
17. MH	37. MH	57. MH	77. N	97. MH
18. MP	38. W	58. E	78. MH	98. C
19. G	39. N	59. E	79. MH	99. MH
20. W	40. N	60. C	80. N	100. MH

TABLE 4-11.
INTERPRETATION RESULTS FOR EACH CATEGORY EXPRESSED AS PERCENT CORRECT AND PERCENT COMMISSION ERROR

CATEGORY	IMAGE RESOLUTION (FEET)				
	5-10	50-100	100-200	200-300	300-500
COMPOSITE (all types)					
Percent Correct	90.3	70.0	63.0	52.7	40.0
Percent Commission	9.7	30.0	37.0	47.3	60.0
MONTEREY PINE (MP)					
Percent Correct	100.0	92.6	77.8	51.9	33.3
Percent Commission	3.6	49.0	41.7	64.1	71.0
EUCALYPTUS (E)					
Percent Correct	91.7	50.0	75.0	50.0	66.7
Percent Commission	0.0	0.0	25.0	58.8	66.7
MIXED HARDWOODS (MH)					
Percent Correct	91.7	63.1	46.4	26.2	21.4
Percent Commission	6.1	28.4	37.1	36.1	56.1
CHAPARRAL (C)					
Percent Correct	85.4	41.6	45.8	45.8	29.2
Percent Commission	30.5	62.3	67.1	75.0	81.1
ANNUAL GRASSLAND (G)					
Percent Correct	89.3	80.0	76.0	69.3	44.0
Percent Commission	4.3	7.6	22.8	29.7	52.8
WATER BODIES (W)					
Percent Correct	100.0	93.3	90.0	83.3	83.3
Percent Commission	0.0	9.7	6.9	0.0	7.4
NON-VEGETATED AREAS (N)					
Percent Correct	75.0	75.0	58.3	62.5	54.2
Percent Commission	10.0	16.7	30.0	28.6	61.8

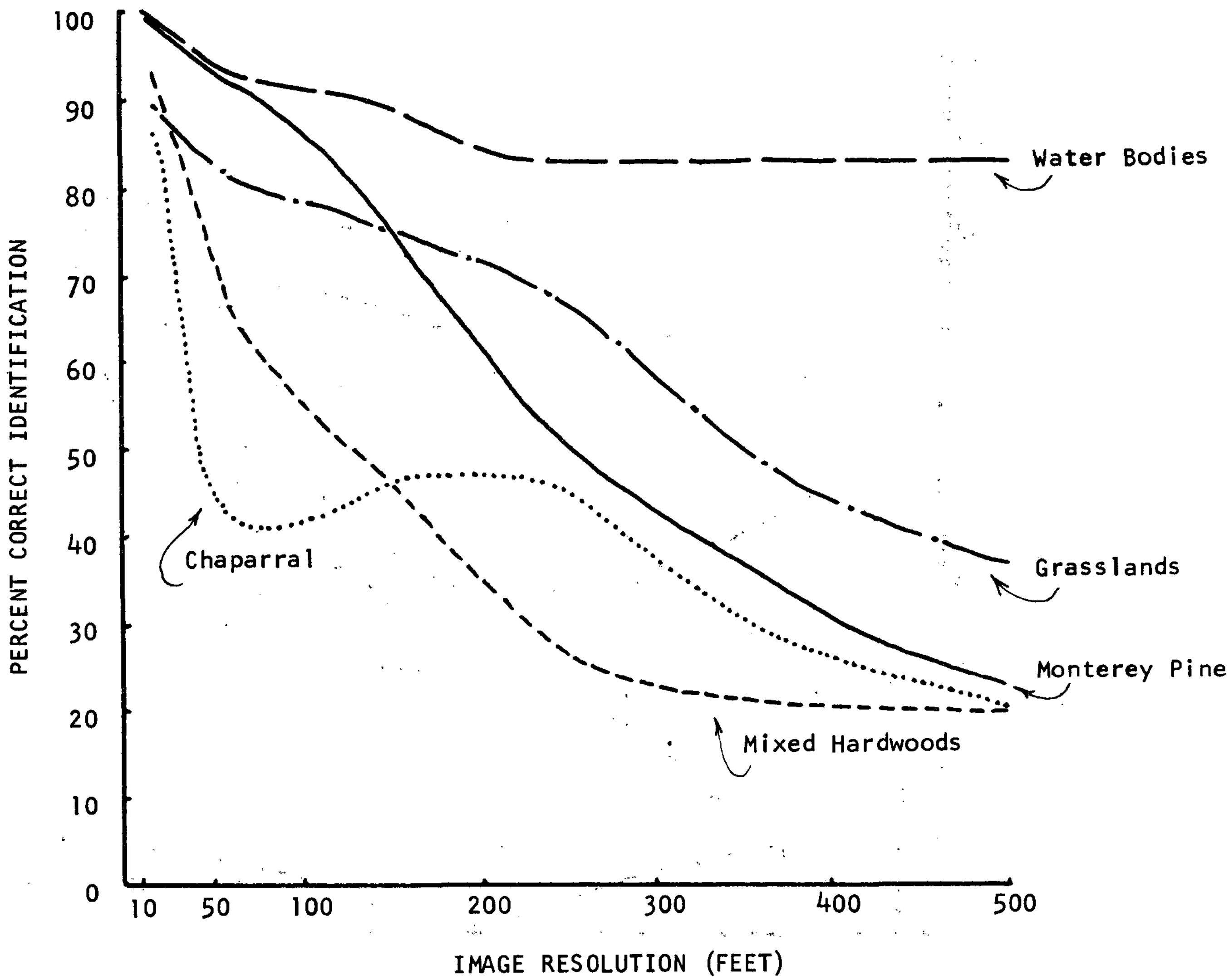


Figure 4.7. Interpretation results for all categories individually expressed as percent correct identification (data on eucalyptus and non-vegetated areas have been omitted due to an insufficient number of sample plots.)

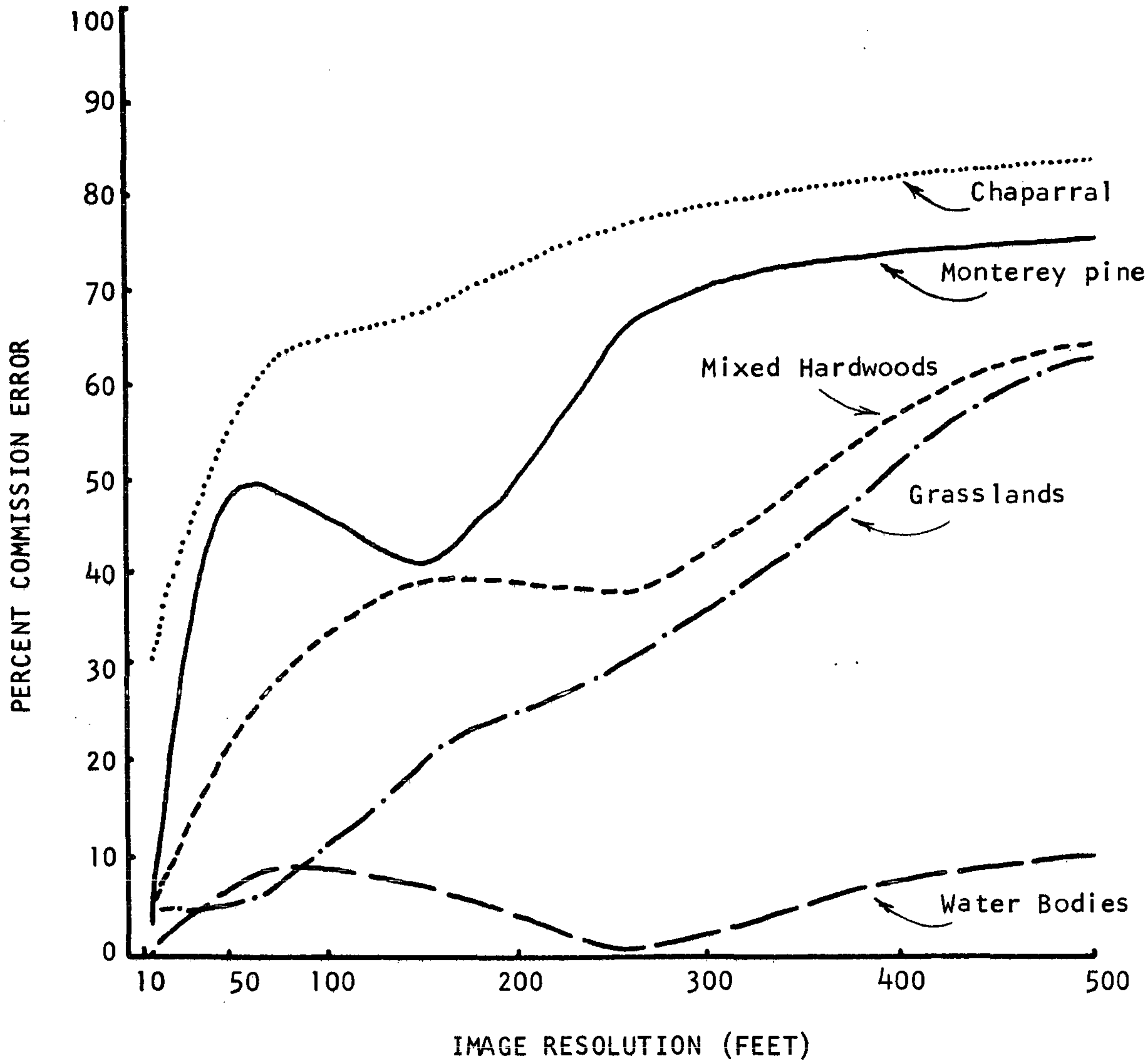


Figure 4.8. Interpretation results for all categories individually expressed as percent commission errors (data on eucalyptus and non-vegetated areas have been omitted due to an insufficient number of sample plots.)

The results presented here indicate that although there is definite decrease in interpretability as ground resolvable distance increases, some valuable information can be gained by using even the poorest photography. The greatest decrease in interpretability between two adjacent photographs (with respect to resolution) was between Image 1 and Image 2. On the best photograph, Image 1 (5-10 ft. GRD), 90.3% of all plots were correctly identified whereas on Image 2 (50-100 ft. GRD) only 70.0% were correctly identified. This decrease seems to be due to an almost complete loss of shape, shadow, and textural differences on Image 2 which were present on Image 1. Due to color similarities, shape and textural differences are very important for the identification of Monterey pine (MP), eucalyptus (E), mixed hardwood (MH), and chaparral (C); MP and E both appear dark red in color and MH and C both appear bright red. It is interesting to note here that in a somewhat similar study conducted last year in the Phoenix area, it was concluded that no improvement was made in the identification of agricultural crops on high altitude aerial photography (20-40 ft. GRD) versus Apollo 9 photography (200-300 ft. GRD). In that study, however, large homogeneous fields exhibiting unique tone signatures were interpreted, and those signatures seen on both types of photography were not significantly influenced by size, shape, shadow and texture characteristics of individual plants. Such identifying characteristics are useful only on extremely high resolution imagery, exhibiting a GRD of less than two feet.

The poorer results from the interpretation of Image 2 can be attributed for the most part to both omission and commission errors within the four above vegetation types. With the exception of MP, the percent correct for each of these four vegetation types decreased by amounts ranging from 28.6% for MH to 43.8% for C. The decrease in percent correct for MP was only 7.4% but the increase in percent commission for MP was 42.4% (from 3.6% to

49.0%) and for the remaining three types the increases in commission errors were as follows: MH - 22.3%, C - 31.8%, and E - 0.0% (no commission errors for E). As can be seen by the above figures (from Table 4-11), the loss of shape and texture as identifying characteristics affected the interpreters' ability to correctly identify MP, E, MH, and C. The absolute values corresponding to the above mentioned omission and commission errors can be seen in Figures 4.2 to 4.6.

The interpretation results also are given in Table 4-11 for the remaining vegetation and terrain types: annual grassland (G), water bodies (W), and non-vegetated areas (N). The interpretability of these types was not as affected by loss of texturel evidence as that of MP, E, MH, and C. The percent correct and percent commission errors for these categories were not found to be significantly different for Images 1 and 2 at a .05 significance level. On the other hand, for both MH and C there was a significant difference for the percent correct between Images 1 and 2 at a .05 significance level and also a significant difference in commission errors between the images for MP, MH, and C at a .05 significance level. (A one sided t-test was used on the absolute values found in Figures 4.2 to 4.6.) Any assumptions based on the figures relating to eucalyptus probably have little significance because the sample size was quite small. The great variation for eucalyptus can be seen by the figures in Table 4-11.

The above trends, i.e., the importance of shape and texture for the correct identification of broadleaf or coniferous vegetation types (MP, E, MH, and C) and the relative unimportance of shape and texture for the identification of G, W, and N are also shown in the graphs in Figure 4.7 and 4.8. In Figure 4.7 the steep drop in percent correct for E, MH and C can be seen whereas there is relatively little drop for G, W, and N from Image 1 to Image 2. Figure 4.8 shows the very steep rise of commission errors for MP, MH and C and the relatively gradual rise of G, W and N.

Apart from the initial drop-off in percent correct between the first two images, the relative drop-off for percent correct for the next three images is more gradual. This gradual decrease in interpretability is to be expected, especially when trying to identify different types of woody vegetation. As resolution becomes worse the interpreter must rely almost entirely on color which makes differentiations such as that between mixed hardwood and chaparral, both which have a bright red tone, very difficult. In fact these two vegetation types were the hardest to identify as soon as the images became more degraded. This is evidenced in Table 4-II where using Image 5 (300-500 ft. GRD) the interpreters were only able to correctly identify 21.4% of the MH plots and 29.2% of the C plots. Monterey pine (MP) was also hard to identify with only 33.3% of the plots being correctly identified.

The annual grassland (G), the water bodies (W) and the non-vegetated areas (N) were more easily identified. The percent correct for W, 83.3%, would have even been higher if the small one-acre pond at point 64 on Image 1, which was resolvable <u>only</u> on Image 1, had been eliminated.

It seems that difficulties are certain to arise when trying to differentiate between woody vegetation types such as MP, E, MH and C on low resolution photography. However, if these are combined into one group, i.e. "woody vegetation", and the interpreter is asked to interpret for woody vegetation, grassland and water bodies, the results might be improved. Table 4-III shows how the results might improve if these categories were used. The graphs in Figures 4.9 and 4.10 also show an improvement in results.

The accuracy of identification for the grassland (G) surely would have been much higher if the photography had been flown a month later, July 1 instead of June 1. At the time of the June 1 photography, some of the

TABLE 4-III.
INTERPRETATION RESULTS FOR COMBINED CATEGORIES, EXPRESSED AS PERCENT CORRECT AND PERCENT COMMISSION ERROR

CATEGORY	IMAGE RESOLUTION (FEET)				
	5-10	50-100	100-200	200-300	300-500
WOODY VEGETATION (MP, E, MH and C)					
Percent Correct	98.8	98.2	93.6	91.2	80.11
Percent Commission	4.4	7.7	9.6	13.9	19.4
GRASSLAND (G)					
Percent Correct	89.3	80.0	76.0	69.3	44.0
Percent Commission	4.3	7.7	23.0	29.7	52.2
WATER BODIES (W)					
Percent Correct	100.0	93.3	90.0	83.3	83.3
Percent Commission	0.0	9.7	6.9	0.0	7.4

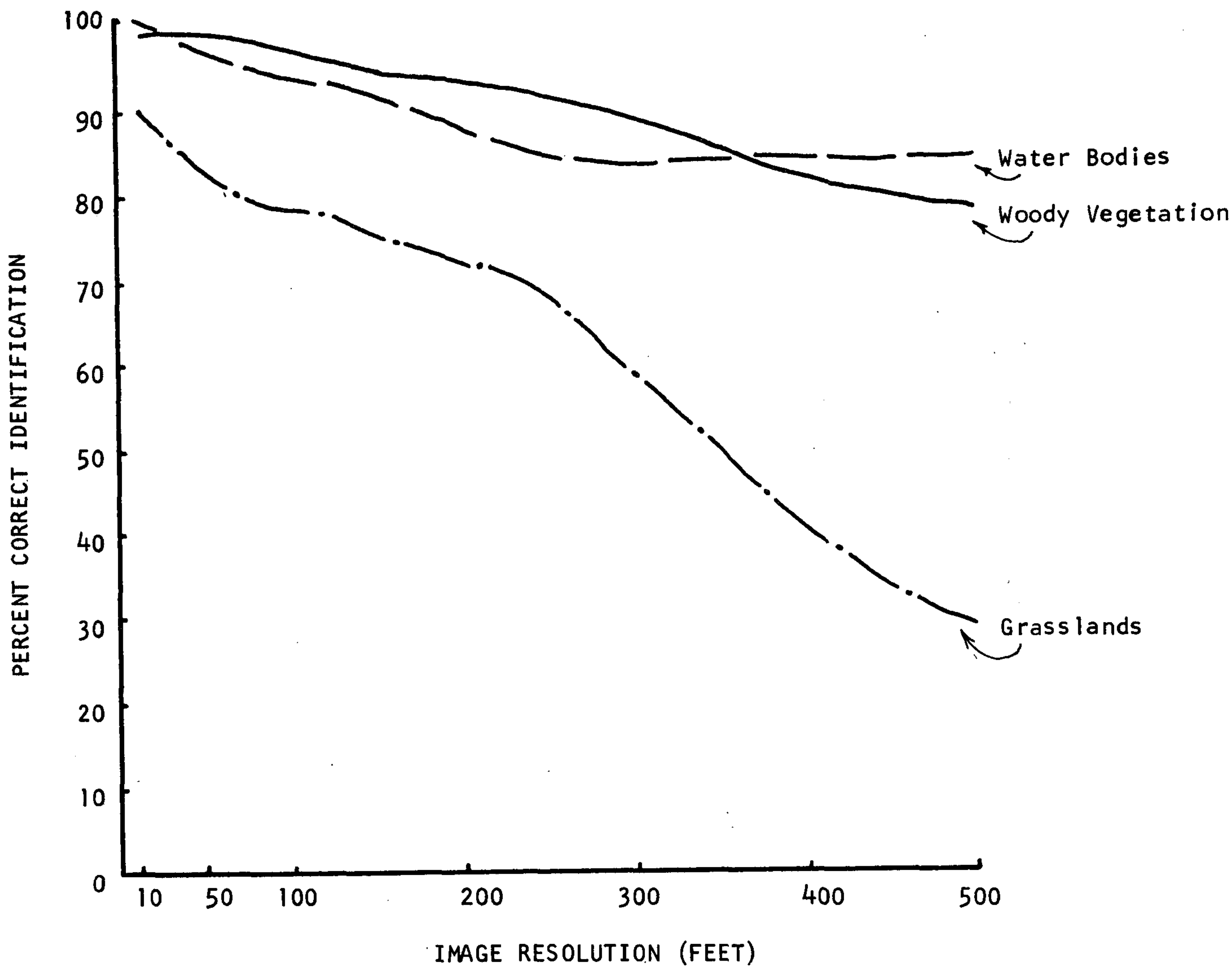


Figure 4.9. Interpretation results for woody vegetation, grasslands and water, expressed as percent correct identification.

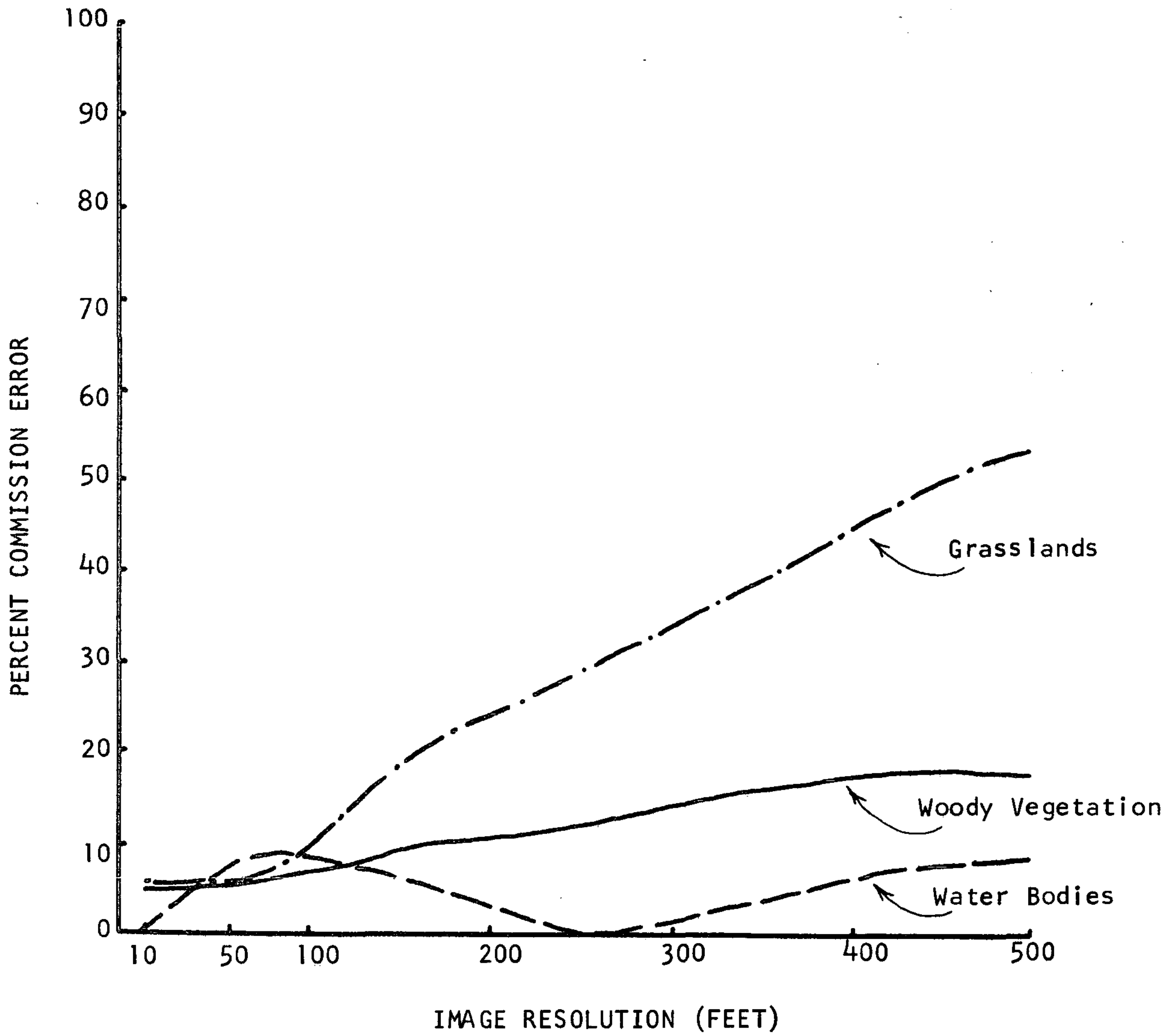


Figure 4-10. Interpretation results for woody vegetation, grassland and water, expressed as percent commission error.

grassland area still had high reflectance in the reflective infrared portion of the electromagnetic spectrum and shows up pink or red (see point numbers 23 and 90 on Image 1) thus making it easy to confuse it with chaparral which is also pink or red at this time of year.

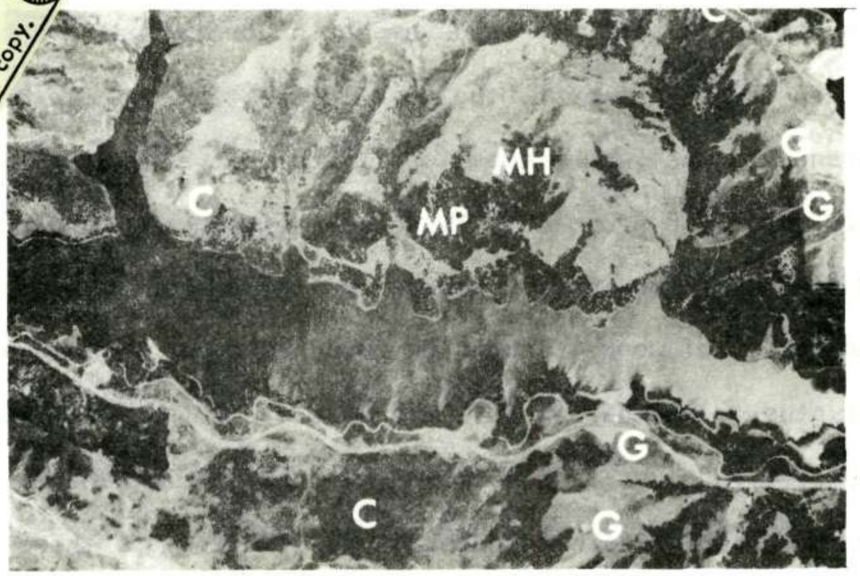
Another factor which tends to make the results lower than what they might be is that, for the sake of simplicity, the photo-interpretation tests were set up using 100 points on each photograph. These 100 points were chosen randomly and often fell close to borders between two vegetation and/or terrain types or on features that were less than 50 feet in areal extent. When the photography was degraded these features became obscured or completely non-existent. If the tests had been conducted with the interpreters delineating these areas of woody vegetation, grassland, water, etc., the accuracy of identification might have been higher because isolated points along borders would not have contributed so highly to the percent error. On the poorer photography the interpreter could merely interpolate as to where the border is between two different types, making use of tonal or color gradients to locate his line. Furthermore, this ability to discriminate between different types on low resolution imagery although correct identification is not always possible, might be of great value when applying a multistage sampling system.

Other anomalous features or conditions which contributed to photo-interpreter errors were as follows: (1) the sprayed chaparral stands at points 27, 39 and 80 were classified as non-vegetated areas (N) but were often called chaparral (C) or water (W) by the interpreters; (2) the number of replicates for eucalyptus (E) on each image was only 4, thus making the percent correct somewhat statistically insignificant for this type; (3) some of the Monterey pine stands were only 50 feet in width and were located on the banks of the reservoir (points 22 and 30 on Image 1). When the photography was degraded, these stands either disappeared or merged into the dark blue color of the lake; (4) Part of the photography was adversely affected by haloing in the area of points 32, 37, and 93, thus tending to wash out the color saturation of the MH stands in the area. These stands were very often misidentified as C.

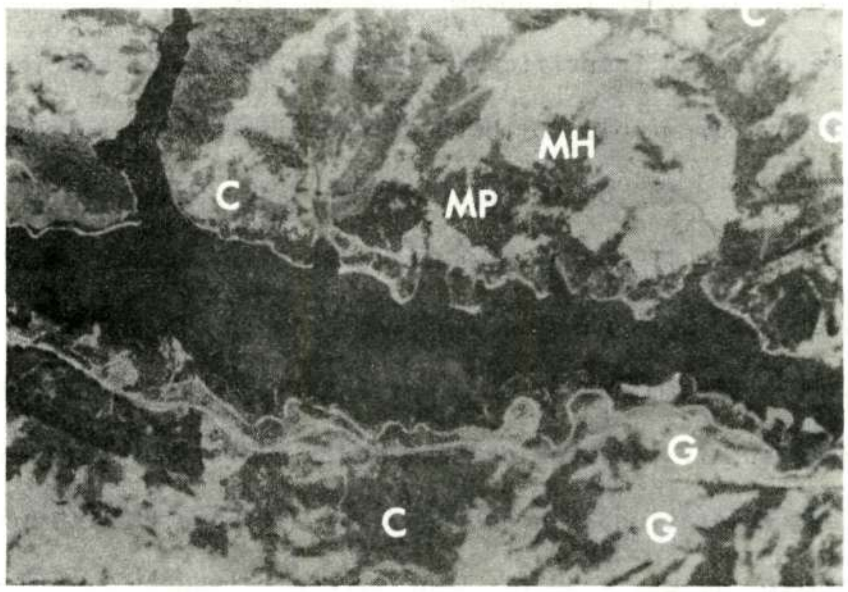
Although interpretability does fall off with increasing ground resolvable distance, very good results were obtained using the photography with the best resolution, and if a more general type of information such as the extent of woody vegetation versus grassland is desired, imagery of the quality obtainable from satellites may be of great utility especially if the optimum dates of photography are flown.

The examples in Figure 4.11 show a photograph taken on June 1, 1968 and one taken on July 17, 1969. In June the grasslands at "G" are still pink or red and easily confused with the chaparral at "C", but there is little confusion between the same points on the July photograph. There is also a greater contrast between the Monterey pines at "MP" and the mixed hardwoods at "MH" and the chaparral at "C" on the July photograph than there is on the June photograph. Thus by using photographs flown later in the year the results reported on herein could be improved upon considerably.

In summary, the results reported above help answer the two questions stated at the beginning of this section. First, given (within the next few years) low resolution ERTS data taken of a chaparral-hardwood-grassland type, one could expect that a skilled image analyst could delineate and identify on these images woody vegetation and water bodies with better than 80% accuracy. In addition, annual grassland areas could also be identified with approximately the same accuracy provided the imagery is taken late in the growing season. (It is reasonable to assume that imagery will be available showing natural vegetation in nearly all seasonal states, since



Film: Ekta Aero Infrared
Aircraft: NASA Convair 240
Date: June 1, 1968



Film: Ekta Aero Infrared
Aircraft: NASA RB57F
Date: July 17, 1969

Figure 4.11. The accurate timing of image procurement greatly influences the interpretability of the resulting imagery. This example shows that in early June the phenological growth stages of annual grasslands in California are such that this cover type is often confused with adjacent woody vegetation. However, later in the year, the grasses have matured and dried and as a result the reflectance characteristics of grassland are quite different than those of hardwood vegetation. Consequently, the interpretation results reported here differentiating grasslands from other types might have been greatly improved if the analysis had been done on July imagery. (Annotations are explained in the text.)

the ERTS vehicle will pass over the same point on the earth approximately every eighteen days.) However, the most interesting outcome of this research is in reference to the second question. Note that even if the image resolution capability of the proposed ERTS sensor system was improved from 400 feet GRD to 100 feet GRD, the imagery would remain inadequate for identifying the four primary types of woody vegetation found to occur in this area: Monterey pine, eucalyptus, mixed hardwoods and chaparral. Discrimination between these kinds of vegetative cover is done mainly by recognizing shape, size, texture and shadow characteristics within each type. To include these kinds of information, imagery must have a ground resolvable distance of at least 50 feet. In some instances the user might be satisfied with merely broad categorizations; in other instances, however, either he or some other users might require detailed identifications as to individual species. Consequently, only by being able to thoroughly define user requirements can the usefulness of ERTS data, or for that matter, any data be determined. For example in this case, if the user wants to discriminate between woody vegetation, grassland and water bodies, ERTS data exhibiting 400-500 feet GRD will contain a sufficient amount of information allowing such discriminations to be made. However, if the user desires additional information on the various types of woody vegetation, spaceborne data will have to be supplemented with higher resolution (i.e., > 50 ft. GRD) aircraft imagery on which individual tree crowns can be seen.

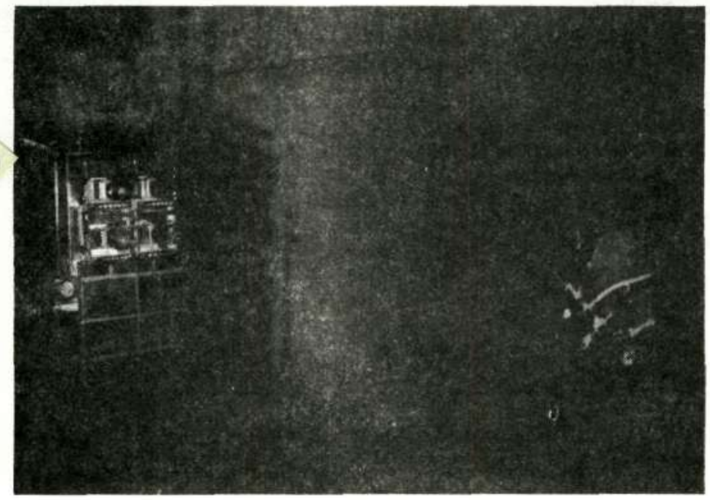
There is still another respect in which user requirements for information may differ: In some instances the user may need only to know the percentage or total acreage comprised by each vegetation or terrain type throughout the entire area that he seeks to manage. Such information is obtainable, as in the present experiment, merely through type identification at each of a suitably large number of selected spots. For any given type, the amount which it comprises throughout the entire area can then be assumed to be proportionate to its occurence in the dot sample. However, in other instances the user may require a complete "in-place" delineation, showing the exact boundaries of each type, wherever that type may occur within the project area. In order for this second type of requirement to be satisfied, a higher order of image interpretability usually will be required. With respect to both types of problems, spaceborne and airborne data most certainly compliment one another in that an analysis of low resolution synoptic view space photos gives guidance to where and, more importantly, where not to procure supplementary aerial coverage.

B. Vegetation Typing -- on Color Enhanced Imagery

Earlier studies performed by the FRSL staff and others have adequately demonstrated that black-and-white multiband photographs obtained simultaneously in more than one spectral band can be efficiently acquired and interpreted. This work has shown that the success of this relatively new and interesting technique is heavily dependent upon the employment of advanced aids to photo interpretation -- such as additive color image enhancement.

The procedure used at FRSL to make additive color image enhancements can be briefly summarized as follows: (1) black-and-white photos of an area are obtained simultaneously in each of several important spectral bands, (2) a positive transparency is made in lantern slide form from each of these photos, (3) by means of a multiple projector system, the multiband photos are optically combined through simultaneous lantern slide projection of them in common register onto a translucent or reflecting screen, and (4) by the insertion of a different color filter into the optical path of each projected image, a single false-color composite image is created (see Figure 4.12). Thus, one can select any set of bands within the visible and near-infrared parts of the electromagnetic spectrum to obtain multiband imagery, and interpretation can then be done on a single color composite. The color presentation can be altered by simply changing projector filters to enhance particular relationships and, in this way, several hundred shades of grey differentiable by the human eye on the black-and-white multiband photos can be expanded (theoretically at least) to several million detectable colors differing in hue, brightness or saturation. Furthermore, one can easily create a rendition of any conventional color or false-color infrared film, provided the proper multiband photos and projector filters are available (i.e., standard broadband photography taken in the blue, green, red and infrared regions of the spectrum and the three primary color broadband absorption filters).

The four projector optical combiner shown in Figure 4.12 has recently undergone major modification. The changes in configuration were implemented with an objective of creating an efficient and inexpensive piece of equipment capable of producing high resolution color composite images. Now, each projector consisting of a lamp, condenser and lens system will produce a large, intense image on a screen just 15 feet from the projector stand. On each projector the lens can be moved in the horizontal and vertical directions and the slide holder can be rotated around the optical axis, thereby facilitating rapid and accurate registration (i.e., congruencing) of the multiband images on the screen. Image brightness can be adjusted by changing the size of the iris diaphragm opening on each projector lens and image hue is manipulated by changing projector filters (image saturation cannot be altered). In addition, the 1000 watt quartz halogen lamps and slide materials are kept cool with a forced air blower. As a result of these improvements, highly interpretable imagery, such as those shown in Figure 4.13, can be created in which light fall-off and image registration problems



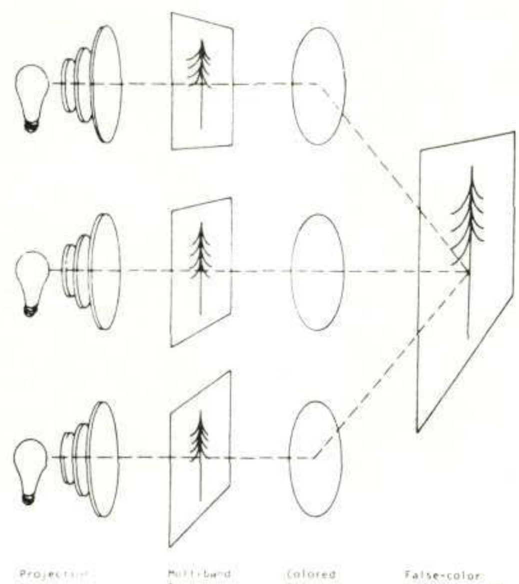
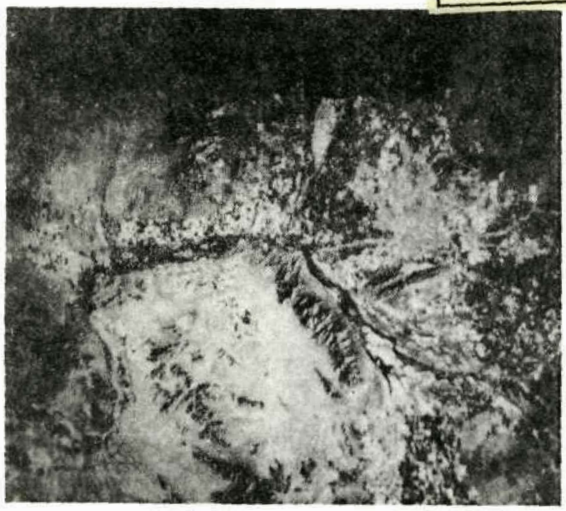


Figure 4.12 The four projector FRSL Optical Combiner (top) used for making additive color image enhancements is shown here. The basic components to the system, i.e., projectors, multiband images, color filters and composite image, are shown in the schematic diagram (bottom). This equipment is extremely useful as an aid to the photo interpreter since several black-and-white multiband images can be viewed simultaneously as a color composite, enhancing minute tonal differences between objects.



Ekta Aero Infrared

Additive Color Enhanced Image (simulated Ekta Aero Infrared)

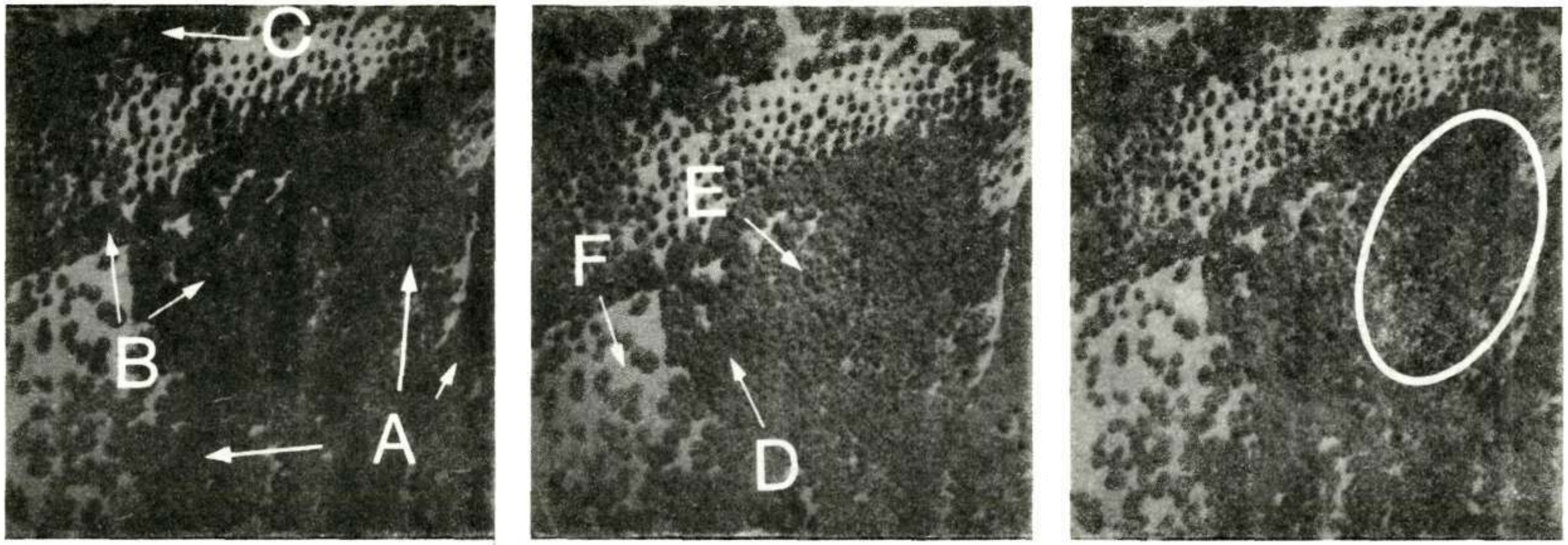
Additive Color Enhanced Image

Additive Color Enhanced Image

Figure 4.13 This series of color images (an Ekta Aero Infrared photo plus three FRSL enhancements) made from Apollo 9 photography taken over the Phoenix Test Site (NASA Test Site #29) illustrates the flexibility afforded by additive color image enhancement. Note that black-and-white multiband photos can be color combined to form nearly any color image desired -- including a close replica of an Ekta Aero Infrared photo. Furthermore, the interpreter can be confident that any particular color composite chosen for study can be easily and reliably reproduced using either the same multiband photo inputs or similar inputs taken on some other date. Herein lies the real advantage to using the multiband technique as compared to most any other photographic method -- the system incorporates both flexibility in terms of results obtainable and reliability in terms of replicating those results.

are significantly reduced.

Figure 4.14 illustrates three color enhanced images made from black-and-white multiband photography taken over a portion of the San Pablo Reservoir Test Site (NASA Test Site #48) in the Coast Range of California. With the aid of these enhanced images evaluations have been made of the vegetation resources occurring on this site. Note that by changing the projector filters the hues in each composite are altered and various false-color images are derived. The image on the left, a close simulation of an Ekta Aero Infrared photo, shows live, healthy vegetation as various shades of red. Forest species composition is readily identifiable on this composite -- Quercus kelloggii (California black oak) at "A" and Pinus radiata (Monterey pine), a young stand at "B" and a mature stand at "C". The image in the middle shows the overstory vegetation as green and the grassland understory as bright pink, allowing for a rapid assessment of timber stand density. Tree crown size and openings between trees are easily seen on such a composite. Density classes are: 80-100% crown cover at point "D", 50-80% crown cover at point "E", and less than 5% crown cover at point "F". The image on the right enhances the appearances of an unhealthy portion of the Monterey pine stand (encircled). The dead and dying trees, under attack by various insects including the turpentine beetle (Dendroctonus valens) and the engraver beetle (Ips radiata) and also by several pathogenic fungi, appear brilliant yellow, contrasting sharply with adjacent healthy trees, appearing blue, and the grassland background, appearing beige. These photo examples demonstrate the unique flexibility afforded by multiband techniques. The interpreter not only can select the color composite of his choice but can easily reproduce the same color composite at any time in the future -- assuming the black-and-white multiband photos used as data input are correctly exposed and precision processed to a



green band projected through a:	blue filter	blue filter	red filter
red band projected through a:	green filter	red filter	green filter
IR band projected through a:	red filter	green filter	blue filter

Figure 4.14 The enhanced color composites shown here, covering a portion of the San Pablo Reservoir Test Site (NASA Test Site #48) near Berkeley, California, were made from the following black-and-white photos: infrared film - 58 filter, infrared film - 25 filter and infrared film- 89B filter (photos courtesy of International Imagery Systems, Mountain View, California). Note that merely by a change of the colored filters through which the multiband images were projected, the hues in the final composite images were altered. In addition, the color balance in these enhancements was readily adjusted merely by manipulating image brightness on any one of the three projectors. For an explanation of points A through E, see accompanying text. (An infrared cut-off filter was employed while taking the Infrared-58 and Infrared-25 imagery.)

common standard.

The area shown in Figure 4.15 is within the Meadow Valley-Bucks Lake Test Site (NASA Test Site #20) located in the northern Sierra Nevada Mountains of California. A false-color infrared photo (Ekta Aero Infrared) and a simulated false-color infrared image optically combined, are illustrated here. A vegetation type map (delineations shown on the accompanying panchromatic photo) has been made of the entire test site using the Ekta Aero Infrared photography. This example shows that, due to the fine quality of the color enhanced imagery, vegetation mapping could be done equally as well on either of the two color images. But, if the end product desired by the photo interpreter is a single color image, an obvious question is often raised: Why bother with black-and-white multiband photos exposed through special filters when conventional color and false-color infrared films by virtue of their tri-emulsion layer construction provide multiband photography directly in a single exposure? Obviously, if a particular standard color film (a) can be exposed and retrieved (this will not be possible on ERTS-A, for example), and (b) can provide the interpreter with enough information to fulfill user requirements, then one certainly should not bother pursuing black-and-white multiband photography. However, this is not always the case; the examples in Figure 4.14 show that, depending on the kinds of information desired, interpretation results often can be greatly improved using reconstituted multiband photography instead of a standard film type.

Note that there is a tremendous amount of information contained within the color enhanced image shown in Figure 4.15 that is of interest to the forest land manager. Take, for example, the timber resources. The large sparsely timbered area on the right side of the photo would be classed:

$$\underbrace{90\frac{2\text{-}C2}{0Y23}}_{a}\underbrace{5\frac{1\text{-}Mw1}{N}}_{b}\underbrace{5\frac{1\text{-}R1}{N}}_{c}$$

Reading from left to right, such a classification means (a) 90% of the area is composed of coniferous trees exhibiting 50-80% crown cover with 50-80% of the ground covered by all types of vegetation present, and 50-80% of the trees are mature trees whereby only 20-50% of those trees are sawlog size, (b) 5% of the area is composed of wet meadow, non-stocked with commercial conifers, exhibiting > 80% crown and ground cover, and (c) 5% of the area is composed of riparian hardwoods, non-stocked with commercial conifers, exhibiting > 80% crown and ground cover.

Not only can vegetation types be classified on the type of imagery shown in Figure 4.15 but also timber volume estimates can be made using a technique reported upon by William Draeger in his 1968 FRSL Annual Progress Report to NASA. This earlier investigation showed that two characteristics of a forest stand, i.e., percent crown closure and average crown diameter, can be accurately measured on small-scale non-stereo imagery and can be related to timber volume. For the timbered area shown in Figure 4.15, both of these parameters were estimated by means of visual comparison of the stand in question with aerial photo examples of stands for which closure and crown diameter were known. These data were used in the following volume prediction equation which was based on regression estimation coefficients calculated using a least-squares line fitted to sampled data:

$$\begin{aligned} \text{Av. Vol/Acre (bd. ft.)} &= 2117 + (30.45)(\text{\% Crown Closure} \times \text{Av. Crown Dia.}) \\ &= 2117 + (30.45)(20 \times 20) \\ &= 14{,}697 \text{ bd. ft.} \end{aligned}$$

The above estimated average volume per acre derived from the Ekta Aero Infrared imagery was then compared with an estimate made using conventional on the ground techniques. Eight field plots were visited by a field crew

Ekta Aero Infrared Photography; June, 1966

Additive Color Enhanced Image; July, 1969

Panchromatic Photograph; July, 1969

Figure 4.15 This example illustrates that a color combined image can be made that closely simulates an Ekta Aero Infrared photograph. The area shown is just a portion of the Meadow Valley-Bucks Lake Test Site (NASA Test Site #20). Based on an analysis of the Ekta Aero Infrared photography, the major vegetation cover types within the entire test site were delineated (see panchromatic photo). Procedures used for classifying each vegetation type and estimating timber volume are discussed in the accompanying text.

within this stand and timber volume was determined using Bitterlich variable-plot procedures and volume tables compiled for the region by the U. S. Forest Service. Results from the field survey were:

Number of plots = 8
Number of trees per plot = 7.4
Number of stems per acre = 63.2
Basal area per acre = 126.9 square feet
Volume per acre = 14,005 bd. ft.

It is interesting to note that the volume of timber estimated by making measurements off the imagery shown in Figure 4.15 was within 5% of the volume estimated by the field crew. Furthermore, the time and effort required to estimate by means of vertical aerial photography the volume of commercial timber on this site was just a fraction of that required by the ground survey team.

Future Research Activities

The work performed to date by personnel of our II&E Unit in both the agricultural and wildland test sites indicates that valuable resource information can be extracted from remote sensing data -- particularly when advanced image procurement and interpretation techniques are implemented. During this past year a great effort was made to develop testing procedures which could effectively be used to determine the best combinations of imagery and enhancement-interpretation techniques needed for solving particular resource inventory problems. Interpretation testing, supported by quantitative results, led to the selection of an optimum method for surveying the cereal grain crop in Maricopa County, Arizona.

Nearly all tests to date indicate that the theoretical implications associated with using multiband and multidate imagery are indeed realistic concepts which can be applied in a practical sense to resource inventory problems -- especially in an agricultural environment. So far, it has been shown that two crops, wheat and barley, can be effectively surveyed on imagery obtained in three spectral bands (viz., Aerial Ektachrome film) on two dates (viz., May and June). The next logical step is to determine if the remaining major crops growing in the Phoenix area can be discriminated on imagery obtained using the most informative spectral bands on carefully selected dates. However, it is probable that as the data base becomes more and more complex (through the use of additional spectral bands and dates), the human interpreter will become hopelessly inundated with imagery. Therefore, to facilitate the task of photo interpretation, experiments will be done by our unit using various data compression techniques. Specifically, procedures for optically color combining multiband and multidate imagery will be developed. As such methods evolve, the interpretability of the resulting composite images will be determined by means of rigorous testing with skilled photo interpreters. The anticipated outcome of this research is to derive a method for inventorying all major crops growing in the Phoenix area using multiband-multidate imagery that we have suitably compressed so that, while the essential information content is retained, it is easily extracted by the human photo interpreter.

The work to be done this next year will be primarily with agricultural resources; however, research will also continue at our two NASA forestry test sites, Meadow Valley-Bucks Lake and San Pablo Reservoir. Analysis of natural vegetation will continue to be the focal point of this research. Building on the recent research results regarding vegetation mapping, mainly type delineation and species identification using enhanced imagery, we will study additional parameters about vegetation cover -- such as, density and distribution. For the forest land manager, rapid assessment of forest stand density and distribution are of maximum importance since these parameters are directly related to wood volume within a forest.

Lastly, a major activity of this Unit will be to continue close cooperation with the other four Units at the Forestry Remote Sensing Laboratory. Cooperation between this Unit and the Automatic Image Classification and Data Processing Unit is necessary when attempting to evaluate or derive an image interpretation system combining the skills of both humans and machines. For example, in the foreseeable future, the ADP Unit will aid in selecting (through rapid analysis of numerical data obtained from density scans of negatives) training samples most suitable for use by human interpreters. In addition, human interpreters will focus their attention and skills on imagery that has been electronically compressed, enhanced, analyzed and displayed by the ADP Unit. Likewise, the Spectral Characteristics Unit can interact with our Unit by collecting spectral data on those resource features and conditions being analyzed by the human photo interpreters. An immediate goal of the SC Unit is to develop methods for determining, for any given resource inventory, the optimum bands for obtaining multiband images, which, in turn, are to be optically enhanced by our Unit. Since the success of the Training Unit is directly related to the quality of research fundings emanating from the other Units, the II&E Unit will continue to actively participate in preparing the necessary materials needed for training personnel from user groups.

CHAPTER 5

AUTOMATIC IMAGE CLASSIFICATION AND DATA PROCESSING

Jerry D. Lent

Introduction

The major activity of the FRSL's Automatic Image Classification and Data Processing Unit during this reporting period has been the design and implementation of an "in-house" image digitizing and analysis system. This effort has been organized in such a manner as to optimize the data processing needs of the entire lab, not just one particular unit.

Our unit has progressed effectively towards the objective of supporting the FRSL's total data handling and analysis requirements, as well as implemented studies of feature classification using digitally recorded data of optical film densities. Section A of this chapter contains a discussion of the hardware components of the FRSL Terminal/Display system, while Section B contains a discussion of the present software components. Some examples of analytical results are presented in Section C. These examples are taken, in part, from the Phoeniz, Arizona test site which is more fully described in other chapters of this report.

Current Research Activities

A. Hardware Components

The current and proposed set of system components comprising the FRSL Terminal/Display system is schematically presented in Figure 5.1. Each part of the system is subsequently discussed in detail with reference to schematics and logic diagrams where appropriate. Primary consideration was given to (1) cost and (2) flexibility of use in each selected component. Flexibility, in this sense, connotes not only simple devices which are easy to use and maintain, but also flexible system configuration which enables many possible applications. For instance, the FRSL Terminal/Display system allows digital-to-analog as well as analog-to-digital data manipulation, as shown in Figure 5.1.

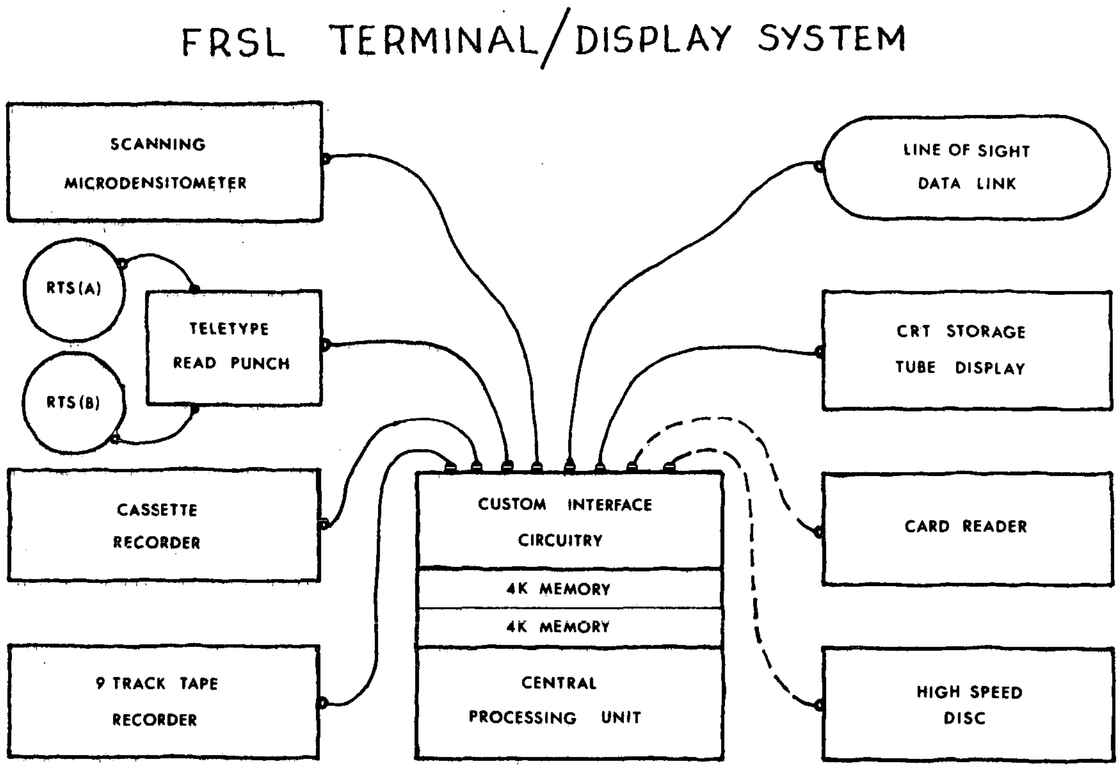


Figure 5.1: Existing and proposed FRSL Terminal/Display system components. For a more detailed description of each, see text below.

1) <u>FRSL Scanning Microdensitometer</u>. This device was custom built "in-house" to meet the film optical density digitizing needs of the lab. It is not very sophisticated in terms of machine tolerance or appearance, but it does provide a very high "Z resolution" (i.e., very good signal-to-

noise characteristics). Thus, it is possible to discount "noise" in any subsequent data analysis as being contributed by the scanning microdensitometer source. The basic sub-components of the scanner, in its present state, are a conventional light source, an X, Y incrementally driven stage, employing two precision lead screws and stepping motors, a detector source (presently a photo resistence cell), and internal circuitry for controlling scanner operation (viz., on-off power, fan for cooling light source, X and Y stage disengage, and stepping motor status display).

The light source is a standard 300 W projection lamp which is optically condensed and focused upon the film transparency plane. The detector receives the intensity-modulated light (which has been electronically calibrated against gains or losses to the input source through the use of a differential amplifier) and directs the voltage changes to the A/D converter, as shown below in Figure 5.2:

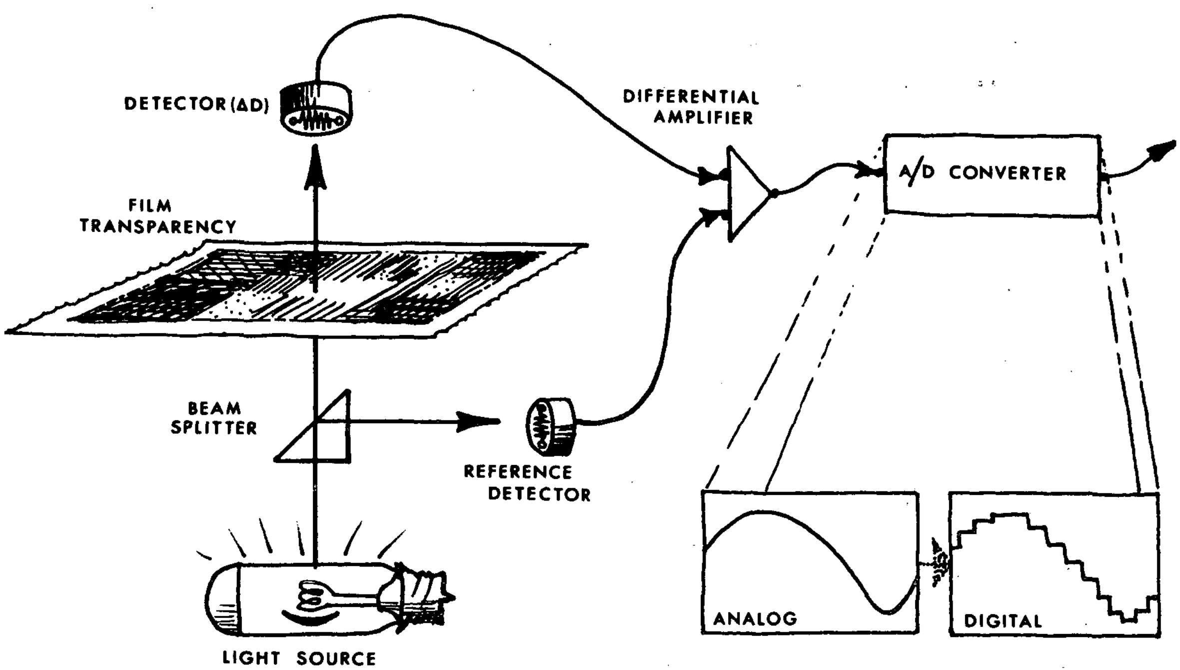


Figure 5.2: Schematic of density measuring and A/D conversion using the FRSL microdensitometer.

The X, Y stage mechanism is driven by two high-speed stepping motors under program control of the computer. It was first believed that the most useful scanning pattern would be an alternating pattern, as shown in Figure 5.3a; however, it was found that the X, Y scanning resolution was somewhat lower than expected due to takeup in the lead screws as directions were reversed. Distortions in data alignment from scan line to scan line occurred, though these were readily corrected with software at processing time. Consequently, we have modified our original program for controlling the scanning pattern, as shown in Figure 5.3b. The result is an X, Y scanning resolution of at least 1 mil, and Z resolution which is limited to 4000 grey levels (i.e., ± 10 V signal; 2.5 mV noise). Effective scanning apertures of less than 25 microns have been achieved.

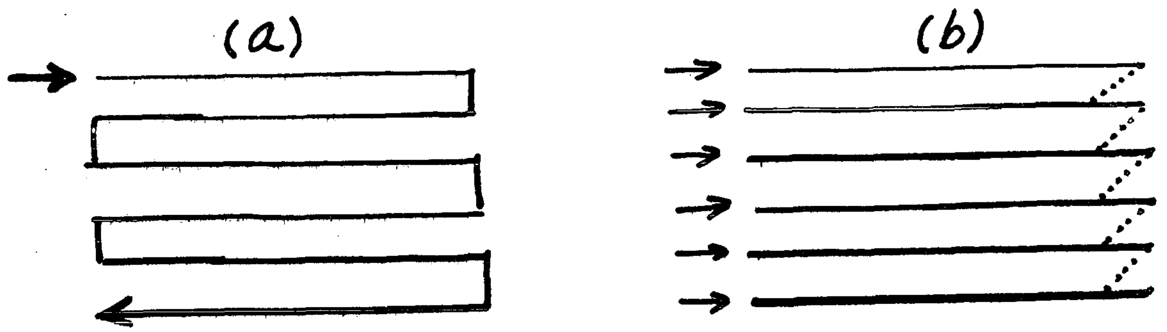


Figure 5.3: The above diagrams indicate the original scan pattern (a) and the revised scan pattern (b) which provides increased resolution and repeatability of measurement.

Scanning rates for the microdensitometer are presently peripheral device limited. That is, the existing I/O device (viz., a paper tape reader/punch) has a response capability of only ten characters of output per second, which means the stepping motors are limited to no more than three density samples per second. This rate is extremely inefficient, even for research purposes, when larger and larger areas are to be scanned. For instance, in the scanner's present configuration a 50 x 50 spot interval scan would require some seventeen minutes to complete. With planned power supply improvements and with magnetic tape recording being substituted for paper tape read/punch, the same 50 x 50 spot interval scan can be completed in less than ten seconds. One million points (i.e., a 1000 x 1000 spot interval scan) can be measured and digitally recorded in approximately one hour, instead of four full days.

2) Teletypewriter Read/Punch. This device is required for input and output to the central processing unit to be described later. It has a standard keyboard set (ASCII coding) with maximum I/O rates for both paper tape read and punch of ten characters per second, as already noted. Presently, this device is line-connected to two separate "terminal station" configurations offered by the campus Computer Center facilities. The RTS "A" line is a simple transmit facility to the CDC 6400 whereby computer "jobs" can be transmitted through the FRSL teletype device, and, depending upon length and extent of processing required, can be received upon completion at the remote terminal station (RTS). The RTS "B" line will be slightly more sophisticated in that it is a "time-sharing" system which will allow computer interrupt and programmer interaction during processing time. The FRSL teletype device has been modified to select either line "A" or "B" by switch selection.

3) Cassette Recorder. This device enables rapid program loading and data storage and retrieval, reducing use of the paper tape to a minimum. It is a two-track recorder with the address track binary encoded for random access search routines. With a packing density of 1000 bits per inch, data can be transferred to or from the tape at the rate of 5000 bits per second. This device was received with an existing "off-the-shelf" interface for our central processing unit.

4) 9-Track Magnetic Digital Tape Recorder. In order to do efficient data recording and provide compatability with other remote sensing installations

and proposed internal activities, it was considered essential that the FRSL terminal/display system be equipped with a standard 9-track magnetic digital recording capability. It is possible to transfer data (e.g., for updating files) or modify programs between the cassette recorder and the 9-track recorder under CPU control. Also data from other data processing facilities, such as Purdue LARS, Willow Run Labs, C.R.E.S., or MSC/Houston, can be handled more efficiently with a standard IBM compatible tape transport.

5) "Mini-computer" Process Control Device. This is a high-speed, 16-bit word length computer with flexibility to control many peripheral devices simultaneously. It also serves as the central component for an "intelligent" remote terminal station. This device presently consists of a 4-accumulator central processing unit (CPU), 8k words of memory, and custom interfacing hardware logic for all of the various devices listed in Figure 5.1. Assembler programs are available for conventional FORTRAN IV, ALGOL, BASIC, or a special 2 or 3 pass assembly language, depending on user application. The interface circuitry enables communication between the CPU and the other devices of the system. Software programs are described in Section B.

6) "Line-of-Sight" Data Link. A near-infrared transmitter and receiver operating at around 1.4 microns is nearing completion which will enable relatively high-speed data transmission capabilities and greater control of computer operations than either the RTS "A" or RTS "B" systems. Generally, such a system requires a small computer at the terminal station to control data transmission and receipt employing conventional transmission lines; up to sixteen remote computer terminals can be tied into the campus Computer Center facilities with normal operation rates of 2.4k baud. However, with the line-of-sight configuration the FRSL is completing in cooperation with the Structural Engineering Department, we will be able to increase this rate during low-use

times to 9.6k baud and possibly 20k baud. Reliability of operation for this type of device (instead of the conventional phone line/modem configuration) should be excellent, based on results of similar devices in the field. For instance, a line-of-sight data link has been in operation at the University of Colorado (Boulder, Colorado) for nearly a year with the only documented failure being caused by a heavy snowfall. It has operated successfully in heavy rains and fog.

7) CRT Storage Tube Display Unit. This device is intended to serve as the primary output component of the FRSL Terminal/Display system. It has a relatively high screen resolution (about 125 dots per inch can be plotted on the 6" x 8" viewing surface). It plots 1000 inches per second under program control (refer to Section B). The display is equipped to retain an "image" or alphanumeric information for approximately fifteen minutes. This will enable photos to be taken of significant images or data for reporting purposes.

8) Card Reader. This device, essential for an efficient running data processing terminal, is to be ordered during the last quarter, CY 1970. The particular device selected will be capable of reading both mechanically perforated and hand-marked data, at rates of either 200 or 400 cards per minute.

9) High-speed Storage Disk. This device is proposed to yield high-speed image storage capabilities for "refresh" purposes when interfaced with the CRT device mentioned earlier. Some potential applications are mentioned briefly in Section B.

B. Software Development

Software development has progressed at a compatible rate with hardware component implementation. Existing programs are discussed separately by category: (1) system operations software, and (2) "picture" processing software.

1) System Operations Software. The major program in this category is the

stepping motor driver program which controls the microdensitometer scanning and digitizing operations. It requires 1044_8 words of memory for operation. The user, wishing to digitize and store density values from a particular frame of imagery, pre-selects the scanning parameters and stores these in core locations for subsequent CPU processing. The sampling intervals (i.e., the number of steps between density measurements) for the X-drive and the Y-drive mechanisms, as well as their total lengths, determine the area to be scanned on the imagery. The smallest sampling interval for either X-drive or Y-drive is 0.0005". The longest length for both X-drive and Y-drive is about 4 inches. Following completion of the scanning, digitizing and recording, the program returns both X and Y stages to their original positions. Thus, if color film is being scanned, a change of filters is possible and a re-scan can be readily performed of a separate emulsion layer, if desired.

A second "system" operation program is the CRT storage tube display program. The display system was developed as a Master's thesis project by Mr. Abbott of the Electrical Engineering Department. The display is initialized by program controlled output (e.g., from the "encoded" digital output produced by the scanner). Data are transferred by means of the CPU controlled data channel, beginning with a starting address and word count and at least one mode control word. The starting address is one 16-bit word while the word count is the two's complement equivalent requiring 11 bits. The mode control word has the following bit configuration and functions:

where,

BITS	FUNCTION
0,1	Display mode (DM); this parameter controls the manner in which data will be displayed on the CRT where: 00 = write and store on screen 01 = write through 10 = write but not store 11 = undefined
2,3	Processor mode (PM); selects operating mode of processor and defines how data shall be interpreted where: 00 = ASCII coded character 01 = incremental point plot 10 = vector generation 11 = point plot
4	If bit 4 is 1, the binary number in bits 6-15 is loaded into the X position scaler.
5	If bit 5 is 1, the binary number in bits 6-15 is loaded into the Y position scaler. If bit 4 = bit 5 = 0, the starting position of the beam is assumed to be upper left corner.
6-15	Starting position of beam. X and Y form a standard right hand coordinate system with origin (0,0) at the lower left corner. The range of X is 1024 points and the range of Y is 742 points (i.e., about 125 points/inch of viewing screen).

The data format is different for each of the processor modes available to the user. In the ASCII coded character mode (i.e., bits 2,3 are set to 00), each 16-bit core word consists of two 8-bit ASCII characters. As shown below, character 1 is plotted first, then character 2:

0	7 8	15
CHAR 2		CHAR 1

A read-only memory (ROM) device is used to generate any of 64 ASCII characters, including punctuation symbols, numerals, upper case letters and three control characters ("line feed," "carriage return," and "form feed"). Upper and lower case plotting is feasible with the scaling capability of the mode control word.

When a "form feed" character is encountered, the program causes the viewing screen to be erased and the CRT beam to be positioned again in the upper left hand corner.

For the vector and point plot mode (i.e., bits 2, 3 are 10 or 11 in the mode control word), the word format is:

0	1	2	8	9
±	U	Y_{DSPL}	±	X_{DSPL}

The CRT beam is moved in an approximate straight line from its current position, C_1 (X_1, Y_1), to its new position C_2 $(X_1 + X_{DSPL})$, $(Y_1 + Y_{DSPL})$ where,

$$-128 \le X_{DSPL} \le +128 \text{ and}$$

$$-64 \le Y_{DSPL} \le +64$$

The new position becomes the initial position for the next word to be plotted. In vector mode (bits 2,3 = 10), if "U" is set to 1, the CRT beam is unblanked to draw a "contiguous" line. If "U" is set to 0, no line is drawn. In point plot mode, if "U" is set to 1, the beam is unblanked upon reaching its final position. The "incremental point plot" data format has not yet, as of this writing, been specified.

2) <u>"Picture" Processing Software.</u> A few preliminary "picture processing" routines have been developed as training exercises for familiarity with the equipment. They can be readily modified for the final component configuration of the terminal/display. One program, which is frequently used for display purposes, provides for ASCII symbol output from digital optical density values. The user can use input data from one of two present sources: (a) directly from the scanning microdensitometer, or (b) from a previously scanned image which has its density values punched onto paper tape. Another routine can be

implemented by the investigator which provides flexibility of display. The scanner, with its A/D conversion system, is capable of measuring density values which can be expressed digitally in the number range of 0 to 4096_{10}. For most images, however, the actual range of values is far less than 0-4096_{10}. Commonly the spread of values is found to be approximately 1000_{10} levels or less. Since it is not practical to visually determine where the density spread will be centered, some useful procedure is required to display the density values for viewing, training sample selection, or some other purpose. The range of values is expressed as one of eight possible ASCII characters chosen to depict eight decreasing levels of optical density. A descriptive example is presented to show how the user might interact in the decision and selection of a suitable grey scale display for subsequent analysis. Suppose the paper tape digital values from a previously scanned image are program loaded. Then, these density values from the tape are converted, as shown in the list below, to the indicated ASCII character (all numbers are octal notation):

DENSITY VALUES	ASCII CHARACTER
0000 - 0777	ϕ
1000 - 1777	$
2000 - 2777	&
3000 - 3777	#
4000 - 4777	*
5000 - 5777	=
6000 - 6777	.
7000 - 10000	(blank)

Now, if the particular image density data being used in this example for the initial grey level display reveal a printout consisting almost entirely of #'s and *'s, with a few ='s, the user knows the optical density range of his image is concentrated between 3000_8 and 5000_8. The display scale can be readily modified for a more detailed "look" at the scan by adjusting the scale to something like the following:

DENSITY VALUES	ASCII CHARACTER
0000 - 2777	ɸ
3000 - 3377	$
3400 - 3777	&
4000 - 4377	#
4400 - 4777	*
5000 - 5377	=
5400 - 5777	.
6000 - 10000	(blank)

Where in the "first pass" look at the data, the user had only three identifying symbols, he now has six symbols, resulting in a more interpretable display for subsequent analysis. The density value scale can be modified in any manner deemed useful for the user's objectives.

Several routines are used to organize the digitized optical density values prior to their classification. Most of this effort is directed toward the selection of suitable feature "training samples."

A frequency distribution of all the scanned density values is conventionally plotted first; this output will display the spread of data points, revealing modal groupings if they exist. Such output can often be useful for selecting alphanumeric characters to display "grey levels" for training sample selection.

The investigator can use up to sixty-four symbols for the grey level display; however, the data are more interpretable when they are compressed into a smaller number of symbols, say ten. An optional routine can be used next which highlights rapidly changing density values -- a form of "edge enhancement," which has been found helpful in locating boundaries between different features within the scanned data. Examples of both a density display and an edge enhancement are included in Figure 5.4.

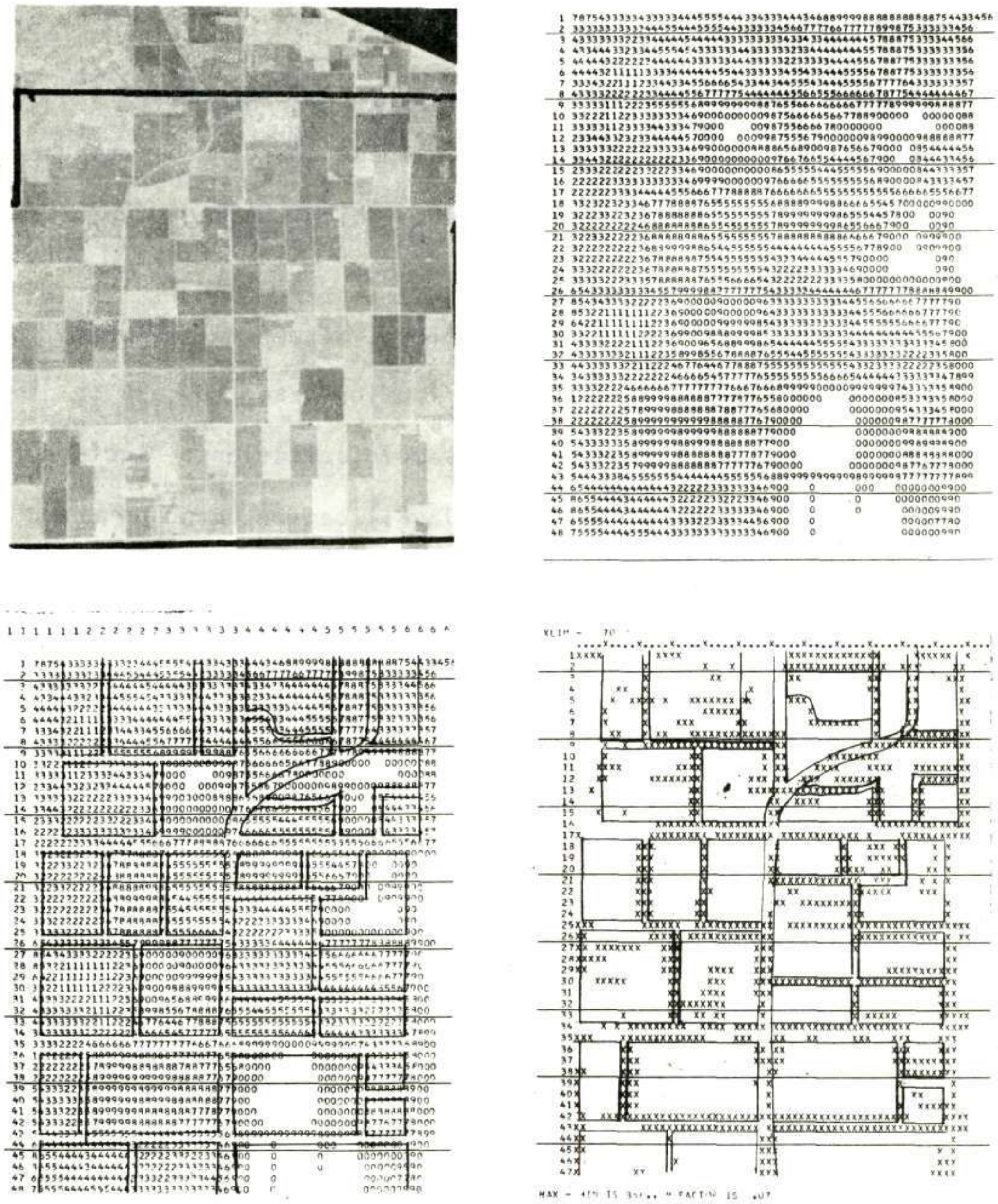


Figure 5.4: Several examples of optical density displays. The terrain boundaries of a six square mile area within the Phoenix Test Site are shown in part (a). This region was designated the "training area" from which the P.I. staff became familiar with the different crop tone signatures for subsequent testing in adjacent areas. It is also the region from which sample points were extracted by the scanning microdensitometer for defining crop signatures. Photo (b) shows the entire training area classified into one of ten density ranges -- the total optical density spread for the image was measured to be 856 levels. Photo (c) shows the same data with the terrain boundary information superimposed. Photo (d) shows the result of "edge enhancement" which often facilitates the demarkation of terrain boundaries by highlighting rapidly contrasting sample points and suppressing those which do not change rapidly.

Training samples which characterize all of the features are selected by line and column coordinates with two reference points per training sample being sufficient to define its entire boundary. These coordinates are then processed to yield "per training sample" statistics to which the user can refer when setting classification limits.

Up to five "pictures" have been combined, either multispectral or multidate imagery being employed, with classification based to date on density range alone within each of the training sample selections. Section five contains some discussion of additional data for classification purposes which can be investigated when the terminal system goes on-line to the large CDC computer.

C. Automatic Classification

Some processing of optical densities has been performed to date using photo examples taken of the Phoenix Multidisciplinary Test Site. Multidate and multispectral series have both been examined in order to test software programs. A special program was written to geometrically align multidate images.

One experiment was conducted whereby Highflight photography (scale 1:500,000 approx.) was used as input to the scanning microdensitometer. Three film types were scanned: Pan-25, Pan-58 and IR-89B. Using an area approximately six miles square from which training samples were selected and analyzed, an adjacent four square miles were classified using the Pan-58 photo with the following results:

Number of fields classified	43
Number of fields correctly classified..................	34
Number of fields incorrectly classified................	9

Two thirds of the errors were attributable to alfalfa being classified as "wheat." Pan-58 was determined to exhibit less "within-field" optical density variability than either of the other two film-filter combinations.

It is interesting to relate these results with those derived from conventional photo interpretation tests conducted in the same test area and discussed in other chapters of this report. While the two tests were conducted independently and under different testing procedures and objectives (i.e., the two tests cannot be considered a fair comparison), they reveal some interesting features which suggest areas of further study. First of all, for the same three black-and-white photos, the photo interpreters performed most accurately using Pan-25, (with Pan-58 and IR-89B following far behind). This is probably attributable to the greater contrast levels exhibited by the Pan-25 film-filter combination. A very sensitive microdensitometer record of all three reveals that while Pan-58 may be less interpretable it enables crop types to be better separated. Field-by-field assessment with actual ground truth data of the Pan-58 photo using both scanner optical densities and human photo interpretation showed -- for the limited measurements available -- that the microdensitometer data were twice as accurate in classifying the test area as the photo interpreter data. Improvements in photo interpreter classification are noted when Pan-25 is used instead of Pan-58. The best photo interpretation results were found to occur with color film which quite closely match the results obtained from the microdensitometer record of Pan-58.

Further work will be done to pursue the quantification of variability in optical density for various crop types. Also, it has been found that classification errors are greatly reduced or even eliminated with proper multispectral combinations and sequential combinations in agricultural sites. Statistical decision rules for classification will be studied to determine the extent to which the present man/machine analysis can be automated.

D. Adaptation of LARSYSAA to U.C. CDC6400

Some effort has been devoted to adapting the LARS pattern recognition programs (LARSYSAA) to the UC-Berkeley Computer Center and FRSL terminal/display system. We have modified our original objective of "making the LARSYSAA program work on the CDC 6400 equipment" to one of reformatting and reprogramming certain portions of LARSYSAA in our own local code. Accomplishing the latter will enable our programmers to better exploit the CDC 6400's increased processor speeds and core availability. A certain amount of the data processing which LARSYSAA would require can be done locally using the NOVA CPU with 8k memory restricting the complex portions of analysis for transmission to the CDC 6400 for processing. This should result in greatly improved "turn-around" times for processing data recorded by the Michigan 18-channel scanner or our own scanning microdensitometer device.

Another motive for modifying the LARSYSAA programs from their original design is to permit incorporation of additional analytical routines designed to improve wildland feature classification. An especially thorough consideration will be given to the matter of <u>texture</u> as a valuable classifier in addition to spectral information. Processing of optical densities, for example, can be done such that the first and second derivatives can be readily monitored (in analog form) to indicate the <u>degree</u> to which scanning point samples are changing and also the <u>rate</u> at which they are changing. Such information should prove useful in trying to separate features which spectrally might be quite similar (for example, certain vegetation types). It is currently estimated that both software and hardware developments will near completion by the end of the first quarter, 1971.

Future Research Activities

A. Feature Classification Activities

Efforts to determine optimum algorithm definition for feature classification will comprise our major emphasis in the future. By adapting the LARSYSAA routines to the University campus facilities, we feel we can make significant progress towards the automatic classification of wildland environments, just as agricultural crop discrimination can now be successfully accomplished. Several modifications employing other than "point-by-point" classifying decision rules will be studied and compared with conventional PI techniques. Edge recognition especially will be an important aspect of the research effort.

Utilizing the scanning microdensitometer's operational sampling speed of over 500 points per second, we will continue studies to determine the optimum sample interval and size for prescribed accuracies of classification. It may be that fewer samples are necessary to provide usable data for classification with photos taken at specified photo scales.

Texture analysis will be further studied as a means of increasing the effectiveness of our decision rules for classifying certain features. We anticipate a close rapport with the C.R.E.S. (University of Kansas) personnel in this effort as we attempt to define those parameters which contribute most to the effectiveness of automatically recognizing features of interest.

B. Data Bank Activities

The data bank system which the FRSL has been developing now has programming personnel directly assigned to working out routines for input, output and update of resource information of interest to scientists and/or land use planners. The Buck's Lake Test Site is serving as the model for organizing the system. We are presently oriented towards use of the UTM coordinate system for referencing terrain plots. It is hoped that a large number of specific "profiles" of data can be stored under computer controlled access for use by other units of the FRSL.

C. ERTS-A, Skylab Activities

Future activities towards ERTS-A data analysis consist of staying abreast of the data collection systems as they near completion in order that our Terminal/Display system will be as compatible as possible for handling raw or pre-formatted data from ERTS-A. We hope to send one individual from our Unit to Goddard Space Flight Center this coming summer to ensure compatibility and also enable us to begin work with experimental "simulated" ERTS-A data.

CHAPTER 6

TRAINING PROGRAM FOR THE INVENTORY OF VEGETATION RESOURCES

Donald T. Lauer
Sharon L. Wall

Introduction

The possibility of acquiring remote sensing data for use in surveying earth resources from high performance aircraft and earth satellites has led to the development of increasingly complex remote sensing data collecting systems and data analysis procedures. Already, large well-staffed data analysis centers are necessary to analyze the data from existing remote sensing systems. Acquisition of data from space and subsequent analysis involves even more advanced techniques of data storage and handling. There is a great danger, however, that earth resource managers and inventory specialists -- the individuals most knowledgeable as to whether the end product of this sophistication is meaningful -- may be forced out of the data acquisition and analysis loop as the systems and procedures become more complex. It is our feeling that a strong training program, drawing on the experience and knowledge of scientists who are active in all phases of remote sensing data acquisition and analysis, offers the best means of bridging this gap.

It is apparent that the problem of producing well-trained remote sensing specialists in adequate numbers for staffing various earth resources survey programs will only intensify in the future. For example, President Nixon recently reported in an address to the United Nations, that there should be a willingness on the part of the United States to provide remote sensing assistance for the solution of earth resource problems in foreign countries. Such pronouncements serve to increase the demand for remote sensing training, not only in this country but in many foreign countries as well.

Virtually all of the remote sensing training programs currently being offered are merely "appreciation courses", i.e., those designed to convey to the attendee that remote sensing techniques offer a powerful means of making accurate, timely, economical inventories of earth resources. While there may be a continuing need for these courses to be presented to various top-level "decision-makers", the major need is to train the actual "doers". Mere appreciation courses definitely will not prepare them to accomplish the all-important task of making operational inventories. Instead, they need to receive rigorous training in how to produce, through an analysis of remote sensing data, a survey of earth resources of the type that will meet the specific informational needs of the resource manager.

The Training Unit of our Forestry Remote Sensing Laboratory was organized with these considerations in mind. We wish to pursue an aggressive program designed to bring results of research to the user through (1) offering of various kinds of training programs and workshops, (2) making our research results available in syllabi and other forms, suitable for use in training programs, and (3) encouraging scientists and resource managers to visit our Laboratory.

Much of the Training Unit's activities entail "on-site" training at various NASA Test Sites in which we have been conducting our research during the past five years under the NASA Earth Resources Survey Remote Sensing Research Program. More specifically, our Training Unit attempts to disseminate information on the following subjects: (1) specific user requirements for earth resource information; (2) basic matter and energy relationships; (3) remote sensing capabilities in various parts of the electromagnetic specturm; (4) sampling techniques including techniques for the acquisition of ground truth; (5) photo interpretation equipment and techniques; (6) image enhancement techniques; (7) automatic data processing techniques; and (8) techniques for optimizing the interaction between those who provide earth resource inventories and those who use them in the management of earth resources.

Completed Activities

A. India Project

Early in 1969 a request was made to NASA by the Indian government for assistance in applying remote sensing techniques to aid in the assessment of coconut blight. This disease is caused by a fungus (Phytophthora sp.) and can severely damage coconut tree plantations.

As a result of this request, Dr. Pisharoty and Dr. Dakshinamurty of the Indian government visited our Forestry Remote Sensing Laboratory on October 29, 1969. During that visit plans were made for a FRSL staff member to visit India to help develop remote sensing techniques for the early detection of this economically important disease. Consequently, Mr. Edwin Roberts of our Laboratory travelled to India and spent more than three weeks working with Indian scientists. A few of Mr. Roberts'accomplishments include (1) visiting a number of areas throughout India and observing plantation conditions, (2) advising Indian personnel on the experimental design for a remote sensing survey, (3) procuring "hand-held" vertical photography from a helicopter of a number of test plots containing both healthy and diseased coconut trees and (4) procurring additional high resolution multiband aerial photographs using a 70 mm Hasselblad camera with several film types (i.e., Aerial Ektachrome, Ekta Aero Infrared, black-and-white panchromatic and infrared) during these test missions.

Following Mr. Roberts' return to the United States, we have learned that several Indian research groups, motivated by this initial partially successful research effort, are now cooperating on the project. For example, the Indian Central Research Institute of Plantation Crops (CRIPC) is making an all-out effort to study the disease and evolve early detection and control methods. In addition, the Central Coconut Research Station (CCRS) is engaged in intensive laboratory and test plot work in support of the project.

B. Workshop on Remote Sensing of the Environment

The Association of American Geographers, through its Commission on Geographic Applications of Remote Sensing, sponsored a one day Remote Sensing Workshop on Thursday, August 27, 1970, following the 1970 annual AAG meetings in San Francisco. The workshop was held at our School of Forestry and Conservation, University of California, Berkeley and was coordinated by personnel of the Forestry Remote Sensing Laboratory. Nine lectures were presented with the intent of introducing the subject of remote sensing to persons engaged in various fields of geography. Lectures were given on basic matter and energy relationships, thermal infrared imagery, automatic data processing, land use classification on aerial and space imagery, and application of remote sensing to urban, cultural and physical geography. A schedule of events for the workshop listing those who participated and the subject matter which they presented is given below in order to emphasize the balance that was sought between the theoretical and the practical, as well as between lectures and field tours:

8:30 Registration - Birge Hall, Room 50, University of California, Berkeley.

9:00 Welcome - Gene A. Thorley, Director, Forestry Remote Sensing Laboratory, University of California, Berkeley.

9:05 Introduction - Frank Horton, President, AAG Commission on Remote Sensing of Environment, Iowa State University.

9:15 Basic Matter and Energy Relationships, and Photographic Systems - Donald T. Lauer, Forestry Remote Sensing Laboratory.

10:00 Coffee Break.

10:15 Thermal Infrared - John E. Estes, University of California, Santa Barbara.

10:45 Radar - Stanley Morain, University of Kansas, Lawrence.

11:30 Automated Data Handling Techniques - Jerry D. Lent, Forestry Remote Sensing Laboratory.

12:00 Field Trip to San Pablo Reservoir (NASA Test Site) and Lunch - Staff of the Forestry Remote Sensing Laboratory.

Return to Birge Hall.

2:30 Classification of Areas According to Land Use: From Simulated Space Photos - Robert Rudd, Denver University.

2:45 Classification of Areas According to Land Use: From Actual Space Photos - Randolph Thaman, Forestry Remote Sensing Laboratory.

3:00 General Geographic Applications of Remote Sensing (Urban and Cultural Applications) - Leonard Bowden, University of California, Riverside.

3:30 General Geographic Applications of Remote Sensing (Physical Applications) - Robert Alexander, Geographic Applications Program, USGS.

4:00 Summary and Conclusions - Robert N. Colwell, Associate Director, Space Sciences Laboratory, University of California, Berkeley.

4:30 Adjourn.

Perhaps the highlight of the one day session was the tour of the San Pablo Reservoir Test Site (NASA Test Site #48). Since this area is just a few miles east of the Berkeley Campus, it was easily visited for a few hours by the entire group. While in the field, FRSL personnel (1) described the various kinds of earth resources within the site and their interrelationships (e.g., water, vegetation, livestock, game and recreation), (2) discussed remote sensing imagery taken of the site, (3) issued representative examples of imagery to each participant for study while in the field, (4) explained "ground truth" collection procedures used at this site during aircraft overflights, and (5) discussed image analysis techniques relating to kinds of imagery, scale differences, vegetation mapping, photo interpretation keys, etc.

In addition to the above, each course participant received a fully illustrated tour guide prepared for the test site (complete with hard copy photo examples) and a detailed course syllabus containing key articles selected to facilitate his being introduced to the complex subject of remote sensing. The table of contents for the syllabus is given below:

C. Visitors to the Forestry Remote Sensing Laboratory

A primary activity of the Training Unit is to disseminate information available at the FRSL to outside individuals or groups. In keeping with this objective, we continue to employ an "open door" policy at the Laboratory whereby all persons interested in our activities are welcome. In fact, we rigorously encourage visits by fellow researchers and representatives of user groups. We have found that during the insuing discussion we, likewise, learn a great deal, particularly with reference to ways in which remote sensing capabilities might better be used to satisfy the informational requirements of earth resource manager.

Rather than list all those persons who have visited the FRSL during the past year, a short list is given below indicating our most recent visitors:

DATE	NAME	ORGANIZATION
6-17-70	Martin L. Benson	Forest Research Institute, Yarrabumla, A.C.T. Australia.
6-17-70	William Barker	Lockheed Electronics Co., Houston, Texas.
6-17-70	Edward Zeitler	NASA Manned Spacecraft Center, Houston, Texas.
7-10-70	Robert D. Reinhardt	Institute of Ecology, U.C. Davis, Davis, California.
7-17-70	Shan Topiwalla	Lockheed Electronics, Co., Houston, Texas.
8-10-70	Evelyn Shaw	The American Museum of Natural History, New York, New York.
8-10-70	W. John Perry	Bureau of Mineral Resources, Dept. of National Development, Canberra, Australia.
8-10-70	Peter Hillman	Bureau of Mineral Resources, Dept. of National Development, Canberra, Australia.

8-27-70	Lawrence E. Wittsell	Biological Research Center, Shell Development Co., Modesto, California.
8-27-70	Leonard W. Bowden	Dept. of Geography, U. C. Riverside, Riverside, California.
9-4-70	Gilbert Long	French National Research Center, Montpellier, France.
9-7-70	P. D. Bhavsar	Indian Space Research Organization, Navrangpura, Ahmedabad, India.
9-8-70	Jim Johnson	Dept. of Range Management, Oregon State University, Corvallis, Oregon.
9-14-70	Mike Steinsnyder	McDonnell-Douglas Corp., Huntingdon Beach, California.
9-18-70	K. S. Hiran	University of Udaipur, Pratap Nagar, Udaipur, India.
9-18-70	R. N. Pahalwan	University of J. N. Krishi Vishwavidyalay, Jabalpur, India.
9-21-70	Ralph Algazi	Dept. of Electrical Engineering, U. C. Davis, Davis, California.
9-25-70	Jack O. Palgen	Allied Research Associates, Inc., Hyattsville, Maryland.
9-30-70	Arch Park	NASA Headquarters, Washington, D. C.
9-30-70	Joe Vitale	NASA Headquarters, Washington, D. C.

C. Training Unit Facilities

A few items which are available at the FRSL for use by interested individuals engaged in remote sensing activities merit special mention in this report. First, the FRSL remote sensing reference library containing over 2600 articles is continually being updated for use by both our staff, students, and Laboratory visitors. Second, our film library, containing imagery obtained by earth orbiting satellites (Tiros, Nimbus, Gemini and Apollo), NASA Earth Resources Program aircraft (Convair 240, Lockheed P3A and RB-57) and private contractors, can provide a means for review of imagery by scientists prior to requesting photo reproductions from NASA.

Lastly, fully illustrated copies of all NASA funded forestry reports, and training syllabi and field tour guides prepared by the FRSL staff are available and are ideal reference aids to those participating in remote sensing activities.

Future Activities

As in other Forestry Remote Sensing Laboratory training exercises conducted thus far, Training Unit personnel will continue to make maximum use of the concept of "learning by doing". Consistent with this concept, when we are discussing remote sensing applications with individual visitors or user groups, actual rather than hypothetical problems will be emphasized. These problems will be centered around the inventory of earth resources at NASA test sites, one of which (the San Pablo Reservoir Test Site) is only eight miles from our classroom facilities at the University of California. Training films, field tour manuals, and display boards based on this and other NASA test sites which our group has studied during the past six years have been successfully used for training in the past and are available for future use. These training materials illustrate various data acquisition and analysis techniques with emphasis on both the gathering of "ground truth" data and the extraction of information from remote sensing imagery. Our extensively illustrated reports of research conducted at these test sites are proving useful as syllabi for undergraduate, graduate and University Extension courses currently being taught by personnel of our Laboratory. For example, under NASA auspices a "Manual of Multiband Photography", in which much of our work is summarized, is nearing completion. In addition a 150-page report entitled "Analysis of Earth Resources on Apollo 9 and High Altitude Photography" is soon to be published by NASA in quantity. All of these items will provide valuable reference material during future training activities.

Generally, but depending on the particular training situation, emphasis will be placed on the analysis of multiband space photographs and multiband-multidate high flight photographs on file at the FRSL. In addition, newly developed multistage sampling techniques will be stressed.

Chapter 7

SUMMARY AND CONCLUSIONS

Gene A. Thorley
Robert N. Colwell

In the introductory chapter of this annual report, the rationale is given for a systematic forestry remote sensing research program of the type in which our Laboratory is engaged. The unit organization of our Laboratory that has been developed in order to conduct a comprehensive program also is described and a statement is given of the types of programs that are investigated by the Laboratory's five major units, viz., (1) Operational Feasibility, (2) Spectral Characteristics, (3) Image Enhancement and Interpretation, (4) Automatic Image Classification and Data Processing, and (5) Training.

Chapters 2, 3, 4, 5 and 6 deal, respectively, with the activities and accomplishments of these five units during the past year. Most of these activities have been oriented toward a single objective: developing a capability for extracting useful, timely earth resources information from data of the type that soon will be provided by ERTS-A and supporting data-collection vehicles.

Among the specific conclusions indicated by our studies this year are the following:

1. The application of remote sensing to zoning for multiple use should be of benefit for a "first cut" analysis of the landscape. Detailed analyses, however, are hampered by the lack of correlation between some zoning criteria (e.g., recreation potential, etc.) and the physical parameters recognizable

on remote sensing imagery.

2. Results of tests with degraded imagery indicate that discrimination between woody vegetation, grassland and water bodies will be possible on ERTS data exhibiting 400-500 feet ground resolvable distance. However, if additional information on the various types of woody vegetation is desired, spaceborne data will have to be supplemented with higher resolution (i.e., 50 ft. GRD) aircraft imagery on which individual tree crowns can be seen.

3. Photo interpreters tend to choose film/filter combinations that exhibit high contrast as optimum, and hence may also choose film/filter combinations with high tone variability for individual objects. For example, Pan 25A was preferred to Pan 58 by the interpreters; however, Pan 58 exhibited less within-type variability when measured by a densitometer. Results of automatic classification of agricultural crop types in Phoenix-Mesa, Arizona utilizing Pan 58 were similar to those obtained by human photo interpreters using color transparencies and superior to those obtained by photo interpreters using Pan 25A photographs.

4. The acreages of wheat and barley in Maricopa County were estimated with a sampling error of 13 percent and 11 percent, respectively, using high-altitude, small-scale photography obtained in May and June, 1970. The acreage of small grains (wheat and barley combined) was estimated with a sampling error of 18 percent and the acreage of all cropland with a sampling error of 3 percent. These results demonstrate the feasibility of using high-altitude, small-scale photography for estimating crop acreages over large areas.

In addition to the above, a considerable amount of effort this year was expended to upgrade the data processing and spectral acquisition capabilities of the laboratory. We have successfully converted the Purdue pattern recognition program (LARSYSAA) to run on the University Computer Center's

CDC 6400, and have developed procedures for calibrating spectral data acquired by our fully portable system.

APPENDIX I

A SEMI-OPERATIONAL AGRICULTURAL INVENTORY USING SMALL-SCALE AERIAL PHOTOGRAPHY

William C. Draeger
Lawrence R. Pettinger
Andrew S. Benson

INTRODUCTION

The photographic experiment performed by the Apollo 9 astronauts in March, 1969 provided the scientific community for the first time with high quality multiband space photography. These photos were obtained specifically for the purpose of developing improved capabilities for the inventory and evaluation of earth resources. One of the principal test sites for this experiment is Maricopa County, Arizona, chosen on the basis of its geographic location (proximity to existing remote sensing research centers and low latitude, which made vertical photography possible from the spacecraft), and the presence of numerous earth resources presenting intriguing possibilities for evaluation on small-scale imagery. The test site contains the urban complex comprising the city of Phoenix, extensive agricultural lands, and varied semi-arid desert and mountainous regions valuable as rangeland and watershed areas (see Figure 1).

In addition to the Apollo 9 photography, the site has been the subject of regular high altitude (60,000-70,000 feet flight altitude) multispectral aerial photographic missions made possible through the NASA Earth Resources Survey Program (Tables 1 and 2). These missions, the first of which coincided with the Apollo 9 experiment, have been flown at approximately monthly intervals during the ensuing year and a half.

It became apparent at the outset of the experiment that the nature of the photography which would be available -- i.e., broad aerial coverage on very small scale photos at regular intervals through a variety of seasonal conditions --

Figure 1. This enlargement of Apollo 9 Infrared Ektachrome frame AS9-26-3801 shows the Phoenix test site where the semi-operational agricultural inventory was performed. The city of Phoenix appears in the right center, surrounded by extensive agricultural lands and wildlands valuable as rangeland and watersheds.

SENSOR PLATFORM	APOLLO 9	HIGH ALTITUDE AIRCRAFT	NASA RB57F AIRCRAFT
ALTITUDE	126 NAUTICAL MILES	60,000 FEET	60,000 FEET
CAMERA SYSTEM / DATE	<u>70mm Hasselblad Cameras</u>: Pan-25, Pan-58, IR-89B, and IR Ektachrome-15 film-filter combinations (S065 Experiment)	<u>35mm Nikon Cameras</u>: Pan-25, Pan-58, IR-89B, and IR Ektachrome-15 film-filter combinations <u>70mm HyAc Cameras</u>: Pan-25 and IR Ektachrome-15 film-filter combinations	<u>70mm Hasselblad Cameras</u>: Pan-25, Pan-58, IR-89B, and IR Ektachrome-15 film-filter combinations <u>RC-8 Cameras</u>: Ektachrome-HF3, and IR Ektachrome-15 film-filter combinations
<u>1969</u>			
March 8-12	X	X*	
April 23		X	
May 21		X	
July 15		X	
August 5		X	
September 30		X	
November 4		X	
December 6			X
<u>1970</u>			
January 13			X
February 6-8			X
March 16			X
April 22			X
May 21			X
June 16			X
July 28			X

* 70mm Mitchell-Vinten cameras were substituted for 35mm Nikon cameras on this date only.

Table 1. Tabulation of the types of imagery obtained through the NASA Earth Resources Survey Program for the Phoenix test site during 1969 and 1970.

MISSION/DATE	Zeiss (1/60,000)	RC - 8 (1/120,000)				Hasselblad (1/500,000)					
	IR EKTA-15	EKTA	IR EKTA-15	IR-89B	PAN	PAN-25	PAN-58	IR-89B	EKTA-HF3	IR EKTA-15	OTHER PAN
116/Dec. 6	S0117/D	S0278/2E	----	----	2402/12	3400	3400	----	2448/UV-17	S0180/15	----
118/Jan. 13	S0117/D	2448/HF-3	----	S0246	----	3400	3400	2424	2448/UV-17	S0180/15	----
120/Feb. 6-8	S0117/D (also S0278/2E)	S0278/2E	S0117/15	S0246	2402/12	3400	3400	2424	S0278/2E	S0180/12	3400/47B
123/Mar. 16	S0117/D	2448/HF-3	----	S0246	----	2402	2402	2424	----	S0117/15 S0117/15 +CC30B	----
127/Apr. 22	S0117/D	2448/HF-3	----	S0246	----	2402	2402	2424	----	S0117/15	----
129/May 21	S0117/B	2448/HF-3	S0117/15	----	----	2402	2402	2424	S0278/3	S0117/15	----
131/Jun. 16	S0117/B	2448/HF-3	S0117/15	----	----	2402	2402	2424	S0278/3	S0117/15 S0117/15 +CC30B	----
139/Jul. 28	2443/15	S0-397/2E	2443/15	----	----	2402	2402	2424	S0168/2E	S0117/15 S0117/15 +CC30B	----

Table 2. Detailed Summary of NASA RB57F Imagery (by film-filter combination) Obtained Between December 1969 and July 1970 for the Phoenix, Arizona Test Site.

would make possible and, in fact, almost demand a regional-operational approach to the research. One of the primary advantages of using small scale aerial or space photography is that it affords a synoptic view of the earth's surface (i.e., large areas of land can be seen in their entirety on one or a very few images), suggesting a particular potential usefulness for conducting broad regional resource analyses. Furthermore, few actual resource inventories as presently undertaken limit themselves to a small area, but rather are usually geared to larger managerial or policy-formulation units such as entire watersheds, counties or states. Thus, most remote sensing surveys, when performed operationally, would probably also be geared to fairly large areas so as to provide maximum utility to the ultimate user. Finally, while the development of remote sensing techniques on small test sites is often quite useful, especially in the early experimental stage, findings of limited tests often cannot be directly applied to the larger operational case. In addition to the obvious problems stemming from increased interpreter fatigue and data handling requirements when large areas are the subject of surveys, the phenomenon of environmental variability often becomes a major factor to be dealt with in the design of information extraction techniques.

For these reasons, it seemed that one of the most meaningful experiments which could be performed with the imagery described above would be to attempt to make a survey of a particular resource for Maricopa County as a whole. By so doing, an attempt could be made to answer questions which would arise only in such a semi-operational survey and which must be solved before the full benefits which might accrue from the use of high altitude or space photography can be realized. In addition, it was hoped that such a study might provide some clues as to the procedures to be followed in evaluating synoptic imagery which will become available from the Earth Resources Technology Satellites, ERTS-A and ERTS-B, due to be launched in early 1972 and 1973, respectively, and the manned Sky Laboratory, scheduled for launch in 1973.

While certainly any number of the varied resources of Maricopa County could be the subject of such a survey, none are more important or more amenable to the application of remote sensing techniques than agricultural crops. According to recent records, over 10 percent of the land in Maricopa County is under cultivation. The county provides roughly half of Arizona's agricultural crop production, and ranks third among all U.S. counties in gross value of such products. In addition, many of the crops grown contribute directly to the livestock and cattle feeding industry, in which Arizona ranks eighth nationally. The nature of agricultural cropland makes it especially well suited to such a study. By and large such land consists of discrete fields, each of which contains a fairly uniform stand of a particular type of vegetation that may vary quite rapidly in its phenological characteristics through a seasonal cycle. This characteristic presents an excellent opportunity for the development of techniques which could be quite valuable in their own right, and which hopefully could contribute to methods applicable to more variable wildland vegetation types. Finally, a very real need exists at the present time for inexpensive, accurate and up-to-date inventories of agricultural crops, as is evidenced by the extensive program carried out by the Statistical Reporting Service of the U. S. Department of Agriculture in cooperation with various state and county organizations. Thus it was decided that, at least initially, research efforts would be concentrated on the agricultural resources of the county.

PRELIMINARY TESTS

Detailed field studies were begun in two areas south of Mesa, Arizona in March, 1969 at the time of the Apollo 9 overflight. A 16 square-mile area containing more than 125 individual fields was chosen as the primary study area. This site was chosen because (1) it was contiguous, (2) it was easy to reach for gathering crop data on a field-by-field basis, (3) it contained many of the important crop types found in the Phoenix area, and (4) it was imaged clearly on the Apollo 9 imagery as well as on most of the photos taken during subsequent aircraft missions. Additional data were also gathered during 1969 for another area of some 22 square miles (more than 250 fields) located in the same general region.

These two areas, totaling over 24,000 acres of agricultural land, were monitored at the time of each photo mission so that distribution and variability of crop type, crop development patterns, and crop signature could be adequately assessed. Coincident with each aircraft mission, each field was visited on the ground and notes were collected regarding crop type, condition, height of stand, and approximate percentage of ground cover.

An interpretation test was devised to establish whether crop type could be determined with greater accuracy using small scale Nikon aircraft photography than with Apollo 9 Hasselblad space photography. It was determined that overall interpretation results for crop identification were quite similar for both types of photographs (Carneggie, et al., 1969). Although the resolution of the high altitude photographs was greater than that of the space photographs of the same area, the improvement was not sufficient to permit detection of image detail which is necessary for increased accuracy of crop identification. For this reason, it is believed that valid inferences regarding the interpretation of crop type on space photography of Apollo 9 quality can be drawn from the conclusions based on studies of high altitude <u>aircraft</u> photography.

The most serious limitation to developing useful crop identification techniques lies in the variability of crop type and cropping practices. Any factor which affects the distribution, development and vigor of a crop will affect its photographic signature, and thus may influence the success with which that crop can be consistently identified. Thus some <u>a priori</u> knowledge or assumptions regarding these factors is necessary before practical interpretation techniques can be developed. Our conclusions regarding these factors were as follows:

1. Crop type and distribution. It is generally true that agricultural practices in an area are relatively stable and that totally foreign crops are rarely introduced. For this reason, interpretation keys can be devised for particular crops in a specific area with little fear that certain crops will totally disappear or that new crops will suddenly be introduced in large number. These generalizations were found to be valid for the main crops grown in Arizona during a recent 4-year period.

2. Seasonal development. Documentation of the seasonal development of crops is important for determination of optimum times of the year for crop type discrimination. Both within-season and between-season variability will affect the specification of optimum dates for obtaining photography. Knowledge of crop sequences and of the variations which affect these sequences must be understood. For agricultural areas, the cyclic changes and the approximate dates when they occur are best summarized in a table or chart known as a "crop calendar." Tone values of individual fields (as seen on photographs of a given date) can be related to the stage of maturity of the crops on that date, as summarized in the crop calendar. The calendar can then be used to determine either (1) at what single date a particular crop type has a unique signature that could be discriminated from signatures of all other crops, or (2) what combination of dates for sequential photography would best permit identification of that crop type.

3. Crop signature. Since little field detail is discernible at the scale and resolution of the high altitude Nikon photographs which were studied during 1969, Photographic tone or color became the critical factor for identification. Either unique spectral signatures must exist at one date so that

individual crop type can be identified, or else sequential patterns of tone or color must exist such that crop type can be distinguished on the basis of changing patterns (i.e., bare soil to continuous cover crop to bare soil) at particular dates throughout the year.

Interpretation tests were administered to determine the value of multidate and multiband photography obtained during 1969 for crop identification. The following conclusions are suggested by the results of these tests: (1) similar results were obtained from Apollo 9 and high altitude photographs, (2) better results were generally obtained from Infrared Ektachrome photos than from Panchromatic-25 photos, (3) improvement in percent correct identification resulted from the selection of specific date(s) for particular crops (e.g., May for identifying barley), and (4) the concurrent identification of crop types using March 12, April 23 and May 21 Infrared Ektachrome photographs produced the most substantial improvement in overall identification.

DEVELOPMENT OF THE SEMI-OPERATIONAL SURVEY

A. Determination of Film-Filter Combinations

As discussed earlier, and based on the above results, it was decided that a semi-operational countywide inventory of one or more particular crops would provide the most logical extension of the techniques initially developed for only one small portion of Maricopa County. The decision to perform this survey for barley and wheat was made for the following reasons: (1) small grains (of which barley and wheat are the only major varieties in Maricopa County) account for approximately 20% of the crop acreage in Maricopa County and thus are important crops for which agricultural statistics are currently prepared using conventional techniques, (2) these crops mature and are harvested within the first half of the calendar year, coincident with the time period for which monthly NASA aircraft missions were scheduled during 1970 and, (3) our previous results indicated that the highest percentage correct identification of any crop was achieved for barley (90% using Infrared Ektachrome photos and 91% using Pan-25 photos) by selecting the appropriate month (May) for conducting the test. For these reasons, it was felt that a survey for barley and wheat would provide the greatest opportunity for initial success using a previously untried technique. Plans for similar surveys for the other major crops will be undertaken in the future when the technique has been refined.

Previous studies of multiband high altitude Nikon aerial photographs of the Phoenix area (Carneggie, et al., 1969; Pettinger, et al., 1969) indicated that, of the 1969 photo dates available (March 12, April 23 and May 21), May photographs were best for identifying small grains; also, of the film/filter combinations available -- Infrared Ektachrome (8443)/15, Panatomic-X (3400)/25, Panatomic-X (3400)/58, and Infrared Aerographic (5424)/89B -- Infrared Ektachrome/15 and Panatomic-X/25 produced the best photo interpretation results. The following table summarizes the interpretation results obtained for the identification of barley in the 1969 study which used high altitude photography taken in March, April and May, 1969 (there were not enough wheat fields in the test area to design a valid test for that crop):

PHOTO INTERPRETATION TEST RESULTS FOR BARLEY IDENTIFICATION ON HIGH ALTITUDE PHOTOGRAPHY (1969)[1]

	Panatomic-X/25			Infrared Ektachrome/15		
	March 12	April 23	May 21	March 12	April 23	May 21
Percent Correct	34	31	91	33	57	90
Percent Commission	38	44	3	34	24	6

[1]Carneggie, et al., 1969.

In the table above, percent correct data indicate the percentage of actual barley fields in the test area that were corrently identified by the interpreters. Percent commission data indicate the percentage of the total number of fields identified as barley which were actually some other crop type.

Studies of crop development patterns during early 1970 (data collected from FRSL field surveys and extracted from Arizona Crop and Livestock Reporting Service newsletters) indicated that the small grain crop was developing in a normal manner. Thus general conclusions based on crop calendar information, which indicate that small grains are mature and most easily distinguishable from other crops during the month of May, were held to be applicable for 1970.

Although barley could be consistently identified on May 21, 1970 photos, wheat and alfalfa were sometimes confused. It was discovered that the identity of fields in question usually could be established by noting the appearance of these same fields on June 28, 1970 photos. For this reason, photos taken on May 21 and June 28 were ultimately provided for the survey.

Previous conclusions regarding optimum film type were not totally acceptable in terms of the 1970 survey. In addition to the four film types tested using high altitude photos in 1969, a color film, namely Ektachrome MS (2448), was also available which had not previously been evaluated. Also, the scales of the RC-8 photos (1/120,000) and Hasselblad photos (1/500,000) which were to be used in the survey were different from the Nikon photos (1/950,000) obtained in 1969; the resolution of the 1970 imagery was also improved. Because of these differences, it was felt that a new test should be made, based primarily on May 21, 1970 photos, to determine the optimum film/filter combination for the identification of various types of crops.

The following film/filter combinations were tested:

CAMERA	FILM/FILTER	SCALE
RC-8	Ektachrome MS Aerographic (2448)	1/120,000
RC-8	Infrared Ektachrome (SO117)/15	1/120,000
Hasselblad	Plus-X Aerographic (2402)/25	1/500,000
Hasselblad	Plus-X Aerographic (2402)/58	1/500,000
Hasselblad	Infrared Aerographic (2424)/89B	1/500,000

It was realized at the outset that the scale differences between RC-8 and Hasselblad imagery would probably affect the success with which crop types could be distinguished. However, imagery at these two scales represented all that was available. The scale difference was accepted as another constraint within which the test must be administered.

Fifteen photo interpreters of equal ability were randomly placed in one of five three-man photo interpretation groups. Five four-square mile test plots were chosen from thirty-two sample plots located in the area (Figure 3). The photo interpretation tests were administered so that (1) each interpreter group would interpret each of the five film/filter types, (2) each test plot would be interpreted using each of the five film/filter types, and (3) no interpreter group would interpret a test plot more than once. Thus each plot was interpreted fifteen times for a total of seventy-five photo interpretation tests.

$$5 \text{ Test Plots} \times \frac{5 \text{ F/F Types}}{\text{Test Plot}} \times \frac{1 \text{ Interp. Group}}{\text{F/F Type}} \times \frac{3 \text{ Interpretations}}{\text{Interp. Group}} = 75$$

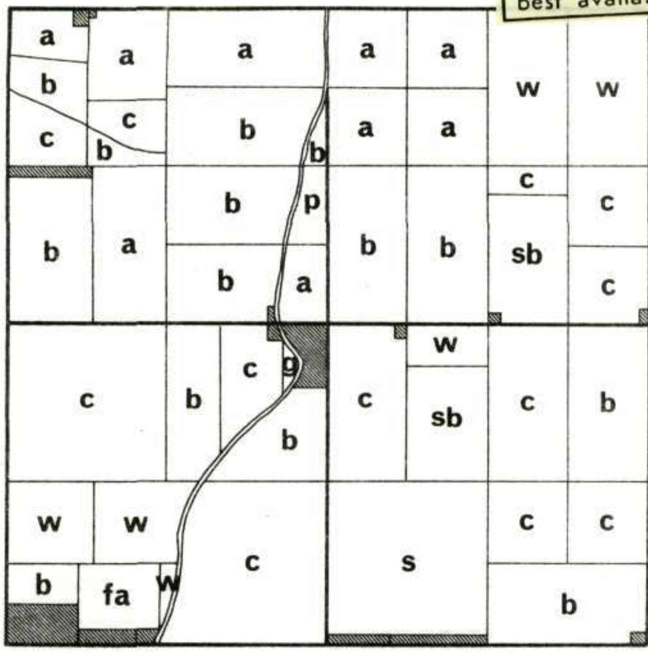
Four additional plots were chosen which would provide training and reference materials. These plots were selected from different parts of the test site and represented a sample of the variability which would be encountered during the test as well as during the semi-operational survey. These training plots were presented to the interpreters in pairs, so that one plot in each pair could be studied with ground data, for familiarization, and the second could be used as a "practice test" (without reference to ground data for that plot). Each interpreter corrected each of his own practice tests, thus learning where correct and incorrect identifications had been made. In each of the training plots, the identity of the crop type in each field was made known so that the interpreters could determine which other crop types were likely to be mistaken for barley and wheat. It is to be emphasized that all of the interpreters used in this experiment were skilled photo interpreters who previously had worked with tests of this type. Hence each of them was asked to study the training material provided and decide for himself which criteria would be used for crop identification.

After each interpreter had trained himself to interpret a particular film/filter combination, he began the interpretation of the test plot assigned to him for that combination (each interpreter examined each of the five test plots on a different film/filter combination). Sample test results appear in Figure 2. That figure also contains (1) photo examples of each of the film/filter combinations, (2) the interpretation results for one of the three interpreters in the group assigned to the Ektachrome image, and (3) the correct identification of the fields in that plot.

For each of the five test plots, a map showing field boundaries was provided. Although a measure of the consistency with which interpreters can estimate field acreage would be needed to evaluate results from the semi-operational survey, it was decided that tests for identification would be separated from tests for acreage estimation. In addition, prior field delineation makes possible more rapid evaluation of crop identification _per se_, for the interpreter is interested only in identity of fields and not their measurement. Training in these two tasks would be given once the final team of interpreters (only three out of fifteen who took the tests) had been chosen for the semi-operational survey.

In order to ascertain the optimum film/filter combination for inventorying wheat and barley, the results of the tests were analyzed in three ways: (1) mean-of-ratio variance analysis, (2) analysis of variance for % correct, and (3) analysis of variance for % commission error.

Mean-of-Ratio Test: In the actual crop survey, the acreage estimates by the photo interpreters were to be adjusted by using a mean-of-ratio estimator.



Crop Type Map: Phoenix Plot 2-1
Date: May 22, 1970

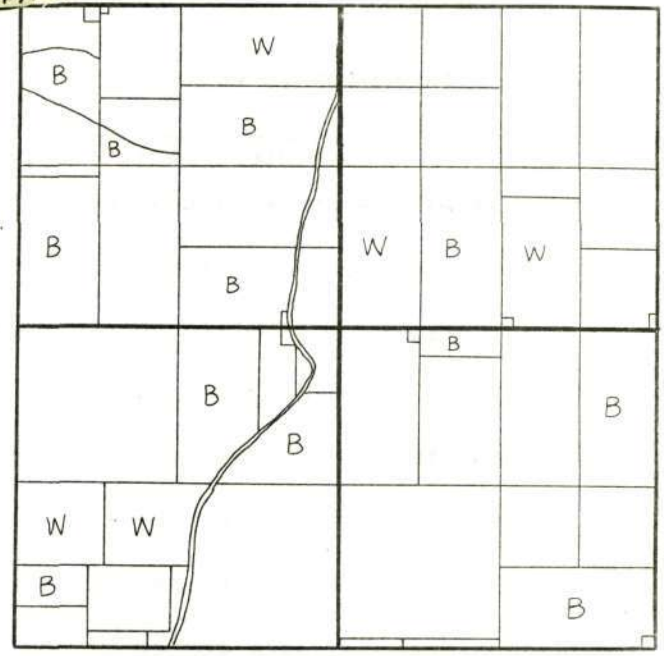
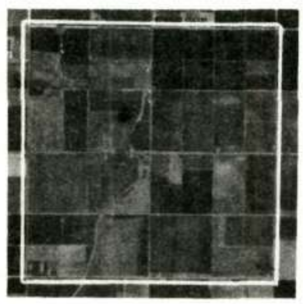


Photo Interpretation Answer Sheet
Phoenix Plot 2-1

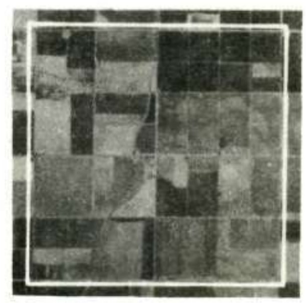
CROP SYMBOL KEY

a = Alfalfa
b = Barley
c = Cotton
fa = Fallow
g = Grass
p = Pond
sb = Sugar Beets
w = Wheat

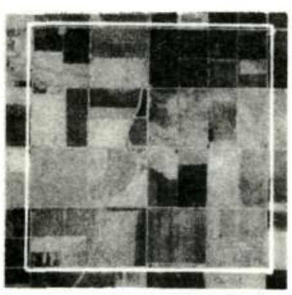
1 Mile



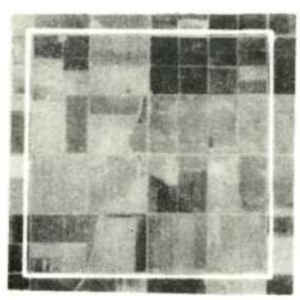
Ektachrome MS (2448)
Filter: HF3 + 2.2 A.V.



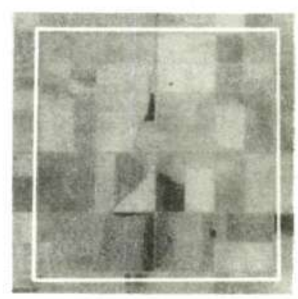
Infrared Ektachrome (SO117)
Filter: Wratten 15



Plus-X Aerographic (2402)
Filter: Wratten 25



Plus-X Aerographic (2402)
Filter: Wratten 58



Infrared Aerographic (5424)
Filter: Wratten 89B

Figure 2. Appearing in this figure are test images (obtained May 21, 1970), ground data, and sample interpretation test results for one 4-square mile test plot. Ground data, top left, were collected in conjunction with the high altitude photo mission. The Ektachrome and Infrared Ektachrome photos above are reproduced at the same scale as the original transparencies. The black and white photos have been enlarged from their original scale (1/500,000) to match the color photos. Each of the test images was interpreted by a group of three photo interpreters. Results from the Ektachrome plot, as obtained by one interpreter (top right), are as follows (based on number of fields): barley - 85% correct, 8% commission; wheat - 40% correct, 33% commission.

This estimator is defined as:

$$R = \frac{\text{actual acreage of wheat (or barley)}}{\text{interpretation acreage estimate for wheat (or barley)}}$$

This estimator is calculated for each of the sample plots, the mean of the ratios calculated, and the acreage estimation for the entire survey area adjusted by multiplying by this mean. The optimum film/filter type, therefore, is that in which the variance of ratios is lowest, (e.g., if the interpreter consistently interprets 60% correct, the adjusted total will be more accurate than if he fluctuates between 70% and 90%.

Variances of the ratios using each of the five film/filter types under consideration were tested at the 95% level of significance. No differences were found between the ratio variances for barley. For wheat, however, Ektachrome, Pan-25, and Pan-58 constituted a homogeneous sub-group of low variance, with Infrared Ektachrome and Infrared-89B showing significantly higher variances. Thus, either Ektachrome, Pan-25 or Pan-58 would be optimum for the operational survey under this criterion.

% Correct and % Commission Error Analyses: Analyses of variance were run to ascertain whether there were differences (at the 95% level of significance) between the film/filter types in terms of % correct acreage and % commission error. If significant differences were found, the types were to be ranked using the New Duncan's Multiple Range Test.

The film/filter types proved to be different in terms of both % correct and % commission error for both barley and wheat, and hence were ranked. The results are illustrated below. Percent correct is ranked with highest values at the top and % commission error with lowest values (and hence "best") at the top. However, types which are included within the same bracket are not significantly different according to Duncan's test at the 95% level of significance.

BARLEY INTERPRETATION

% Correct	% Commission Error
Ektachrome	Ektachrome
Infrared Ektachrome	Infrared Ektachrome
Pan-25	Pan-25
Infrared-89B	Pan-58
Pan-58	Infrared-89B

WHEAT INTERPRETATION

% Correct	% Commission Error
Infrared Ektachrome	Ektachrome
Ektachrome	Infrared Ektachrome
Pan-58	Infrared-89B
Infrared-89B	Pan-25
Pan-25	Pan-58

Based on the results of both the mean-of-ratio analysis and the analyses of % correct and % commission error, Ektachrome film was chosen as the film/filter type to be used for the operational survey. Although in some cases it was not significantly superior to other film types, it was the only type which was at least in the superior group in all tests.

B. Field Data and Sampling Rationale

Attempting to administer a photo interpretation survey involving the entire county immediately presented a number of problems not faced on the 16 square-mile study area. The principal questions raised were: (1) Will a sample provide a satisfactory estimate of crop acreage, or is 100% interpretation required? (2) Will stratification lead to a more accurate estimate? (3) How much ground information will be required for interpreter training and for evaluation of the interpretation? In an attempt to answer several of these questions simultaneously, the agricultural area within the county was delineated into six strata based wholly on their appearance on the Infrared Ektachrome Apollo 9 photo. Thirty-two plots, each consisting of a square, two miles on a side, were allocated to the strata on the basis of proportional area, and plot centers were located randomly (Figure 3). Maps of each plot showing field boundaries were drawn based on their appearance on earlier high-flight photography, and each plot was visited by a field crew at the time of overflights for the months of April, May and June 1970.

Information gathered in this manner included the category of crop growing in each field, the condition of the crop, the percent of the ground covered by vegetation, crop height, and the direction of rows, if any (see Figures 4 and 5). The crop category code which was used, and which appears in Appendix II of this report, is an adaptation of a coding system originally developed by the U. S. Government for categorizing land use (U. S. Urban Renewal Administration, 1965) and subsequently refined for specific use in agricultural land use mapping by researchers at the University of California, Riverside (Johnson, et al., 1969).

In order to facilitate access to this information pertaining to each of the more than 2500 fields present in the thirty-two four-square-mile sample plots (comprising a total of more than 80,000 acres), field data were punched on computer cards. Programs were then written which made possible the compilation of data by stratum, cell, crop type, and date, and which provided for subdivisions or consolidations of fields over time. Thus data are available not only for each date of photography, but for the sequential changes in crop type and condition through the growing season as well.

Based on a knowledge of the distribution and variability of crop acreage thus obtained, tests were conducted regarding the value of stratification

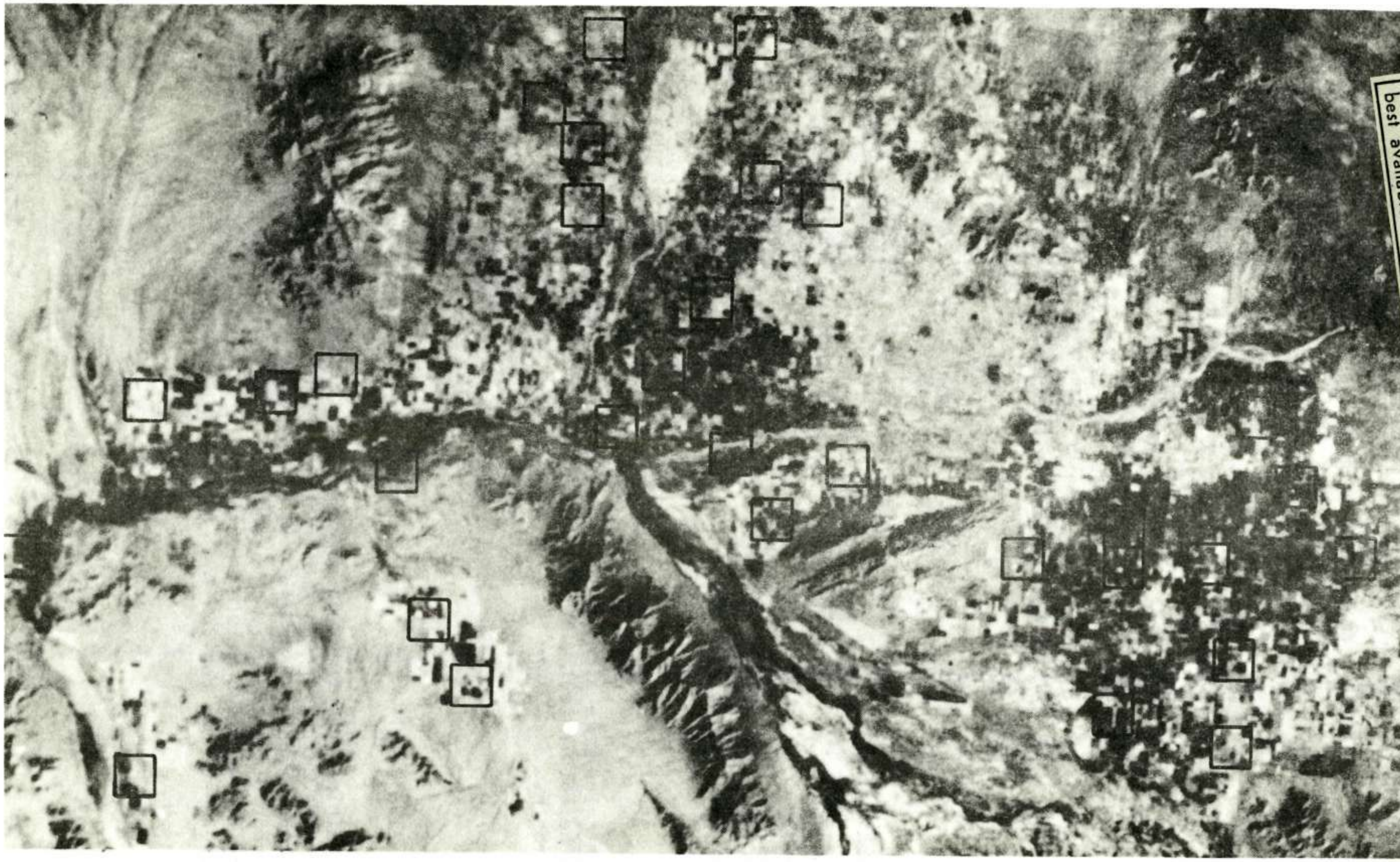
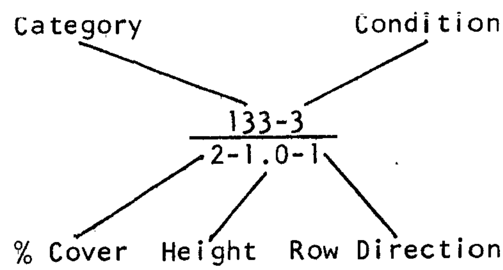


Figure 3. This black-and-white enlargement of an Apollo 9 space photo shows the portion of Maricopa County for which the semi-operational survey was performed (compare with Figure 1). The location of each of the 32 4-square-mile plots selected for ground survey at the time of each NASA overflight is indicated on the overlay.



Condition Code

1 seeded
2 young
3 mature
4 dry (not harvested)
5 cut back (e.g., alfalfa)

% Cover Code

1 80-100%
2 50-80%
3 20-50%
4 5-20%
5 0-5%

Height: Indicate average crop height in feet and tenths.

Row Direction Code

1	N-S	|
2	E-W	—
3	NW-SE	\
4	NE-SW	/

Figure 4. This coded fraction represents a typical field code as recorded by field crews gathering information pertaining to the sample plots. Field category codes appear in Appendix II of this report, while the coding system used for recording other field parameters is described above. The example shown here represents a mature alfalfa field one foot in height, with 50-80% ground cover and rows running in a north-south direction.

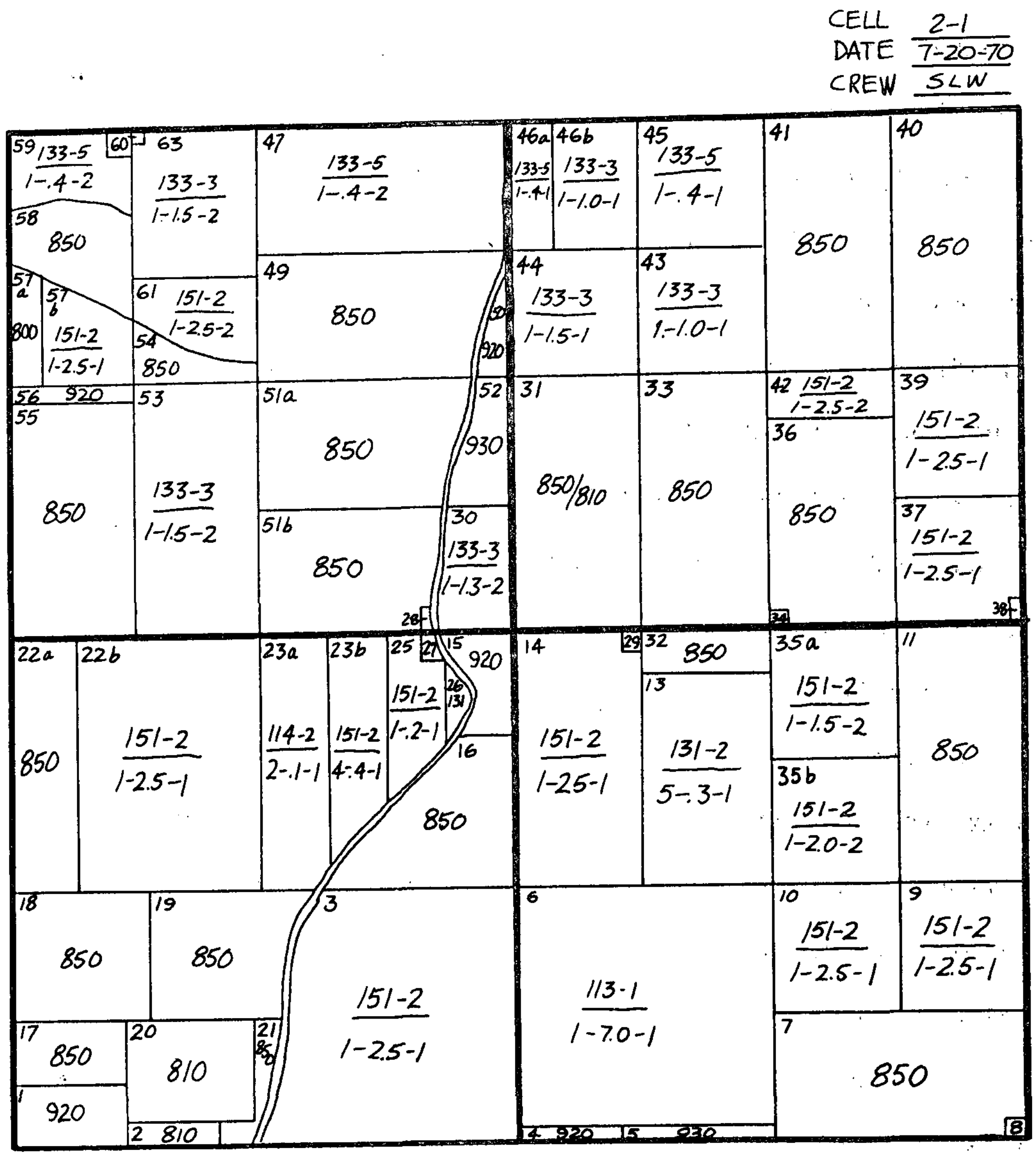


Figure 5. This map contains field data collected for one of the 4-square-mile plots in Maricopa County at the time of a NASA high altitude overflight. The coded fraction in each field is explained in Figure 4 (and a complete listing of the field category codes appears in Appendix II). Representative high altitude aerial photographs of this cell appear in Figure 2. Computer storage of survey data collected at the time of each flight on a field-by-field basis facilitates sequential analysis of crop patterns as well as evaluation of photo interpretation test results.

based on gross appearance on space photography, and the possibility of sampling within the agricultural areas to obtain overall crop acreages for the county. Analyses of variance indicated that no significant differences existed between strata in terms of acreages of major field crops, thus indicating that stratification would not improve acreage estimates. In addition, calculations indicated that the acreage distribution of major crops was so variable that for any plot size, extremely large samples would be necessary in order to assure acreage estimates that would satisfy accuracy requirements. For example, in order to estimate the acreage of wheat with a standard error of ± 10% of the total acreage using a plot size of four square miles, a 75% sample would be necessary.

Thus, it was decided that the most efficient and realistic method of estimating crop acreage would entail a 100% photo interpretation of the agricultural areas, with ground data being gathered for thirty-two four-square-mile plots only. In this way photo interpretation results could be compared with the ground conditions on the field plots, and the overall photo interpretation results adjusted as appropriate using standard ratio sampling procedures.

Some problems were also encountered in the development of the method of compilation of photo interpretation data. First of all, in order to make a measure of interpretation accuracy, interpretation findings must be tied to some actual unit of land area. However, the preparation of detailed field boundary maps from small-scale photos by the interpreter, while possible, would constitute an extremely time consuming task. Also, the tabulation of interpretation data on the basis of numbers of fields is not necessarily indicative of accuracy of acreage estimates which in most cases is the item of interest to the ultimate user. Furthermore, to evaluate "number of fields" data, the researcher must assign arbitrary weight to "correct", "omission error" and "commission error" values, a task which in many cases might best be left to the discretion of the ultimate user of the information.

In order to avoid these problems while still collecting data which would be as meaningful as possible, it was decided to require the interpreter merely to grid agricultural areas into regular square-mile cells (thus making possible direct comparisons with ground data on the thirty-two sample plots) and to tabulate estimates of the acreage of barley and wheat in each cell without regard to the specific location of individual fields.

The agricultural areas within Maricopa County were divided into three nearly equal portions, with one interpreter assigned to each area. The interpreters, chosen on the basis of high scores on preliminary tests, were first trained using photos and ground data maps of areas which they would not interpret later. Training included both identification of wheat and barley, and estimation of field acreage. The interpreters were then supplied with Ektachrome photos for May 21 and June 16 (scale 1/120,000) of their test areas, as well as maps indicating township boundaries. Each township (nominally a six-mile square, but not invariably so because of ground survey errors made many years ago) was located on the test photography and interpreted as a unit, section by section. For each section the interpreter recorded total acreage of wheat, barley, and all cropland. (Deductions from cropland included farmhouse-barn complexes, freeways, major canals, and general urban and developed areas, but did not include secondary service roads or local irrigation ditches.) In addition, each interpreter was asked to interpret one township in another interpreter's area, as well as to repeat the interpretation of one township in his own area without reference to his earlier results.

RESULTS

The results of the semi-operational survey were obtained in the following manner:

1. Each interpreter's estimates of acreage of barley, wheat, wheat and barley combined, and total cropland for the sample plots within his area

were compared with the actual acreages for each of the plots as determined by on-the-ground surveys.

2. Ratios of actual acreages to interpretation acreages for each category were calculated for each interpreter, and this ratio was used to adjust the results for the <u>entire</u> area as estimated by each interpreter by the formula

$$\hat{Y}_I = Y_{PI} \times R$$

where $\hat{Y}_I$ = estimate of total acreage of category within an interpreter's area

Y_{PI} = initial photo interpretation of acreage within an interpreter's area

R = the correction ratio as derived from the sample plots.

3. The category estimates for the three interpreters were summed to form a total county estimate.

4. Sampling errors were calculated for the various category estimates by each interpreter as well as for the overall county estimates in order to give an indication of the accuracy of the crop estimates. In calculating the overall county statistics, each of the three interpreters' areas was handled as an individual stratum.

A summary of the survey results is presented below (Tables 3 through 6). Note that sampling error is presented as a precentage figure calculated by:

$$\text{Sampling Error \%} = S_{\hat{Y}}/\hat{Y}$$

where $S_{\hat{Y}}$ = standard error of the estimated acreage

$\hat{Y}$ = estimated acreage.

A correction ratio greater than 1 indicates that the interpreter underestimated the acreage of that category, while a ratio less than 1 indicates that he overestimated the acreage.

ACREAGE ESTIMATES AND SAMPLING ERROR

CATEGORY	TOTAL ESTIMATE (ACRES)	SAMPLING ERROR
Barley	50,044	11%
Wheat	41,714	13%
Barley and Wheat	92,207	8%
All Cropland	452,000	3%

Table 3

RATIO CORRECTION FACTORS

INTERPRETER	BARLEY	WHEAT	BARLEY AND WHEAT	ALL CROPLAND
1	1.1225	.9846	1.0481	.9913
2	1.1131	.9012	1.0352	.9809
3	1.1234	.9388	1.0309	1.0094

Table 4

SAMPLING ERROR OF INTERPRETERS

INTERPRETER	BARLEY	WHEAT	BARLEY AND WHEAT	ALL CROPLAND
1	18%	17%	14%	5%
2	30%	32%	16%	3%
3	14%	21%	11%	6%
TOTAL AREA	11%	13%	8%	3%

Table 5

INTERPRETATION TIME

INTERPRETER	TRAINING TIME	INTERPRETATION TIME	AVERAGE TIME/TOWNSHIP
1	8 hr. 55 min.	26 hr. 20 min.	1 hr. 20 min.
2	7 hr. 30 min.	13 hr. 40 min.	1 hr. 03 min.
3	6 hr. 30 min.	28 hr. 05 min.	1 hr. 02 min.
TOTAL	22 hr. 55 min.	68 hr. 05 min.	1 hr. 08 min.

Table 6

The results of greatest interest are, of course, the estimated acreages of each category for the entire county, and their accuracies. In this case, however, there are no reliable statistics gathered in the conventional manner with which to compare these results. While the Statistical Reporting Service does publish monthly estimates of crop acreages for the U. S. as a whole and for individual states, their methods are such that no accurate estimates are available for specific counties. until months after the time of harvest, and even then they are much less accurate than the state and national estimates. This, of course, only serves to emphasize the potential value of estimates obtained by means of the methods described here. It is possible, however, to discuss the accuracy of the estimates by reference to calculated measures of statistical reliability derived from the sample data.

The sampling error (standard error of the estimate expressed as a percent of the estimate) for barley was 11% and for wheat was 13%, while the figure for both barley and wheat combined was 8%, indicating that a good deal of error resulted from a confusion of the two small grain crops. This same phenomenon is evident in the correction ratio figures. In general, the interpreters underestimated barley and overestimated wheat, while they were only slightly low in their estimates of the two grains combined. These results indicate that considerable improvement in the measurements could be realized if a more definite differentiation between the two small grains could be made. Nevertheless, the accuracies as shown are quite encouraging, especially considering the rapidity with which the data were produced, the relatively large area interpreted, and the lack of any other reliable estimates with which they could be compared.

In the table listing the individual interpreter's accuracy levels (Table 5) it can be seen that one of the interpreters had a significantly higher error for both barley and wheat than the other two interpreters, but all three were nearly equal for barley and wheat combined. This indicates that while this one interpreter had more trouble differentiating between the two crops, he did nearly as well as the others in distinguishing the two small grains from all other field conditions. Furthermore, the large differences in performance point up the importance of screening and training interpreters before undertaking operational surveys. The sampling error could have been significantly reduced if the performance of the one "inaccurate" interpreter had been equal to the other two. Also, all three interpreters indicated that their confidence in their interpretations increased as they progressed through the survey. Certainly any fully operational survey would include considerably more interpreter training than has been undertaken in this study.

CONCLUSION

The stated purpose of the experiment was to investigate the feasibility of performing inventories of agricultural resources using very small scale aerial or space photography. Further, it was hoped that by remaining cognizant at all times of the constraints that would be faced when carrying out an operational survey, findings would be more valuable than those resulting from the more usual limited-area tests.

Certainly the results to date are encouraging on two counts: (1) the questions posed initially are being answered, i.e., the very practical problems of an operational survey are being faced and solutions are being found, and (2) it would seem that a fully operational agricultural inventory using space photography is not beyond the scope of present technology.

Probably the biggest problems that will be faced in establishing a functional inventory system are those concerning logistics and data handling. For example, it will be necessary to ensure that ground crews are at the proper place at the proper time over widely scattered areas in order to provide calibration data. Imagery must be obtained at specific times to permit differentiation among various crop types; interpretation of large areas must be performed rapidly to ensure that the information is not outdated before it is available; and interpretation results must be compared with calibration data and the necessary adjustments made before distribution.

Finally, data must be provided, not at those times and for those geographic units which lend themselves well to the data gathering techniques, but rather at times and for area units which are geared to user requirements as nearly as possible.

However, most of the data handling problems are not much more complex than those faced by government agencies gathering agricultural data by more conventional means at the present time. Furthermore, a number of systems are presently being developed which, it is hoped, will possess a capability to automatically extract image data from aerial or space photographs, perform crop identification functions, combine this information with other parameters keyed to the same geographic coordinate system, and produce graphical or tabular output in a wide variety of desired formats. It appears that such systems would lend themselves particularly well to agricultural surveys wherein nearly all the image interpretation is based on tone or color discrimination (a function much more accurately performed by a machine than a human interpreter) rather than complex deductive decisions. In fact, it is planned that further studies of agricultural inventory method by the Forestry

Remote Sensing Laboratory will involve an investigation of the extent to which automatic image interpretation and data handling methods can contribute to operational surveys of the type described in this report.

LITERATURE CITED

Carneggie, D. M., et al. 1969. Analysis of earth resources in the Phoenix, Arizona area. In an Evaluation of Earth Resources Using Apollo 9 Photography. R. N. Colwell, et al. Final Report. NASA Contract No. NAS-9-9348. University of California, Berkeley.

Johnson, C. W., et al. 1969. A system of regional agricultural land use mapping tested against small scale Apollo 9 color infrared photography of the Imperial Valley. University of California, Riverside. USDI Status Report III, Tech. Report V, Contract 14-08-0001-10674.

Pettinger, L. R., et al. 1969. Analysis of earth resources on sequential high altitude multiband photography. Special Report Forestry Remote Sensing Laboratory, University of California, Berkeley. 31 December 1969.

U. S. Dept. of Commerce, Urban Renewal Administration. 1965. Standard Land Use Coding Manual. January 1965.

APPENDIX II

LAND CATEGORY CODE

The coding system presented here is an adaptation of a coding system originally developed by the U. S. Government for categorizing land use (U. S. Urban Renewal Administration, 1965) and subsequently refined for specific use in agricultural land use mapping by researchers at the University of California, Riverside (Johnson, et al., 1969). This code was used by crews recording field data for the agricultural survey described in Appendix I of this report.

100 Field and Seed Crops

110 Cereal and Grain Crops

111 Barley
112 Buckwheat
113 Corn (Maize)
114 Sorghum, Grain
115 Oats
116 Rice
117 Rye
118 Wheat
119 Cereal and Grain Crops, Other Differentiated

120 Legumes for Seed Crops

121 Beans, Field
122 Peas, Field
123 Lentils
124 Beans, Lima
125 Peanuts
126 Soybeans (Food)
127
128
129 Legumes for Seed, Dry, Other Differentiated

130 Forage Crops (Non Grains)

131 Grasses, Short (i.e., Bermuda, Ryegrass, Timothy, etc.)
132 Grasses, Tall (i.e., Sudan/Sorghum, Corn, etc.)
133 Legumes (i.e., Alfalfa, Clover, Vetch, etc.)
134 Roots
135
136
137
138
139 Forage Crops, Other Differentiated

140 Sugar Crops

141 Sugar Cane
142 Sugar Beets
143
144
145
146
147
148
149 Sugar Crops, Other Differentiated Field Crops

150 Fiber Crops

151 Cotton
152 Fiber Flax
153 Hemp
154
155
156
157
158
159 Fiber Crops, Other Differentiated

160 Beverage, Drug, Flavoring, or Spice Crops

161 Beverage Crops, Undifferentiated
162 Cacao
163 Coffee
164 Tea
165 Beverage Crops, Other Differentiated
166 Spice Crops
167 Flavoring Crops
168 Drug Crops
169 Beverage, Drug, Flavoring, or Spice Crop, Other Differentiated

170 Oil Crops

171 Castor Bean
172 Flax, Seed
173 Perrilla
174 Safflower
175 Sesame
176 Soybean (oil)
177
178
179 Oil Crops, Others Differentiated

180 Rubber Crops

181
182
183
184
185

186
187
188
189 Rubber Crops, Other Differentiated

190 <u>Other Differentiated Field and Seed Crops</u>

191
192
193
194
195
196
197
198
199

200 <u>Vegetable Crops</u>

210 <u>Perennial Vegetable Crops</u>

211 Asparagus
212 Artichoke, Globe
213 Horseradish
214 Rhubarb
215
216
217
218
219 Perennial Vegetable Crops, Other Differentiated

220 <u>Green Legume (Pod) Crops</u>

221 Beans, Green (Snap, Pole, Kentucky Wonders, String, etc.)
222 Beans, Green Lima
223 Peas, Green
224 Okra
225 Black Eyed Peas (Canned Green)
226
227
228
229 Legume Crops, Green, Other Differentiated

230 <u>Salad and Greens Crops</u>

231 Lettuce (Salad)
232 Celery (Salad)
233 Cress (Salad)
234 Parsley (Salad)
235 Chinese Cabbage (Salad)
236 Chard and Kale (Greens)
237 Mustard Greens
238 Spinach Greens
239 Salad and Green Crops, Other Differentiated

240 Cole Crops

241 Broccoli
242 Brussels Sprouts
243 Cabbage
244 Cauliflower
245 Collards
246 Kohlrabi
247
248
249 Cole Crops, Other Differentiated

250 Curcubits (Vine) Crops

251 Cantaloupes
252 Cucumbers
253 Melons (Other than Cantaloupes)
254 Pumpkins
255 Squashes
256 Watermelons
257
258
259 Other Differentiated Curcubits (Vine) Crops

260 Solanaceous Crops

261 Eggplant
262 Peppers
263 Tomatoes
264
265
266
267
268
269 Solanaceous Crops, Other Differentiated

270 Root and Tuber Crops

271 Beets (Other than Sugar Beets)
272 Carrots
273 Parsnips
274 Potatoes (Tuber)
275 Radishes
276 Rutabagas
277 Sweet Potatoes
278 Turnips
279 Root and Tuber Crops, Other Differentiated

280 Bulb Crops

281 Chives
282 Garlic
283 Leeks
284 Onions
285

286
287
288
289 Bulb Crops, Other Differentiated

290 Other Differentiated Vegetable Crops

291
292
293
294
295
296
297
298
299

300 Fruit and Nut Crops

310 Small Fruits

311 Brambles (Blackberry, Dewberry, Boysenberry, Raspberry)
312 Blueberry (Huckleberry) and Cranberry
313 Currant and Gooseberry
314 Grapes
315 Strawberries
316
317
318
319 Fruit, Small, Other Differentiated

320 Deciduous Tree Fruits

321 Apple (includes Crabapple and Quince)
322 Apricot
323 Cherry
324 Fig
325 Nectarine
326 Peach
327 Pear
328 Plum (includes Prune)
329 Deciduous Tree Fruit, Other Differentiated

330 Citrus Tree Fruits

331 Grapefruit
332 Kumquat
333 Lemon
334 Lime
335 Orange
336 Tangelo
337 Tangerine
338
339 Citrus Tree Fruit, Other Differentiated

340 Miscellaneous Evergreen Tree Fruit

341 Avocado
342 Date
343 Mango
344 Olive
345 Papaya
346
347
348
349 Evergreen Tree Fruit, Other Differentiated

350 Herbaceous Perennial Fruits

351 Banana
352 Guava
353 Pineapple
354
355
356
357
358
359 Herbaceous Perennial Fruit, Other Differentiated

360 Deciduous Nuts

361 Almond
362 Filbert (Hazelnut)
363 Pecan
364 Pistachio
365 Walnut
366 Nutmeg
367
368
369 Deciduous Nuts, Other Differentiated

380

381
382
383
384
385
386
387
388
389

390 Other Differentiated Fruit and Nut Crops

391
392
393
394
395
396
397
398

400 Livestock

410 Beef Cattle (Other than Dairy -- includes Feed Lots)

420 Horses

430 Swine

440 Dairies and Dairy Feeding

450 Sheep

460 Goats

470

480

490 Other Differentiated Livestock

500 Animal Specialties

510 Chicken (Meat)

520 Chicken (Eggs)

530 Turkey

540 Other Differentiated Poultry

550 Rabbits

560

570

580

590

600 Pasture and Rangeland

610 Pasture

620 Rangeland

700 Horticultural Specialties

710 Cut Flowers Stock, Covered

720 Cut Flowers Stock, Open Field

730 Nursery Stock

740

750

760

770

780

790 <u>Other Differentiated Horticultural Specialties</u>

800 <u>Non-Producing and Transition Cropland</u>

810 <u>Fallow Cropland</u>

820 <u>Plowed Cropland</u>

830 <u>Leached Cropland</u>

840 <u>Abandoned Cropland</u>

850 <u>Harvested Field (Stubble, includes cropland open to grazing)</u>

860 <u>Prepared Cropland (ready for seeding, or seeded, and/or irrigated)</u>

870

880

890 <u>Other Differentiated Non-Producing Cropland</u>

900 <u>Other Uses</u>

910 <u>Urban</u>

920 <u>Farmhouses and Adjacent Buildings</u>

930 <u>Agricultural Related Activities</u>

940 <u>Native Vegetation</u>

950

960

970

980

990 <u>Not Recorded</u>