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REMOTE SENSING APPLICATIONS IN FORESTRY

A report of research performed under the auspices of the

FORESTRY REMOTE SENSING LABORATORY,
BERKELEY, CALIFORNIA

A Coordination Facility Administered By

The School of Forestry and Conservation,
University of California in Cooperation with the
Forest Service, U.S. Department of Agriculture

For

EARTH RESOURCES SURVEY PROGRAM
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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REMOTE SENSING APPLICATIONS IN FORESTRY

ANALYSIS OF REMOTE SENSING DATA FOR RANGE RESOURCE MANAGEMENT

By
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School of Forestry and Conservation
University of California

Annual Progress Report — 30 September, 1968

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ABSTRACT

The research reported herein seeks to determine the feasibility of using remote sensing techniques for evaluating range resources. Various remote sensing devices, including photographic systems, optical mechanical scanners, and thermal infrared scanners obtained remote sensing data at different seasons and scales. Portions of the electromagnetic spectrum in which remote sensing was accomplished ranged from the ultraviolet, through the visible and near infrared to the thermal infrared. Analysis of the data for three range test sites showed that the season when imagery is obtained is critical in determining the amount of useful information obtainable from remote sensing imagery. This is due to the changing nature and characteristics of the forage resource. Combined sensing in the visible and near infrared portions of the spectrum promises to be the most fruitful for extracting information of value to the range manager. Range applications are discussed under two major categories: (1) obtaining range resource inventories and (2) assessing range management problems. For the most part high image resolution is desirable although broad vegetation and soil typing can be accomplished using lower resolution imagery. The level of detail required is partially determined by the intensity of management that is to be practiced.

ACKNOWLEDGEMENTS

This research was performed under the sponsorship and financial assistance of the National Aeronautics and Space Administration for the Manned Earth Orbital Experiment Program in Agriculture/Forestry (Contract number R-09-038-003--Earth Resources Program).

Presentation of the material contained in this report has been made possible through the cooperative effort of several individuals and organizations. Among the personnel of the Remote Sensing Laboratory, School of Forestry and Conservation, University of California, who contributed to the collection of ground truth, interpretation and compilation of the imagery used in this report were: Dan Gaut, Don Lauer, Bill Lynam, Eric Janes, Larry Pettinger, John Thomas, Owen Bomar and Curtis Peterson.

The discussion and results of analysis of large scale 70 mm aerial photography presented in this report come from a cooperative research project between the author, and Jack N. Reppert of the Rocky Mountain Forest and Range Experiment Station, U.S.F.S. Special acknowledgements are given to Mr. Reppert as well as Richard E. Francis and Dr. Richard S. Driscoll, also from the RMF & RES, USFS, for their participation in the collection of ground information and interpretation of the large scale aerial photos.

Grateful acknowledgements also go to Robert C. Heller and his personnel of the Forestry Remote Sensing Project, Pacific Southwest Forest and Range Experiment Station, Berkeley, California for procurement and processing of the large scale 70 mm color photos discussed in this report.

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ANALYSIS OF REMOTE SENSING DATA FOR RANGE RESOURCE MANAGEMENT

by

David M. Carneggie

INTRODUCTION

This annual report summarizes research performed during fiscal year 1968-69 under NASA contract, and builds upon research performed during the past three years. This research seeks to determine the feasibility of using remote sensing, either from aircraft or spacecraft, as a tool for improving the inventory and/or management of range resources.

The term "range resources" applies to all physical or biological features found on rangelands, together with the products which now or in the future are expected to produce an economic return from the range. "Range" may be considered to be any nonarable land capable of producing native forage or browse for consumption by domestic or wild grazing animals. Hence, when we speak of "range resources", we include forage and browse, animal products, wildlife, timber, minerals, soil and fish derived from the range.

"Range" encompasses a variety of wildland environments. It includes tundra, semi-arid ranges, mountain meadows, open forests with forage in the understory, and perennial and annual savannas. On a global basis, nearly half of the land mass is classified as range, suitable for grazing use. On this land, 60% or more of the world's grazing animals forage for their food. In the United States (including Alaska and Hawaii) there are nearly a billion acres of grazing land, of which about 50% is classified as range, while the remainder is classified as pasture and grazable forest land.

The forage crop, like the agricultural crop, develops through a sequence of growth stages, culminating at crop maturity. This crop must be harvested during its growth period if it is to provide an economic return. Unlike the agricultural crop, however, the forage crop is more subject to high variability in annual production due to seasonal variation in the amount and distribution of precipitation, to varying temperature regimes, and to previous management practices. Hence, the range manager, whose goal is to operate within a framework of sustained yield, must be prepared to adapt his ranching operation to meet these changing environmental conditions. Only by so doing can be achieve efficient utilization of the annual forage crop while minimizing factors which may cause the deterioration of subsequent crops.

On most rangeland, where grazing is the primary use, obtaining an inventory of the kind, quality and amount of forage, and the detecting of associated management problems are generally the major concerns of the range manager. The importance placed on the forage crop is due to its annually renewable character, and to the fact that it is converted by the grazing animal, either domestic or wild, into useful animal products such as meat, milk, hides and wool, to be consumed by the world's population.

On some rangeland, grazing may presently be the most immediate use of the land. However, economic returns from this activity may be quite low when compared to other potential benefits including the water, recreation, timber, wildlife and even agricultural and urban values derived from the same land. Thus, rangelands can be looked at as complex ecosystems within which many biological and physical features interact with each other and with their environment. Of the many range resources and uses, any one may be important enough in itself to justify preparation of an inventory that will lead to better range management.

Remote sensing from aircraft or spacecraft provides a means for rapidly collecting data about range resources. However, in order for remote sensing to provide meaningful information to the ultimate user (i.e., the land manager) it must be accomplished in accordance with proper specifications. Such specifications include: (a) selecting a sensor which records either emitted or reflected radiation in a specified band of the electromagnetic spectrum, such that the features of interest are readily discriminated from each other and from less important features; (b) selecting a sensor whose data record is on a format from which information can be either rapidly or inexpensively extracted (there is surely a trade off here between automatic data processing and visual interpretation techniques using stereoscopes, light tables, etc., depending upon the kind of information, and the time needed to extract the information) (c) selecting a sensor, whose resolving capabilities at the specified flight altitudes will provide sufficient detail so that features of interest can be consistently detected and identified; (d) selecting the time(s) of day which will take maximum advantage of shadow patterns and reflectance phenomena, and (e) selecting the season(s) of year during which phenological characteristics of plants and moisture regimes of the soil can best be analyzed.

In view of the foregoing, the primary emphasis of the research described in this report has been (a) to examine how the various image procurement specifications (as listed above) affect the ease and accuracy of obtaining usable range resource information and (b) to determine the feasibility of using remote sensing as a tool for evaluating range resource problems.

The primary objectives of this report are: (1) to present the results of our analysis of various kinds of remote sensing data (recorded in different bands of the spectrum and flown at different scales, seasons, etc.) and relate them to the possible inventory of earth resources from orbiting spacecraft; (2) to identify those management problems which can best be evaluated by means of remote sensing capability; (3) to indicate the relative feasibility for using various remote sensing systems; and (4) to consider the merits of procuring imagery at various flight altitudes and spatial resolutions, thereby involving double and even triple sampling procedures.

TEST SITES

Remote sensing data were procured for three range locations in northern California. A brief description of each is given here. A more comprehensive description of the characteristics of each range study area is given in later sections dealing with the analysis of the data gathered.

1. The Harvey Valley Range Test Site is a perennial grass-sagebrush range within the Eagle Lake District of the Lassen National Forest, near Susanville, California in the Southern Cascade Mountains. This test site, designated as NASA test site number 135, has been under investigation since 1966.

2. The Clover Valley study area is a perennial grass-sagebrush range in the Sierra Nevada Mountains located within the Plumas National Forest, north of Portola, California. This site was studied in 1968 for two reasons: (a) Many of the range types at Clover Valley are analogous to those at Harvey Valley. This fact afforded an opportunity to apply in this "extended area" some of the specifications developed at the "primary area", at Harvey Valley. (b) Experimental panchromatic aerial photos, taken in 1944 at four different scales were available for the Clover Valley area.

Thus, an excellent opportunity was provided for studying ecological and managerial changes that have occurred during the 24-year interval--1944 to 1968. Perhaps no other area in the world offers such excellent opportunities for the comparative analysis of sequential photographs.

3. The San Pablo Reservoir Test Site (designated as NASA test site No. 48) has been studied by other NASA investigators for its naturally occurring and artifically introduced tree species. However, much of the area is covered with annual range vegetation. This test site is conveniently located about 12 miles east of Berkeley, California, and includes both privately and public owned range.

Within these three test sites, most of the important range management problems and characteristic vegetation types encountered in California and the adjacent states can be studied. In fact, much of the knowledge of remote sensing applications gained from a study of these test sites can be applied to other vast areas of rangeland throughout the world where similar vegetative characteristics are found.

REMOTE SENSING DATA ANALYZED

One of the stated objectives of this report was to analyze various kinds of remote sensing data, taken at different seasons and at different scales. More data have been procured and analyzed than could be illustrated in this report. However, the existence of such data has served a useful function by providing a reservoir of knowledge concerning the reflectance and emittance characteristics of innumerable range features and in many parts of the electromagnetic spectrum. This information is most valuable for determining the usefulness of different remote sensing systems in making range resource inventories and in evaluating range resource problems.

A majority of the research reported here involves the analysis of imagery obtained with various film-filter combinations through the use of various photographic systems, including the Zeiss RMK-A-15/23, the Wild RC-8 and RC-9, the Mauer KB-8, the military K-17 camera, and the four-lens spectrozonal camera. Emphasis is placed on determining the optimum film-filter combination(s) for studying specific range problems. Attention has been given to the merits of interpreting color enhanced black-and-white multispectral photos, and of comparing these with photographs obtained by using conventional color films (Anscochrome D-200, Aerial Ektachrome and Ektachrome Infrared Aero). For each photographic study (as reported in a subsequent section), consideration is also given to the level of detail required in a range resource inventory. Special emphasis is placed upon the seasonal appearance of range features as an aid in the analysis of remote sensing data.

In addition, line scan imagery obtained by the University of Michigan's optical mechanical scanner, by NASA's Reconofax IV, and by a Bendix thermal mapper, provided an opportunity to examine range resources on as many as 18 different spectral bands ranging from the U.V. to the thermal infrared regions of the spectrum, and to make a detailed study of the value of each band for range resource evaluation.

The remote sensing data illustrated in this report for the three test sites includes:

Harvey Valley:	Figures
Comparison of film-filter combinations------------------	2,3,4,5
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Comparison of ground objects with aerial photo image----	3,4,5,
Very large scale color photos---------------------------	4,5
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INVENTORY AND MANAGEMENT PROBLEMS INVESTIGATED

The second stated objective of this research was to identify feasible applications of remote sensing within the range environment. This aspect of the research is particularly critical because the development of image procurement and analysis specifications has little relevance unless directly related to a specific management problem. Unfortunately, it has not been possible to investigate specific range problems in depth. Consequently, the criterion that has been used in this study to evaluate any given sensor capability, scale, season of year, etc., is the extent to which various important range features can be discriminated on the resulting imagery. In order to qualify as a feasible remote sensing application, the information derived from the data in this study had to be of real benefit in terms of time and dollars saved, to the ultimate user--the range manager.

Feasible applications in range management fall within two categories--Range Resource Inventory and Assessment of Management Problems. Let us consider first those applications of remote sensing that would be useful in preparing a Range Resource Inventory (specific reference to sensor or resolution required not considered here). It can be shown that remote sensing can provide: (1) quantitative data on the amount, kind, condition, and distribution of range vegetation, (2) quantitative estimates of animal populations, either domestic or wild, and (3) a suitable map base which shows the location and extent of forage types (by ecological groupings of vegetation and soil), physical and cultural features within the range, and other surface features that may effect forage production and utilization, e.g., soil types, rock outcrop and surface rockiness, moisture regimes (streams, springs, etc.).

Similarly, it can be shown that remote sensing is an effective means for assessing management problems. The remote sensing data, by their very nature, provide an instantaneous picture of phenomena at the earth's surface. Consequently, when the data are procured at prescribed intervals they constitute an ideal record for use in detecting, monitoring and evaluating: (1) poisonous and undesirable (noxious) plants, (2) rodent activity which causes deterioration to the range, (3) insect and disease problems, (4) conditions causing soil instability (erosion, etc.,), (5) fire, both as a hazard and as a management tool, and (6) management practices (e.g., overgrazing in some areas, leading to a deterioration of the forage resource; inadequate grazing in other areas, leading to a waste of the forage resource).

RESEARCH FINDINGS

A very brief statement of research findings will be given in this section so that the reader will have some preliminary idea of the problems of and results from data analysis for the various test sites. A more detailed statement of the research findings will be presented in subsequent sections of the report.

The results of the research can be discussed under two major headings: First, results related to certain characteristics of the range resources which affect the feasibility of inventorying them by remote sensing, and secondly, results related to certain factors affecting the collection and interpretation of remote sensing data of rangeland areas.

Category I: Characteristics of range resources which effect remote sensing.

1. No single "optimum" remote sensing system can be recommended categorically for collecting meaningful data without first specifying the range environment and the specific range problems to be investigated. This is because ranges of the world are diverse and often complex ecosystems that differ in speciation, forage production, soils, climate, kind of grazing animal and management practice. The number of range conditions and problems is nearly infinite; hence no single system is likely to be most efficient for all range inventory and management problems.

2. Individual forage plants, e.g., grasses, forbs and shrubs, are generally small and low-lying. The detectability of these forage plants is a function of their size and density. On ranges characterized by sparse forage, high resolution and/or large scale imagery is needed to detect and classify the vegetation. On ranges characterized by dense forage (e.g., annual grassland vegetation and meadow vegetation in California) smaller image scale and lower image resolution may be adequate for detecting and classifying the vegetation. Similarly, high resolution systems are required for the detection of other small range features such as rodent holes, mounds or burrows, cattle droppings, insect infested shrubs, surface rock

and animals.

3. Range plants progress through distinctive growth stages each year. This is true for both "annuals" (which develop each year from seed) and "perennials" (which develop a new shoot system each year from a previously established root system). These morphological changes which range plants undergo in the course of their development are referred to as phenological changes. Phenological changes such as growth rate, time of plant maturity, flowering, and length of the growing season vary with the forage species in accordance with the genetic characteristics of the species. They also vary with the climatic regime; latitude and longitude or geographic location of the range; topographic factors, such as aspect and slope; and disturbance factors, such as grazing and trampling. Consequently, the time when imagery is procured is of the utmost importance in relation to its usefulness for discriminating amongst range plants. Some forage species develop very early and others progressively later in the same growing season; furthermore, because length of the growing season varies from place to place, discussion of a single "optimum" time for procuring remote sensing of a vast rangeland area becomes meaningless. This being the case, sequentially obtained imagery proves to be very useful in augmenting the number of plant species and other rangeland features which can be detected and identified.

4. Early in the growth period, new forage may be difficult to detect because it is small or obscured by dead plant material from the previous growth season. Late in the growth season, the forage may be difficult to see due to drying or dropping of foliage. Hence, our analysis indicates that a growth state corresponding to near maximum development of the foliage

is a good time for detecting the kind and amount of forage by remote sensing methods. Other times in the growth stage may be better for identifying some species, as for example when plants of that species display distinctive phenological characteristics, such as numerous brightly-colored flowers that distinguish them from other plants.

5. Range forage production (amount of forage) is variable from one growing season to the next in response to the amount and timing of precipitation, the temperature regime, and previous management practices. In order to make reliable estimates of the amount and availability of forage for a given year, it is necessary to monitor changes due to plant growth and forage utilization at intervals throughout the growing season.

6. Ranges are generally comprised of many plant communities which differ in species composition, plant density and forage production as a response to the associated soil, moisture regime and environment. Usually the same distinctive attributes of the various plant communities that constitute the basis for differentiating among them in the field are used to differentiate them on remote sensing imagery. In certain instance, however, very different plant communities fail to exhibit distinctive characteristics on remote sensing imagery. Under such conditions vegetation mapping may be a very complex undertaking--especially if only small scale or low resolution imagery is available.

7. The range crop may be harvested either continually throughout the year or during specified seasons of the annual growth cycle; unlike an agricultural crop which is generally harvested at one point in time upon reaching maturity. On some ranges grazing may be primarily by wild animals where the intensity of grazing is difficult to control. Furthermore, for any given range grazed by domestic animals the intensity of

grazing will vary depending upon the grazing system and management objectives of the landowner. Range use varies with season and this in turn effects the appearance of a range at any given time. This factor must be carefully considered when evaluating range conditions or predicting forage yield by means of remote sensing.

Category II: Remote sensing data collection and interpretation.

1. Photographic systems presently provide the best data of all the remote sensing devices used or considered in this study of range resources because they possess the following characteristics: (a) such systems can use different film-filter combinati ons, sensitive to carefully selected broad or narrow bands of the ultraviolet, visible, or near infrared spectrum; (b) the data can be readily rectified for mapping and making photo measurements; (c) the imagery thus obtained can provide stereoscopic coverage; (d) the imagery is of high resolution; (e) photographic systems are simple to operate and mechanically reliable; (f) the data (photographic images) are easy to work with; and (g) the information can be extracted both by photo interpreters and by photo scanning devices or densitometers.

Characteristics of a photographic system which may limit its operating capability include the following: (a) photographic film has a limited exposure range, i.e., there is a smaller dynamic range in photographic tonal signatures than is available when using electronic sensors; (b) photographic systems cannot be operated at night or when cloud cover or other atmospheric conditions obscure the features of interest; (c) more information may be stored on the film than is needed; hence visual interpretation and measurement techniques may be slow compared with other data processing techniques; (d) camera-film sensors used in space present problems of film storage, weight and recovery; although in-space processed film telemetered back to earth , as in the lunar orbitor experiment, was quite successful.

2. The optical mechanical scanner procures data in as many as 18 different spectral bands from the ultraviolet (.32 - .38 u) to the thermal infrared band (8.0 - 14.0 u). This is an advantage over photographic systems only when it can be demonstrated that either the ultraviolet or the thermal infrared region is needed for discriminating among features. Although line scan data can be presented as photo-like printout (as in Figure 8), the intended format is magnetic tape, and the intended data extraction process is one based upon computerized tone signature matching. Nonetheless, the ground resolution of line scan data by the optical mechanical scanner is relatively poor compared with camera-film data obtained at equivalent altitudes.

In addition, tone signature analysis of line scan data by use of a densichron shows a greater in-band density spread for range resource features on ultraviolet, near infrared and thermal infrared, than for the visible bands, despite the fact that the visible bands showed more of the true vegetation-soil relationships than the other bands. This perhaps indicates that in the absence of good ground resolution, greater reliance may be placed on bands other than the visible for discriminating certain range features (conclusions based on data procured May 18, 1966).

3. Thermal infrared scanners (Bendix and Reconofax IV) have procured nighttime and daytime imagery. The capability for obtaining a record of temperature relationships at night as well as during the daytime is a unique one which distinguishes this sensor system from photographic systems.

Ground resolution is relatively poor, however. Applications of this sensor include animal inventory from very low altitudes and surveillance of moisture regime changes by means of sequential passes over an area. Beyond these applications, range inventory and the assessment of management problems are more efficiently made using data obtained by photographic systems.

4. Radar imagery, although not presented in this report, has been examined over forested areas interspersed with rangeland. Conclusions based on actual interpretation and supported by the literature indicate that radar sensors can have unique and very important use in preparing inventories of rangelands for areas that have persistent cloud cover. Ground resolution of the resultant imagery, however, is sufficiently poor that only broad categories of range vegetation having distinctive characteristics can be differentiated.

5. Ektachrome Infrared Aero (color infrared) photos are more interpretable than Panchromatic (plus-X Aerographic) Infrared Aerographic, or Ektachrome Aero photos, for detecting and for delineating forage types, moisture regimes and some surface (geologic) features. The foregoing statement, however, should be qualified by stating that it applies for rangelands having characteristics similar to those studied in this research report, and at a time of year and photographic scale which assures maximum use of the unique color renditions and color contrasts of the false color film.

Ektachrome Aero (color) photos are more interpretable than the other film types considered when the objective is to delineate surface soil types and conditions.

6. Black-and-white multispectral photos (see Figure 9) individually do not discriminate features as well as color films; however, when two or

more selectively chosen bands are interpreted in concert, more features can be discriminated than on any one black-and-white band alone. Going a step further, one can measurably increase the number of features which can be discriminated from multispectral photos if he employs image enhancement techniques. False color signatures can be produced which are unique to particular range features, thus enhancing the interpretability of such features. Image enhancement is not restricted to photographs nor to the visible and near infrared spectrum. However, the bands for which there is presently an operational capability that promises to provide the most useful information in evaluating range resources are the green (.55 - .58 u), red (.62 - .68 u) and the near infrared (.7 - .9 u) bands.

7. Ground resolution requirements become critical when studying the range resources, for although ranges themselves are extensive, the individual features which comprise the range are relatively small. There are, of course, exceptions, particularly in inventory work when perhaps the smallest area of interest would cover 40 or more acres. Because initial remote sensors placed in earth orbit (to evaluate earth resources) may not provide data having ground resolution better than 100 feet, a sub-sampling (double sample) procedure that employs a higher resolution system is warranted to maximize the level of information that can be obtained by both systems.

8. Investigations of very large scale photographs (Figures 4 and 5) demonstrate the practical and potential application for assessing management problems and improving inventory efforts. The very large scale photographic system described in the text is one such promising means for collecting sub-sample imagery. Because only a very small ground area is seen per photo at very large scales, such large scale photography ordinarily would

not be recommended for mapping purposes. By virtue of the high resolution obtained and the dimensions of hue, value and chroma in the color films, the information derived from interpretation and direct photo measurement provides immediate benefit to the range and wildlife manager.

ANALYSIS OF REMOTE SENSING DATA, HARVEY VALLEY RANGE TEST SITE

(NASA Test Site No. 135--Perennial Grassland and Shrubland Range)

Description of Test Site:

Harvey Valley Range is a 35,000 acre experimental range allotment in the Southern Cascade Mountains of California whereon grassland research and grazing management are administered by the U. S. Forest Service. The dominant native forage types comprising the range include perennial grasses, sedges, rushes, forbs and shrubs. A general listing of range sites within Harvey Valley includes:

Grassland (native and introduced)	1.5%
Meadow	4.1%
Sagebrush-grass	12.7%
Timber-shrub, timber-grass	45.5%
Waste (rocky, inaccessible)	36.2%

Harvey Valley Range is located 28 miles northeast of Mt. Lassen (see Figure 1). The range is relatively flat--the average elevation being about 5600 feet--and is surrounded by volcanic basalt cones of recent geologic origin, which rise to elevations of 6500 to 7000 feet.

Average rainfall throughout the range is about 18 inches. This precipitation falls mainly during the winter months as rain and snow. Occassional thunder showers during the summer yield only a small proportion of the precipitation. Generally the snow has melted by April; however, in some years, snow from late spring storms may cover the ground in May and early June.

Harvey Valley Range is divided into five units of about equal grazing capacity, and a rotation system of grazing management is practiced (one unit may be grazed during the first half of the season and then rested during the second half after the cattle have been moved to another unit.) Hereford and Angus beef cattle are the predominant grazers at Harvey Valley; however they have competition from Mule deer, black-tail deer, antelope, and rodents. The grazing season for cattle begins on about the first of June and terminates in October, the exact dates depending upon the wetness of the range early in the season, and the dryness and availability of forage later in the season.

Within the range, five relatively small study sites, ranging in size from a few acres up to 100 acres, were selected for detailed study because they contained representative features and conditions. Ground information collected within these small study sites included: species composition, plant density, estimate of plant cover, plant and soil color, surface roughness, rockiness, phenological characteristics of plants, etc. From close analysis of the remote sensing imagery both in the field, and in the office and aided by ground information, interpreters learned to recognize important features in other parts of the range that were analogous to those seen in the study sites.

Remote Sensing Data Acquired at Harvey Valley:

The first remote sensing data of Harvey Valley oriented toward these NASA financed studies were obtained in May, 1966. Since that time there have been many data-gathering missions over Harvey Valley during the summer and fall grazing season. The list below indicates the remote sensing devices used, the date of the mission, and the agency acquiring data at Harvey Valley:

May 18, 1966: (data acquired under contract with University of Michigan)

*Optical mechanical scanner; 18 channels from .32 to 14.0 microns
16-lens multispectral camera
P-11 camera using panchromatic film

June 11, 1966: (Cartwright Aerial Surveys, Sacramento, Calif.)

Zeiss RMK-A-15/23 mapping camera; f=6" (scale 1/8500)

Plus-X Aerographic (Wr. 12)
Infrared Aerographic (Wr. 89B)
Ektachrome Aero
Ektachrome Infrared Aero (Wr. 12)

Ektachrome Aero
Ektachrome Infrared Aero (Wr. 12) (scale 1/35,000)

September 1, 1966: (NASA-Houston Convair, Mission 30, Site 135)

RC-8 Wild, f=6"; (scale 1/10,000)

Ektachrome Infrared Aero (Wr. 12)

Itek 9-lens Multiband camera

June 10, 1967: (U. S. Forest Service, PSWF&RES)

Mauer KB-8, f=150mm; (scale 1/900; 1/2100)

Anscochrome D-200
Ektachrome Infrared Aero (Wr. 12)

July 25, 1967: (U. S. Forest Service, PSW&RES)

Mauer KB-8, f=150mm (scale 1/750)

Anscochrome D-200
Ekta Infrared Aero (Wr. 12)

October 18, 1967: (NASA-Houston Convair; Mission 59, Site 135)

RC-8 Wild, f=6"; (scale 1/35,000)

*Ektachrome Infrared Aero (Wr. 12)

Itek 9-lens Multiband camera

*Reconofax IV thermal infrared imager (8-14 microns)

* illustrated in this report.

October 25, 1967: (U. S. F. S. - PSWF&RES)

Mauer KB-8, f=150mm; (scale 1/650)

Anscochrome D-200
Ektachrome Infrared Aero (Wr. 12)

June 25, 1968: (U. S. F. S. - PSWF&RES)

Mauer KB-8, f=150mm; (scale 1/700)

*Anscochrome D-200
*Ekta Infrared Aero (Wr. 12)

June 25, 1968: (Cartwright Aerial Surveys, Sacramento, Calif.)

Zeiss RMK-A-15/23 Mapping camera; f=6" (Scale 1/10,000 and 1/35,000)

*Plus-X Panchromatic
*Infrared Aerographic
*Ektachrome Aero
*Ektachrome Infrared Aero (Wr. 12)

RC-9 Wild mapping camera; f=3¼ (scale 1/80,000)

*Ektachrome Aero
*Ektachrome Infrared Aero (Wr. 12)

4-lens Spectrozonal camera; f=80mm.

*Plus-X film (Wratten 61 and 25A)
*Infrared Aerographic (Wratten 89B and 47B)

Small Scale Aerial Photography:

As indicated by the foregoing list, a rather large amount of small scale photography (scales ranging from 1/10,000 to 1/80,000) has been procured of the Harvey Valley Test Site. This has been done as the initial step in the investigation of problems and applications that could arise from interpreting space photographs acquired from earth-orbital altitudes. Although the aerial photographs analyzed in this study are not intended to simulate space photos they provide a basis for studying the tone and color signatures of range features and the analysis of other variables which will affect the interpretability of space imagery.

Results from analysis of Panchromatic, Infrared Aerographic, Ektachrome Aero and Ektachrome Infrared Aero photos taken in 1966 at scales of 1/8500 and 1/35,000 were reported in two previous annual reports (Carneggie, D. M., et. al., 1966 and Carneggie, D. M., et. al, 1967). Briefly, it was found that color infrared photos were more interpretable than the other film-types for delineating vegetation and soil boundaries and for classifying the vegetation into broad types. This finding was due to the color renditions and color contrasts discernible on such photography at the time when the dominant forage species were approaching near maximum foliage development (an event which normally occurs in June or early July at Harvey Valley).

Building on this information, additional photographs were obtained with the same four film-filter combinations in June, 1968, at scales of 1/10,000; 1/35,000; and 1/80,000. Although the 1968 aerial photos were obtained at a slightly later phenological stage than those in June, 1966, the color infrared photos at all scales were again judged most interpretable. In this instance the advantage given to the color infrared photography is attributed to its ability to emphasize those sites having a fairly high percentage foliage cover.

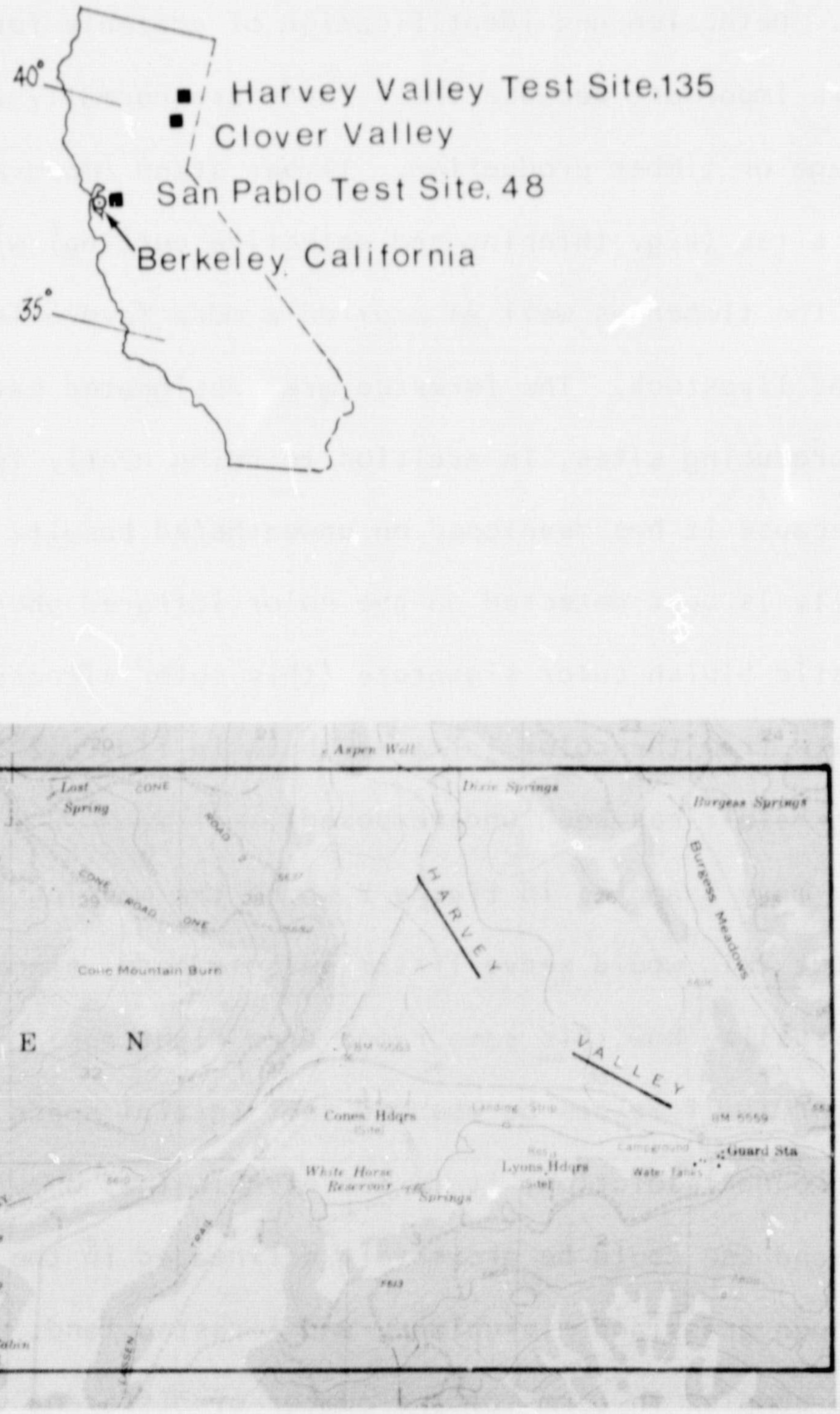
Figure 2, shows matching color and color infrared photos (scale 1/80,000) of an area that contains about 80% of the grazable land in the entire Harvey Valley Allotment. The accompanying type map in Figure 2 shows six categories of range land that can be consistently mapped at the photo scale shown.

The meadows, (category I) in particular are most conspicuous on the color infrared photos. It is significant to be able to recognize meadow sites, for they have the highest forage yield of all range sites, and the cattle spend the greatest proportion of their grazing time on or near these sites. The open-grassland, shrubland types (categories II and III) are more difficult to differentiate, especially at scales of 1/80,000 because (a) the forage is not dense enough in these types to provide a unique signature on either color or color infrared photos, and (b) the individual shrubs are rarely resolved. For these reasons, the dominant color signature for separating these types is attributable largely to the associated soil. Categories II and III have been separated on the type map (figure 2) because there are real differences in the present and potential productive capacities of the two sites. Category II has deep loam soil on which management practices such as brush removal, seeding and fertilization, could produced significant increases in forage production. Category III contains a complex of soil types that would respond only marginally to management practices. These two categories would not be readily differentiable, however, on lower resolution imagery.

Rocky, nonproductive sites (category IV) are most readily detected on color infrared photos. Such sites have a characteristic color signature derived from either the rock or soil surface. These sites likewise may not be readily detected on low resolution imagery.

The forested areas adjacent to the open rangeland in Harvey Valley are separated into two categories (V and VI) because one has grazable forage in the understory (V) whereas in the other (VI) there is little or no forage present in the understory because of the high density of the tree canopies, or because the underlying surface material is too rocky to sustain forage. Detection and identification of grazable forested land (category IV) is important because these lands are normally well suited for either forage or timber production. Timber stand improvement practices on these sites (e.g. thinning and selective cutting) will improve the quality of the timber as well as provide a more favorable habitat for wildlife and livestock. The forested area designated category VI is a poor timber producing sites, in addition to being nearly inaccessible to livestock because it has developed on unweathered basalt. This basalt material normally is best detected on the color infrared photo because of its characteristic bluish color signature (this color signature is difficult to appreciate from the color infrared photo in figure 2 because the area containing basalt has been underexposed).

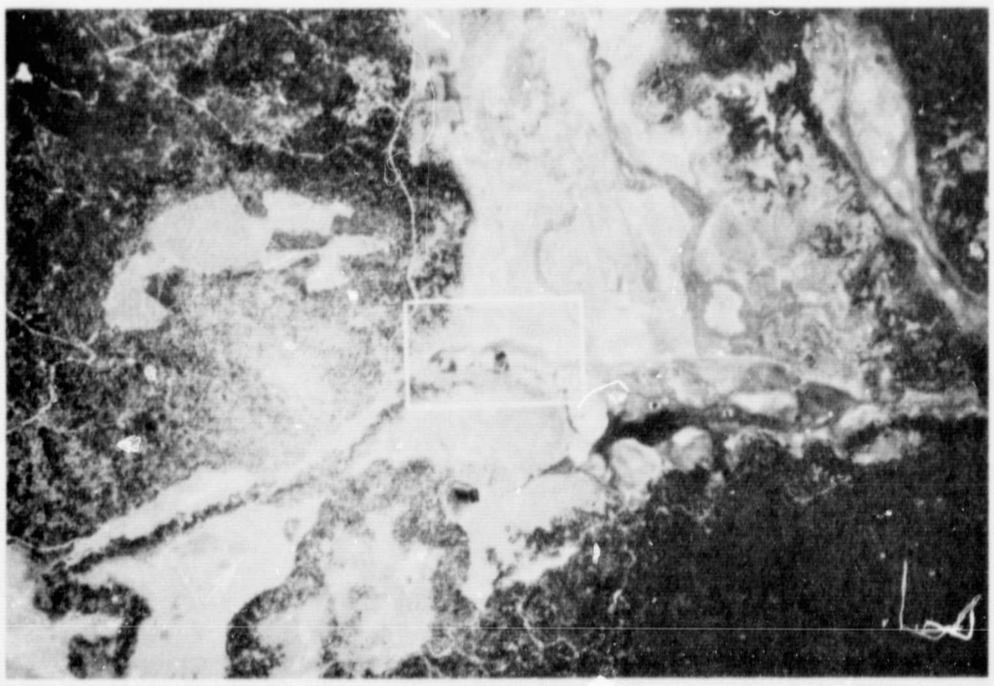
There are many examples in figure 2 where the mapping could have been refined, but this would serve little purpose here, since it is our objective to visualize how this same range area might appear and be mapped from space imagery. If it can be assumed that initial space imagery will give 100 foot ground resolution, it is conceivable that only three broad categories of land use could be accurately delineated in the Harvey Valley area; meadow, open grassland-shrubland, and forested land. Because Harvey Valley is quite complex in terms of the number of different vegetation and soil types, the broad type maps made from space imagery would be of only superficial benefit to the rancher or manager. However, it could be very valuable to an agency charged with preparing broad land use maps of extensive areas that heretofore have not been inventoried.



Harvey Valley Range Test Site, No. 135

Figure 1. Outline map (upper) of the state of California, showing the relative locations of range study areas with respect to the Forestry Remote Sensing Lab, University of California, Berkeley, California. The detailed topographic map (lower) shows that portion of the Harvey Valley Range Test Site seen on the photographs in figure 2.

Ektachrome Aero Photo
(Type 8442)



Ektachrome Infrared Aero Photo
(Type 8443) Wratten 12 filter

Rectangle indicated in white designates special study area seen at larger scale in figure 3. White arrow designates study site for investigating very large scale photos seen in figure 5.

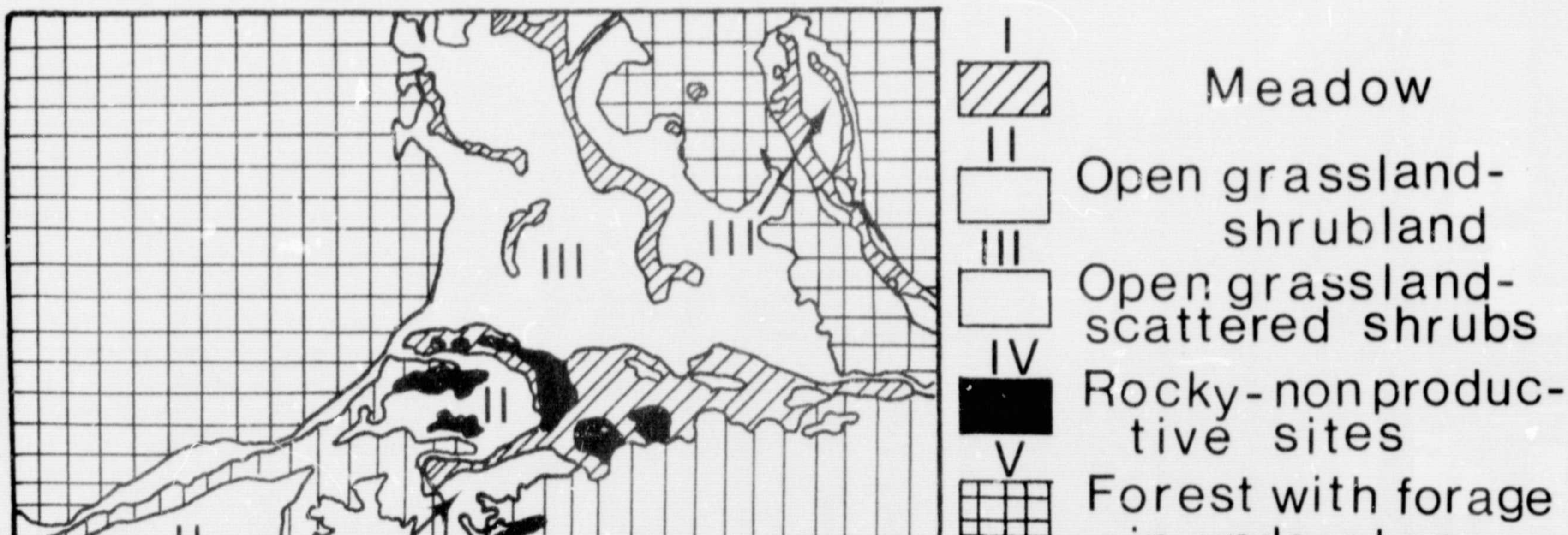
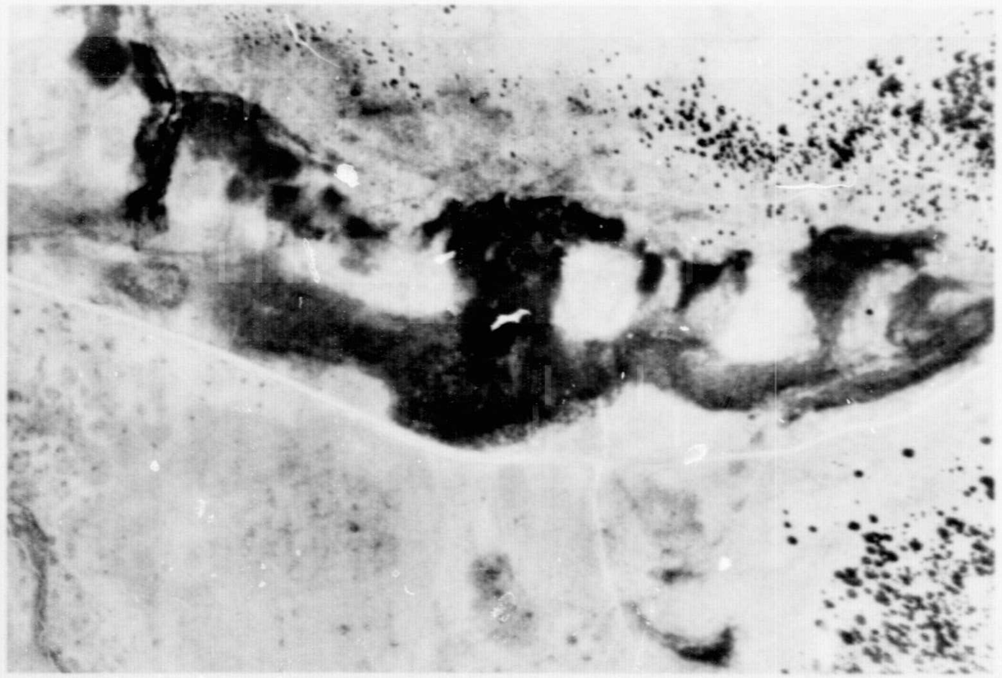


Figure 2. Harvey Valley Range Test Site, number 135. Photos taken June, 1968 using a Wilde RC-9 aerial camera with a $3\frac{1}{4}$" focal length lens. Photo scale 1/80,000. (Area shown approximately 20 sq. mi.) Type map shows delineations differentiating broad categories of grazing and nongrazing land. (See text for explanation of major type delineations.)

The kinds of information which the range manager needs almost certainly will have to be derived from larger scale imagery. Notice for example that the increased detail seen in the aerial photos, scale 1/10,000, in figure 3, permits an interpreter to map vegetation boundaries more accurately. (The Ektachrome Infrared Aero photo in figure 3 is the same area as that indicated within the white rectangular outline on the color infrared photo in figure 2.)

Figure 3 provides the reader with an opportunity to directly compare four film types for ease and accuracy of detecting features and mapping biological, physical and cultural features in a small portion of the Harvey Valley Range. The four ground photographs on the accompanying page show four plant communities which appear on the aerial photos. The direct comparison made in the field by relating features on aerial photos with corresponding features on the ground, and that made in the office by comparing aerial photo images and corresponding ground photo images, was the basis for determining which film type was best suited for evaluating range conditions. Also the ground photos and the aerial photos coupled with a description of characteristic features associated with each important range type formed the basic reference material for preparing interpretation keys and training aids that an image analyst needs in order to delineate and classify rangeland.

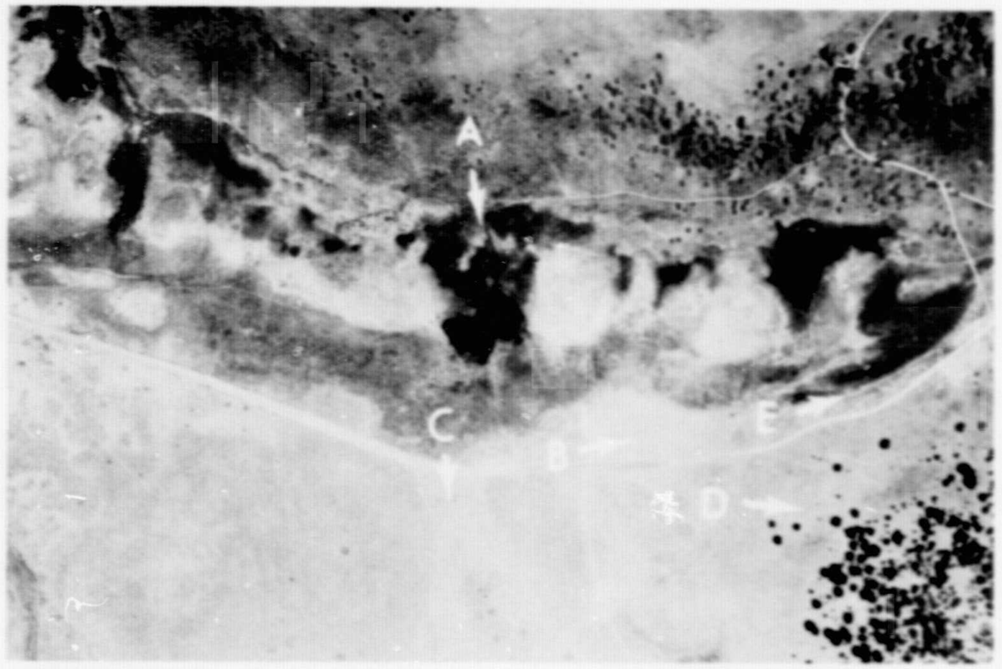
Up to this point the discussion has been about photographs taken in June, the time at Harvey Valley when range conditions are best evaluated. This conclusion has not been determined however independent of analysis of photos taken at different times in the season. In figure 7 for example there is a color infrared photo taken in June (1966) and one taken in



Plus-X Aerographic Photo (Type 2401) Wratten 12

Aerographic Infrared Photo (Type 5424) Wratten 89B

Ektachrome Aero Photo (Type 8442)



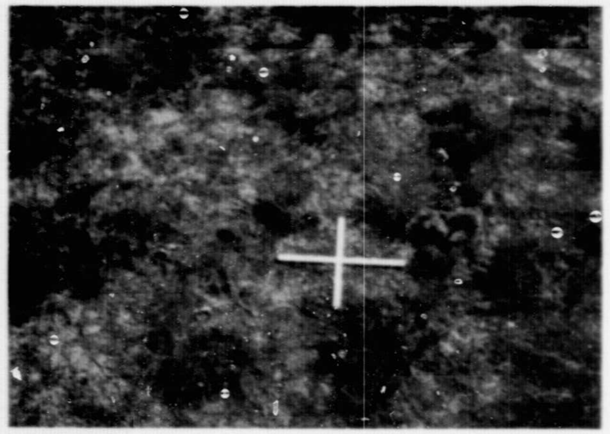
Ektachrome Infrared Aero Photo (Type 8443) Wratten 12

Figure 3. Four film types interpreted for ease and accuracy of evaluating range features. These photos were taken in late June, 1968 with a Zeiss RMK-A-15/23 camera with 6" focal length lens. Photo scale approx. 1/10,000. Compare the detail seen here with photos in figure 2. White arrows A through D point to four range types seen on the ground photographs (with corresponding letters) on the accompanying page. The ground photos combined with a brief description of the range type provide the reference material needed for training interpreters to identify these and other analogous range sites in the area. The white arrow, lettered E, points to the area seen on large scale color photos in figure 4.

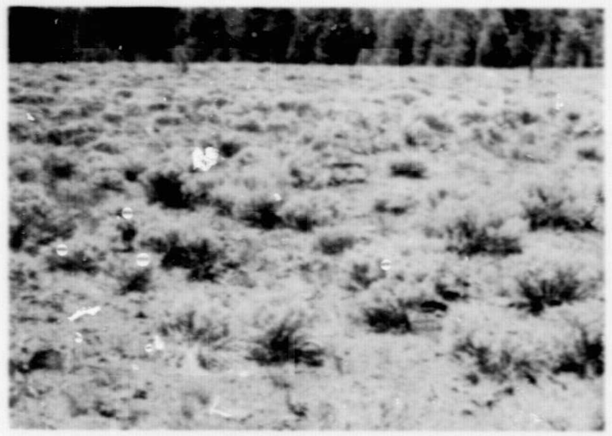
A. Meadow Site: Dominant forage species include sedges (Carex sp.), forbs (many very palatable species), grasses, and rushes (Juncus sp.). Foliage cover characteristically near 100%. On aerial photos meadows appear smooth in texture; variation in tone or color frequently associated with change in species composition, density or presence of standing water from springs. Meadows have a conspicuous white tone on Aerographic Infrared photos and conspicuous bright red color on Ektachrome Infrared Aero photos. Standing water and meadow vegetation appear similarly dark toned on plus-X and Ektachrome Aero photos. Highest forage yields on this range result from meadow sites.

B. Low Sagebrush Site: Sparse foliage, light colored soils, and surface rockiness characterize sites dominated by low sagebrush (Artemisia arbuscula) and its major associated grass species, Sandberg bluegrass, (Poa sandbergii), and Squirreltail (Sitanion hystrix). The shallow soil (12") and abundant surface rock contribute to the low productivity of forage on this site. On each of the aerial photos these near-nonproductive sites vary in tone and color as a function of changes in foliage density and surface rockiness. Low sagebrush sites are more readily detected on the two color photos (Ektachrome and Ektachrome Infrared).

C. Silver Sagebrush Site: Silver sagebrush shrubs (Artemisia cana) and an associated grass species, Poa nevadensis, dominate on low lying sites characterized by clay soils having relatively poor drainage. On these sites, as on low sagebrush sites, herbage density is relatively low, hence the tones or colors of these sites seen on the aerial photos are mainly due to the reflectance from the soil surface. Silver sagebrush plants range in size from 12-24" and are generally larger than low sagebrush shrubs; hence the individual shrubs can often be seen at photo scales up to 1/10,000.



D. Big Sagebrush Site: Big sagebrush shrubs (Artemisia tridentata) together with four important forage species (Idaho fescue, Festuca idahoensis; western needle grass, Stipa occidentallis; Squirreltail, Sitanion hystrix; and a sedge, Carex rossii) are the most common species on these sites. The underlying sandy-loam soil is relatively deep (24-36") hence forage production could be increased by removal of the non-palatable Big Sagebrush plants. On the aerial photos these sites are identified by noting the presence of the shrubs which average from 24-36" in diameter. The reddish-brown loam soil readily seen on the Ektachrome photos also characterizes these sites.



October (1967). The reader can therefore compare the photos taken at two different seasons. He should observe that at the scale of photography illustrated that the forage types are more readily seen in June when the range is green, than in October when the range is dry. However, it was found that certain plant species can best be identified in October, and in addition, the greenness or dryness of the range can also be determined by obtaining imagery late in the grazing season. Thus further consideration of obtaining imagery in October should not be summarily dismissed, for the combined information contained in the imagery taken early and later in the season i.e. from sequentially obtained imagery, better equips the manager to evaluate the availability of forage and the degree of range utilization.

Large Scale Aerial Photographs:

Let us suppose now that more information is desired concerning plant composition, plant structure and soil surface phenomena. It is this kind of information which will be more useful to the range man than just a broad vegetation type map of his range area. One way of collecting more detailed information is by employing a low-flying aircraft to procure very large scale photographs of small, representative areas as part of a double sampling procedure. Such areas are best selected from an interpretation of a small scale photograph.

An investigation of very large scale color and color infrared photographs was begun during the 1967 summer season, as a cooperative research project between the author, and Jack N. Reppert from the Rocky Mountain Forest and Range Experiment Station. The objectives were to determine (1) what practical applications could be derived from interpretation and measurement from very large scale color and color infrared photographs, (2) whether one film was better than the other, and (3) if there is such a thing as an "optimum" date to obtain photographs of rangeland.

Aerial photo missions were flown on June 10, July 25, and October 25, 1967 and again on June 25, 1968 using two 70mm Mauer cameras mounted in a twin engine Aero Commander, operated by personnel of the Forestry Remote Sensing Project, at the Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

At each flight date special markers were placed within the study area to: (1) align and orient the aircraft along specified flight lines which passed over the study area; (2) point to specific range features such as forage plants, rocks, rodent activity, etc., so that they could be easily relocated for study on the aerial photos; and (3) mark the boundaries of various sized plots within which data could be collected about forage species, plant density, shrub intercept measurements, and the exact position of important forage plants.

On each flight date the following information was collected: (1) phenological characteristics of plants; (2) species composition, (3) leaf and soil color; (4) estimate of foliage cover; (5) plant density*; (6) shrub intercept measurements and (7) surface conditions, e.g. disturbance by grazing, rodents, rockiness, moisture regime.

Ground photographs of selected areas were taken on each flight date to document for later study the appearance of plant conditions and surface features. Polaroid photographs were taken of special photo plots, and

*Plant density refers to the number of individual plants in a given area; foliage cover refers to the amount of surface area obscured by the forage as viewed from a vertical position.

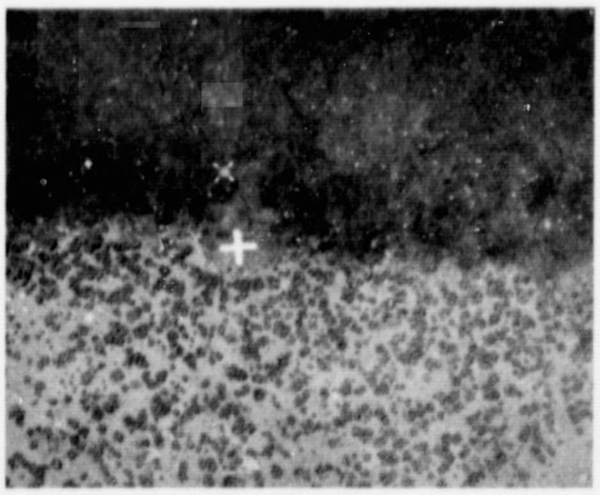
within each, plant species and other features of interest were annotated on the photos in the field. Color and color infrared ground photos were also taken. After each flight the 70mm aerial photos were taken back into the field in order to make direct comparisons with ground objects. Detailed study of the aerial photos in the office was facilitated by the notes and ground photos taken at each flight date.

Descriptive characteristics for each significant and discernible range object have been prepared for every flight date and arranged in table form for easy comparison of the features. These tables will serve as reference material for training interpreters who are unfamiliar with the study areas to identify range features. Descriptive photo image characteristics found to be useful to the interpreter in differentiating range features include: color, size and shape, texture, pattern, and shadow characteristics. An interpretation test has been prepared, but at this date there are insufficient data to base conclusions of interpretation on such a test. However, preliminary conclusions from detailed analysis of the photographs taken during the 1967 summer season are as follows: (1) No single date of photography is best for differentiating between all of the important range plants due to differences in rate of development and flowering. Because of phenological differences, the greatest number of plants can be accurately identified when the photo interpreter simultaneously interprets photos from all three dates; (2) Of the two film types and three dates of photography, the color infrared photos taken on July 25, 1967 were judged most interpretable, based upon the number of plant species and other features which could be detected and identified at that date; (3) Shrubs and small trees could be detected and more accurately identified because of their larger size. Low growing grasses and forbs were not as readily differentiated except when they possessed unique phenological characteristics; (4) Color infrared photos are superior to color photos for evaluating plant health and the ratio of stem-to-leaf material; (5) Many surface features are readily observable at this very large scale; e.g. erosion, rocks, cattle tracks and droppings, and rodent activity; (6) Evaluation of soil surface conditions together with the identification of plant species provides the information needed for classifying grassland and shrubland areas into meaningful habitat types or sites.

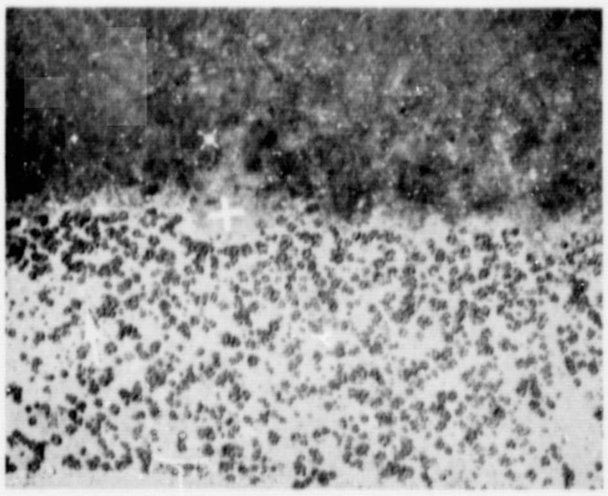
Only large scale color and color infrared photos from June 25, 1968, appear in this report (figures 4 and 5). By referring to figure 4, one can appreciate the ease of determining the structure and composition of plant communities from interpreting large scale photos, as compared with interpreting smaller scale photos of the same area (see figure 3).

Figure 5 shows very convincingly the detail observable from large scale photographs. Within the two white irregular shaped plots all plants have been mapped and identified and the shrub intercepts measured (see also figure 6). White arrows scattered throughout the study area point to plants and other range features. The accompanying ground photos in figure 5 show in even greater detail the features seen in the two plots. The reader is encouraged to pick out a few range plants from the ground photos and find the corresponding plants and associated features on the aerial photos. Hopefully, the reader will conclude that all but the smallest plants are detectable at this scale. Furthermore, the foliage development at this time (June 25, 1968) permits an interpreter to estimate forage cover, differentiate species, and determine plant health from an

Ground photo showing distinct vegetation-soil boundary between a wet meadow site (left) and a Big Sagebrush site (right); this boundary is indicated at the white arrow lettered "E" in figure 3 and is shown on large scale aerial photos immediately below.

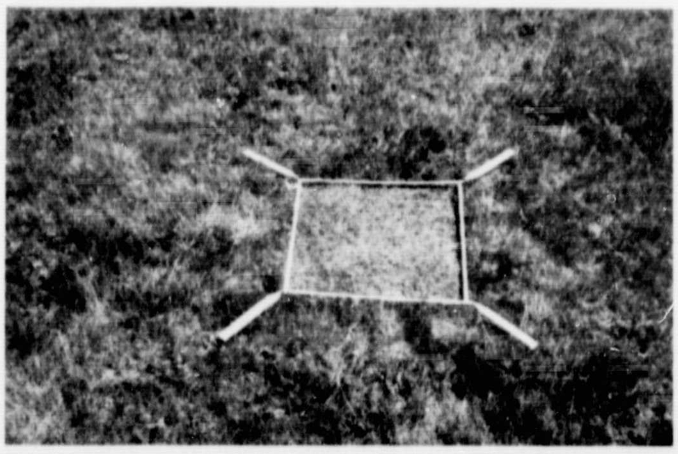


Anscochrome D-200 photo



Ektachrome Infrared Aero photo

Color aerial photos (reproduced from 70mm photos) scale 1/800 show a sharp vegetation boundary between meadow and Big Sagebrush sites. The detail seen on these very large scale photos permits an interpreter to observe rodent trails and cattle droppings in the meadow and to count individual shrub groups and to assess shrub health. On the original images, many of the low herbaceous forage species could be detected and their abundance estimated.



36" x 36" sample plot in which herbage has been removed to estimate forage production at the time aerial photos were procured. This same plot can be seen in the meadow on the aerial photo above.

Ground photo plot shows Big Sagebrush shrubs, scattered forage species, mainly *Carex rossii* and *Stipa occidentallis*, and other surface features. Compare this photo with corresponding area seen on the aerial photo (above) at the white arrow.

Figure 4. Aerial and ground photographs show in detail the range features associated with a wet meadow and Big Sagebrush site. This study area is shown at smaller scale at E in figure 3. Sub sampling techniques which use very large scale photos are being investigated as a means for improving the interpretation of lower resolution photography and imagery, as for example, space photographs.

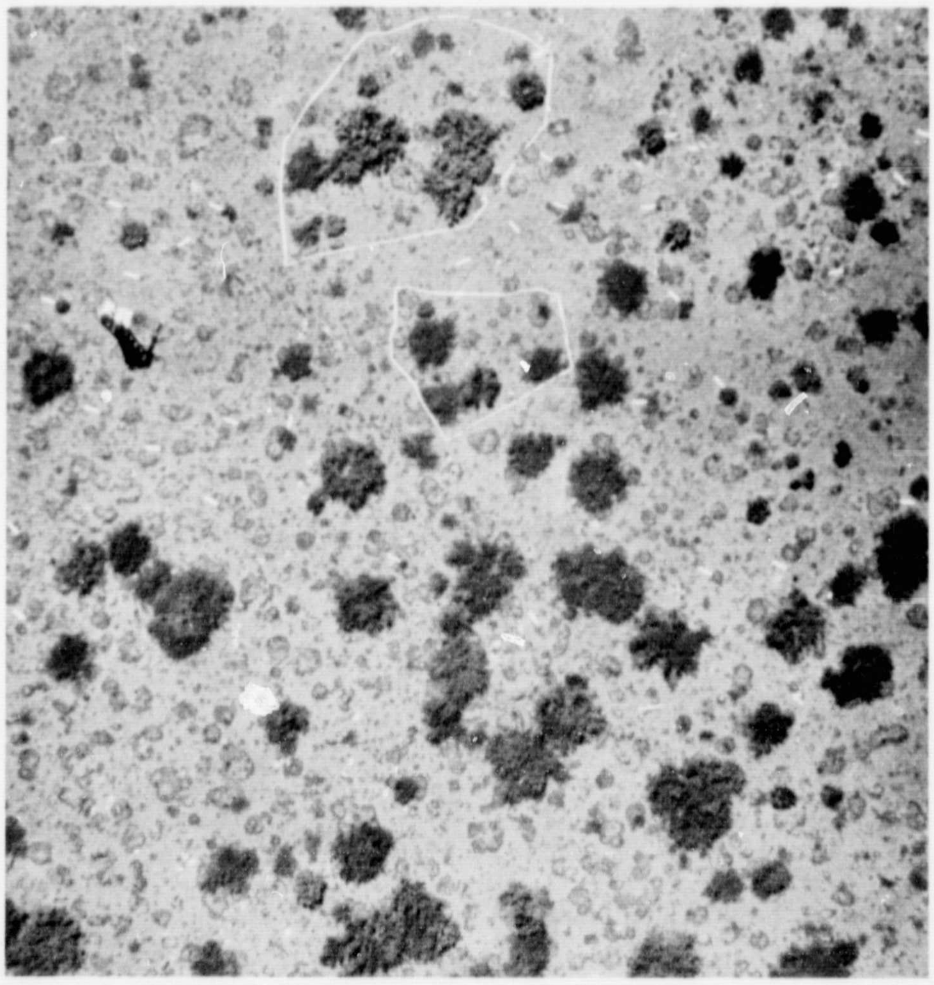
interpretation of the color infrared photos.

Shrub intercepts (greatest horizontal distance across a shrub viewed from the vertical) were measured for 48 shrubs belonging to three species: Bitterbrush (Purshia tridentata); Big sagebrush (Artemisia tridentata); and Rabbitbrush (Chrysothamnus sp.). Statistical comparison of the ground measured intercepts with the measurements made directly from the photos, using a 10X Bausch and Lomb magnifying lens, revealed that there is no significant difference (95% level of significance) between (a) the measurements made from the two film types and (b) the photo measurements and ground measurements. These results point optimistically toward large scale photos as a rapid and practical means for estimating foliage cover on a range site. Determining plant cover in the field is time consuming and laborious, whereas direct measurements of plant cover or estimates made from the photos can facilitate the gathering of this important information.

Research efforts are presently being conducted to determine the accuracy of estimating plant density from the photos. Some allowance will have to be made however, for small plants, or plants hidden beneath or within other plants. In the case of shrubs, often one encounters two or more growing together, thus causing them to appear as a single shrub. In these cases, a count of "shrub units" may be more appropriate for comparing shrub densities on different range sites and for observing vegetational changes.

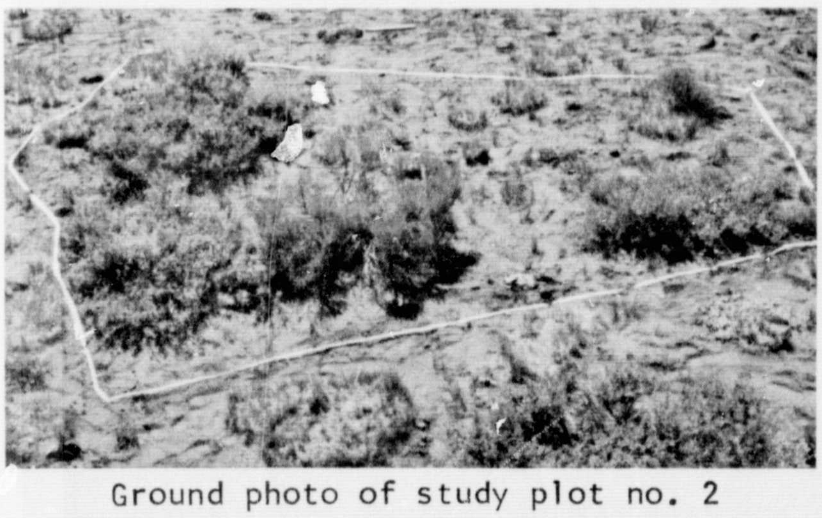
In view of our desire to determine what one can do with remote sensing from space, one might well ask why we are interested in interpreting large scale photos. The answer becomes clear when we consider

Anscochrome D-200 (photo scale 1"=25.21')



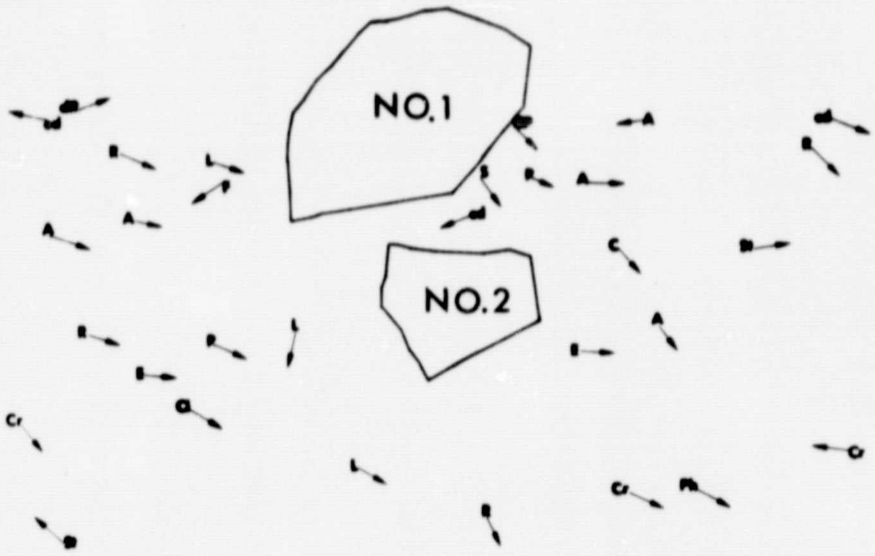
Ektachrome Infrared Aero (photo scale 1"=21.55")

Ground photo of study plot no. 1

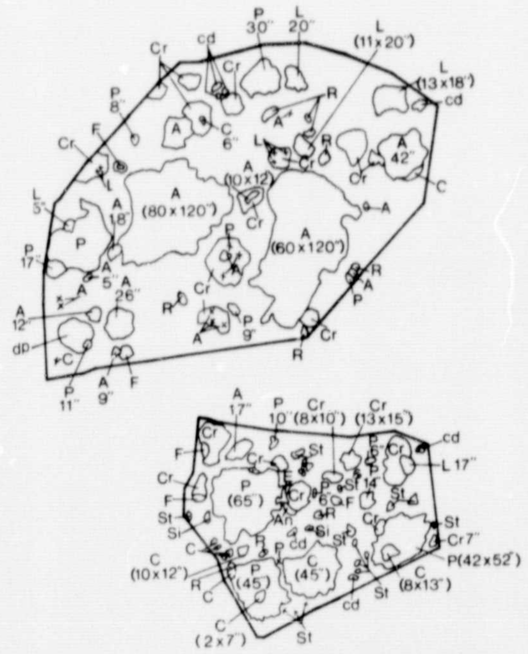


Ground photo of study plot no. 2

Figure 5. Large scale aerial photos at top provide a detailed picture of an open grass-shrub type in Harvey Valley Range Test Site. (See white arrow in figure 2 for small scale view of this area.) These photos were reproduced from color and color infrared 70mm aerial film taken on June 25, 1968. Original photo scales were 1/735 and 1/635 respectively. The ground photos (bottom) show in even greater detail plants and soil surface features in the two study plots (no. 1, upper, no. 2, lower.)



a.



LEGEND

Shrub, half-shrub
- A — Artemisia tridentata
- C — Chrysothamnus sp.
- E — Eriogonum umbellatum
- L — Leptodactylon pungens
- P — Purshia tridentata

Grasses
- F — Festuca idahoensis
- Si — Sitanion hystrix
- St — Stipa occidentalis

Sedge
- Cr — Carex rossii

Forb
- An — Antennaria dimorpha

Other
- cd — Cattle dropping
- dp — Dead plant material
- R — Rock

b.

STUDY PLOT NO.1

Shrubs:	Intercept Measurement (Ground):	Photo Measurements Film: Anscochrome D-200 Scale: 1:740	Ektachrome Infrared Aero 1:625
A	9 inches	6.66 inches	7.50 inches
A	26	24.86	26.25
A	42	35.52	41.25
A	60 x 120	66.60 x 124.32	66. x 123.
L	20	17.76	18.75
P	30	26.64	26.25

STUDY PLOT NO.2

A	17 inches	19.54 inches	18.75 inches
C	10 x 12	5.33	7.50
C	45	48.84	48.75
P	6	4.44	5.25
P	45	44.4	45
P	42 x 52	35.52 x 53.28	37.50 x 56.25
P	65	63.94	61.50

NB: Photo measurements made with 10X Bausch & Lomb magnifier and scale graduated in .001 feet.

c.

Figure 6. As an aid in the procurement and interpretation of large scale aerial photos, various marking materials were laid out at each study area to (1) designate the flight line; (2) point out specific range features for later examination on the aerial photo; and (3) define boundaries of small study plots within which the position, identity, size and numbers of important plants and other surface features may be determined. Two kinds of ground markers can be seen in the aerial photos on the adjacent page. Pointed arrows, painted white (3/4" x 2" x 18") point to range features of interest, and white plastic "flagging" tape, was used to form irregular study plots. Diagram (a) above, shows the position of the two kinds of markers. Diagram 6b shows the mapped position of range features within study plots numbered 1 and 2. In study plot no. 1 all of the larger range plants and some of the smaller ones were identified and mapped, while in study plot no. 2, all of the range plants have been mapped. Compare these diagrams with the actual study plot seen on the adjacent aerial photos. Within each of the two study plots shrub intercepts of most shrub species were measured on the ground (intercept refers to a horizontal distance measured across the plant; usually the longest horizontal dimension.) In table 6c shrub intercepts measured directly from the two color aerial films are compared with a few shrub intercepts measured on the ground. Research efforts are presently being directed towards determining the accuracy of estimating vegetation parameters employing photogrammetric techniques.

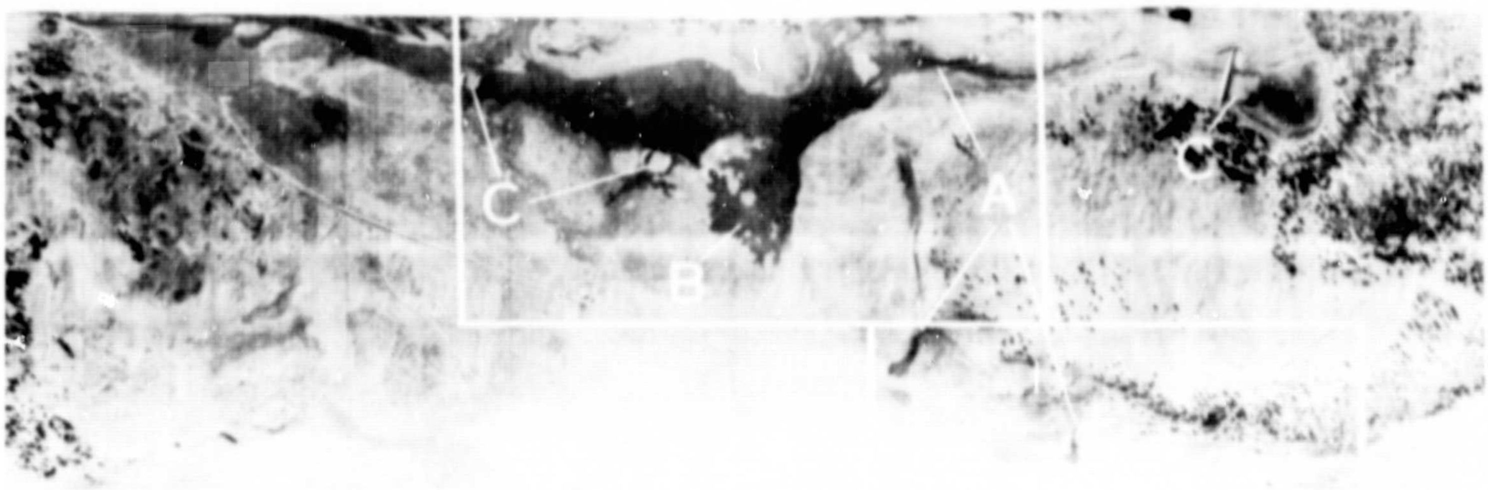
various intensities of range management. If capital resources (dollars) are lacking for range improvements with the result that grazing management must be extensive, a broad inventory such as can be prepared from space photos may be sufficient for the level of management that can be practiced. But if the management objectives are intensive in nature, i.e. maximizing production of animal products without jeopardizing the forage resource, more intensive management of the land is required. Such an intensive look at the range is provided by large scale photos. The most workable inventory procedure could employ both the space system and aircraft system in a multiple sampling framework, whereby the information derived from direct interpretation of the high resolution imagery, combined with a limited amount of field checking, provides the "ground truth" for more accurately interpreting lower resolution imagery obtained from space.

Line Scan Data:

Analysis of line scan data for the Harvey Valley Test Site includes the investigation of optical mechanical scanner imagery (figure 8) and thermal infrared imagery (Reconofax IV, figure 7). Looking first at the thermal infrared image in figure 7, (taken during midday) one can detect both the springs which flow out over the range, and the standing water from these springs. Water which has been ponded during the summer in specially constructed watering holes, or behind small check dams, has acquired more heat and hence appears warmer than the spring water, as indicated by the lighter tone. By comparing the thermal infrared image with the color infrared photographs taken at the same time, one will note that the springs, water holes, and other terrain features are seen more readily on the color infrared photographs. Differences in water temperature cannot be determined from analysis of the color infrared photos, however. There is considerably more detail seen on the photo than on the thermal infrared image, due to the lower resolution of line scan devices. One advantage of thermal infrared devices however, is that they can detect a wide range of temperatures or can be adjusted to whatever narrow temperature range is desired, thereby accentuating only those objects of interest.

The question of the value of thermal infrared imagery from space, for evaluating rangelands becomes very germane. One of the more important applications is in monitoring changes in the moisture regime that take place between early springtime, (when the range is very wet from winter rain and snow melt) and late fall (when the range soils and vegetation have dried.) Monitoring these changes is important for determining (1) "range readiness", i.e. the time when animals can begin grazing without causing damage to the forage crop, and (2) the availability of stock water, a factor of great importance because the efficiency of range utilization is often a function of the distribution of drinking water.

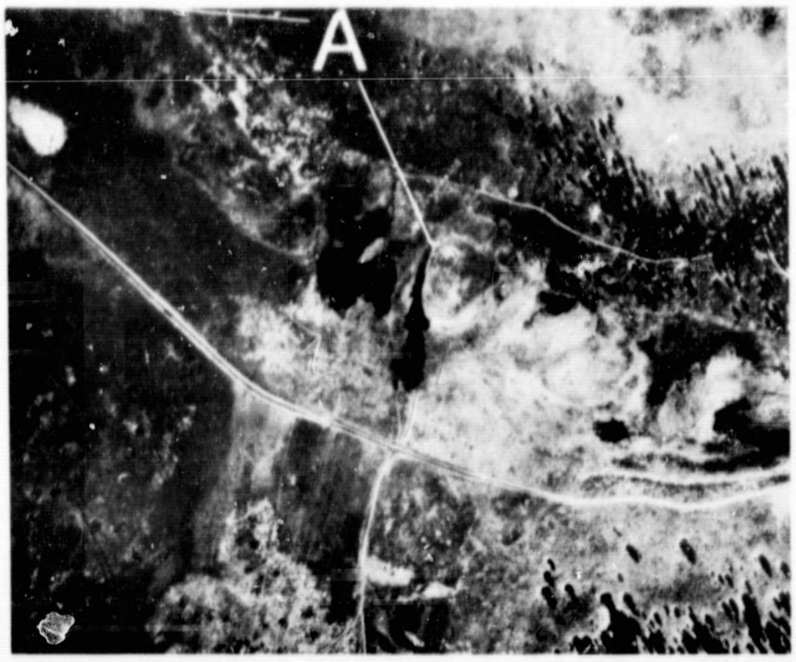
The use of thermal infrared sensors has been proposed for counting livestock or wildlife under special situations, (e.g. at night when the animals are active, or when animals are partially obscured by the limbs of deciduous hardwoods in the winter). The feasibility of detecting animals on thermal IR imagery obtained from low flying aircraft (500-1000 ft.) has been demonstrated (Garvin, L. E., et. al, 1964; Croon, G. W. et. al., 1968). Whether or not the making of animal surveys by this means would be beneficial depends upon cost-efficiency, reliability of sensing equipment,



Reconofax IV (HRB-Singer) Thermal Infrared Image (8-14 microns) October, 1967

Ektachrome Infrared Aero photos, taken at about 11:00 a.m. on Oct. 18, 1967, simultaneously with the thermal infrared image shown above. These two color infrared photos coincide with the areas outlined in white on the thermal infrared image. (A) designates the origin of springs, (B) points out marshy areas associated with standing water, and (C) shows ponded drinking water for cattle.

Ektachrome Infrared Aero June, 1966



Ektachrome Infrared Aero Oct., 1967

Figure 7. The thermal infrared (top) image and color infrared photos provide the opportunity to compare the detail of range features discerned on each when they are taken simultaneously over the same area. The two bottom photos (color infrared) provide a comparison of seasonal change in moisture regime and plant health. Note the presence of ponded spring water (ps) and healthy sedge (<u>Carex exserta</u>) at (x) on the June photo. On the October photo, the spring water is absent and the sedge has dried (indicated by the light color).

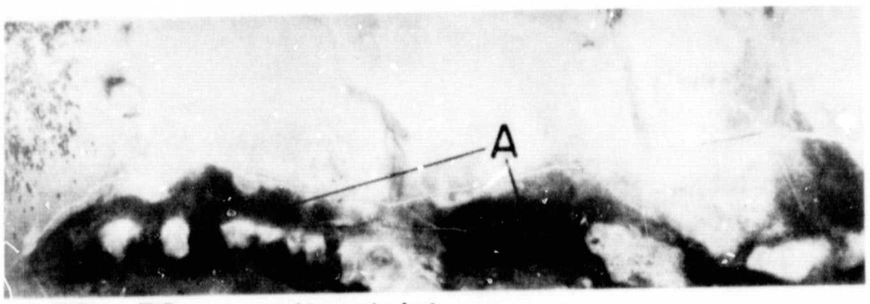
and the accuracy of counts. Adequate evaluation of these factors must await further research.

Line scan signals obtained by the optical mechanical scanner are initially recorded on magnetic tape and are normally analyzed by matching tone signatures in a computer. However, photographic printouts also can be made. Such printouts were made of Harvey Valley line scan data; hence it was possible to examine the tone signatures of range features in 18 different bands of the spectrum, from the ultraviolet through the visible and photographic infrared bands to the thermal infrared. Upon initial study of printouts made from the 18 bands, six bands were chosen for more detailed study (the remaining 12 bands were eliminated from further study because they did not visually appear to contribute unique signatures to aid in discriminating important range features.)

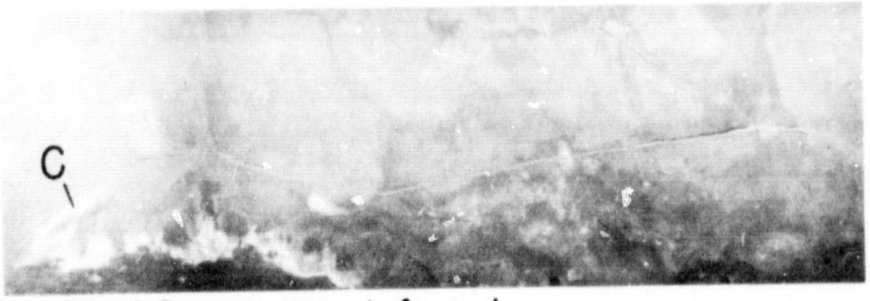
The six bands selected for more detailed study are as follows: .32 - .38 u; .55 - .58 u; .62 - .68 u; .80 - 1.0 u; 1.5 - 1.8 u, and 8.0 - 14.0 u. With the exception of the green band (.55 - .58 u), type maps were prepared for all selected bands, based on tone and texture. These type maps were compared with type maps prepared from photographs and associated ground truth of the same area. From this comparison, it was concluded that the type map made from the visible red band showed the greatest number of vegetation boundaries existing on the range. (This comparison of conventional photographs with line scan imagery reveals geometric distortions in the line scan data which are not desirable for mapping purposes.)

Density values for the various range sites that had been delineated

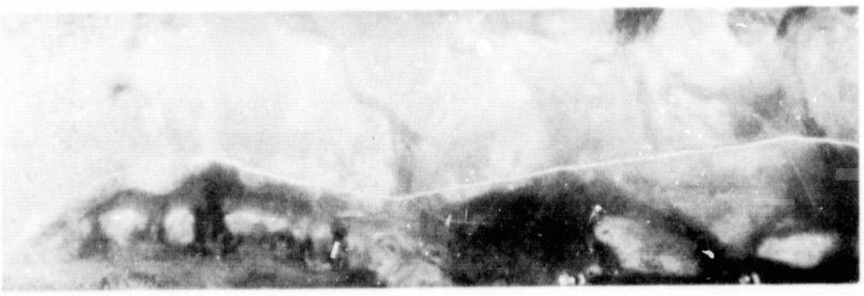
MULTIBAND LINE SCAN IMAGERY SHOWING RANGE RESOURCES



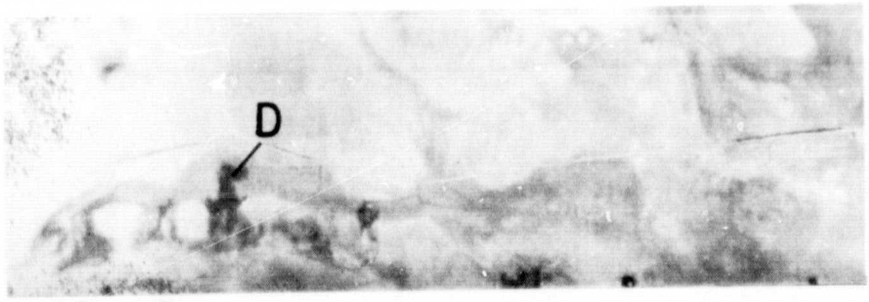
.32-.38 u ultraviolet



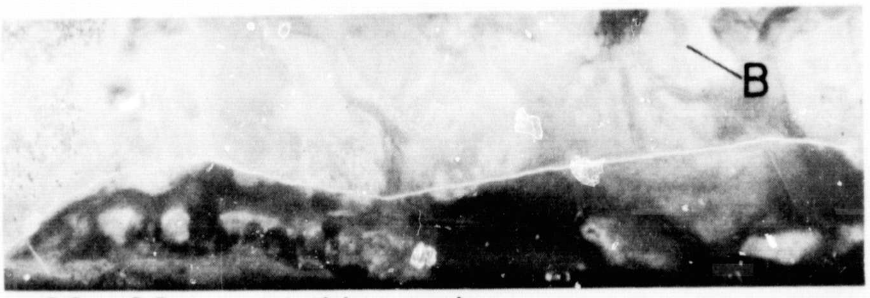
.80-1.0 u near infrared



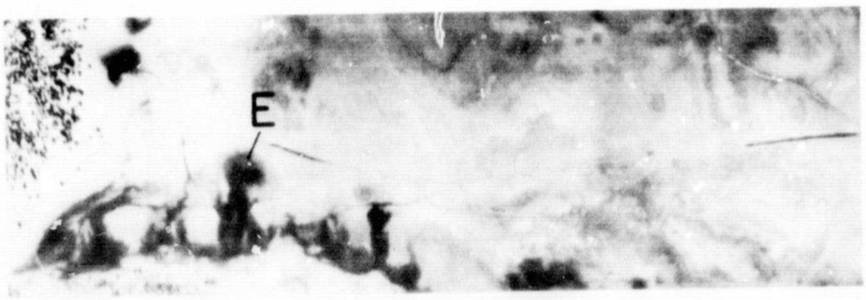
.55-.58u



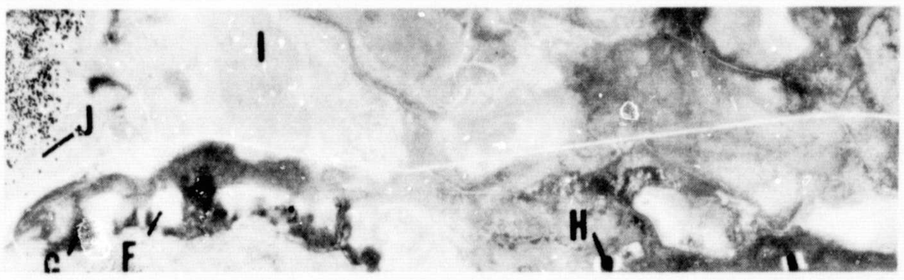
1.5-1.8 u



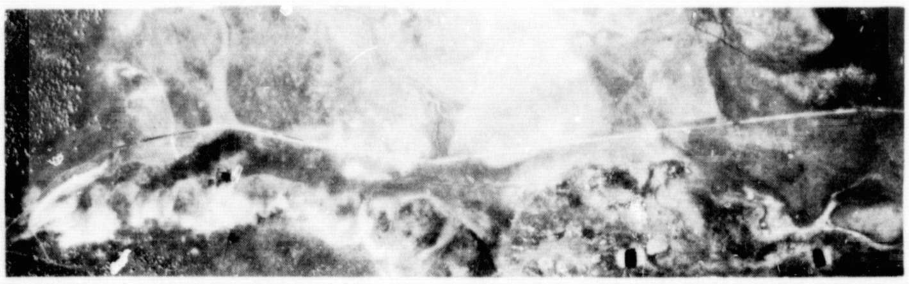
.62-.68u visible-red



8.0-14.0 u thermal infrared

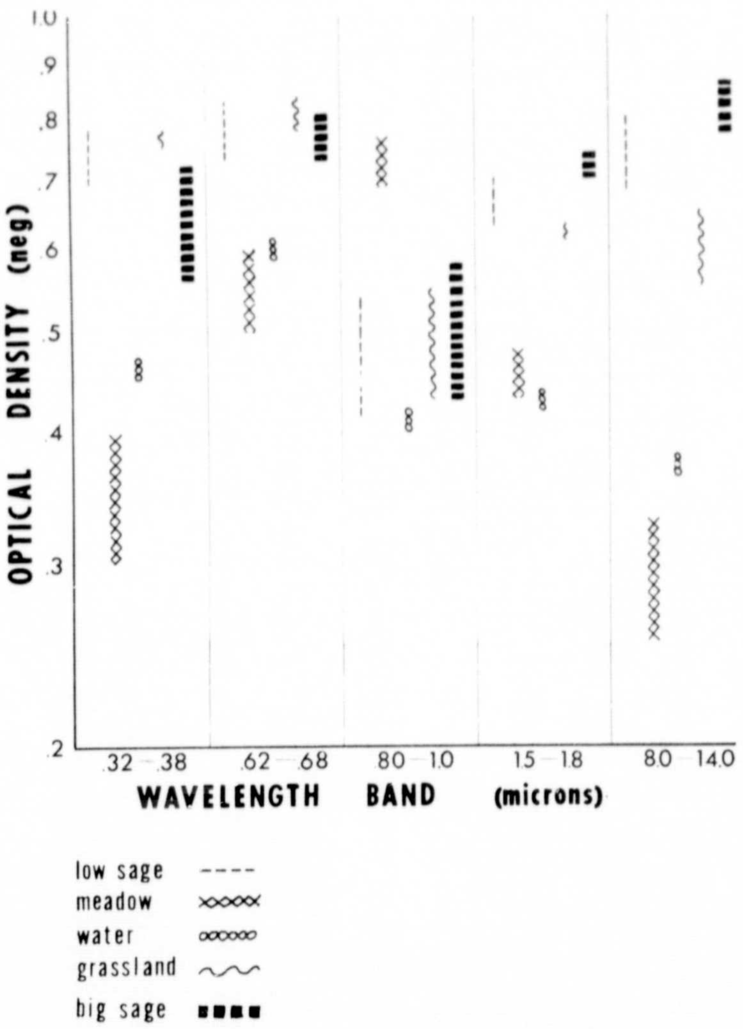


Plus-X Panchromatic Photo (.5-.7u) Wratten 12

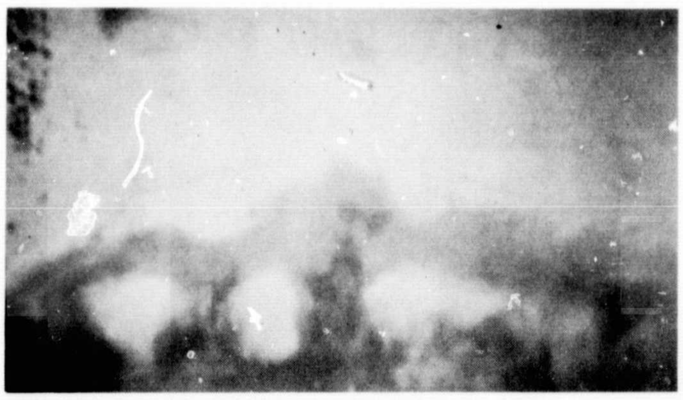


Infrared Aerographic Photo (.7-.9u) Wratten 89B

Figure 8a. Six bands of line scan imagery (top) procured simultaneously by an optical mechanical scanner (University of Michigan)emphasize the different tonal signatures of range features resulting from their characteristic reflectance and/or emittance phenomena within the specific spectral bands indicated. To compare scanner data with photographs, the two bottom photos show the same area at essentially the same seasonal stage (scale approximately 1/30,000). Features of interest annotated on the images above include: (A) dark-toned areas are moist sites which contrast with the light-toned areas which are characteristically drier sites, (B) distinct vegetation boundary (the greatest number of vegetation-soil boundaries are seen on the visible red band), (C) dense meadow vegetation (differentiated most conspicuously from other features on the near infrared, .8-1.0 u band, (D) dark-toned area corresponds with standing water from a nearby spring, (E) dark area corresponds with sites having a high soil moisture percentage, (G) dense meadow vegetation, (H) standing water in a developed watering area for livestock, (I) open grassland with scattered sagebrush shrubs, (J) dense sagebrush site adjacent to timbered area where ponderosa pine is the principal species.



The relative tone difference of five range features within each of five spectral bands is expressed in terms of optical density of the negative printout, using a Welch Densichron. The positive photo printout for these five spectral bands is shown on the accompanying page. Because image tones can shift due to electronic gain control settings and processing variables, only the within band tonal differences can be studied and compared. Notice, for example, the wider range of density values for range features on the .32-.38 and 8.0-14.0 micron bands, compared to a much narrower range of density values for range features in the .62-.68 micron band. Also note that within specific bands certain range features are more readily differentiated, while in still other bands specific features cannot be differentiated, due to similarity of tone, from other features. As an example, meadow vegetation is readily distinguished from other features in the .8-1.0 micron band, but in this same band it is nearly impossible to separate low sage, open grassland and big sage sites.



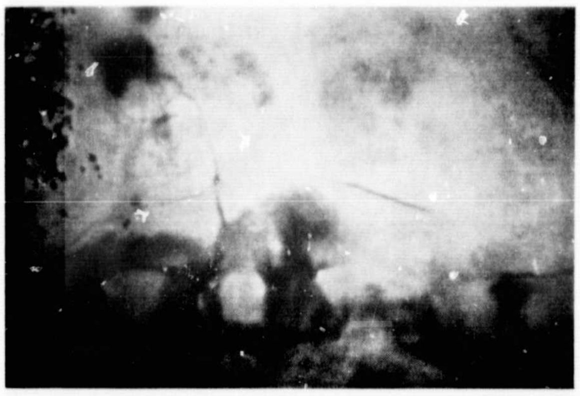


Figure 8b. An obvious advantage of multi-channel line scan imagery is to provide a record of reflectance or emittance phenomena, both within and outside the photographic portion of the electromagnetic spectrum. The intended data format, however, was not a photographic printout as seen on the accompanying page, but rather analog format (magnetic tape) to be analyzed rapidly by means of a computer. One can readily appreciate that visual interpretation of as many as 18 bands of line scan imagery would be tedious and time consuming. One possible method for increasing the interpretability of spectra-band imagery is by image enhancement. The color composites above are but two of many combinations of spectral bands and filters. The left color composite was made by superimposing three black-and-white spectral bands (from the adjacent page); .32-.38u, .8-1.0u, and 1.5-1.8u, with a blue, red and green filter, respectively. The right color composite was made using two spectral bands; 1.5-1.8u and 8.0-14.0u with a yellow and blue-green filter, respectively.

on the type maps were determined from the negative of the line scan print-out, using a Welch Densichron. In figure 8b optical density values for five range types are plotted for each of the five wavelength bands. Notice that the within-band density spread of the .62 - .68 u band has the narrowest range (the greatest number of vegetation and soil boundary lines were mapped on this band). Note also that in the other bands, the increased density spread increases the possibility that a feature will exhibit a distinguishable tone signature. In particular, the meadow vegetation was found to have a distinct signature in the .8 - 1.0 u band, and the 8.0 - 14.0 u band.

Cross examination of the six bands of line scan imagery in figure 8b should convince the reader that the portion of Harvey Valley that is portrayed there contains a complex of vegetation and soil types. Under these and similar range environments it is conceivable that an inventory of the range types could best be prepared by sensing in several bands, within and outside the visible spectrum, especially when ground resolution is poor.

Feasibility Table:

Having investigated various film-filter combinations and compared them with each other and with the thermal infrared imagery, and having examined imagery at various scales of remote sensing data ranging from 1/600 to 1/84,000, plus Gemini and Apollo space photography, we summarized our important findings, as shown in Table I. That table indicates the feasibility of making significant interpretations of range features and conditions at varying levels of ground resolution. It also indicates which film-filter combinations are most interpretable and the ground

TABLE I
Feasibility Table

Range Feature or Condition	Ground Resolution (in feet): .1' - .3'					1' - 3'					10'-30'					100'-300'				
Film-Filter Combination or Sensor	Pan 12	IR (89B)	Color	Color IR (15)	Thermal Infrared (8-14 u)	Pan 12	IR (89B)	Color	Color IR (15)	Thermal Infrared (8-14 u)	Pan 12	IR (89B)	Color	Color IR (15)	Thermal Infrared (8-14 u)	Pan 12	IR (89B)	Color	Color IR (15)	Thermal Infrared (8-14 u)
VEGETATION FEATURES, CONDITIONS																				
Grazing vs. non-grazing land	++	++	++	++	+	++	++	++	++	+	+	+	++	++	+	+	-	+	++	-
Gross vegetation types	++	++	++	++	++	++	++	++	++	++	++	++	++	++	+	+	+	+	++	+
meadow	++	++	++	++	++	++	++	++	++	+	+	+	+	++	+	-	+	+	++	+
open grassland	++	++	++	++	+	++	++	++	++	+	+	+	++	++	+	-	-	+	+	-
brushland	++	++	++	++	++	++	++	++	++	+	+	-	+	++	+	-	-	+	+	-
open timber	++	++	++	++	++	++	++	++	++	++	++	++	++	++	+	+	-	+	++	+
non-productive sites	++	+	++	++	+	+	+	++	++	+	-	-	+	++	-	-	-	+	+	-
Range grasses and forb species	+	+	++	++	-	-	-	-	-	--	--	--	--	--	--	--	--	--	--	--
Range shrub species	++	++	++	++	-	-	-	+	+	-	-	-	-	(+)-	--	--	--	--	-	--
Gross forage density, cover classes	++	++	++	++	+	-	-	+	++	-	-	-	-	+	--	--	-	-	+	--
Plant healt' (greenness dryness)	+	+	++	++	+	+	+	++	++	-	-	-	+	++	-	--	--	+	++	--
Gross assessment of forage utilization	+	++	++	++	-	-	-	+	+	-	-	-	-	+	--	-	--	-	-	--
SURFACE FEATURES, CONDITIONS																				
Soil texture	++	+	++	++	-	-	-	+	+	-	--	--	-	-	--	--	--	--	--	--
Rockiness	++	++	++	++	+	+	-	+	+	-	--	--	-	-	--	--	--	--	--	--
Soil disturbance due to																				
rodents	++	++	++	++	--	-	-	-	+	--	--	--	--	-	--	--	--	--	--	--
livestock use	++	++	++	++	-	+	+	+	+	-	-	-	-	-	--	--	--	--	--	--
erosion	+	+	++	++	-	+	+	++	++	--	+	+	++	++	--	-	-	+	+	--
Burned rangeland	++	++	++	++	+	++	++	++	++	+	+	+	++	++	+	-	-	+	++	--
Numbers of animals	++	++	++	++	+	++	+	++	++	+	--	--	--	--	--	--	--	--	--	--
MOISTURE REGIMES																				
Standing water	++	++	++	++	++	+	++	+	++	++	+	+	+	++	+	-	-	-	+	+
Springs	+	++	++	++	++	+	+	+	++	+	-	-	-	+	-	--	--	--	--	--
Permanency of streams	+	++	++	++	++	+	++	+	++	++	-	-	-	-	-	--	-	--	-	-

In this table the four feasibility symbols have the following significance:

++ signifies that the feature is readily and consistently interpretable (i.e. detected, identified, estimated or measured, depending upon feature or condition) even by those having limited photo interpretation training and experience.

+ signifies that the feature usually is interpretable but only through careful study by photo interpreters who, by virtue of training, experience and motivation are expert in identifying such features.

- signifies that the feature is not consistently interpretable even though expert photo interpreters are able to identify such features occasionally on photography of the film-filter-scale combination indicated.

-- signifies that, although the feature is an important one from the Earth Resources standpoint, it is almost never interpretable even by expert photo interpreters.

resolution required on the imagery to begin preparing improved range resource inventories. It should be recognized that the interpretability of certain range features is dependent upon the date when the data are obtained, and upon the size or areal extent of the feature. These considerations are implied within the feasibility table.

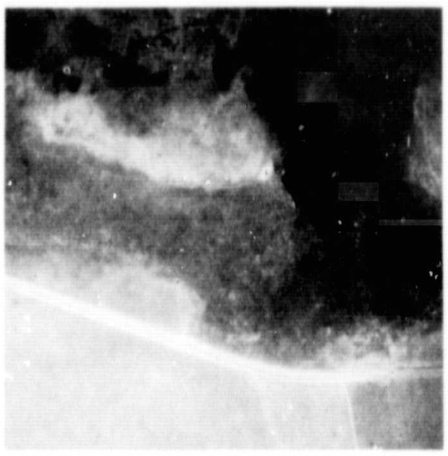
Analysis of Multispectral Images--Image Enhancement Techniques:

In the preceding section consideration was given to the tone signatures of range types seen in six bands of the electromagnetic spectrum. Whereas it was possible to go from band to band and pick out features that showed up quite well on one band but not as well on another, the job of extracting information from two or more spectral bands by visual interpretation techniques proved to be very tedious and time consuming. For this reason, the magnetic tape record of the 18 channel line scan imagery will be analyzed by a computer at the Laboratory for Agricultural Remote Sensing, Purdue University.

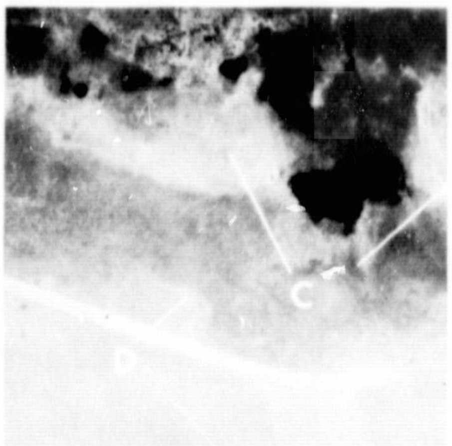
Another technique for increasing the interpretability of many black-and-white spectral band images is that of image enhancement by additive color. In this process two or more bands are superimposed on a screen by projecting the positive or negative images through color filters. By changing the filters one can create any number of false color renditions for a given combination and number of spectral bands. The best color composites are those which give a unique and easily discerned color to the particular objects of interest. Through selection of the proper bands and filters one can simulate either the natural coloration of conventional color films or the false coloration of color infrared film.

Figure 8b shows two color composites made from selected black-and-white bands of the line scan imagery shown in figure 8a. By superimposition of the ultraviolet, and two near infrared bands (left color composite in figure 8b) it was possible to readily see the meadow vegetation as orange or yellow; spring-water flows as dark purple; rocky low sagebrush sites as light blue; open grassland as pinkish-purple; and big sagebrush sites light green. In the other color composite of figure 8b a near infrared (1.5 - 1.8 u) and thermal infrared band (8.0 - 14.0 u) were superimposed to enhance moisture patterns.

Figure 9 shows three black-and-white multiband photographs taken with a four lens spectrozonal camera owned and operated by Cartwright Aerial Surveys (Sacramento, California). These photos were taken at the same time as the color photos in figure 3. It was found that delineation of range types could be done almost as accurately on the black-and-white photos as on the color photos. However, the identification and classification of the types was found to be a more difficult task. If the black-and-white images are enhanced by additive color techniques (as in figure 9) the job of delineating and classifying types is facilitated. Note that the color composite in figure 9 is a simulation of a color infrared photo because the spectral bands and filters used in making the composite are similar to those in the color infrared film. As indicated in an earlier section, color infrared photos of the Harvey Valley Site yield the best information on forage types and range conditions. Since multispectral photos can be reconstituted into color composites that simulate color infrared photos--a remote sensing system which has a capability for sensing in the green, red, and near infrared spectrum, be it television, optical mechanical scanners or photographic cameras, will be best suited for preparing inventories of rangelands.



.46 - .61 microns
Wratten 61 Filter
Panchromatic Photo

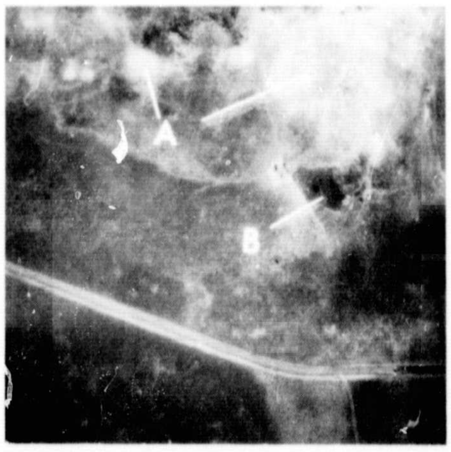


.60 - .72 microns
Wratten 25A Filter
Panchromatic Photo

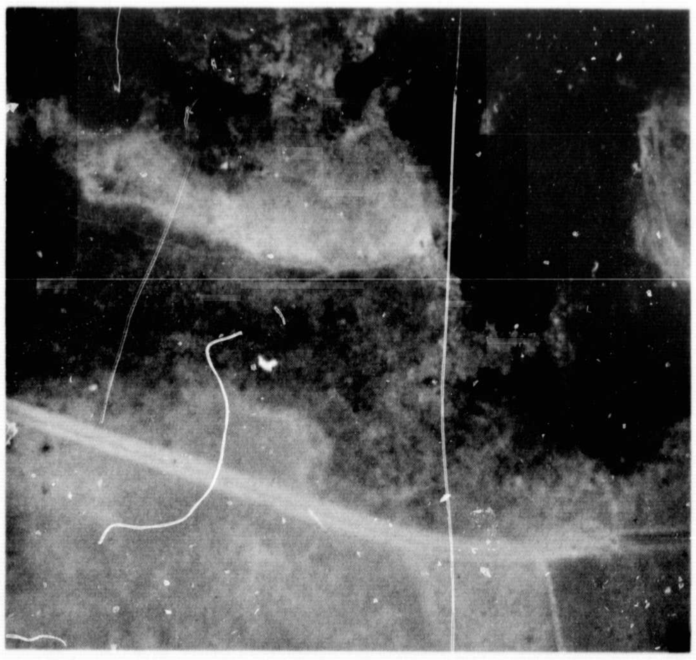
green

blue

red



.72 - .95 microns
Wratten 89B Filter
Infrared Aerographic Photo



Color Composite

Figure 9. The black-and-white multispectral photographs, above, were taken simultaneously with a four-lens Spectrozonal Camera by Cartwright Aerial Surveys, Sacramento, California. The top two photos were exposed on Plus-X panchromatic film and the lower black-and-white image was exposed with Infrared Aerographic film. Compare tone and texture contrasts among these three photos. Observe that healthy meadow vegetation at (A) is conspicuously seen on infrared film due to its white tone caused by high near-infrared reflectance. Note that the marshy area at (B) is differentiated from the meadow vegetation in the near infrared photo. On the filtered panchromatic film other features are more pronounced; for example, a low sage site at (C) and a distinct soil-vegetation boundary at (D). Visual interpretation of many black-and-white images from different spectral bands permits an interpreter to discern many more features than if he were to interpret any single spectral band alone, but this process is often tedious and time-consuming. Now compare the black-and-white photos with the color composite made by superimposing the images of the respective black-and-white photos through the respective filters indicated in the diagram. The color composite simulates a color infrared photograph because similar spectral bands and filters were used. Compare the photos on this page with the color and color infrared photos in Figure 3, taken at the same time.

ANALYSIS OF REMOTE SENSING DATA, CLOVER VALLEY
(Perennial Grassland and Shrubland)

Description of Test Site:

The Clover Valley study area is located within the Plumas National Forest, north of Portola, California. This site was selected for study in the summer of 1968 because it was similar in elevation, forage types, and rainfall to the Harvey Valley Site. Consequently, this study area provided an opportunity to apply what was learned at Harvey Valley to a similar range area. In addition, panchromatic photos dating back to September 1944 were available for studying changes in the range that have occurred in the 24 year interval - 1944 to 1968. Since panchromatic photos had been taken in September, 1944, panchromatic photos were again taken in the month of September, 1968 in order to show the same areas in about the same phenological stage. Based upon the research at Harvey Valley, however, the fall season is not the best time of the year to delineate range features. Consequently, Panchromatic, Infrared Aerographic, Ektachrome and Ektachrome Infrared Aero photos were taken at Clover Valley in June, 1968 in order to have interpretable photos from which to map range features and provide a base for comparing features seen on the September photos.

Data Acquired:

September, 1944 (Procured for the U. S. F. S.)

K-17 aerial camera; f=8¼" (scale 1/15,840)

*Panchromatic aerial photos

June 25, 1968 (Cartwright Aerial Surveys, Sacramento, Calif.)

Zeiss RMK-A-15/23 mapping camera; f-6" (scale 1/15,840)

*Plus-X panchromatic (Wr. 12)
*Infrared Aerographic (Wr. 89B)
*Ektachrome Aero
*Ektachrome Infrared Aero (Wr. 12)

RC-9 Wild mapping camera; f=3¼" (scale 1/80,000)

Ektachrome Aero
Ektachrome Infrared Aero (Wr. 12)

September, 1968 (Cartwright Aerial Surveys)

K-17 aerial camera; f=8¼" (scale 1/15,840)

*Plus-X Aerographic (Wr. 12)

Comparison of Sequential Photographs:

Detailed ground information was not available regarding the range condition in 1944. However, some very useful generalized information could be obtained from the local ranchers in the area. It is assumed that most of the dominant plant species still occupy the same sites; however, it is difficult to evaluate the validity of that assumption except by comparing tone values on the above-mentioned sequential photographs. Determination of probable changes in the vegetation, stream channels, and associated features also are based upon the ground information collected in conjunction with the June, 1968 photo mission. The color infrared photos taken in June were the easiest on which to discern and identify important range conditions, and proved valuable for locating the conditions within the range where notable changes had taken place. Hence by studying areas which appeared to have changed both on the June photos and on the ground, little further ground checking was needed in September to compare the 1944

*Illustrated in this report

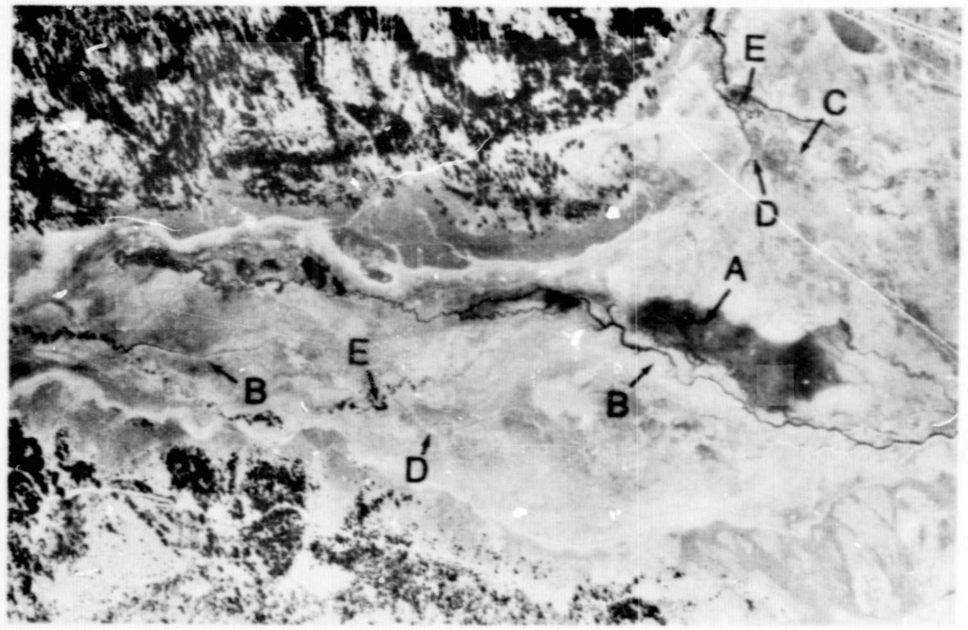
panchromatic photos with the 1968 photos.

The most striking change, and of course the one of the most importance to a range manager, was the encroachment and reestablishment of big sagebrush plants in a meadow area where in 1944, it apparently did not exist (see figure 10). The significance of such a change lies in the fact that either a change in grazing management or failure to make needed range improvements, (e.g., to treat shrub areas with herbicides) may explain the presence of the sagebrush. Not only does the sagebrush rob water from the more palatable forage species in the meadow, but its presence precludes forage species from occupying the same site.

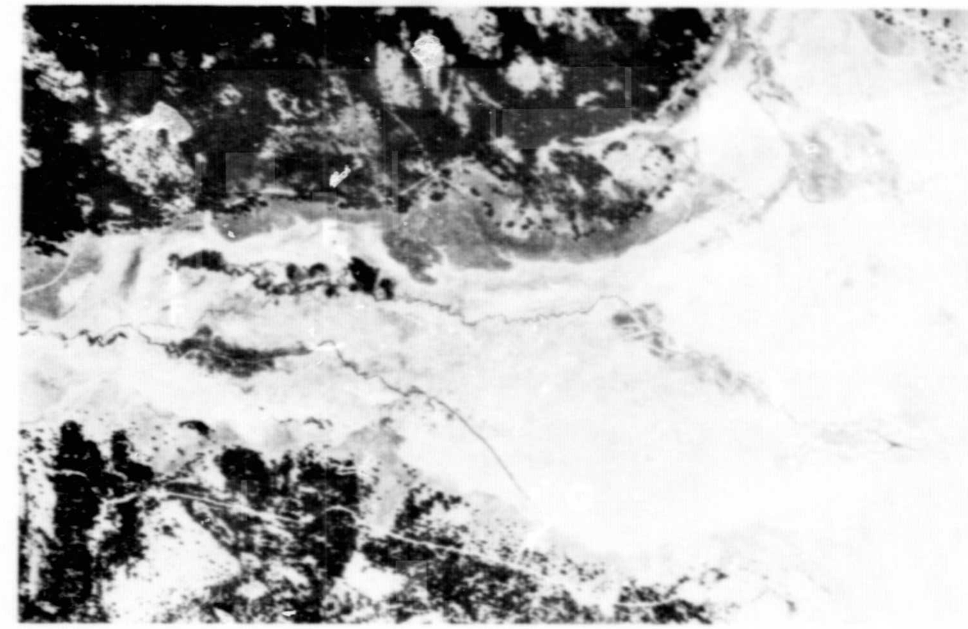
Another striking change noted on the September, 1968 photos is in the relocation of streams which provide moisture for forage species throughout the range. In some cases only small changes in the meander of the stream were noted, while in other instances, the stream has taken a new course through the meadow. Granted that some of these changes may have been man-induced, such changes may indicate a redistribution of available water for forage or for the livestock, a source of erosion, or other soil disturbance.

Forest tree species fringing the range area have increased in size. In addition, new trees can be noted in the range area. An increase in the area occupied by forest trees causes a reduction in the area that produces forage. A determination such as this can be made simply by observing sequentially obtained photos, and can greatly benefit the manager in recommending needed range improvement.

Of equal importance is the observing of features which have not



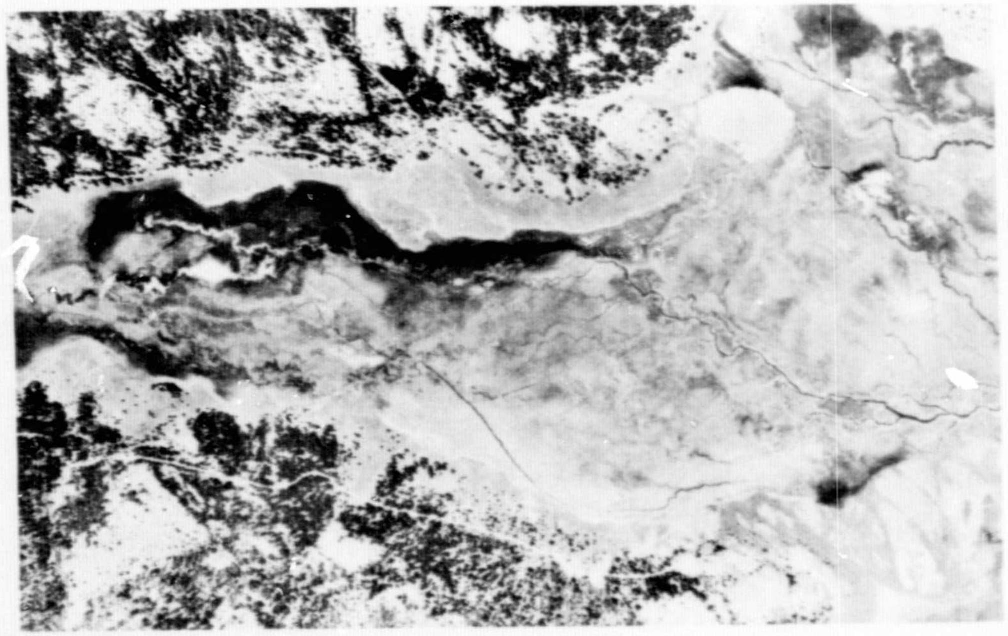
Panchromatic Photograph, September, 1944



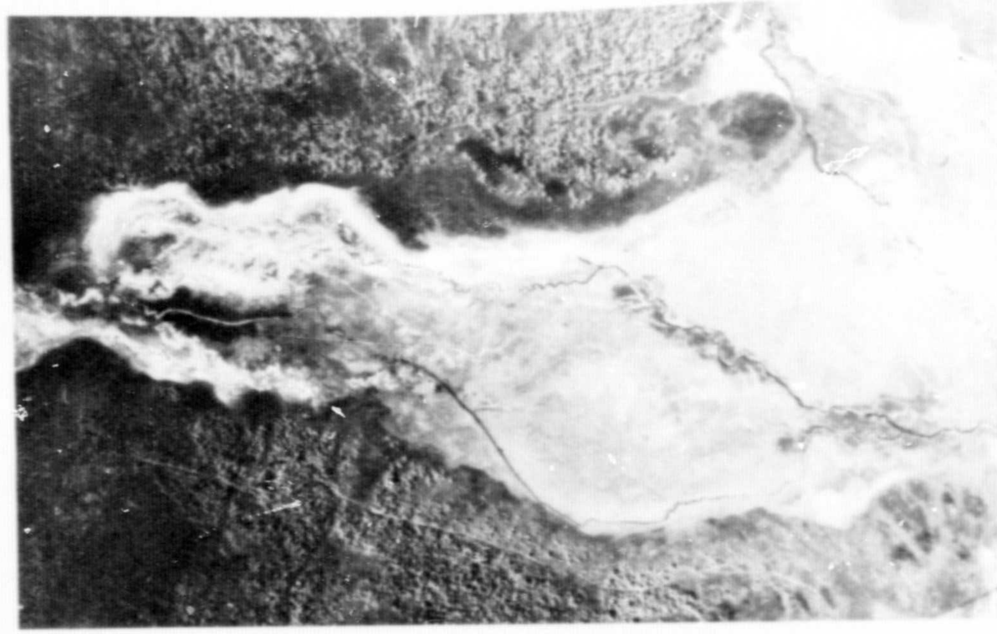
Panchromatic Photograph, September, 1968

Figure 10. Panchromatic aerial photographs, taken 24 years apart with the same type of camera (K-17, $8\frac{1}{4}$" lens) and at the same seasonal stage, illustrate the value of sequentially obtained photos for evaluating changes in forest and rangeland environments. As an example, the conspicuous dark-toned area at A appears to be a moist meadow site sustained by ground water from a spring or from the adjacent stream. This moisture condition no longer exists, as evidenced by the 1968 photo. The explanation for this may be the enchroachment and establishment of Big Sagebrush shrubs (Artemisia tridentata) which deplete soil moisture. Notice that the range site at B (1944 photo) does not appear to support Sagebrush plants; however, their presence is quite conspicuous on the 1968 photo. Also, the density of Sagebrush plants at C appears to have increased during the 24 year interval. Changes in the direction of stream channels are readily observed at D, which no doubt have caused a redistribution of available water in this range area. Riparian vegetation seen at E (1944) is no longer present in 1968; it was probably removed to conserve water. Spring water seeps along the stream bank at F are detected by the dense vegetation which appears dark in tone. These seeps have remained unchanged in number and location during the 24 year interval. Such springs could easily be developed to provide drinking water for stock. Finally, increase in growth, size and numbers of the timber species, ponderosa pine, along the fringe of the range at G often results in a lowering of forage production, hence monitoring such changes over time may be especially important to a manager concerned with maintenance of grazing capacity for domestic and wild animals.

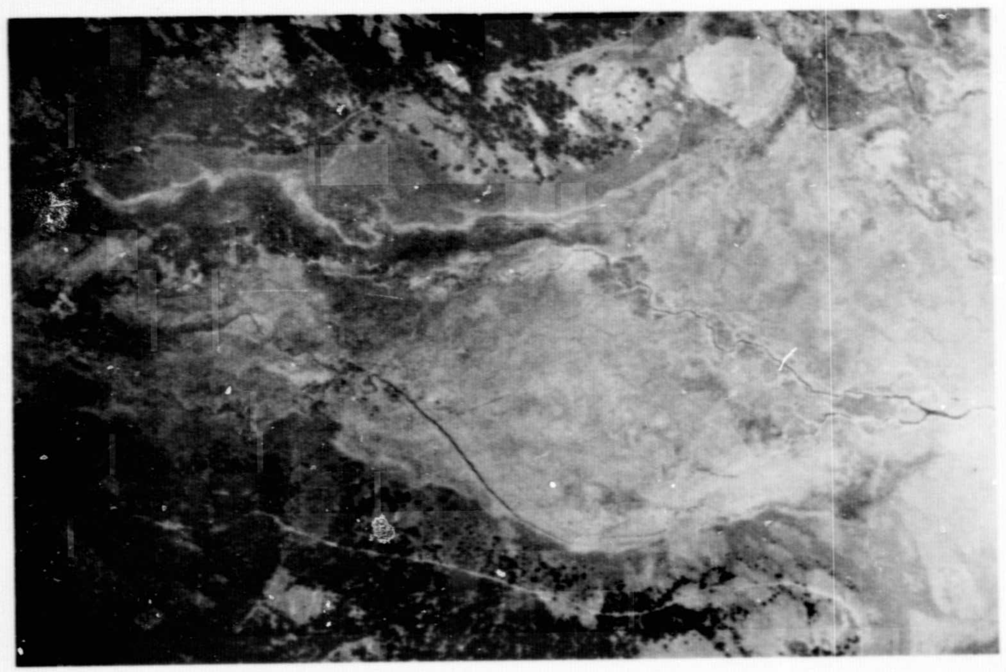
On the accompanying page are four photographs of this same range area taken in June, 1968. In order to complete the analysis of panchromatic photos discussed above, look in particular at the Plus-X Panchromatic photo taken in June, 1968. On this photo, note that the dense green meadow vegetation (area #2) appears dark in tone with smooth texture. Also, the Big sagebrush, which has invaded along the stream courses at 5, is not so readily differentiated from the adjacent grass and meadow vegetation types.



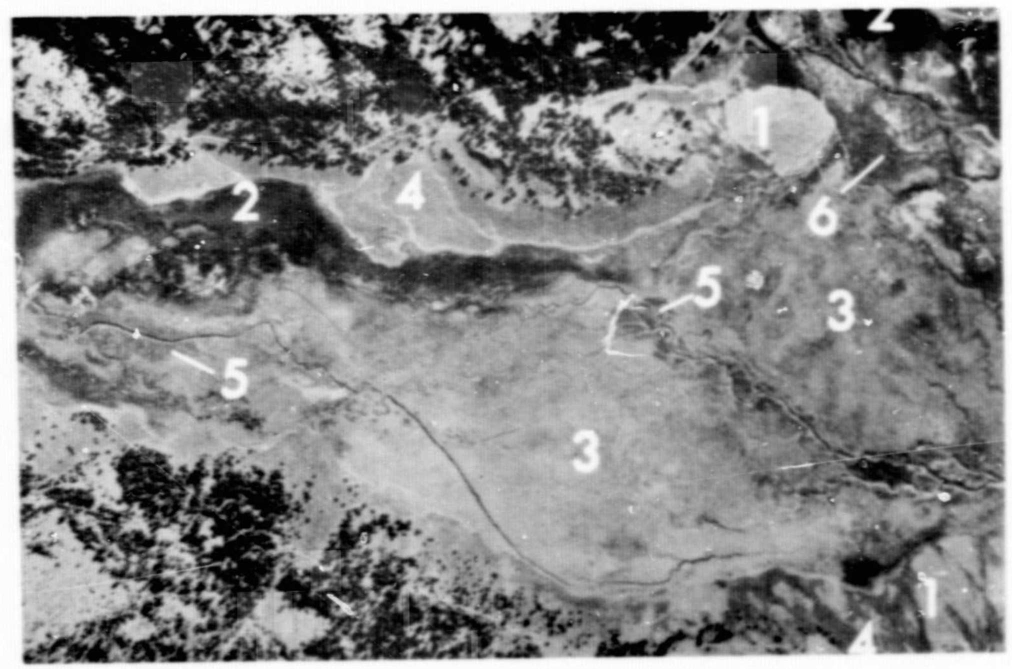
Plus-X Panchromatic (Wratten 12) June, 1968



Infrared Aerographic (Wratten 89B)



Ektachrome Aero photo



Ektachrome Infrared Aero (Wratten 12) June, 1968

Figure 11. Four film-filter combinations of Clover Valley range, provide the opportunity to assess the interpretability of each for the evaluation of range resources. The above photos were taken in June, 1968, at the seasonal stage judged to be most desirable for interpreting range features, based upon the results of similar studies conducted at the Harvey Valley Test Site, located 45 miles to the north. Again, the Ektachrome infrared film was judged the best film for determining vegetation health, differentiating vegetation types, and identifying soil, rock and moisture features. Significant features identified on these photos include: (1) unweathered basalt rock; (2) dense healthy meadow forage; (3) less dense grass and meadow vegetation, partially dry; (4) high density of Big sagebrush shrubs; (5) Big sagebrush shrubs which have become established since 1944; these are more difficult to see on the panchromatic photo; and (6) sagebrush site where shrubs have increased in density since 1944.

changed on sequentially obtained photos. For instance, natural springs (figure 10) are a source of moisture which sustains high producing meadow areas. These have changed but little during the 24 year period. Some springs also provide a season long supply of drinking water for livestock.

Thus sequentially obtained photos, although taken over a long interval provides a base for comparison of change in range conditions from one point in time to another. In the absence of better information, the photo record may be the only means for determining if the management or mismanagement of rangeland has caused a trend toward an improvement or deterioration of the range.

Comparison of Film-Filter Combinations:

We expected, on the basis of our experience working with different film-filter combinations at Harvey Valley Range Test Site, that color infrared photos taken in June would be more interpretable than either panchromatic, Infrared Aerographic, and Ektachrome Aero photos taken in June or panchromatic photos taken in September. Even so, all four film-filter combinations were obtained at Clover Valley in order to make direct comparisons of film types. The panchromatic photos taken in June provided the opportunity to make seasonal comparisons with the September, 1944 and September, 1968 photos previously discussed.

If one considers first the panchromatic photos taken in June, 1968 (see figure 11) he will note that the meadow can be identified by its characteristic dark tone, whereas on the September photos the meadow site is hardly distinguishable from other less productive sites adjacent to it. However, the established big sagebrush plants in the meadow are not so readily detected on the June panchromatic photos.

The Ektachrome Infrared Aero (color infrared) photo also taken in June, 1968 is a dramatic example for showing how much more information of value to the range man can be extracted from it than the other photos. On the color infrared photo (unlike the panchromatic photo taken at the same time), Big sagebrush communities are readily distinguished from the dense meadow types. The intensity of red tones gives an accurate clue to differences in the density and amount of forage in the meadow. The greenness and dryness of the forage is also accurately portrayed. As would have been expected, stream courses, with and without water, are readily seen and the encroachment of timber species and increases in their size are equally well exhibited.

These kinds of interpretations are valid not only for the scale of photographs illustrated (1/15,840)but all evidence suggests that the color infrared photos would be far superior to the other film-filter combinations at considerably smaller scales. By virtue of the strong color contrasts and unique color renditions, color infrared photos are best for differentiating between high and low density meadow types and between the meadow, sagebrush types, dry meadow sites, and exposed basalt rock within and adjacent to the range. The results of these interpretations add to and substantiate the findings on the Harvey Valley Range Test Site.

ANALYSIS OF REMOTE SENSING DATA, SAN PABLO RESERVOIR TEST SITE
(California Annual Grassland)

Description of Test Site:

The San Pablo Reservoir Test Site is located along the east side of the Berkeley Hills, just five to ten miles east of the Berkeley campus of the University of California. San Pablo Reservoir, for which the test site is named, is an artificial catchment for reserve water not utilized by the Municipal Water Utility District of the East Bay Area. Part of the watershed immediately adjacent to the reservoir has been planted with various tree species and these, along with the native trees and shrubs have provided an opportunity to investigate remote sensing applications for tree species identification (Lauer, 1967, 1968). For the most part, however, the foothill country surrounding the reservoir produces a new crop of annual grasses and forbs each year.

The "annual grassland type" is characterized by a dense cover of foliage from many different species of grass, forbs, and clovers. Since each year's crop must start from seed, the species composition will vary from year to year depending upon the amount of available seed (which is often governed by the intensity of grazing), the timing and amount of rainfall, and the temperature regime. Principal forage species on the highest producing sites include: Wild oats (*Avena fatua* and *A. barbata*); soft chess (*Bromus mollis*); ripgut brome (*B. rigidus*); annual ryegrass (*Lolium multiflora*); and wild barley (*Hordeum* sp.); while vegetation on the lower producing sites consists primarily of annual fescue, (*Festuca megalura*); filaree, (*Erodium botrys*); ripgut brome, (*B. rigidus*) and various clovers

(*Trifolium* sp. and *Medicago* sp.)

Each year (usually in October or November) the seeds of most of these species germinate after the first good fall rain. The new leaves of the annual grasses grow quickly to a length of three to five inches, but they do not grow much beyond that in December and January due to the cooler temperatures. With the warming temperatures in February and March the annual plants begin to grow rapidly. At this time the range appears nearly homogeneously green. By the end of March the early developing plants mature and begin to set seed, whereas the late maturing plants reach maturity in late April. Again, depending upon the species and the available moisture, the plants begin to dry in April and May. By late June nearly all of the forage plants have set seed and dried. Thus, during the summer, the range appears homogeneously dry until the rains bring out the new foliage in the late fall.

From year to year the amount of forage produced and the timing of the growth stages are regulated by the weather. Grazing of these ranges is usually yearlong. However, both cattle and sheep require supplemental feeding in late summer, throughout the fall, and early winter, when the crude protein content of the forage is very low.

From a remote sensing viewpoint the range is continually undergoing change in appearance, resulting from plant development and from grazing disturbances. Questions concerning (a) the resolution of imagery needed to study this range, (b) the time or season to obtain interpretable imagery and (c) the kind of information which can be extracted from the imagery to benefit the land manager, are the subjects of the research in this test site.

Remote Sensing Data Acquired:

June, 1965 (NASA-Houston Convair) (scale 1/10,000)

Plus-X Aerographic (Wr. 12)
Infrared Aerographic (Wr. 89B)
Ektachrome Aero
Ektachrome Infrared Aero (Wr. 12)

September, 1965 (NASA-Houston Convair) (scale 1/5000)

Ektachrome Aero
Ektachrome Infrared Aero (Wr. 12)

April, 1966 (Small aircraft-hand held cameras) (scale 1/15,000)

Plus-X Aerographic
Infrared Aerographic (Wr. 89B)
Kodachrome II
Ektachrome Infrared Aero (Wr. 12)

August, 1966 (Cartwright Aerial Surveys, Sacramento, Calif.) (scale 1/30,000)

Plus-X Aerographic (Wr. 12)
Infrared Aerographic (Wr. 89B)
Ektachrome Aero
Ektachrome Infrared Aero (Wr. 12)

August, 1967 (NASA-Houston Convair) (scale 1/30,000)

Ektachrome Infrared Aero (Wr. 12)

April 11, 1968 (Cartwright Aerial Surveys)

Bendix thermal infrared mapper; (imagery taken at 3:30 AM)

*Thermal infrared imagery (3.5 - 5.5 u)

May 1,2, 1968 (Cartwright Aerial Surveys, Sacramento, Calif.)

Zeiss RMK-A-15/23 mapping camera; f=6" (scale 1/40,000)

*Plus-X Aerographic (Wr. 12)
*Infrared Aerographic (Wr. 89B)
*Ektachrome Aero
*Ektachrome Infrared Aero (Wr. 12)

RC-9 Wild mapping camera; f=3¼" (scale 1/84,000)

Plus-X Aerographic
*Ektachrome Infrared Aero (Wr. 12)

May 27, 1968 (NASA-Houston, Mission 73, site 48)

RC-8 Wild mapping camera; f=6" (scale 1/35,000)

*Ektachrome Aero
*Ektachrome Infrared Aero (wr. 15)

Reconofax IV

*Thermal infrared imagery (8.0 - 14.0 u)

Ground Information Collected:

Field study of the annual range test site was conducted within the study site outlined by white ink on the small scale photo in figure 12. This study area was chosen for its diverse conditions, (e.g. upland and bottomland sites, north and southfacing slopes and aspect, different grazing systems - continuous and rotational, agricultural land, and water courses) its accessibility and proximity to the Forestry Remote Sensing Laboratory.

Ground information collected in this study area consisted of: (a) identifying the principal forage species by sites; (b) removing the forage from 3' x 3' plots to estimate quantity and height of the forage; (c) interviewing local ranchers to determine the timing and intensity of grazing and (d) digging soil pits to establish relationships between the depth of soil and the amount of forage produced. Ground photos were taken at frequent intervals throughout the 1968 growth season and during the overflights to document the changing appearance of the range.

* data illustrated in this report.

Comparison of Sequentially Obtained Film-Filter Combinations:

Ground photographs taken of the range vegetation in the study area at frequent intervals during the growth season appeared in the previous two annual reports (Carneggie, D. M., et. al., 1966, 1967). These photos demonstrate that during the winter and early spring the range appears nearly homogeneously green, whereas in the summer and fall the range appears nearly homogeneously dry (straw colored),--despite the fact that there are significant differences in species composition and forage production on different sites. During the period between late April and early May, however, the plants begin to mature and dry. (The exact time when this occurs is a function of the available moisture on the site.) Thus, it is at this season that the differences in the range sites are readily detected on remote sensing data.

The Ektachrome Infrared Aero photo in figure 12, and the film-filter combinations in figure 13 were taken on May 1 and 2, 1968, which for the 1968 growth season was nearly an optimum time for accurately differentiating site conditions. The many features of interest for preparing an inventory of this area are annotated on the photos in figure 13.

The color infrared photos were judged the most interpretable in terms of the number of accurate discriminations that could be made. These include: (a) differentiating upland from bottomland sites; (b) differentiating dry forage from green forage; (c) evaluating the intensity of grazing; (d) evaluate the quantity of forage, based upon the intensity of the color signature; (e) detecting sources of drinking water for livestock and (f) detecting relatively large areas occupied by noxious perennial plants such as thistle. The Ektachrome photo in figure 13 was overexposed and hence does not permit a fair comparison to be made between it and the color infrared photo.

A Wratten 15 filter was used when exposing the color infrared film on May 27. This made the green forage appear more yellowish red in rendition on the photograph. Initially this appears to be undesirable since we are concerned with differentiating the green forage from the dry forage, and the latter taken on a yellowish-straw color on the photos taken during the period of rapid vegetation change.

The bottom photos in figure 14, show the annual vegetation as it appears in late August--completely dry. Only the agricultural crops and the evergreen shrubs and trees are green. During this dry season there would be no advantage to using either of the two color films in place of panchromatic photos to map differences in the annual vegetation. Furthermore, photos of any kind taken during the dry season are very difficult to use in mapping vegetation types, because site differences within the annual grassland vegetation just are not readily discerned.

Sequentially obtained imagery of the annual grassland range could be very beneficial for: (a) determining the availability of green forage; (b) monitoring the rate of growth and development of the forage species; (c) evaluating environmental and site factors which influence forage production and (d) predicting the time when the forage will dry, based upon the rainfall patterns, and the rate of plant development.

If our attention is now directed back to the color infrared photos in figures 12 and 13, we will note that most of the interpretations made on the larger scale photo (1/40,000) are still readily made on the smaller scale photo (1/84,000). Consequently, on this kind of rangeland, lower ground resolution is adequate for the mapping of vegetation types, given the right kind of imagery, obtained at the right time of the year. The identifying of individual species is not as critical on an annual range, since composition of the vegetation will be different from year to year. Rather, the dominant kind of vegetation in a type, e.g. grass, forbs, or clover, becomes a more important consideration. This kind of information can be obtained from small scale color infrared photos.

Grazing is presently the primary use of the rangeland seen in the color infrared photo in figure 12. This rangeland, however, is bordered by intensive suburban development (not shown on the photo). Hence, there will be increased efforts in the next decade to surplant grazing animals with houses and recreational developments. Consequently there is an increased need for an accurate inventory of this rangeland for the purpose of maintaining the quality of the land, and for planning the development of the resources of this area consistent with the needs and welfare of the people.

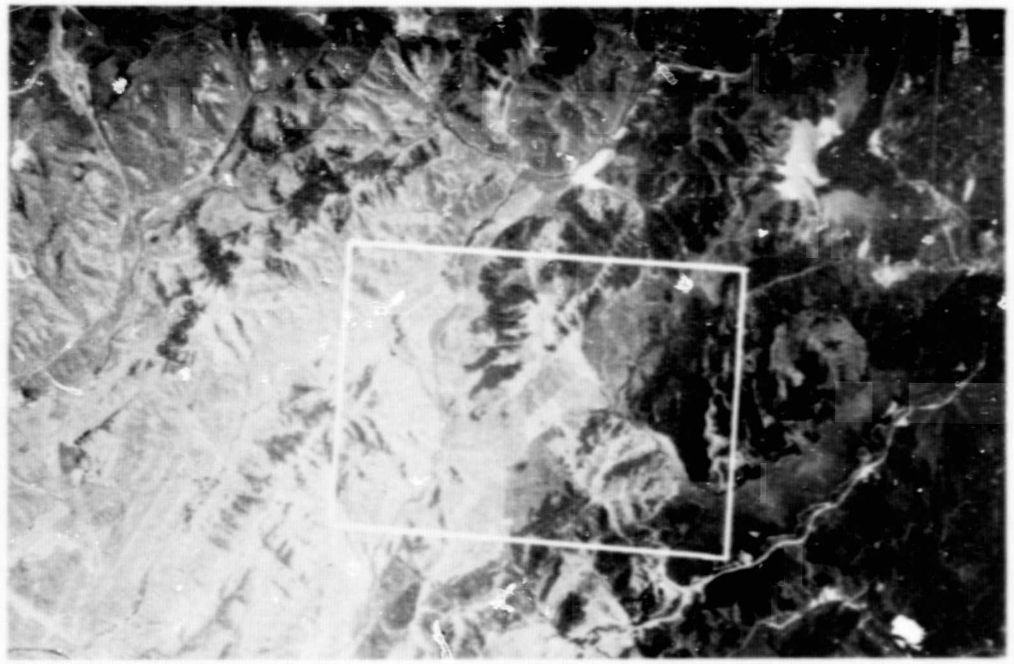
Line Scan Imagery of Annual Range:

The line scan imagery of range land analyzed for the San Pablo Reservoir test site consists of Bendix thermal infrared imagery (3.5 - 5.5 u taken at 3:30 A.M.) and Reconofax IV thermal infrared imagery taken at mid-day. By referring to figure 15 the reader can examine the thermal infrared imagery taken at night (early morning), on April 11, 1968. Roads, brushfields and water bodies are easy to pick out, but range site

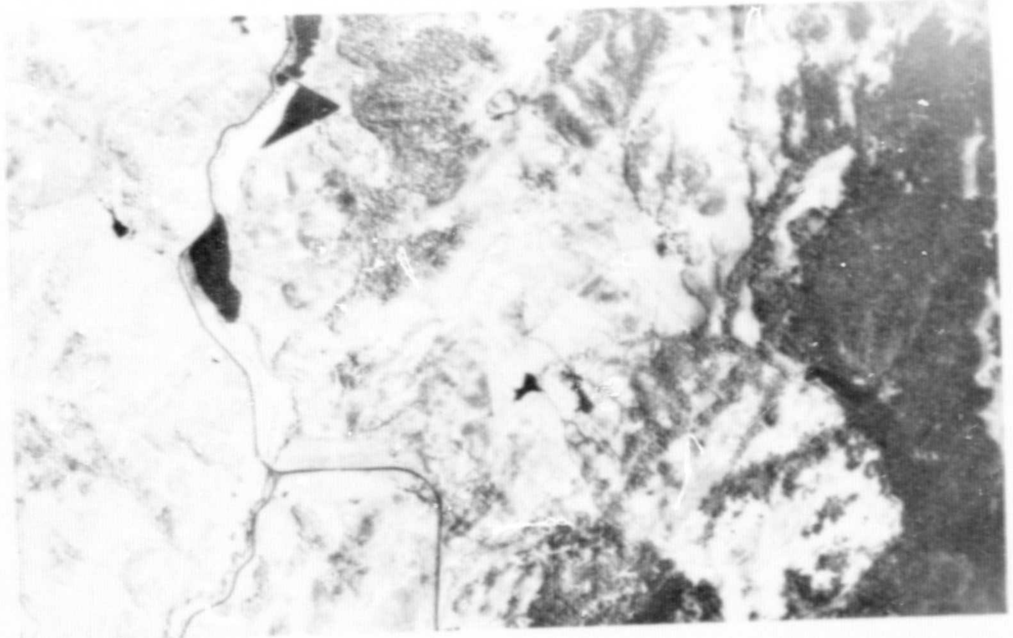
Figure 12. The small scale aerial photo (bottom right) shows a large portion of the San Pablo Reservoir Test Site, No. 48, located 5 miles east of Berkeley, Calif. This photo was take with a Wild RC-9 aerial mapping camera with a $3\frac{1}{4}$" lens on May 1, 1968, at the seasonal vegetation stage, judged from previous research in this area to be optimum for extracting information concerning amount of standing vegetation, vegetation health, i.e., greenness or dryness, and degree of livestock utilization. The area outlined in white is being investigated particularly to evaluate the range resources, and is seen at different seasonal stages in the following illustrations.

The bottom left photo shows a group of students who attended the University of California Extension Course on Remote Sensing (Sept., 1968) on site in the San Pablo study area, examining range and other related resources on the various kinds of photography and other imagery seen on the following pages. Note how dry the annual range vegetation is at this time of year.

Ground photo of California Annual range vegetation in typical undulating foothill country. Note upland sites beginning to dry. The vegetational stage photographed here normally occurs in late April or early May.

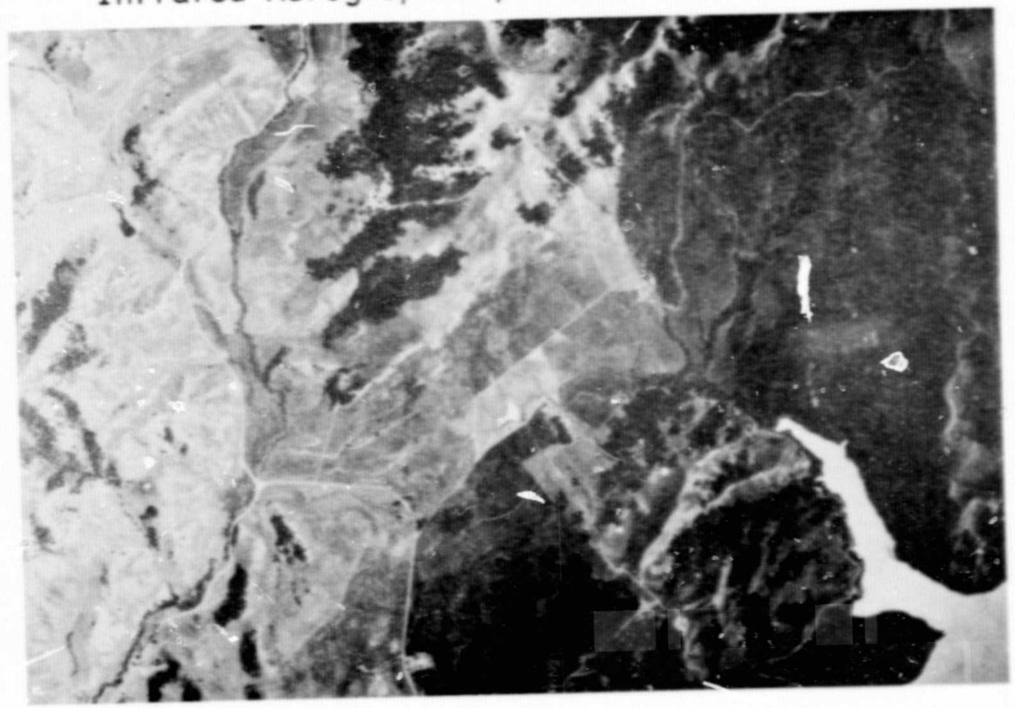


Plus-X Aerographic photo (Wratten 12)



Infrared Aerographic photo (Wratten 89B)

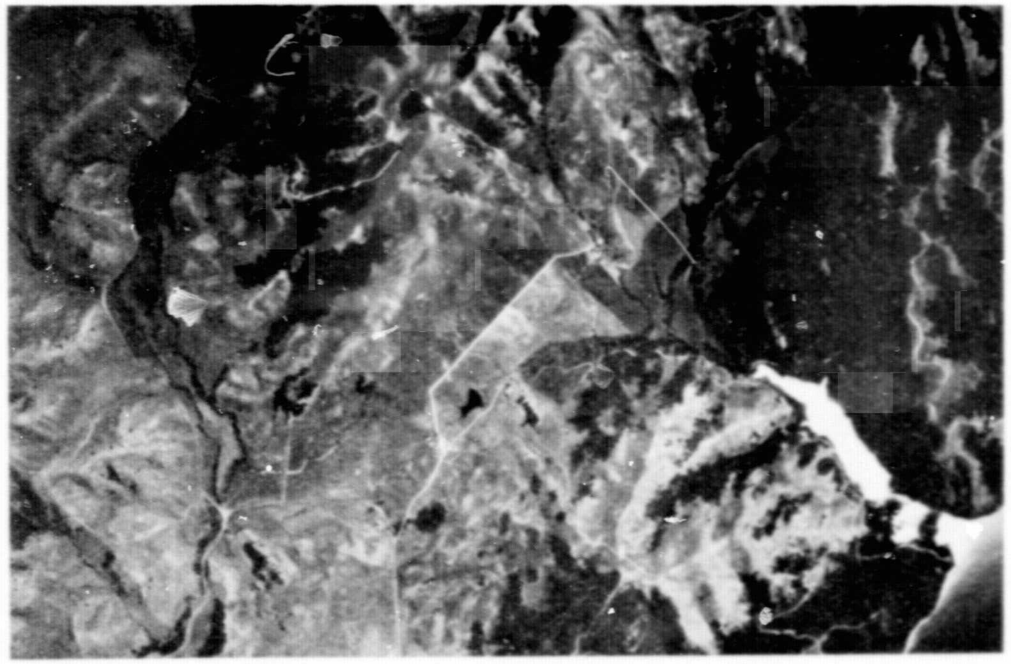
Ektachrome Aero photo



Ektachrome Infrared Aero photo (Wratten 12)

Figure 13. Aerial photos of California annual range vegetation in the San Pablo Reservoir Test Site. These photos (scale 1/44,000) were taken on May 1, 1968, with a Zeiss RMK-A-15/23 aerial mapping camera with a 6" lens, at the same time as the small scale Ektachrome infrared photo seen in figure 12. Compare the detail of range features seen on the color infrared photos at the two scales. Annotated features of interest for making a resource analysis of this area include: (1) dry forage on upland sites; (2) healthy forage on bottomland site; (3) bottomland pasture ungrazed; (4) pasture moderately grazed; (5) bottomland pasture heavily grazed; (6) dense healthy forage on a north-east facing ridge; (7) dry vegetation on a south-west facing ridge; and (8) dark alluvial soil recently cultivated.

Ektachrome Aero photo   May 27. 1968.



Ektachrome Infrared photo   (Wratten 15)

Ektachrome Aero (left) and Ektachrome Infrared Aero(right-with Wratten 12 filter). Late summer seasonal stage (August).

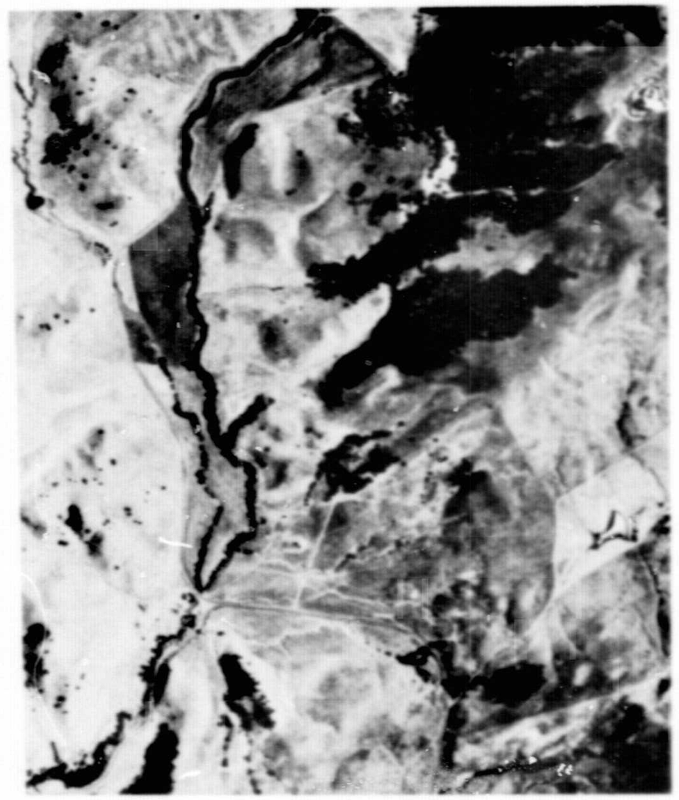
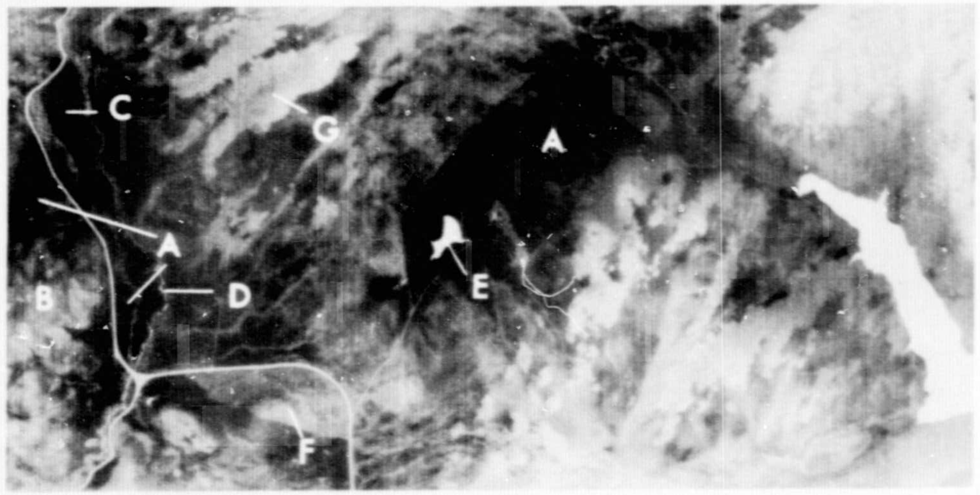


Figure 14. The top aerial photos were taken 26 days after the corresponding color and color infrared photos at the bottom of figure 13, using the same films (a different filter was used when exposing the color infrared film), but a different camera; in this figure the photos were taken with a Wild RC-8 mapping camera with a 6" lens. Observe the color changes which have occurred due to drying of the annual range vegetation. The bottom two photos show the annual range vegetation in late summer, when all of the annual vegetation has dried. Perennial shrubs and trees however, remain green at this seasonal stage.



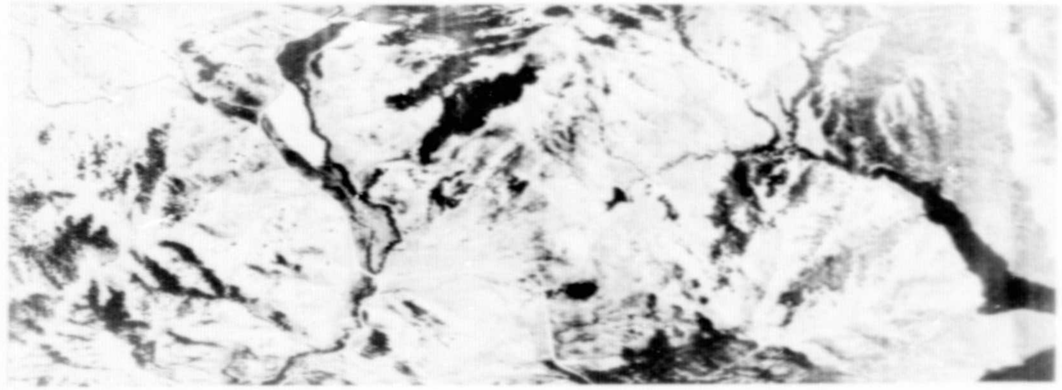


Figure 15. Two thermal infrared images of the annual range study area seen in figures 13 and 14. The left image was obtained at 3:30 A.M., April 11, 1968, using a Bendix thermal infrared mapper, which records emitted radiation in the 3.5 to 5.5 micron band. Annotated features include: (A) bottomland sites, characterized by deep soil and dense forage; (B) upland sites, characterized by shallow soil and relatively low forage production; (C) cultivated bottomland soil; (D) linear light toned feature is stream; (E) small reservoir; (F) light toned area was burned at the end of the previous growing season; (no visual difference between burned and unburned areas was apparent on color aerial photographs taken within a few days of the thermal image); (G) dense brush and scattered trees. The right image was taken at about noon, May 27, 1968, with a Reconofax IV thermal infrared sensor (records emitted radiation in the 8 to 14 micron band). Compare this thermal image with the two upper photos in figure 14, which were taken at the same time as the thermal image.

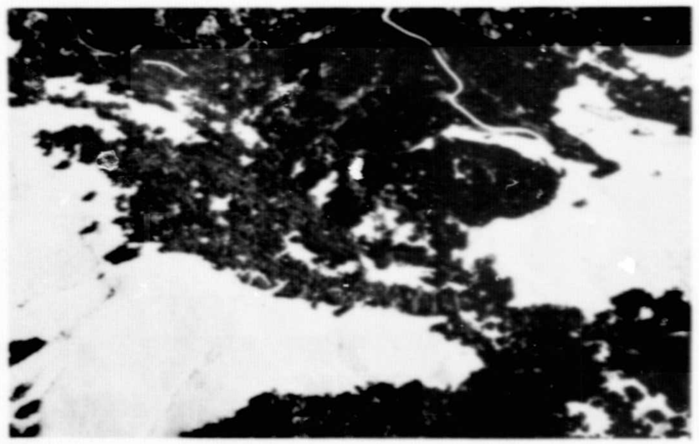


Figure 16. During the late summer season the dry annual range vegetation is highly combustible, creating hazardous fire conditions. The color and color infrared aerial oblique photos show a portion of a burned area in the annual range type. Sequentially obtained photographs of annual ranges can be used to assign fire hazard ratings to specific range areas, assess extent of burned areas, and monitor adverse (e.g. erosion) or advantagous (e.g. higher quality forage) effects of burning.

differences are not so readily seen. The low level of resolvable detail makes this imagery difficult to use in any practical range application except to show some general temperature relationships. For example, on April 11, when this imagery was obtained, the upland and bottomland sites looked about equally green; despite that fact there are considerable differences in the amount of forage produced on these sites. On the thermal infrared image it appears that there is a noticeable difference in the thermal pattern for these two different sites. The upland sites appear to be slightly warmer (i.e. lighter grey in tone), perhaps due to the aspect, the shorter and less dense forage, and the lower moisture holding capacity of the soil.

The Reconofax IV thermal infrared image in figure 15, looks almost like a panchromatic photo, but the light and dark tones correspond to relatively warm and cool objects respectively. The image was taken on May 27, 1968 at the same time as the two color photos in figure 14. By comparing the thermal image with the color photographs the reader can decide for himself whether there is any interpretative advantage to obtaining the thermal infrared image at this particular time of day. It is the opinion of the author that the color photos are far superior to thermal infrared images obtained at midday for discriminating range features, because they contain a much higher level of detail, and are readily rectified to serve as a mapping base. (Geometrical distortions of the thermal image make it undesirable for mapping purposes).

Thus, based upon the analysis of the two thermal infrared images, it would appear that the information derived from the thermal infrared portion of the spectrum may not be of much practical value to the range manager. Consideration should be given, however, to possible applications at a different season or at different times of the day. The imaging of animals at night, for example, is one possible application. However, this would require the obtaining of imagery at a very low altitude, which in foothill country at night could prove to be hazardous.

REMOTE SENSING APPLICATIONS FOR EVALUATING ECONOMIC MANAGEMENT PROBLEMS

Throughout the earlier sections dealing with analysis of remote sensing data, many applications of remote sensing for making inventories and assessing management problems were suggested based upon the detectability of various important range features. In this section we recognize some of the more important economic range problems which can be handled by means of remote sensing and suggest briefly various approaches to solving such problems by remote sensing techniques. The following applications are considered as solving economic range problems because they relate to (1) activities in the field of range management and research where federal, state, county and private agencies presently invest large sums of money, and (2) activities wherein judicious use of remote sensing can provide real benefits by rapidly collecting meaningful information to be used in finding solutions to the problems.

Inventory of Forage Types and Associated Soils:

Mapping vegetation and soil types is one of the most important tasks of a range inventory, and a good range inventory is almost always prerequisite to good range management. The use of aerial photographs, however, to prepare range inventories is not new. In fact, some of the earliest vegetation and soil maps made from aerial photographs date back to the 1930's. Standard mapping procedures generally call for using available panchromatic photos to delineate vegetation and soil boundaries which can be differentiated, in the office, and to check the accuracy of the mapping in the field.

On a typical photograph, the interpreter uses photo image characteristics such as tone, texture, pattern and shape or size of objects to draw boundaries which delineate homogeneous areas. In some instances an interpreter may be quite familiar with the area which he is mapping and he may do a creditable job of delineating the important range types in the office. However, the interpreter frequently is not familiar with the vegetation, soil and moisture conditions which he maps in the office; hence, he may need to spend a considerable amount of time in the field checking his work.

The time a man spends in the field can rapidly add up to a sizable proportion of the cost of preparing an inventory, especially if the interpreter has had to map from poor quality, outdated panchromatic photos. Considerable efficiency in time and in savings of dollars could be achieved in the standard procedure of preparing an inventory simply by procuring panchromatic photos flown to specifications of date and scale which enhance the interpretability of the vegetation and soil. By so doing, the job of mapping in the office could be facilitated and the increased efficiency in interpreting features could reduce the mapping time and the amount of subsequent field checking.

Still further efficiency in preparing inventories is possible by diverging from standard procedures and specifying that other film-filter combinations be obtained from which to map. Color films (Ektachrome and Ektachrome Infrared Aero) for example, are far superior to black-and-white photos for discriminating features. And the increase of information and the saving of interpretation time can more than offset the additional cost of color photos. Because color photos are more interpretable, they can be obtained at higher altitudes compared to black-and-white photos, and still yield the same information; hence, fewer exposures are required to obtain complete coverage of a given range area. This is a savings in itself.

The flight altitude to be specified (in order to obtain interpretable remote sensing data) depends upon the level of detail required and this, in turn, on the mapping intensity desired. Where only the most general categorization of native vegetation and soil types is required, color space photos, taken from orbital altitudes may be adequate as a mapping base. But if the level of detail needed for planning management activities is at the plant community level or individual species level, then it may be necessary to obtain imagery at altitudes of 40,000 feet down to 300 feet (assume f = 6") in order to get the desired image resolution for accurate mapping. As has already been suggested in this report, a multiple sampling procedure, whereby remote sensing data are gathered at two or more flight altitudes is the most likely technique for gathering information at different levels of detail.

Determining the Quantity of Forage:

Another very important task of the range manager is to determine the carrying capacity of the range, i.e., the number of animals that can be grazed, depending upon the amount of forage available. Since the forage crop varies in amount from season to season depending upon the weather and other factors, it would be beneficial to have sequential imagery to help evaluate the amount of available forage from season to season and within a season. The interpretation of remote sensing data alone, however cannot yield a determination of the amount of forage growing at any particular site. What the remote sensing data can do is discriminate sites which differ in amount of standing forage. A color infrared photo for example, provides a good record of vegetation types whereby the interpreter can discriminate forage density classes. For each forage density class, he can make an estimate of standing forage by ground sampling, and extend this information throughout the range area.

Estimates of the amount of forage (at the time remote sensing data are obtained) can also be made by estimating or measuring foliage cover from very large scale photos, and in turn, by correlating foliage cover estimates with amount of forage as determined from ground sampling. For ranges which characteristically have sparse vegetation, it would be necessary to have higher image resolution to discriminate forage density and foliage cover classes, than for ranges characterized by dense forage vegetation.

Determining the Kind, Quality and Health of Forage:

Information concerning the kind, quality and health of forage, combined with estimates of forage quantity is the basis for determining carrying capacity of the range. When we speak of the "kind" of forage we refer to the species that are found in the plant communities that occupy range sites. Also implied is the "quality" of the forage which refers to the nutrient content of the plants and factors which affect palatability of the forage, e.g., coarseness of leaves, hardness or softness, presence or absence of thorns, etc. Plant health refers to the greenness or dryness of the forage, its vigor in relation to its age, decadency, etc.

In order to make evaluations of "kind" and "quality" of forage by remote sensing, one requires detailed imagery. Remote sensing data cannot give us information directly on the nutrient content of plants nor their palatability, but often just knowledge of the plant species on the range is the best clue to determining this information. This being the case, the data needed would have to be of sufficient high resolution that an interpreter could identify or discriminate amongst species by tone or color signature. Optimum techniques for identifying individual species in mixed stands have been suggested by the interpretation of very large scale photos (scale 1/600). But even so, some field checking may be needed to distinguish among similarly appearing species that are difficult to discriminate. If a plant of a certain species is growing in a nearly pure stand, relatively smaller scale imagery could be used to detect and identify the species.

The health of a stand of forage can also be evaluated on small scale imagery. For example, the dryness or greenness of annual range vegetation was readily determined on color infrared photos having a scale of 1/84,000. However, if we are concerned with determining the health of a single plant such as a shrub, large scale imagery, preferably obtained with color infrared film, is again needed. For this type of image analysis, just as for mapping, we need to specify the scale and the type of imagery, depending upon the level of detail needed and the spectral characteristics of the features of interest.

Detecting Poisonous and Noxious Plants:

In this application, the requirement may consist of locating either single plants that may be scattered over a wide area, or groups of plants concentrated on small areas irregularly distributed over an extensive range area. In the former case, we need a sensor system that can either discriminate the particular plant on the basis of its spectral signature or that provides sufficient ground resolution to permit plant identification by morphological characteristics. On subsample areas we would want to know by remote sensing if the poisonous or noxious plant was present or absent. In the latter case, a lower resolution system could be employed as long as the group of plants could be recognized by a unique tone or color signature. Small scale photographs, for example, of specified film-filter combinations may cover quite an area and prove useful for showing the distribution of groups of poisonous or noxious plants. Once plants are located , control measures could be planned to remove their threat to grazing animals.

Noxious plants are ones which may occupy space but provide little or no forage value, or plants which have parts that are injurious to an animal. Sagebrush plants, for example, occupy space and provide little forage for cattle. Removal of such plants from an area and seeding the area to palatable forage species can increase the carrying capacity of the range. Again, remote sensing systems can provide a record from which detection and identification of the unwanted plants can be made and, again, the procurement specifications depend upon the size and distribution of the plants, and their respective spectral signatures.

Detecting Insect and Disease Problems:

Insect and disease problems can be thought of on a scale which ranges from defoliation of single plants to locust infestations of entire range areas. In each instance we must consider the level of detail which will be most suitable for evaluating the cause and extent of the damage. If, through remote sensing, we can achieve early detection of an impending problem, considerable money can be saved in terms of the size of the control measures which must be taken and the value of the forage saved by early control.

The key, then, to determining whether an insect or disease problem exists and, hence, to evaluating the extent of the problem by means of remote sensing, lies in our ability to detect loss of vigor in plants as caused by pathogens or insects. Use of infrared sensitive film (color infrared in particular) provides the best opportunity for detecting defoliation or other evidence of a loss of vigor. Hence, when photos of this kind are obtained sequentially and at appropriate scale it is possible to monitor the extent of insect or disease problems, using only a limited amount of direct on-the-ground observation. Likewise, one can use infrared sensitive film to evaluate the success of planned defoliation, as in the case of applying herbicides to eradicate certain undesirable plants.

Assessing Degree of Range Utilization:

Assessing the degree of forage utilization involves a determination of the amount of forage that has been removed by grazing animals. However, the absolute amount of forage unutilized at any given time is ultimately what the range man needs to know so that he does not allow a range area to be overgrazed to the point of killing the forage species. Interpretation of the remote sensing data alone does not provide this information. Instead, the remote sensing data provides a record whereby differences in the degrees of utilization can be detected by interpretation and estimates of the amount of utilization can be made from ground sampling.

From an analysis of the color infrared photos of the annual grassland range it was possible to discriminate range units which had been heavily, moderately and lightly grazed (as well as units that had not been grazed) by virtue of their characteristic signatures on the infrared photos. This would be expected because removal of the forage by grazing reduces the amount of foliage surface area and, consequently, the amount of infrared reflectance from the area. Also, as expected, we were able to detect differences in the amount of grazing use from interpreting very large scale photographs. At very large scales it is virtually possible to see which plants have been grazed and which have not.

Assessing Soil Erodability:

Soil erosion in any form is usually an indication of disturbance caused by mismanagement or lack of management. Overgrazing, for example, can reduce the number and size of plants below what is needed to stabilize the soil, resulting in surface erosion. Erosion, resulting in a loss of top soil, is a loss not only to the forage resource but adversely affects recreation, wildlife and water values as well. Gross examples of erosion have been identified from interpretation of space photos, but for the most part higher image resolution will be needed to adequately monitor soil surface conditions. Both color and color infrared photos at scales ranging from 1/600 to 1/80,000 have been useful for evaluating different degrees of soil instability. Sequentially obtained imagery can be very useful for determining trends either toward soil stability or toward increased damage resulting from increased soil instability.

Assessing Rodent Activity and Damage:

If rodent populations are allowed to build up, the rodents will actively compete with grazing animals for the foliage and seeds of forage species. Furthermore, the disturbance caused by borrowing can be a source of soil erosion and instability. Hence, the early detection and monitoring of these rodent populations in remote areas of a range can lead to prompt control measures. Very large scale photographs, both color and color infrared, have proved valuable for detecting rodent activity.

Assessing Burning Practices and Hazardous Fire Conditions:

In some ranges of the world the excess forage is burned annually in order to maintain a certain species composition and to improve the quality of the new forage crop. Indiscriminate burning, however, may not always be desirable if a favored forage species is not fire tolerant. In such range areas, small scale imagery could be used effectively in planning burning programs. The near infrared absorbing properties of charcoal make infrared sensitive films particularly well suited for detecting the extent of a recent burn (see Figure 16).

In addition, remote sensing data can be used to assess the fire hazard on rangeland where burning could threaten structures or other valuable resources. This kind of evaluation is best made on sequential imagery, on which the amount of forage in an area and the degree of utilization that it receives are the key factors in determining the amount of fuel present. Infrared sensitive photos (color infrared) provide a good opportunity to make these kinds of interpretations, especially just before the forage dries. Once the forage is dry the amount of dry residual forage is difficult to determine.

SUMMARY AND RECOMMENDATIONS

This report recognizes two categories of information which the range manager needs in order to effectively perform his management responsibilities. These are (1) the making of a Range Resource Inventory and (2) the assessing of Management Problems.

In earlier sections of this report we discuss the results of our analysis of various kinds of remote sensing data, pointing out how meaningful information can be extracted from the data when the changing characteristics of the range resources and image procurement specifications are taken into account. These results are listed in the section under RESEARCH FINDINGS.

One of the most important considerations governing the interpretability of rangeland imagery is the season when the imagery is procured. For many ranges the critical period for obtaining highly interpretable imagery may last only a week or two, and this period occurs at different times of the year depending upon the characteristics of the range. The optimum period in one geographic area, such as the annual grassland at San Pablo Reservoir, differ from that in another, such as the perennial grassland range at Harvey Valley. This uniqueness of the optimum period probably applies also from state to state, country to country and hemisphere to hemisphere.

Management of the forage resource is one of the prime responsibilities of the range manager. Remote sensing imagery that emphasizes the various species of plants and contrasts them with their associated features, will be most useful to him as a management tool. Photographic systems which use either color infrared photographs or multispectral black-and-white photos filtered for green, red and near infrared sensitivity, presently are of greatest value to the range manager. Certain other systems, including vidicon devices and optical mechanical scanners also can sense in the visible and near infrared spectral bands, but usually provide poorer spatial resolution.

Most of the range applications of remote sensing require moderate to high image resolution such as that obtained at conventional aircraft altitudes and at scales ranging from 1/600 to 1/100,000. However, broad vegetation mapping can be done even on low resolution imagery (e.g., 100 ft.) of the type offered by space photos. The accuracy of detecting, identifying and evaluating features from low resolution imagery can be improved by employing a double sampling procedure. In this procedure high resolution imagery is obtained of representative sample areas. The data thus obtained give detailed information regarding the resources in a small area. Findings thus obtained can be extended to other analogous areas as determined by interpreting imagery of lower resolution.

This report would not be complete if it did not discuss the very important questions, 'Who is going to use information derived from remote sensing data?", and "How will the information be used?" Throughout this report we have stipulated that it was the "range manager" who needed and could use the information. But if we critically consider the average ranch manager, we might find that there is very little information that he could afford to collect by means of remote sensing that he could not otherwise obtain by his normal daily or weekly on-the-ground inspection of his rangeland. If, however, we consider as "range managers" those charged with the wise management of large tracts of public land (as, for example, certain Forest Service or Bureau of Land Management personnel) we find the major potential users of remote sensing techniques and applications as discussed in this report. In order to maximize the usefulness of remote sensing, however, continuing research efforts are needed to discover additional remote sensing applications and additional users in the field of range management.

Special emphasis is given in this report to those types of information, derivable through remote sensing, that can provide real benefits in terms of time and dollars saved compared to other techniques for obtaining the same information. Such applications are discussed in the section entitled, REMOTE SENSING APPLICATIONS FOR ECONOMIC MANAGEMENT PROBLEMS.

REFERENCES: Remote Sensing Techniques Applied to Studies of Vegetation (from 1967 Annual Report)

Aldrich, R.C. 1966. Forestry applications of 70mm color. Photogrammetric Engineering 32(5):802-810.

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

Barnes Engineering Co. 1965. Theory, application and instrumentation for infrared non-destructive testing. 30 Commerce Rd., Stamford, Conn.

Becking, R.W. 1959. Forestry applications of aerial color photography. Photogrammetric Engineering 25:559-565.

Carneggie, D.M. and Lauer, D.T. 1966. Uses of multiband remote sensing in forest and range inventory. Photogrammetria 21:115-141.

Carneggie, D.M., Roberts, E.H. and Colwell, R.N. 1966. The use of high altitude, color and spectrozonal imagery for the evaluation of wildland resources: Volume II The Range Resource. Annual Progress Report for National Aeronautics & Space Administration.

Choats, 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.

Claveran A., Ramon. 1966. Two modifications to the vegetation photographic charting method. Journal of Range Management Vol. 19(6): 371-373.

Clouston, J.G. 1950. The use of aerial photographs in range inventory work on the National Forests. Photogrammetric Engin. 16(3):329-331.

Colwell, R.N. 1961. Aerial photographs show range conditions. California Agriculture Volume 15(12).

Colwell, R.N. 1963. Aerial photography benefits agriculture. Agric. Research in the Space Age. Proceedings of 12th Annual Meeting of Agricultural Research Institute. National Academy of Science, NRC.

Colwell, R.N. et al. 1963. Basic matter and energy relationships involved in remote reconnaissance. Photogrammetric Engineering 29(5):761-799.

Colwell, R.N. 1964. Uses of aerial photography for livestock inventories. Proceedings of 13th meeting, Agr. Res. Institute.

Colwell, R.N. and Olson, D.L. 1964. Thermal infrared imagery and its use in vegetation analysis by remote aerial reconnaissance. Proc. 3rd Symposium on Remote Sensing of Environment. Univ. of Michigan.

Colwell, R.N. 1966. Uses and limitations of multispectral remote sensing. Proc. 4th Symposium on Remote Sensing of Environment. University of Michigan.

Colwell, R.N. 1966. Aerial photography of the earth's surface; its procurement and use. Applied Optics Volume 5(6):883-892.

Committee on Geography, Advisory to the Office of Naval Research Division of Earth Sciences. 1966. Spacecraft in geographic research. National Research Council, National Academy of Sciences, Washington, D.C.

Cooper, C.F. and Smith, F.M. 1966. Color aerial photography: toy or tool? Journal of Forestry 64(6):373-378.

Dudzinski, M. L. and Arnold, G.W. 1967 Aerial photography and statistical analysis for studying behavior patterns of grazing animals. Jour. of Range Mgt. 20(2):77-83.

Eastman Kodak Company. 1962. Kodak wratten filters for scientific and technical use. Rochester, New York.

Finley, V.P. 1959. Photo interpretation of vegetation. A literature survey and analysis to determine the capabilities of existing photo interpretation techniques of evaluating physical properties of vegetation. Report by U. S. Army Snow, Ice & Permafrost Research, Corps of Eng.

Fritz, N. L. 1967. Optimum methods for using infrared-sensitive color film. Paper presented at 33rd Annual Meeting of the Amer. Soc. of Photogrammetry in Washington, D.C.

Frost, R. E. 1953. Factors limiting the use of aerial photographs for analysis of soil and terrain. Photogram. Eng. 19(3):427-436.

Gates, D.M. 1964. Characteristics of soil and vegetated surfaces to reflected and emitted radiation. Proc. of 3rd Sym. of Remote Sensing of Environment. University of Michigan.

Harris, R. W. 1951. Use of aerial photographs and sub-sampling in range inventories. Jour. of Range Mgt. 4(4):270-278.

Heller, R.C., Doverspike, G.E. and Aldrich, R.C. 1964. Identification of tree species on large scale panchromatic and color aerial photographs. Agriculture Handbook No. 261. U.S. Forest Service.

Hoffer, R.M. and Miller, L. D. 1965. Potential applications of remote multispectral sensing in agriculture. 30th Semi-annual convention of the American Society of Photogrammetry. Dayton, Ohio.

Holter, M. R. 1967. Infrared and multispectral sensing. BioScience 17(6):376-383.

Kollmorgen, W.M. and Simonett, D.S. 1965. Grazing operations in the Flint Hills bluestem pastures of Chase Co., Kansas. Annals Assoc. Amer. Geog. 55:260-290.

Laboratory for Agricultural Remote Sensing 1967. Remote multispectral sensing in Agriculture. Research Bulletin No. 832. Purdue Univ. Agr. Expt. Station. Lafayette, Indiana.

Lyons, E.H. 1966. Fixed air-base 70mm photography, a new tool for forest sampling. The Forestry Chronicle 42(4):420-431.

Moore, R.K. 1966. Radar as a sensor. CRES Report No. 61-7 University of Kansas Center For Research Inc. Eng. Sci.Div. Lawrence, Kan.

Moore, R.K. and Simonett, D.S. 1967. Radar remote sensing in biology. BioScience 17(6):384-390.

Morain, S.A. and Simonett, D.S. 1966. Vegetation analysis with radar imagery. CRES Report No. 61-9. Presented at 4th Sym. on Remote Sensing of Environment. University of Michigan.

Morain, S.A. 1967. Field studies on vegetation at Horsefly Mountain, Oregon and its relation to radar imagery. CRES Report No. 61-22 University of Kansas.

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.

Nicholson, I. A. and Hughes, R. 1963. A method for the characterization of range type vegetation. Jour. of Range Mgt. 16(6):293-299.

Olson, C.E., Jr. 1960. Elements of photographic interpretation common to several sensors. Photogrammetric Eng. 26:651-656.

Olson, D.P. 1964. The use of aerial photographs in studies of marsh vegetation. Maine Agric. Expt. Station Bulletin 13.

Paijmans, K. 1966 Typing of tropical vegetation by aerial photographs and field sampling in Northern Papua. Photogrammetria 21:1-25.

Park, B.C. 1955. Use of photo mosaics as a base for range resource inventory in the Hashemite Kingdom of the Jordon. Jour. of Range Mgt. 8(6):257-260.

Reid, E.H., and Pickford, G.D. 1944. An appraisal of range survey methods. Jour. of Forestry 42:471-479.

Schulte, O.W. 1951. The use of panchromatic, infrared and color photography in the study of plant distribution. Photogrammetric Eng. 17:688-714.

Soil Conservation Service, USDA. 1966. Aerial-photo interpretation in classifying and mapping soils. Agriculture Handbook 294.

Steiner, D. 1965. Use of air photographs for interpreting and mapping rural land use in the United States. Photogrammetria 20:65-80.

Strandberg, C.H. and Lukerman, C. 1963. Development of livestock and crop survey technique--phase I. Vidya Report No. 118.

Tarkington, R. G. and Sorem, A. L. 1963. Color and false color films for aerial photography. Photogram. Eng. 29:88-95.

U. S. Army Corps of Engineers. 1967. Earth resource surveys from spacecraft. Volumes I and II. Prepared for Earth Resources Survey Program, Space Applications Program Office, NASA.

Welch, R. 1966. A comparison of aerial films in the study of the Breidamerkur Glacier area, Iceland. The Photogrammetric Record. Volume V(28):289-306.

Wickens, G.E. 1966. The practical application of aerial photography for ecological surveys in the savanna regions of Africa. Photogrammetria 21:33-44.

Willow Run Laboratories. 1966. Peaceful uses of earth-observation spacecraft. Volume II: Surveys of Applications and Benefits. Institute of Science and Technology, University of Michigan.

ADDITIONAL REFERENCES FOR 1968 ANNUAL REPORT

Agricultural Research Service, U.S.D.A. 1967. Spectral sensing in agriculture, NASA Contract R-09-038-002. Fruit, Vegetable, Soil and Water Research Laboratory, Weslaco, Texas.

Aldred, A.H. and F.W. Kippin. Plot volume from large-scale 70 mm air photographs, 1967. Forest Science 13, 419.

Avery, G. and C.B. Serna 1965-1966. Photo interpretation keys for identifying vegetation. Proc. Soc. AM. For. 159-162

Badgley, P.C., Colvocoresses, A.P. and C.D. Centers, 1968. NASA earth-sensing space experiment. Photogrammetric Engineering 34 (2): 162-167.

Benson, M.L. and W.G. Sims, 1967. False-color film fails in practice. Journal of Forestry Vol. 65, No. 12: 904.

Carneggie, D.M., Poulton, C.E. and E.H. Roberts, 1967. The evaluation of rangeland resources by means of multispectral imagery. Annual Report for Earth Resources Program, Office of Space Sciences and Applications, NASA pp. 76.

Carneggie, D.M. 1968. Interpretation of color photography for range management. Manual of Color Aerial Photography, Amer. Society of Photogrammetry. pp. 409.

Carneggie, D.M. 1968. Applying remote sensing technology for improving range resource inventories. Proceedings of the Fifth Symposium on Remote Sensing of Environment. The Univ. of Michigan, pp. 373-385.

Carneggie, D.M., and J.N. Reppert, 1969. L -scale 70mm aerial color photography--a potential tool for ..oving range resource inventories. Photogram. Eng. Vol. 35(3) March.

Center for Aerial Photographic Studies. 1967. Potential benefits to be derived from applications of remote sensing of agricultural, forest and range resources. Cornell University, Ithaca, New York.

Colwell, R.N. 1968. Determining the usefulness of space photography for natural resource inventory. Proceedings of 5th Sym. on Remote Sensing of Environment. Univ. of Mich. pp. 249-289

Colwell, R.N. 1968. Remote sensing of natural resources. Scientific American, Vol. 218(1):54-69

Croon, G., D.R. McCullough, C.E. Olson and L.M. Queal. 1969. Infrared scanning techniques for big game censusing. Jour. Wildlife Mgt. Vol. 32(4):751-759.

Culver, R.N. and C.E. Poulton. 1968. Application of ecology and remote sensing in the analysis of range watersheds. Range Mgt. Program. Oregon State University, Corvallis, Ore.

Dalke, G.W. and J.E. Estes. Multi-image correlation systems study for MGI. Final Report, CRES, Univ. of Kansas, Lawrence, Kan.

Draeger, W.C. 1968. The interpretability of high altitude multispectral imagery for the evaluation of wildland resources. Annual Report for Earth Resources Survey Program, OSSA/NASA by School of Forestry & Conservation, Univ. of Calif. Berkeley.

Driscoll, R.S. and J.N. Reppert. 1968. The identification and quantification of plant species, communities and other resource features in herbland and shrubland evnironments from large scale aerial photography. Annual Report for Earth Resources Survey Program, OSSA/NASA, Rocky Mt. Forest & Range Expt. Sta., Ft. Collins, Colorado.

Dudzinski, M.L. 1968. Scanning of aerial photographs for animal grazing patterns, amount and quality of available plant material. Problems in Picture Interpretation. Proceedings of a Workshop held at CSIRO Div. of Computing Research in Canberra, Australia. pp. 130-132.

Falkner, E.H. 1960. Applying photogrammetry to range allotment planning. Photogrammetric Engineering. Vol. 26 pp. 672.

Fritz, N.L. 1967. Optimum methods for using infrared-sensitive color films. Photogrammetric Engineering. Vol. 33(10):1128-1138.

Haefner, H. 1967. Airphoto interpretation of rural land use in western Europe. Photogrammetria 22(4):143-152.

Heller, R.C., et al. 1967. A test with large-scale aerial photographs to sample balsam wooly aphid damage in the northeast. Jour. of Forestry 65(1):10-18.

Huddleston, H.F. and E.H. Roberts. 1968. Use of remote sensing for livestock inventories. Proceedings of 5th Symposium on Remote Sensing of Environment. University of Michigan, Ann Arbor.

Kippen, F.W. and Sayn-Wittgenstein, L. 1964. Tree measurements on large-scale vertical, 70mm air photographs. Dept. of Forestry, Canada. Forest Research Branch. Pub. No. 1053.

Laboratory for Agricultural Remote Sensing. 1968. Remote multispectral sensing in agriculture. Research Bull. No. 844. Vol. 3. Annual Report of Purdue Univ. Ag. Expt. Sta., Lafayette, Indiana.

Lauer, D.T. 1967. The feasibility of identifying forest species and delineating major timber types by means of high altitude multispectral imagery. Annual Report for Natural Resources Program, OSSA/NASA, by School of Forestry, University of California, Berkeley.

Lauer, D.T. 1968. Forest species identification and timber type delineation on multispectral photography. Annual Report for Earth Resources Survey Program, OSSA/NASA by School of Forestry & Conservation. University of California, Berkeley.

Lent, J.D. 1968. The feasibility of identifying wildland resources through the analysis of digitally recorded remote sensing data. Annual Report for Earth Resources Survey Program, OSSA/NASA, by School of Forestry and Conservation, Univ. of Calif., Berkeley.

Lent, J.D. and G.A. Thorley. 1968. Some observations on the use of multiband spectral reconnaissance for the inventory of wildland resources. Paper submitted for publication in Remote Sensing Journal Vol. 1(1).

Lord, T.M. and A. McLean. 1969. Aerial photo interpretation on British Columbia rangelands. Jour. of Forestry. Vol 22(1):3-9.

Lyons, E.H. 1967. Forest sampling with 70mm fixed air base photography from helicopters. Photogrammetria. Vol. 22(6):213-231.

Meyer, M.P. and E.J. Woolfolk. Anthill infestation. Photogrammetric Eng. Vol.33(11):1247-1249.

Morain, S.A. and D.S. Simonett. 1967. K-band radar in vegetation mapping--discrimination studies of pine, fir and hardwood forests, juniper woodland, sagebrush, chaparral, grassland. Photogram. Eng. Vol. 22:730-740.

Myers, V.I. and W.A. Allen. 1968. Electro-optical remote sensing methods as nondestructive testing and measuring techniques in agriculture. Applied Optics. Vol 7(9):1819-1838.

Parker, B.S. and E.C. Slater. 1968. Applications of photographic techniques to wildlife research problems. Problems in Picture Interpretation. Proceedings of a Workshop held at CSIRO Division of Computing Research in Canberra, Australia. pp. 134-140.

Poulton, C.E. and R. Culver. 1967. Application of ecology and remote sensing in the analysis of range watersheds. Progress Report Summary. Ore. Agric. Expt. Sta., Oregon State U., Corvallis, Ore.

Poulton, C.E. 1968. Applications and potential of remote sensing in the analysis of range resources. Remote Sensing of the Environment: a two-week course sponsored by Eng. & Phys. Sci. Ext., Univ. of Calif., Los Angeles.

Poulton, C.E., B.J. Schrumpf . ' E. Garcia-Moya. 1968. The feasibility of inventorying native egetation and related resources from space photography. Annual Report for Earth Resources Survey Program, OSSA/NASA, by Dept. of Range Mgt., Oregon State Univ., Corvallis, Ore.

Reid, E.H., G.D. Pickford and N. T. Nelson. 1942. An appraisal of range survey methods from the standpoint of effective range management. Pacific Northwest Forest & Range Expt. Sta., Range Res. Rept. No. 2.

Sayn-Wittgenstein, L. 1961. Phenological aids to species identification on air photographs. Dept. of Forestry, Canada, Forest Research Branch. Tech. Note 104.

Sayn-Wittgenstein, L., and A.H. Aldred. 1967. Tree volumes from large scale photos. Photogram. Eng. Vol. 33(1):69-73.

Stellingwerf, D.A. 1968. Practical applications of aerial photographs in forestry and other vegetation studies. Pub. of International Inst. for Aerial Survey and Earth Sciences (ITC) Series B No. 46. Delft, the Netherlands.

Weber, F.P. and C.E. Olson. 1967. Remote sensing implications of changes in physiologic structure and function of tree seedlings under moisture stress. Scientific and Tech. Aerospace Rept., NASA.

Wieslander, A.E. 1942. Classifying forest and other vegetation from air photographs. Photogram. Eng. Vol. 8:203.

Wobber, J.F. 1968. Orbital photography: applied earth survey tool. Photographic Applications in Science, Technology and Medicine.

Yost, E.F. and S. Wenderoth. 1967. Multispectral color aerial photography. Photogram. Eng. 33(9):1020-1033.

REFERENCES: Range Resources (from 1967 Annual Report)

Agricultural Statistics. 1966. U. S. Department of Agriculture U. S. Printing Office, Washington, D.C.

Bruins, H. W. 1966. Getting essent'al protein to hungry people around the world. Proc. 15th Annual Meeting of Agricultural Research Institute. National Research Council, National Academy of Sciences.

Byerly, T.C. 1966. The relation of animal agriculture to world food shortages. Proc. 15th Annual Meeting of the Agricultural Research Institute. National Research Council, National Academy of Sciences.

Cox, M. L. 1966. Animal agriculture in Latin America--present status and possibilities for expansion. Proc. 15th Annual Meeting of Agricultural Research Institute. National Research Council, National Academy of Science.

Guidry, N. P. 1964. A graphic summary of world agriculture USDA Misc. Pub. 705.

Humphrey, R.R. 1963. Arizona natural vegetation. University of Arizona Bulletin A-45 (map) Ag. Expt. Sta. & Coop. Ext. Ser. Tuscon, Arizona.

Konnerup, N.M. 1966. The outlook for animal agriculture in Africa. Proc. 15th Annual Meeting of Agricultural Research Institute. National Research Council, National Academy of Science.

Kuchler, A.W. 1964. Potential natural vegetation of the conterminous United States. American Geographical Society. Spec. Pub. No. 36.

Moore, W.E. 1964. Distribution of grasslands. Chapter 11 Grasses and Grasslands. Edited by C. Barnard. Macmillan & Co. LTD. London

Peterson, R.A. 1966. The training needs of grassland workers in developing countries. Proc. of 10th International Grassland Congress. Helsinki, Finland.

Pool, R.J. 1948. Marching with the grasses. University of Nebraska Press. Lincoln, Nebraska.

Shantz, H.L. 1954. The place of grasslands in the earth's cover of vegetation. Ecology 35(2):143-145.

Shantz, H.L. and Zon, R. 1924. Natural vegetation; grassland and desert shrub. USDA Government Printing Office, Washington, D.C.

Sprague, H.B. 1952. Importance of grazing lands in the agricultural economy. Jour of Range Mgt. Vol. 5:266-270.

Thomas, G.W. and Ronningen, T.S. 1965. Rangelands-our billion acre resource. Agricultural Science Review Vol. 3 No. 4. Cooperative State Research Service, USDA, Washington, D.C. pp. 11-17.

The Times Atlas of the World. 1958. Edited by John Bartholemew. Times Publishing Co. LTD. Printing House Square, London, Volume I.

U. S. Census of Agriculture 1959. Farms and land in farms. Vol. II, Chapter 1 U.S. Government Printing Office, Washington, D.C.

Wahlen, F.T. 1952. Grassland resources and potentials of the world. Proc. of the 6th International Grassland Congress. Vol. 1:103-113.

ADDITIONAL REFERENCES FOR 1968 ANNUAL REPORT

Arnold, J.F. 1955. Plant Life-form Classification and its Use in Evaluating Range Conditions and Trends, 1955. Journal of Range Management Vol. 8 No. 4: 176-181.

Condon, R.W. 1968. Estimating of Grazing Capacity on Arid Grazing Lands, pp. 112-124. CSIRO Symposium August, 1968, Land Evaluation. Organized in cooperation with UNESCO. Macmillan of Australia.

Heyligers, P.C. 1968. Quantification of Vegetation Structure on Vertical Aerial Photographs. CSIRO Symposium, August 1968, Land Evaluation, organized in cooperation with UNESCO. Macmillan of Australia.

Julander, Odell 1955. Determining Grazing Use by Cow-Chip Counts, 1955. Journal of Range Management. Vol. 8 No. 4: 182.

U.S.D.A., 1968. Major Uses of Land and Water in the United States with Special reference to Agriculture; Summary for 1964. U.S.D.A., Economic Research Service, Agricultural Economic Report No. 149. 1968.

Williams, R.E., Allred, B.W., Denio, R.M. and H.A. Paulsen, Jr. 1968. Conservation, Development, and Use of the World's Rangelands. Journal of Range Management. Vol. 21, pp. 355-360.