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
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

REMOTE SENSING APPLICATIONS IN FORESTRY

THE INTERPRETABILITY OF HIGH ALTITUDE MULTISPECTRAL IMAGERY FOR THE EVALUATION OF WILDLAND RESOURCES

By

William C. Draeger

School of Forestry and Conservation
University of California

Annual Progress Report — 30 September, 1968

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
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ABSTRACT

This research has as its goal the determination of optimum image specifications for the procurement of useful inventory and survey data relevant to wildland resource management. Particular emphasis is placed on very small-scale imagery as can be expected from very high-flying aircraft and/or earth-orbital vehicles. Included in this report are (1) an investigation of optimum spectral bands for the discrimination of various important wildland features, (2) a determination of optimum time of day for obtaining thermograms from which to quantify subsurface soil moisture, and (3) an investigation of the feasibility of determining gross timber volumes on intermediate scale (approx. 1/30,000) aerial photography.

In addition, preliminary studies pertaining to the detection of wildland water pollutants and the determination of the potential for converting non-forested areas to timber-producing types are discussed. Also included is a photo-interpretation key to the wildland terrain features of the NASA Bucks Lake Test Site.

ACKNOWLEDGMENTS

This research was performed under sponsorship of the National Aeronautics and Space Administration for the Earth Resources Survey Program in Agriculture/Forestry by personnel of the School of Forestry and Conservation, University of California.

Presentation of the material contained herein has been possible through the cooperation of a number of individuals and organizations. Among the students and staff of the University of California who rendered vital service in research and preparation of particular sections of the report were Edwin H. Roberts, John W. Thomas, Jr., and William T. Lynam. Much of the collection of ground data and interpretation of aerial imagery was performed by Michael Gialdini, Joseph Berry and Andrew Benson.

Acknowledgment is also given to Cartwright Aerial Surveys, Inc., Sacramento, California for procurement of aerial imagery, to Mr. Fred Stang of Barnes Engineering Co., for assistance in reduction of thermal infrared data, and to Berkeley Commercial Photo Co., Berkeley, California, for the photo reproduction of illustrations used in this report.

TABLE OF CONTENTS

THE INTERPRETABILITY OF HIGH ALTITUDE MULTISPECTRAL IMAGERY FOR THE EVALUATION OF WILDLAND RESOURCES

by

William C. Draeger

INTRODUCTION

The initial step in management planning for any wildland area is that of obtaining an accurate inventory of the resources, present or potential. This often necessitates the procurement of suitable aerial imagery at a scale and resolution which will permit the trained interpreter to identify, delineate and, if appropriate, to describe quantitatively the terrain features of importance to the land manager in the decision-making process. Until recently, the common procedure was to obtain panchromatic minus-blue photography at a scale of from 1/10,000 to 1/20,000 for such photo interpretation. Such conventional photography has indeed proved to be entirely satisfactory for a multitude of purposes. Among the tasks that have been performed quite regularly on conventional aerial photography are the development of maps of stratified vegetation types, with information as to timber volumes, species composition, stand structure or animal carrying capacity; the mapping of soil and geologic resources; the determination of existing and potential access systems; the delineation and evaluation of watersheds; and the estimation of recreation potential.

However, the procurement of conventional aerial photography of vast tracts of wildland is a very expensive and time consuming process. Furthermore, there has been a steadily increasing need for more intensive evaluations of wildlands that previously were either not photographed or, at best, were only partially covered. Consequently, research is needed to develop more efficient systems to procure imagery of wildland areas and to extract meaningful data from that imagery.

This research effort is designed to investigate the feasibility of evaluating wildland resources on high altitude multispectral imagery. Jensen and Colwell (1949) demonstrated that in certain cases a greater number of terrain features could be discerned when panchromatic and infrared photography were interpreted in unison than when either one of the two types of photography were interpreted alone. This concept of using two or more film types or sensors in conjunction, thus utilizing radiation in several portions of the electromagnetic spectrum simultaneously, has been termed, "multiband spectral reconnaissance". Terrain features which exhibit similar tone or signal values on sensors sensitive to wide portions of the spectrum (such as standard panchromatic film) may vary significantly in their reflection or emission characteristics in various narrow portions of the spectrum. Therefore, the use of several different narrow spectral bands in the sensing processes will often allow such terrain types to be discriminated. One objective of this study has been to determine the particular spectral bands or combinations of bands which would most readily facilitate the identification of a number of terrain features of interest to a wildland manager; a related objective has been to demonstrate methods that might best be used in specifying the optimum imagery system for any particular array of terrain features.

The choice of the appropriate spectral bands to be used does not completely solve the problems encountered in attempting to evaluate these resources in vast wildland areas. It has been estimated that it would require more than 15 million aerial photos to provide stereo coverage at the conventional scale of 1/20,000 of the 34 million square miles of forest and grassland on the earth. However, it would require only eleven thousand 9" by 9" photos at a scale of 1/750,000 taken from an earth orbital vehicle to provide coverage of the same area. In this regard, the present study has investigated the spatial resolution which such orbital systems would have to provide if meaningful interpretation were to be made of such imagery for wildland management purposes.

The material is presented in a number of sections, each of which focuses on a particular specification problem. In a section dealing with the optimum spectral bands to be used for discrimination of particular natural features, a preliminary analysis of 18-channel multispectral imagery is included. Similarly, a study is included which involves spectral reflection measurements that were taken of brush types in order to more accurately understand reflection phenomena affecting the choice of optimum spectral bands for particular applications. Also reported is an investigation underway concerned with the detection of several types of "natural" water pollutants occurring in the wildland environment.

Work is currently being performed using both simulated and actual satellite photographs which will attempt to ascertain the degree to which broad type mapping can be performed on very small scale photography (scale 1:100,000 and smaller). Due to the low ground resolution of such imagery, however, the acquisition of detailed quantitative data pertaining to the environment will probably best be obtained through sampling procedures utilizing intermediate scale images. An example of the use of such intermediate scale photography for the estimation of gross timber volume is discussed in some detail in the body of this report.

Another specification parameter often overlooked in many cases is that of optimum timing of acquisition of imagery. Two sections which follow, one concerned with the evaluation of snow retention characteristics of wildland vegetation types, and the other with the determination of soil moisture content using thermal infrared imagery, illustrate the time-critical nature of specific imagery requirements.

Finally, while it is true that proper image specifications are essential for the extraction of the maximum amount of data from an image, equally important is the method of data extraction. It is recognized that the human photo interpreter will continue to play a vital role in this data extraction process and that his effectiveness can be improved by equipping him with certain photo interpretation aids.

The Feasibility of Determining Gross Timber Volumes on Small Scale Photography

1. Objective

A number of procedures for estimating timber volumes of forest stands using aerial photography have been developed and tested in recent years; however, nearly all such methods involve height measurements which would be nearly impossible to perform on small-scale, high-altitude photography such as would be obtained from orbiting vehicles. A study was initiated, therefore, to investigate the feasibility of classifying timber stands into at least broad volume-per-acre classes on the basis of photo parameters which could be measured or estimated on small-scale imagery.

2. Procedure

Through earlier investigations (Draeger, 1967) it had been found that two characteristics of a forest stand that can be quantified on small-scale non-stereo photography, and that are related to timber volume are percent crown closure (the percentage of the total ground area of the stand that is obscured by crowns of commercial species when viewed from vertically above), and average crown diameter. A portion of the Bucks Lake Test Site, including a wide range of timber types and densities, was delineated on Ektachrome Infrared Aero photography, scale 1:30,000. A total of 20 such stands, covering a total a area of approximately 5000 acres were selected for study. Each stand was cruised by a field crew and timber volume estimates were made from their ground measurements. Over 250 cruise plots were established within the test area by the field crew and volume determined using Bitterlich variable-plot procedures and volume tables compiled for the region by the U. S. Forest Service. The same stands were independently classified by trained photo interpreters on the basis of crown closure and average crown diameter. Both of these photo parameters were estimated by means of visual comparison of the stands in question with aerial photo examples (at the same scale as the imagery being interpreted) of stands for which closure and crown diameter were known.

Correlation coefficients of the photo parameters with the ground estimates were calculated and regression estimation coefficients were obtained.

3. Results

It was found that using an independent variable consisting of percent crown closure multiplied by average crown diameter, a correlation of .916 (significant at the .01 level), existed between this variable and the dependent variable; namely, timber volume in board feet per acre as measured by the conventional ground survey methods. These results were based on the sample of twenty stands discussed above (see Figures 2 and 3). Based on the same data, regression estimation coefficients were calculated using a least-squares line fitted to the data. The prediction equation thus calculated was:

$$\text{Av. Vol/Acre (bd. ft.)} = 2117 + (30.45)(\%\ \text{Crown Closure} \times \text{Av. Crown Dia.})$$

Figure 1. A portion of the Bucks Lake Test Site, delineated on the basis of crown closure percent and average crown diameter. The twenty classes cover a total of approximately 5000 acres. More than 250 ground plots were measured by a field crew, using Bitterlich variable-plot procedures.

Stand Designation	Average Volume Per Acre (bd.ft.)	Crown Closure of Commercial Conifers,%	Average Crown Diameter, feet
A	11,000	25	12
B	5,000	5	20
C	700	2	15
D	8,000	15	12
E	14,000	15	25
F	8,000	4	18
G	7,000	10	25
H	19,000	20	25
I	17,000	25	15
J	16,000	15	25
K	1,500	3	30
L	16,000	20	25
M	14,000	15	25
N	20,000	20	30
P	13,000	20	17
R	2,500	3	12
T	14,000	25	20
U	14,000	15	20
V	9,000	10	15
W	10,000	15	25

Figure 2. Tabulation of the results of the photo interpretation estimates of crown closure and crown diameter and the independent on-the-ground survey of average volume per acre of the twenty stands delineated in Figure 1.

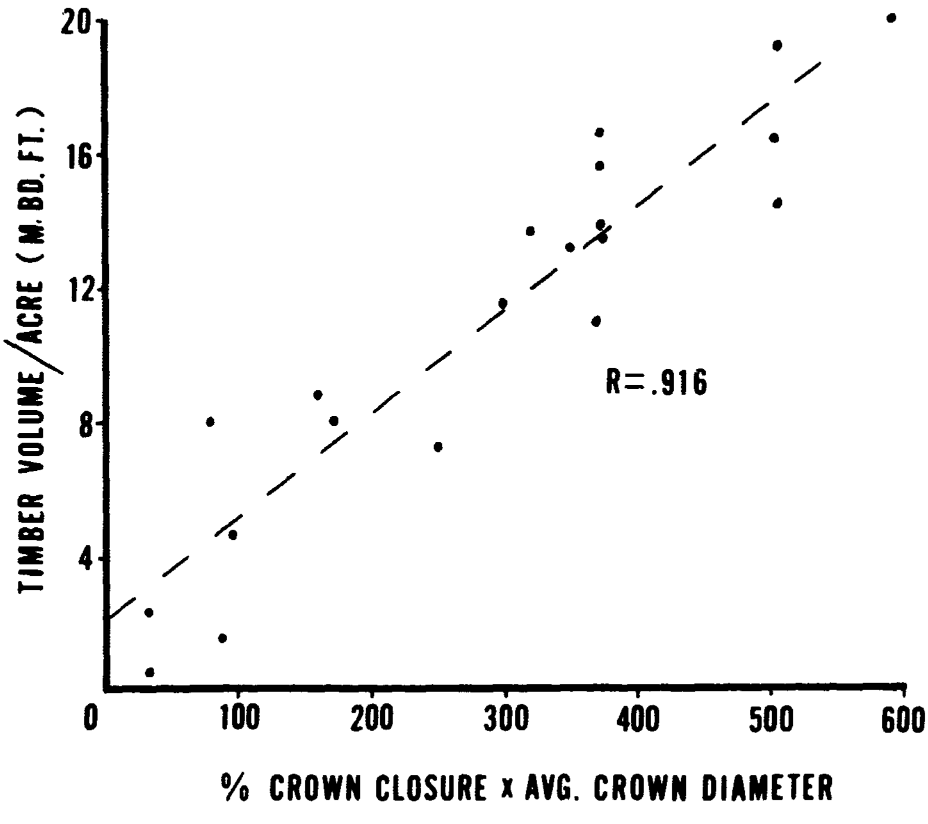


Figure 3. A plot of the data tabulated in Figure 2 and the least-squares line fitted to the data. For discussion, see text.

4. Conclusions

To many forest photogrammetrists it would seem impossible to obtain highly accurate estimates of timber volume from small scale imagery through a process whereby stand height is ignored. However, an examination of the results of this experiment indicates that it is indeed feasible to classify forest stands into broad volume classes using such methods. The classifications may be quite valuable in two respects: (1) regional policy decisions often necessitate a knowledge of general patterns of timber volume distribution over fairly large areas, and (2) more intensive volume estimation sampling procedures are made much more easily and accurately if the area in question can first be stratified on the basis of broad volume categories.

Thermal Infrared Sensing of Subsurface Soil Moisture Differences

1. Objective

The principal objective of this study was to determine the utility of thermal infrared imagery utilizing the 8 to 14 micron range of the electromagnetic spectrum for differentiating various degrees of subsurface soil moisture content through the radiant energy fluctuations of a diurnal cycle. A determination of soil moisture is often useful in ascertaining such information as suitability of agricultural areas for planting, the need for irrigation, the ability of a range area to withstand trampling damage associated with intensive grazing, or the potential of a wildland area to support specific vegetative communities.

2. Experimental Procedure

The target array consisted of 16 wooden boxes, each 36" x 36" x 8", aligned 150 feet below a water tower camera station. Each group of four trays received equal amounts of a specific soil type. The four soils, as seen from left to right in Figure 1, are Davis Sandy Loam, Cornutt Sandy Loam, Black Meadow Loam and Yosemite Sand. Three of these soils were transported to the water tower site in Davis, California, from previously investigated areas. The Davis Sandy Loam came from alongside the test array beneath the tower, the Cornutt Sandy Loam from a peridotite rock area near Bucks Lake, Plumas Co., California, the Black Meadow Loam from a rich alluvial soil in Meadow Valley, also in Plumas Co., and the Yosemite Sand from a sandbar of the Merced River in Yosemite National Park.

The moisture treatments were applied to the various soils from one to three days prior to sensing. One tray of each soil was left to air-dry, the others were sprinkled or soaked. The soaked soils varied in their moisture content by the time sensing began, since one soaking was given three days before September 13 and the other, one day before. Sprinkling of the soils was also done one day before, on the 12th. No re-applications of water were made after the test began, but it was found that moisture content remained relatively constant throughout the experiment. Within each group, different amounts of water were added to the various soil trays. Figure 2 indicates the arrangement of the soils in the target array and gives percent soil moisture by weight of each plot from readings taken at noon on September 14.

A Barnes Infrared Camera, with an immersed thermistor bolometer detector operating in the 8 to 14 micron wavelength region of the electromagnetic spectrum, was used at a near vertical angle from a camera station that was 150 feet above the soil targets. This was done to obtain thermographic images which would closely simulate those obtainable from an aircraft, but with the advantages of (1) much lower cost and (2) precise duplication of both the camera station and of camera orientation with respect to the target array on all sequential imagery. The imagery was obtained at intervals of approximately 20 minutes, both day and night, for a period of three days.

A completed thermogram as obtained in these experiments is actually a measure of the infrared radiation received from the surface of the object sensed. This is a function of both the temperature of the object and its emissivity. The result is a thermal map of the target surface which looks very much like a photograph. On positive prints, <u>white</u> areas represent high thermal emission, <u>black</u> its absence, and shades of gray show emission levels between the two pre-selected extremes. Attenuation settings on the Barnes Infrared Camera were varied depending on the time of day. During daylight hours, there were greater temperature differences between

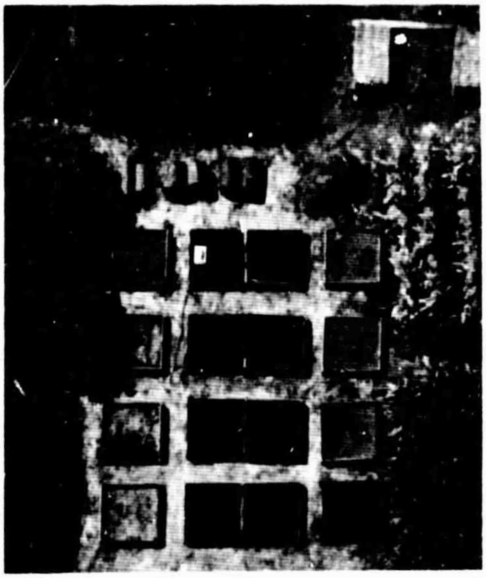


Figure 1. Ektachrome photograph showing the soil moisture target array as seen from the catwalk of the water tower.

Davis Sandy Loam	Cornutt Sandy Loam	Black Meadow Loam	Yosemite Sand
Air Dry 3.2	Sprinkled 1 day prev. 10.4	Soaked 1 day prev. 37.0	Soaked 3 days prev. 3.8
Sprinkled 1 day prev. 7.1	Soaked 1 day prev. 19.6	Soaked 3 days prev. 32.6	Air Dry 3.4
Soaked 1 day prev. 16.2	Soaked 3 days prev. 16.2	Air Dry 8.6	Sprinkled 1 day prev. 4.0
Soaked 3 days prev. 9.2	Air Dry 4.1	Sprinkled 1 day prev. 19.5	Soaked 1 day prev. 9.6

Figure 2. Diagram of the target array indicating soil type, the treatment applied to each plot, and the soil moisture percent as measured during the period in which imagery was obtained.

Figure 3. Ground view of the target array, including the soil moisture plots as well as agricultural crops and goniometric targets, which were the subject of additional experiments.

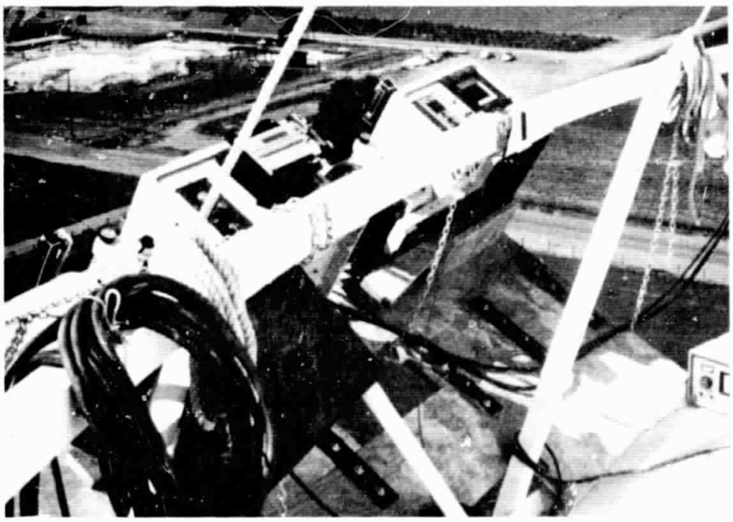


Figure 4. Two Barnes thermal infrared cameras, with sensitivity in the 3.5 to 5.5 and 8 to 14 micron bands respectively, in place on the catwalk of the tower, 150 feet vertically above the targer array.

Figure 5. An aerial view illustrating the target array and the water tower, with the thermal infrared cameras in place on the catwalk.

the soil targets. This demanded camera attenuation settings which would sense a broader emission range. At night, however, the temperatures were nearly the same between all soil targets and a more critical attenuation setting was used to enhance the differences. The result of broad (day-time) and narrow (night-time) attenuation settings can be seen in Figure 6. Notice on the thermograms made during the day that more detail can be discerned among the various soil moisture plots, and that these differences diminish or fade as thermography is taken later at night. The least distinction between soil plots appears in the imagery taken around 7:00 a.m. on the 14th and 15th. The targets had cooled progressively through the previous night until their temperature responses by morning were nearly alike. At the time of this thermography, the targets had not yet been exposed to the solar radiation of the subsequent day and were still expressing a "cold" return. After only a few hours of sunlight, though, their emittance rates changed considerably and they began to express distinctive radiation responses.

The camera was used in a fixed-mount in order to obtain repetitive thermography with the same axis orientation, and to allow it to be used later for additive-color enhancement studies. The total monitoring time span amounted to over 60 hours, from before sun-up to past midnight, on September 13 through 15, 1967.

A Barnes Engineering Precision Radiation Thermometer (PRT-5) was employed on the ground coincident with the taking of each thermogram to record the apparent surface temperature of the soil plots. Further surface temperature recordings were made with the contact probe of a Yellow Springs Instrument Company tele-thermometer. This double check

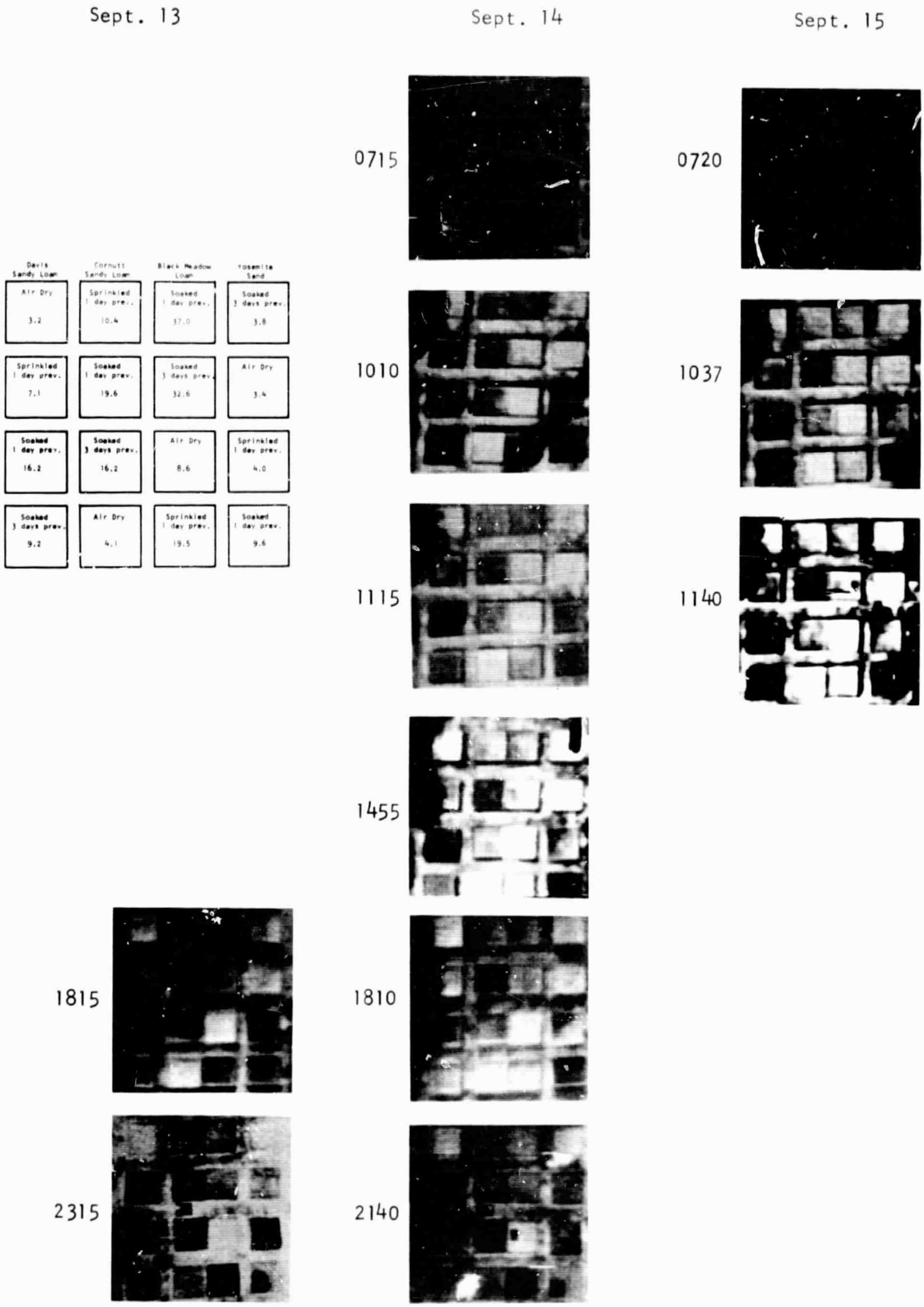


Figure 6. A sequence of thermograms taken through two diurnal cycles extending from the afternoon of September 13 to the afternoon of September 15.

enabled the investigators to assess the reliability of the data reduced from the thermograms.

In order to reduce and interpret the density of the thermographic negatives, it was necessary to process and quantify the data through densitometric analysis and a performance equation. Each time a thermogram was prepared, an eight-stepped gray scale was automatically included along the top of the negative so that the apparent temperature of any point could be determined by densitometric inspection. From this, one of the parameters in the performance equation was calculated; the others were derived from the manufacturer's calibration data sheets. Using these techniques, it was possible to quantify the recorded thermal emission in terms of apparent temperature. The soil moisture readings taken with a moisture density gauge manufactured by Nuclear Chicago were also reduced yielding data on soil moisture percent. The information resulting from this data reduction was used to analyze and interpret, graphically and statistically, the significance of diurnal imaging with regard to soil moisture and temperature relationships within soil types.

The radiation rates for all the soil targets were computed on the basis of the densitometric analysis of the thermograms. These temperatures were compared with readings taken on the ground at the same time as the thermography and were found to compare favorably. The actual temperatures of the targets were found to be consistently greater than the apparent temperatures measured remotely.[1] This was predictable since the emissivity of the respective targets was known to be less than unity.

---

[1] "Apparent" temperature refers to that temperature calculated using the radiance as sensed by the thermal infrared camera. Apparent temperature sould be expected to correspond exactly to actual temperature only if the object in question were a perfect blackbody; i.e., if its emissivity were 1.0.

3. Interpretation and Results

The interpretation of the data was carried out in several steps. Initially, the results of the data reduction were graphed (see Figure 7) and some general conclusions were drawn. It appeared that the optimum time of day to distinguish soil moisture differences within a given soil type was in mid-afternoon, at which time there existed the greatest spread in apparent temperatures between soils of different moisture contents. During the evening, night and morning hours, nearly all the soils exhibited the same thermal emission characteristics. The initial analysis also suggested that it might be possible, by means of grey scale differences on thermograms, to detect moisture differences <u>within</u> a given soil type. Because thermal properties vary with soil type, however, it would be impossible to ascertain from thermograms the relative moisture differences of soils of different types unless those types were known through access to auxilliary information.

In order to test these tentative conclusions, a number of statistical testing procedures were employed. The correlation between apparent temperature (as derived from the thermograms) and soil moisture percent was calculated for each of the four soils separately as well as for all soils combined, at a number of different times throughout the diurnal cycle. The results were that high correlations (significant at the .10 level) occurred for nearly all the soils taken separately during the afternoon hours, whereas low correlations were found during the evening, night and early morning hours. Thus the hypothesis that the afternoon hours are best for sensing was upheld. Furthermore, very low correlations were found at all times of day when all the soils were lumped together, thus verifying the hypothesis that ranking of soils by moisture percent is only feasible if dealing with one soil type; if different soil types are involved, the between-soil variability is such that no reliable estimates of soil moisture can be made. As a further test of the "best time of day", an analysis of variance was conducted with a randomized block design. Blocks consisted of the four soil plots of the same type (in order to isolate the between-soil variance). As was expected, significant (α = .05) differences between treatments as imaged on the thermograms were found during the afternoon hours, but not in the evening, night or morning hours.

4. Conclusions

From the results of this preliminary study, it can be concluded that thermal sensing in the 8 to 14 micron band seems feasible for the determination of relative soil subsurface moisture content provided sensing is conducted during the appropriate time of day; in this case, mid-afternoon, and that these determinations are made within a specific soil type. It appears that the variability between soils in terms of the effect of soil moisture on thermal emission is such that inter-soil type moisture determinations would be extremely difficult. However, if a soil type map of the area were available and the thermal properties of each type of soil had been investigated previously, then it should be possible to determine the subsurface soil moisture content of each soil type through proper use of the thermograms. Finally, it would seem that investigations pertaining to certain complicating factors such as depth of surface drying, surface texture and vegetation cover should be undertaken, as well as a more sophisticated extension of the experiment utilizing airborne thermal sensors and a larger sample size in order to further verify these findings.

Analysis of 18-Channel Multispectral Line-Scan Imagery of Wildland Terrain Features

1. Objective

The primary objective of this study was to determine the usefulness of multispectral line scan imagery for the identification of significant wildland terrain and vegetation features within the NASA Bucks Lake Test Site.

2. Experimental Procedure

Eighteen-channel multispectral line-scan imagery of selected portions of the Bucks Lake NASA test site was obtained on May 18, 1966, by the University of Michigan's scanning radiometer. A specific area which included a large number of features of interest to the wildland manager, and which had been covered by the imagery was selected for intensive analysis. The area of interest was then visited on the ground and the vegetative communities and other features were identified and mapped. It was found that six terrain features, either individually or in various combinations, could adequately characterize nearly all of the area studied. These features were timberstands, riparian vegetation, bare soil, brush type #1 (manzanita), brush type #2 (snow brush) and snow patches.

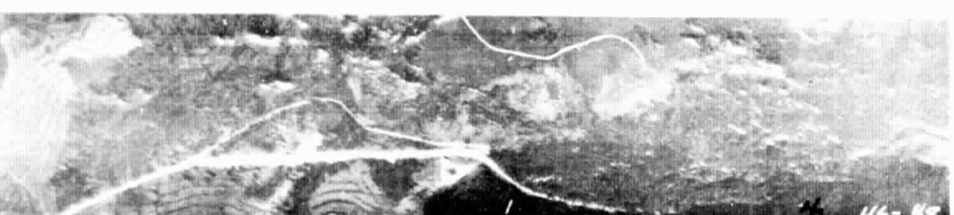
In order to quantify the tonal values of the various features as seen on the imagery, a densitometric analysis of the image negatives was conducted. Representative examples of each of the features as seen on the imagery were selected and the density of the negatives in percent transmittance were read with a Welch Densichron. The areas measured are annotated in Figure 3 and the resultant negative densities tabulated in Figure 4.

Aerial Ektachrome

Band 1: .32-.38 microns

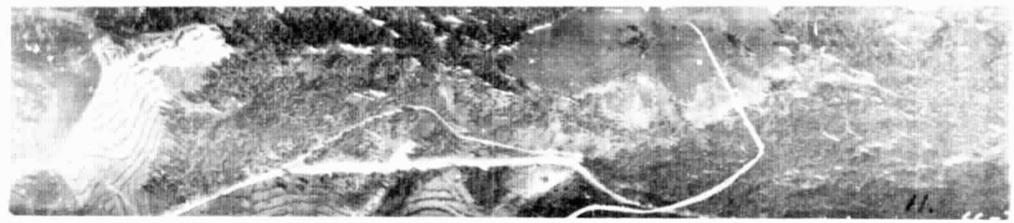
Band 2: .40-.44 microns

Band 3: .44-.46 microns

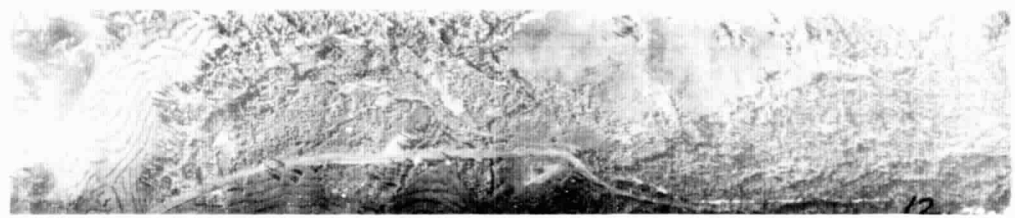


Ektachrome Infrared Aero

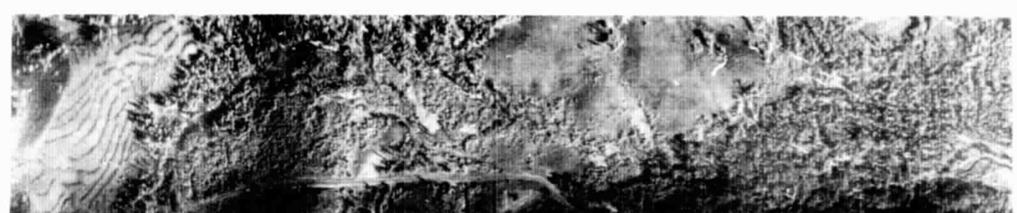
Band 10: .62-.66 microns



Band 11: .66-.72 microns



Band 12: .72-.80 microns

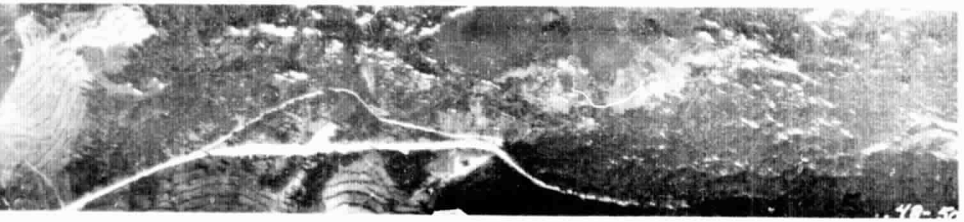


FOLDOUT FRAME 1

FOLDOUT FRAME 2

Band 3: .44-.46 microns

Band 4: .46-.48 microns

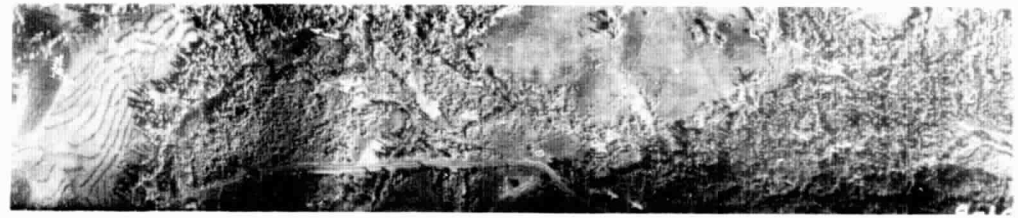


Band 5: .48-.50 microns

Baad 6: .50-.52 microns

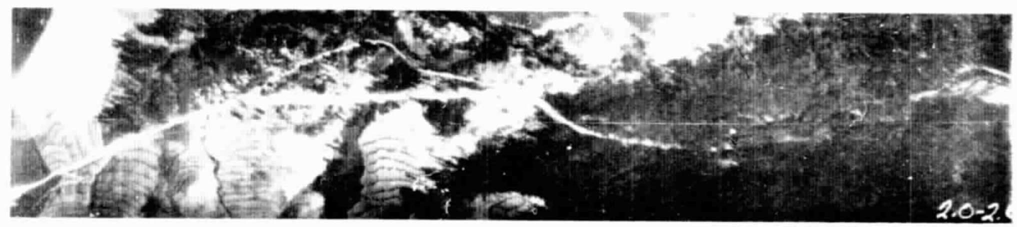
Band 7: .52-.55 microns

Band 12: .72-.80 microns



Band 13: .80-1.0 microns

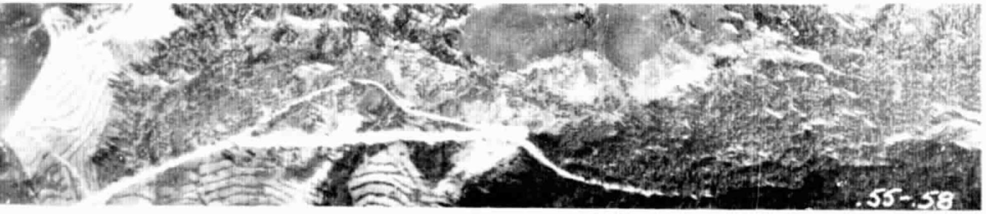
Band 14: 1.5-1.8 microns



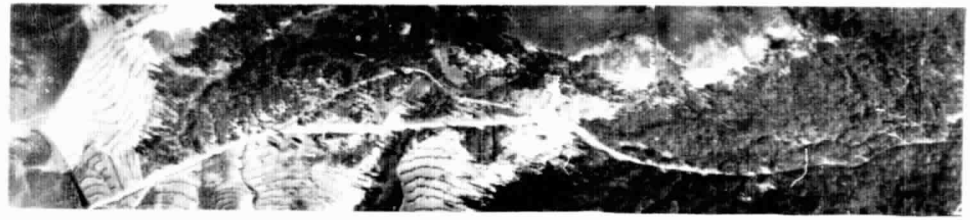
Band 15: 2.0-2.6 microns

Band 16: 3.0-4.1 microns

Band 16: 3.0-4.1 microns



Band 8: .55-.58 microns



Band 17: 4.5-5.5 microns

Band 9: .58-.62 microns

Band 18: 8.0-14.0 microns

Figure 1. Eighteen channel line-scan imagery of a portion of the NASA Bucks Lake Test Site, with Aerial Ektachrome and Ektachrome Infrared Aero photographs of the same area.

Spectral Band #	Wavelength Range in Microns	Detector Employed
1.	.32-.38	photo multiplier tube
2.	.40-.44	photo multiplier tube
3.	.44-.46	photo multiplier tube
4.	.46-.48	photo multiplier tube
5.	.48-.50	photo multiplier tube
6.	.50-.52	photo multiplier tube
7.	.52-.55	photo multiplier tube
8.	.55-.58	photo multiplier tube
9.	.58-.62	photo multiplier tube
10.	.62-.66	photo multiplier tube
11.	.66-.72	photo multiplier tube
12.	.72-.80	photo multiplier tube
13.	.80-1.0	photo multiplier tube
14.	1.5-1.8	filtered Indium Antimonide
15.	2.0-2.6	filtered Indium Antimonide
16.	3.0-4.1	filtered Indium Antimonide
17.	4.5-5.5	filtered Indium Antimonide
18.	8.0-14.0	Mercury-doped germanium

Figure 2. The spectral band designation of the eighteen channels imaged, their corresponding wavelength range of sensitivity, and the detector employed in the sensing of each band.

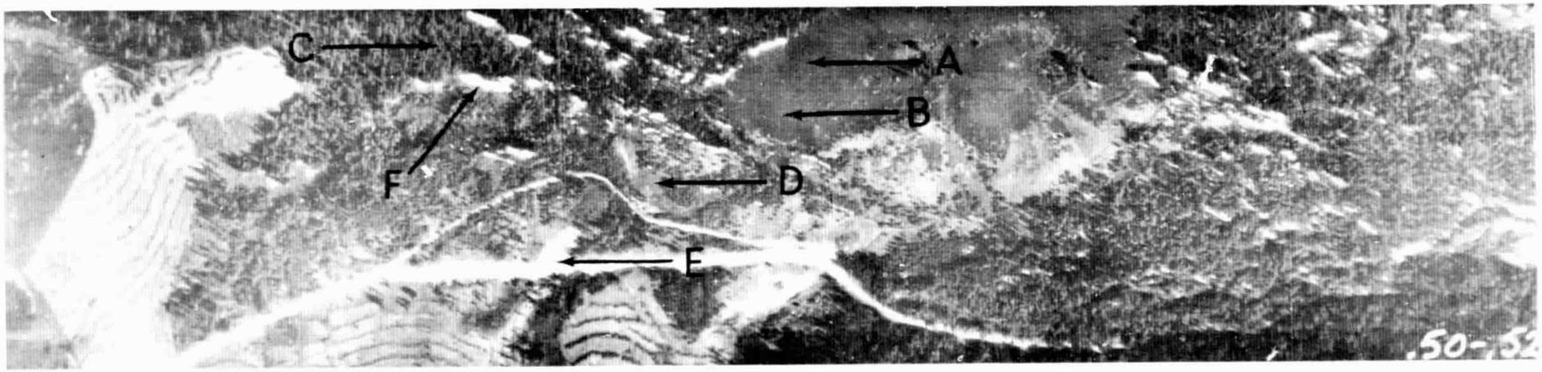


Figure 3. An enlargement of spectral band #6 (.50 to .52 microns) with the areas subjected to densitometric analysis indicated by arrows. The features of interest are: A. Manzanita brush (Arctostaphylos patula); B. Snowbrush (Ceanothus velutinus); C. Mixed conifer timber stands; D. Riparian vegetation (primarily White Alder, Alnus rhombifolia); E. Bare soil; and F. Snow.

Spectral Band #

Feature Designation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Manzanita Brush	41	31	28	27	29	26	23	23	24	26	25	24	31	23	25	25	32	17
Snowbrush	34	25	25	24	26	22	20	20	22	25	23	23	30	20	26	23	29	17
Timber	41	30	29	28	30	29	25	27	28	29	28	25	35	26	37	36	38	22
Bare Soil	14	7	8	8	10	6	6	3	4	5	10	17	19	6	7	10	10	9
Riparian	32	20	21	21	23	21	17	17	18	21	21	19	21	14	22	23	22	13
Snow	13	10	11	13	10	8	9	8	10	12	16	22	31	21	17	19	23	45

Figure 4. The densitometer readings (in percent transmission) of the various terrain features as imaged on each of the eighteen channels. It should be remembered that relative tone values are only comparable within a particular spectral band.

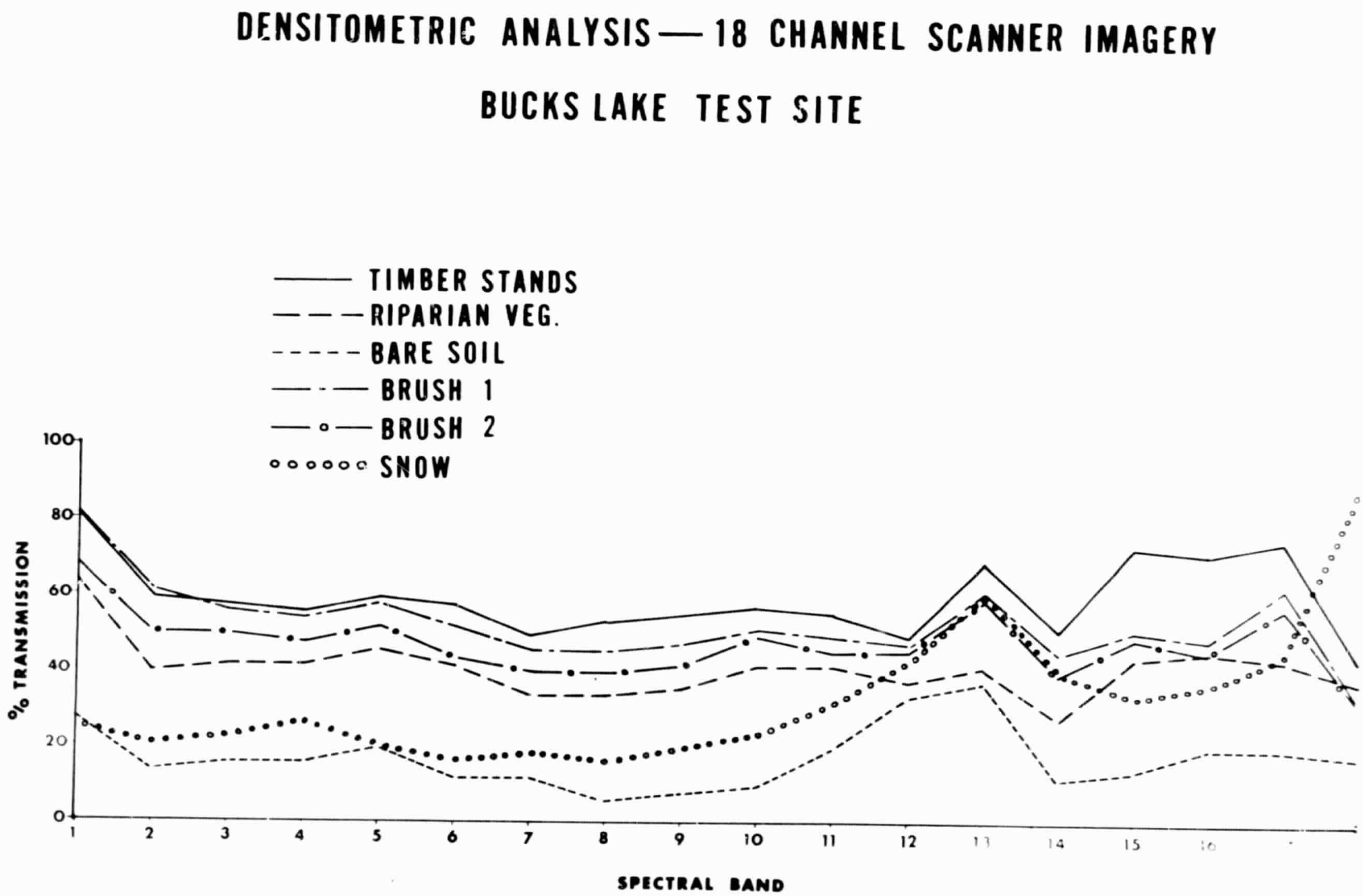


Figure 5. This graph illustrates the densitometric data tabulated in Figure 4. Generally speaking, the ease of discrimination of two objects on the basis of tone is dependent on the difference in tonal values (expressed here in percent transmission) between the two objects. Here the slopes of the lines are meaningless; of interest is the vertical distance between lines within a given spectral band.

In order to ascertain those bands which would be of greatest use for the differentiation of wildland features, pairs of features were examined on all bands of imagery and that band which best differentiated between the paired features on the basis of tone was noted.

3. Results

The results obtained through use of the procedures described above are tabulated in Figure 6. It will be noted that the concurrent interpretation of bands 1, 2, 10, 13, 14 and 15 would allow all the indicated differentiations between pairs of features to be made.

Discrimination to be Made	Optimum Spectral Band
Timber from Brush	15 or 16
Timber from Riparian Vegetation	13 or 15
Timber from Soil	1
Brush from Riparian Vegetation	13
Timber from Snow	1
Brush from Soil	10
Brush from Snow	1 or 18
Riparian Vegetation from Soil	1 or 10
Riparian Vegetation from Snow	1
Soil from Snow	14 or 18
Manzanita Brush from Snowbrush	2

Figure 6. Based on the densitometric data, the optimum bands (i.e., that band which provided the greatest difference in tonal values) for the discrimination of various pairs of features were selected and the results are tabulated above.

4. Discussion

While the results of the procedure described above are obvious, their interpretation and implications are not quite so uncomplicated. First, it should be noted that these results apply only to the images themselves, and not to the original scanner data, which is in an analog tape form, suitable for automatic data processing. While certain advantages can be found for automatic interpretation, often interpretation of the data in image form allows the application of deductive reasoning and convergence of evidence to the interpretative process, which might be quite difficult to accomplish through automated procedures. Also, it should be realized that tonal values as measured on the imagery are comparable only <u>within</u> a given band. Due to such complicating factors as electronic gain settings for the detector system for each spectral band, and uncontrolled variables in the process of conversion of data from tape to image form, tonal values should not be compared from one spectral band to another. However, relative tonal values of various features can be compared within a given band, if gain settings are held constant. Thus, in Figure 5, the slopes of the lines are meaningless, but the item of interest is the vertical distance between readings for the various features within a given band.

Furthermore, the limitations of the results found here should be fully recognized. The results are applicable only to a few vegetation and terrain types found in the Bucks Lake Test Site, and only to imagery obtained in mid-afternoon during the late spring seasonal state. Certainly, if such findings were to be applied operationally to a large area, information as to the variability in tonal values exhibited by each terrain feature would be necessary before those bands which would consistently provide significant differences between features could be chosen.

Finally, the results of this study pertain only to the discrimination of one terrain or vegetation feature from another. Clearly, if it is desired to identify all six of the test features on the basis of tone only, it would be necessary to employ several spectral bands in concert, a process commonly referred to as "multiband" sensing, wherein features are identified not on the basis of their tone values in one spectral band, but rather from their relative "tone signatures" in a number of bands imaged simultaneously.

5. Conclusions

From the results of this limited test is can be concluded that for the discrimination of the six features of interest (namely, manzanita brush, snowbrush, timber stands, riparian vegetation, bare soil and snow) on the basis of tone alone, on 18-channel line-scan imagery, it is possible to ascertain those bands which best differentiate between the features. This experiment was not intended to provide conclusive results which could be applied to wide-spread areas, but rather to simply illustrate the applicability of densitometric analysis to the determination of optimum spectral bands for particular interpretation problems.

Remote Sensing Techniques for Evaluation of
the Snow Resource

1. Introduction

The wildland manager is concerned with snow accumulation and retention for a variety of reasons, including the following: (1) The snowpack provides the greatest natural reservoir of the forest's most valuable product--water; (2) A great increase in popularity of winter sports has given an added value to snow itself; (3) Intensified management activities and the desire for winter access to wildland areas has brought attention to various snow hazards.

The type of information needed from a snow survey varies somewhat with the investigator and his specific objectives. The study reported upon in this section will serve to illustrate how remote sensing can be utilized by each of several types of investigators.

Figure 1. This stream in the NASA Bucks Lake Forestry Test Site illustrates a most valuable product of western forests--water. Largely a result of the winter snowpack, approximate timing and relative yield may be estimated by comparing snow conditions as imaged on similar dates of past seasons.

2. Use of remote sensing in snow inventory and evaluation

In recent years, much attention has been devoted to manipulating forest vegetation in an effort to increase water yield from the associated snowpack (West, 1967). Aerial photography has shown promise in evaluating forest stands in terms of their effects on the snowpack both before and after cutting. A permanent record of the snow retention and melt pattern is provided by sequential imagery flown to proper specifications. Such information may aid the forester in estimating rate of melt in terms of areal coverage, in comparing the extent of snow cover to conditions at similar times for previous seasons, and in predicting the timing and relative quantity of water yield from such cover. Commonly, ground data are collected along established snow courses (Figure 2). The use of

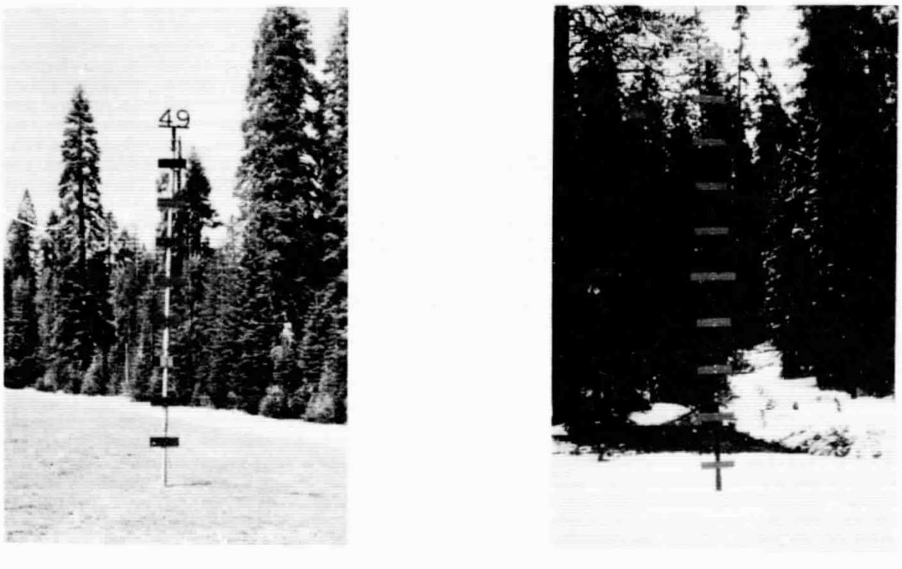


Figure 2. Fixed snow courses are periodically visited to obtain data on moisture content and density of the snowpack. These markers have been established in the NASA Bucks Lake Forestry Test Area for the cooperative western snow survey system.

aerial photos to select and locate actual sites for markers and measurements offers the advantage of providing for stations which most adequately represent surrounding terrain and vegetation, thus ensuring a more representative sample of the snowpack. Furthermore, an aerial view of the winter scene is a helpful guide to locating snow courses for both ground and aerial parties (Figure 3). At least two studys (Cooper, 1965; Smith, Cooper and Chapman, 1967) have shown that photogrammetric techniques may be used to obtain reliable depth measurements of the snowpack. Except for use on small research areas, however, the expense of this method currently limits its wider application.

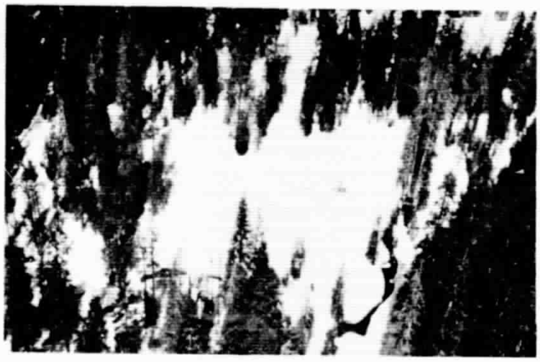


Figure 3. Forest terrain and vegetation, under a mantle of snow, often present a different appearance than that found under summer conditions. By studying and marking winter photography in the office, investigators may be better prepared to navigate accurately to specific sites. Here, a snow survey crew has landed by helicopter at course #54 (shown in the right photo of Figure 2).

The recreational value of the snowpack is of tremendous importance to many local areas. Winter sports provide an ever increasing boost to the economy of small wildland communities. Detailed evaluation of terrain to ascertain the most favorable areas to locate and develop ski lifts, sled runs, etc., and associated lodging and service facilities can be greatly enhanced by utilizing aerial photography of the region. Delineation of areas of longest snow retention, location of suitable slopes, vegetation assets or obstacles are some of the items of interest which may be derived from analysis of favorable imagery (Figure 4).

Figure 4. Aerial photography is commonly used for making vegetation type maps (or overlays). The vegetation boundaries here were transferred from imagery obtained during the summer season. It is also quite easy to ascertain terrain factors such as aspect and relative elevation. This information may be useful for predicting conditions of snow retention. For instance, it is readily seen that snow generally can be expected to remain latest on north facing slopes (A). Minor exceptions (B) may be found in deep drainages where south facing slopes are shaded by ridges or certain kinds of vegetation. The vegetation type and density appear to be major influences since more open stands (type #1) tend to loose the snowpack before areas with a little more cover (type #2).

The influence of the snowpack reaches beyond the direct relation of water yield and recreation use. Opposed to these benefits, there are several snow hazards which a wildland manager may have need to evaluate. Avalanches are important in both populated and remote areas. Their prevention and control are related to two basic factors--terrain and snow. Aerial photography provides a means of discovering and recording avalanche sites and terrain as well as vegetation conditions which may indicate potential slides. The subsequent routing of trails and roads and the locating of dwellings and service structures may avoid these sites. A seasonal series of photographs may aid in determining where stabilization structures are needed. The detection of potential trouble zones away from populated points may be useful when planning reseeding or planting activities,camp site development, etc. Areas recently denuded by wildfires may require special structures to stabilize the snowpack or to break up or stop moving snow slabs until vegetative regeneration has once again become established.

Delineation of snow retention patterns may also aid in selecting specific sites for establishing plantations. Locations near long-standing snow banks may require delayed planting in order to avoid frost and cold damage to young seedlings. On the other hand, sites adjacent to or below such snow accumulations may benefit from the irrigation provided by melt water released throughout the summer.

Snow retention patterns also reveal trafficability conditions likely to be encountered and indicate the ground accessibility to specific locations (Figure 5).

For detailed use of aerial photos in snow cover evaluation, it is necessary to account for the effects of local variations in terrain and

Figure 5. As management plans extend to remote areas, it is necessary to ascertain conditions of accessibility to these locations. The above aerial photo illustrates trafficability factors along a dirt road during the critical spring thaw period. Normal vehicular traffic would likely be restricted by lingering snowbanks. The "stream" along the road may also suggest vulnerability to damage of the roadbed itself if heavy travel were allowed too early.

vegetation.

3. Potential of remote sensing for the inventory of snow

The greatest potential of remote sensing for the inventory of snow is in acquiring data directly related to the snowpack itself. The areal extent of snow accumulation and retention patterns can be readily plotted from vertical black-and-white, color or color infrared photography by means of acetate overlays. Sequential imagery, combined when necessary with ground checking, provides an efficient means of tracing the gradual reduction of the snowpack. Snow depth may be estimated rapidly with a fair degree of accuracy at fixed ground points by means of aerial markers or more teduous and expensive means (Cooper) may provide continuous and highly accurate snow depth data.

The critical need for a measure of snow density and water content remains as a primary problem to be met. The use of active sensing systems, such as radio telemetering devices, shows a potential for this purpose.

Water Quality

1. Introduction

Water is recognized as one of the most valuable products yielded from the forest environment. The increasing demand for water serves to increase the importance of placing this resource under wise management. Reliable estimates (De La Rue, 1967) have indicated that withdrawal rates will exceed dependable water supplies in the United States by 1970. Our national water crisis is compounded by the fact that much of the water resource is rendered unusuable because of pollution. Table 1 lists some of the more important pollutants which can contribute to poor water quality.

Table 1

Major Types of Water Pollutants as Recognized by the U. S. Public Health Service

1) Domestic sewage and other oxygen-demanding wastes
2) Infectious agents
3) Plant nutrients
4) Organic chemicals, such as insecticides, pesticides and detergents
5) Other minerals and chemicals, including chemical residues, petro-chemicals, salts, acids, silts and sludges
6) Sediment from land erosion
7) Radioactive substances
8) Heat from power and industrial plants

As population pressures continue to increase, wildland managers must deal with more and more of the items on this list and to an ever-increasing extent.

The task of detecting and correcting causes of water pollution over vast areas of extensively managed forests is an enormous one. It is thus appropriate that attention should be directed at investigating some of the ways in which remote sensing techniques could be developed and applied to this problem.

2. Objectives

The initial objectives of the study reported herein included ascertaining prevalent causes of pollution in forest areas, determining parameters of measurement applicable to these causes, and investigating the feasibility of obtaining these data by means of remote sensing techniques.

3. Procedure

At the outset, a literature search and review was made on the subject of water pollution, directing special attention to the problems encountered in wildland areas. Usually, in such areas the major water pollutants derive from the land itself. Among the more troublesome causes are siltation and associated turbidity from land erosion (Figure 1) caused

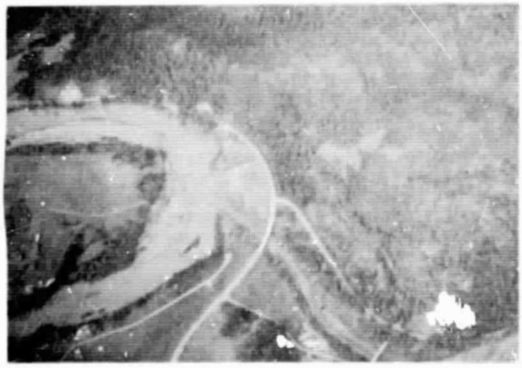


Figure 1. Much natural water pollution in wildland areas relates to land deterioration and siltation. Evaluation of turbidity may aid in identifying the source of trouble and in estimating the extent of dispersion levels.

by disturbances of man, debris and ash from forest fires, and undesirable forms of aquatic plants. Frequently, the water pollution problems are aggravated by unwise land use activities that may seem far removed from contributing to water quality deterioration. For instance, clearing land for cabin sites or the actual subdivision of areas for recreation lots may lead not only to accelerated erosion of the scarred land, but also to an increased load of material reaching drainages which may plug natural channels, destroy fish spawning beds and render recreational swimming areas unusable. Exposed watersheds allow solar insolation to raise the temperature of runoff, and this, together with the nutrient-rich erosion material, can completely change the ecological balance of the equatic environment (eutrophication) and perhaps lead to unsightly algal blooms. Such waters are then no longer usable for local water supplies or certain industrial processes unless expenditures are made to restore tolerable conditions.

Aerial photography is a valuable means of surveying the land use activities in wildland regions. An extension of the technique of vegetation type mapping may be made to "zone" specific locations as to their major actual or potential use; thus, likely areas of heavy human activity may be anticipated, and disturbances foreign to an area may be quickly documented. Sequential imagery, obtained over a time span of days or years depending on the objective, is a practical way of recording changing conditions which might not otherwise have noticeable impact until some later time. The synoptic view afforded by aerial imagery is also valuable for tracing pollutants in their dispersion as well as discovering likely sources causing the problem. Standard photography thus may be readily utilized in monitoring vast areas for indications of water pollutants; closer evaluation, coupled with well directed ground investigation, could then lead to the enforcement of water quality standards designed to solve the difficulty.

These procedures have themselves suggested more specific needs and areas of investigation. Our ability for the detection of water pollution needs to be improved and once that is accomplished more detailed information on identification, measurement and evaluation of various factors of water quality is desirable. Hence, work has been directed in the present study at investigating suspended materials in various bodies of water. Turbidity (Figure 2) is a dramatic indicator of polluted water, and pre-

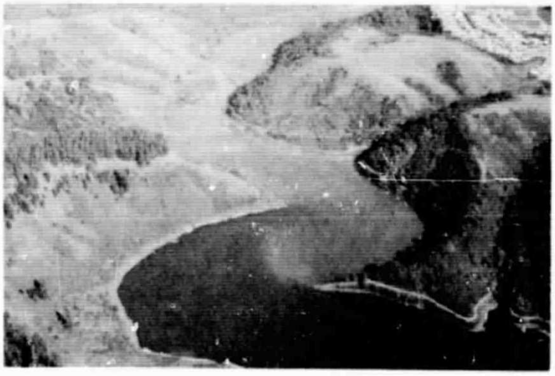


Figure 2. Turbidity can foul local water supplies, degrade fishing and recreation activities and necessitate expensive treatment before use in domestic and industrial processes. Remote sensing may provide a means for better regulation and control of water supplies, thereby insuring the most efficient use of this critical resource.

liminary steps have been taken to study the significance of this factor in remote sensing of wildland water quality. Initial data are being derived from ground experiments with actual samples of algae and suspended silt; spectroradiometer readings are being made to determine the reflectance distribution of various targets (species, concentration, angle of view, etc.) in order to choose film-filter combinations likely to give desired results. Field work is being extended to include study of "natural" bodies of water, such as the San Pablo Test Site reservoir, the California Aquaduct, Clear Lake and other applicable sites. Densichron measurements are being made in an effort to relate film response to the criteria of interest. The California Department of Water Resources and the East Bay Municipal Utility District have already provided assistance with trial ground data, and these agencies have expressed interest in further research cooperation. In addition, Leslie Salt Company has been contacted about assistance in an aerial evaluation of the salinity levels and associated algae populations of their concentrator system near Newark, California.

4. Summary and Conclusion

As indicated in the preceding section, the studies on water pollution of NASA Test Sites in California are barely beginning. Quite appropriately, the conduct of field tests has been deferred until an adequate review could be made of work already done, including that of personnel working for the NASA Earth Resources Survey Program.

Brush Species Identification Studies

1. Objective

In almost all inventories that are made of wildland areas, the many different species that are found in brushfields are merely grouped under the common heading of "brush". For many types of management planning such as fire control, wildlife management, tree planting, conversion to grazing range or pasturage or farming, watershed management and others, there is a need for more detailed information about the species composition and the site characteristics of brushfield areas.

This study has been undertaken to determine the extent to which brush species can be identified using energy returns detected and recorded by remote sensors. A later phase of the research will be concerned with evaluating the ecological site potential of brushfield areas.

2. Experimental Procedure

Several short flight lines were flown over brushfield areas within the Bucks Lake test site using a variety of film-filter combinations on 70mm film. These combinations include the following: Plus X Aerographic, type 5401 with Wratten 25A filter and with Wratten 61 filter; infrared Aerographic, type 5424 with Wratten 47 filter and with Wratten 89B filter; Ektachrome Aero, type 8442 with no filter and with an HF3 filter; Ektachrome infrared Aero, type 8443 with Wratten 15 filter and with Wratten 15 plus a CC30B color compensating filter. In addition, one flight was made using Ektachrome MS, type SO-151 which was developed to a negative in order to obtain paper prints.

A field crew identified and marked on aerial photos individual brush plants and areas of pure stands of single brush species. These annotations were used later as part of the "ground truth" with which to compare photo interpretations and tone signature predictions from spectral reflectance data.

Spectral reflectance measurements in the past have been made with laboratory spectrophotometers. When such instruments are used, the reflectance data are expressed as a ratio between the intensity reflectance from the target and from a standard reference (usually MgO) as a function of wavelength. Laboratory measurements of reflectance from leaf surfaces have several limitations when used to estimate reflectance to a sensor located in an airborne vehicle. The most important limitation is that the spectral reflectance of an entire plant is not the same as that of its individual leaves. Plant reflectance is a composite of reflectances from variously oriented and illuminated leaves, stems and underlying litter, soil and rocks (see Figure 1). The density of foliage and the orientation of leaves may have as much influence on the spectral reflectance of a brush plant of a given species as do the reflectance characteristics of a single, normally oriented leaf.

Late in the field season a program for obtaining spectral reflectance data from brush species *in situ* was initiated. An E. G. & G. model 580/585 spectroradiometer was used to determine the spectral reflectance of brush plants in the field. The radiometer can be operated from a self-contained rechargeable battery and is completely field portable. Reflectance can be measured in the wavelength interval 350-1200 nanometers. In field use to date the instrument has been mounted on a heavy-duty tri-

Figure 1. As can be seen in this photo, taken from a point vertically above a stand of Snowbrush (Ceanothus velutinus), the net reflectance of an entire plant is an integration of reflectances from variously oriented leaves, stems and underlying litter, soil, rocks and shadow areas.

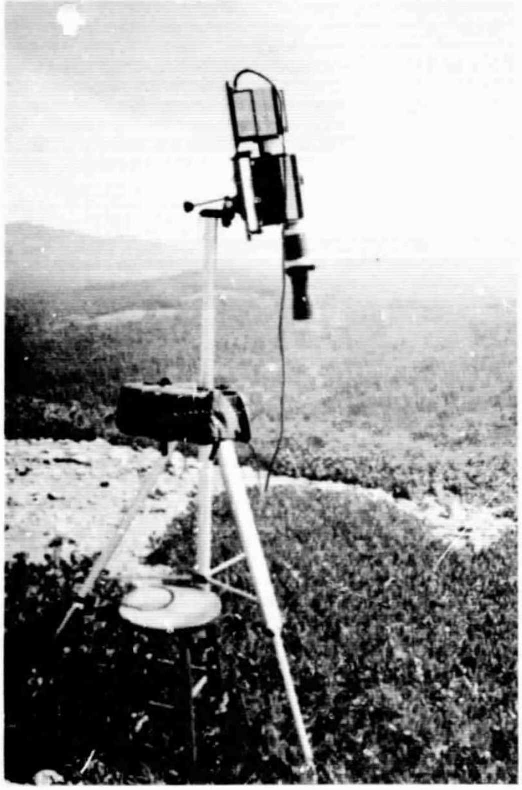


Figure 2. The E. G. & G. spectroradiometer mounted above the stand of Snowbrush pictured above. Measurements of reflectance made in this manner are much more analogous to the signal received by an airborne sensor than are those obtained from a laboratory spectrophotometer.

pod and elevated above the plant canopy to obtain measurements (see Figure 2). The plant is illuminated by natural sunlight and hence the reflectance measured by the radiometer is the same as that "seen" by the airborne sensor except for the effects of attenuation by the intervening atmosphere.

3. Results and Conclusion

Preliminary results indicate that by using multispectral tone signatures it is possible to discriminate among several of the brush species under investigation.

Field data are still being gathered and standardization procedures are being derived in order to allow direct comparison of data. The accuracy with which spectral returns can be predicted for brush species must await an analysis of the standardized data and a comparison with observed sensor returns.

Further analysis of spectral reflectance of brush species as a function of season of year should substantially increase the ability to discriminate among and to identify brush species.

A Photo Interpretation Key to Wildland Terrain Features of the Bucks Lake Test Site

The primary emphasis in this report has been on the solution of specific problems related to the remote sensing of the wildland environment. However, it should be remembered that in the making of many operational surveys, a problem equally difficult is that of training qualified interpreters. Properly specifying image type and other acquisition parameters is, of course, basic to the procurement of meaningful data, but the ultimate step is the extraction of data from the imagery, an operation usually performed by human interpreters. It has been predicted that, within the next decade, earth orbital vehicles will become operational which have the sole purpose of providing remote sensing data for earth resource survey applications. With the advent of such vehicles, vast quantities of data which will become immediately available will merit careful study. Consequently, image interpretation keys and other guides should be available at that time to facilitate the task at hand.

The following key has been prepared primarily to demonstrate one approach to the preparation of interpretative guides, and to point out some of the particular problems encountered. Specifically, the key applies to the identification of the important gross terrain and vegetation features of the NASA Bucks Lake Forestry Test Site, as imaged on Infrared Ektachrome Aero Film at a scale of approximately 1:30,000. It is obvious that in general a key is only applicable to specific areas which may be quite limited in extent, and will apply only to a certain set of image specifications. Keys applicable to a certain area might vary considerably depending on the ultimate use to which the data are to be put. For example, the key presented here is applicable in the middle elevation areas (i. e., those areas between 3,000 and 7,000 feet in elevation) of the Sierra Nevada of California, and its applicability to other regions is questionable. The features discussed in this key are of primary interest to the wildland manager concerned with the vegetative resources of the area. A quite different key might well be prepared if, for example, the principal concern were the geologic resources of the same region. Thus, a prime requisite for the construction of such a key is the determination, in quite specific terms, of the kind of information required by the management personnel who will use the data.

The key itself consists of several parts. The first is a dichotomous word key based on the color and texture of the features as they appear on small-scale color-infrared photography. However, there are inherent difficulties in describing color and texture in terms with the same meaning for all persons. Furthermore, there is troublesome variability among features considered by the key to be in the same group. There also is variability in the appearance of the same feature on different film batches, and in different positions on the photo image. Consequently, a word description, although useful, is often not sufficient. Thus, a second section of the key, consisting of both aerial and ground photographs of the features of interest, as well as brief description, ordinarily should be used in conjunction with the word key. Where possible, several examples of a particular feature type should be presented as they appear on aerial photography of the type being interpreted, in order to illustrate some of the variability that can be expected.

The ground photos and word descriptions which appear in the key that follows will assist the interpreter in the process of deductive reasoning. Such a process is necessarily involved in reaching a final conclusion as to the identity of a feature after reaching a tentative conclusion based on the dichomous key.

Photo Identification Key to Wildland Terrain Features of the Bucks Lake Test Site. Film: Ektachrome Infrared Aero. Scale 1/30,000

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

HH. Billowy texture discernible, vegetation generally occurring along gullies and other natural drainage areas, color bright red or pink--------------------Riparian Hardwood Vegetation

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

II. No regular linear patterns apparent---L

J. Features linear or sinuous--K

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

K. Features narrow, often forming a network of large extent---Roads

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

L. Features very light in tone---M

LL. Features dark in tone--O

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

MM. Areas light grey, blue or yellow--N

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

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

O. Color brown, texture smooth, associated generally with red-colored brushfields---------------------------------Sprayed Brush

OO. Color black, deep blue or dark grey------------------------------------P

P. Outline of feature continuous, uniform deep blue-black color except for occasional white reflections----------Deep Lakes and Ponds

PP. Outline of feature irregular, often mottled in tone, occasionally containing red aquatic vegetation throughout---Shallow Lakes and Ponds or Marshes

Dense Mature Conifers

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

Sparse Mature Conifers

While individual crowns are easily discernible, the crown canopy comprises less than 50% coverage of the area. Often light-colored soil or red, smooth textured low vegetation is apparent between crowns. Black conical shadows are often obvious.

Dense Young Conifers

Usually individual pointed crowns are only barely discernible, resulting in a fine stippled appearance. Tree crowns comprise greater than 80% coverage of the area.

Sparse Young Conifers

Small pointed crowns barely discernible against a light soil or red, smooth textured vegetation background (or white snow background in winter and early spring). Individual shadows only barely visible. Tree crowns comprise 5 to 80% coverage of the area.

Dense Brushfields

Texture is smooth or only slightly mottled. Color may vary from bright red to dark bluish-red. Usually occurring on gentle or steep slopes, only very occasionally on bottomland sites. Less than 20% of the area consists of light-colored soil or rock.

Sparse Brushfields

Smooth-textured reddish brush intermingled with light-colored rock or soil. 20 to 80% areal coverage by brush. Nearly always occurs on steep upland sites.

Lush Meadow Vegetation

Very smooth-textured bright red or pink areas, usually occurring on level bottomland sites. Occasionally drainage or irrigation ditches may be apparent. Often intermingled with either black-colored marshes or light-toned areas of dry meadow vegetation.

Riparian Hardwood Vegetation

Color always bright red or pink, sometimes with a barely discernible billowy texture. Generally occurring along stream channels or in gullies and other natural seepage areas in upland sites.

Windrowed Brushfields

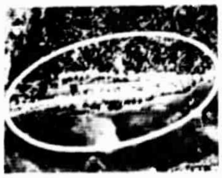
 

Very characteristic appearance consisting of light-colored soil crossed by dark-toned linear piles (windrows) of brush. Generally associated with reddish brushfields on gentle to moderately steep upland topography. Light soil areas may appear slightly pink as vegetation becomes established on the disturbed sites.

Roads

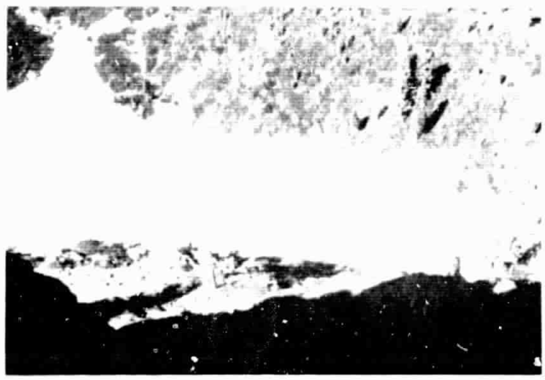
The sinuous linear appearance of roads is quite characteristic. Generally, dirt roads appear light-colored, while paved roads appear dark blue (see left photograph above). Also, paved roads generally do not possess very sharp curves and angles often possessed by dirt roads.

Dredge Tailings



Remnants of early gold mining activity, tailings are light in tone and linear or sinuous in shape. Generally wider than roads, and occurring only on level bottomland areas.

Snow



Intense white color and smooth texture differentiate snow from bare soil with which it might be confused. Usually associated with higher elevations, and generally non-existent on late summer or fall photography.

Bare Rock or Soil

Often irregular in shape, generally light in tone, and often with some scattered trees or brush.

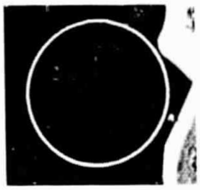
Dry Meadow Vegetation

Very smooth textured light-colored areas, often intermingled with red or pink lush meadow vegetation. Usually occurring on nearly level bottomland sites, but occasionally on level portions of upland sites. Often meadows appearing reddish on late spring or early summer photography will appear light-colored in late summer and fall after vegetation has dried.

Sprayed Brush

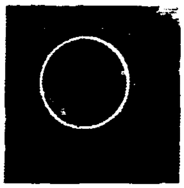
Smooth texture and light brown color, usually associated with dense brush-fields and areas of windrowed brush. This treatment is preparatory to windrowing or crushing prior to planting of coniferous seedlings.

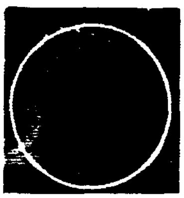
Lakes and Ponds



Very smooth texture and black or deep blue color, sharp continuous outline, and level aspect serve to distinguish lakes and ponds from shadows, with which they may sometimes be confused. Often bordered at least partially by riparian hardwood vegetation.

Shallow Ponds or Marshes





In contrast to deeper lakes and ponds, shallow ponds and marshes usually exhibit irregular boundaries and are often mottled with pink herbaceous vegetation (in the case of marshes) or aquatic vegetation (in the case of shallow ponds).

Shallow Ponds or Marshes

In contrast to deeper lakes and ponds, shallow ponds and marshes usually exhibit irregular boundaries and are often mottled with pink herbaceous vegetation (in the case of marshes) or aquatic vegetation (in the case of shallow ponds).

BIBLIOGRAPHY

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

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

Avery, G. 1965. Evaluating the potential of photo interpreters. Photogrammetric Engineering 31(6):1051-78.

Bird, J. B. and A. Morrison. 1964. Space photography and its geographical applications. Geographical Review 54(4):464-86.

Badgley, P. C. and W. L. Vest. 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.

Baumgardner, M. F. et al. 1967. Contributions of automatic crop surveys to agricultural development. AIAA Paper # 67-766.

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

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

Carneggie, D. M., E. H. Roberts and R. N. Colwell. 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.

Carneggie, D. M. and W. C. Draeger. 1966. The use of high altitude, color and spectrozonal imagery for the evaluation of wildland resources: Volume I The Forest Resource. Annual Progress Report for National Aeronautics and Space Administration.

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

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.

Colwell, R. N. 1954. A systematic analysis of some factors affecting photographic interpretation. Photogrammetric Engineering 20(3): 442-448.

Colwell, R. N. 1961. Some practical applications of multiband spectral reconnaissance. American Scientist 49(1):9-36.

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

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

Colwell, R. N. 1965. The extraction of data from aerial photographs by human and mechanical means. Photogrammetria 20:211-228.

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.

Colwell, R. N. 1967. Agricultural and forestry uses of thermal infrared data obtained by remote sensing. American Institute of Aeronautics and Astronautics Paper No. 67-281. 14 pp.

Colwell, R. N. 1967. Remote Sensing as a means of determining ecological conditions. BioScience 17(7):444-449

Colwell, R. N. 1968. Remote sensing of natural resources. Scientific American. New York.

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. Wash. D.C.

Cooper, C. F. 1965. Snow cover measurement. Photogrammetric Eng. 31(4)611-9.

De La Rue, R. E. 1967. Water pollution. McGraw-Hill Yearbook of Science and Technology. McGraw-Hill Book Co. New York. 20-29 pp.

Draeger, W. C. 1967. The interpretability of high altitude multispectral imagery for the evaluation of wildland resources. Annual Progress Report for National Aeronautics and Space Administration.

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

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

Evans, R. N. 1948. An introduction to color. John Wiley & Sons, Inc. 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 Engineers.

Food and Agricultural Organization of the United Nations. 1966. Wood and woods trends in the world. Unasylva 20(1-2):80-81.

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 Symposium of Remote Sensing of Environment. University of Michigan.

Gates, D. M., H. G. Keegan, J. C. Schleter and V. R. Weidner. 1965. Spectral properties of plants. Applied Optics 4(1):11-20.

Gates, D. M. 1966. Spectral distribution of solar radiation at the earth's surface. Science 151(3710):523-29.

Haack, P. M. 1962. Evaluating color, infrared and pan aerial photos for the forest survey of interior Alaska. Photogrammetric Eng. 28(4): 592-598.

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

Katz, A. H. 1960. Observation satellites: problems and prospects. Astronautics (American Rocket Society, Inc., New York).

McLerran, S. H. 1967. Infrared thermal sensing. Photogrammetric Eng. 33(5):507-523.

Mikhailov, V. 1962. The use of colour sensitive films in aerial photography in the USSR. Photogrammetria 17(99):104.

Moore, R. K. and D. S. Simonett. 1967. Potential research and earth resources studies with orbiting radars; results of recent studies. AIAA Paper #67-767.

Moore, R.K. 1966. Radar as a sensor. CRES Report No. 61-7. University of Kansas Center for Research, Inc. Lawrence, Kansas.

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

Morain, S. A. and D. S. Simonett. Vegetation analysis with radar imagery. CRES Report No. 61-9

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.

Olson, C. E. and R. E. Good. 1962. Seasonal change in light reflectance from forest vegetation. Photogrammetric Engineering 28(1):107.

Reifsnyder, W. E. and H. W. Lull. 1965. Radiant energy in relation to forests. U. S. Dept. Agri. Tech. Bull. No. 1344. 112 pp.

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

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

Sims, W. G. and M. L. Benson. 1966. Color aerial photography in forest photo interpretation. Australian Forest Research Nol. 2 No. 2.

Smith, F. M., C. F. Cooper and E. G. Chapman. 1967. Measuring snow depths by aerial photogrammetry. Proceedings, 35th Western Snow Conference, April 38-20, 1967. Boise, Idaho.

Stone, K. H. 1950. Aerial photographic interpretation of natural vegetation in the Anchorage, Alaska area. Survey and Mapping 10(3):261.

Tarkington, R. G. and A. L. Sorem. 1963. Color and false color films for aerial photography. Photogrammetric Engineering 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.

U. S. Forest Service. 1954. Field manual, soil-vegetation survey in California. Calif. Forest & Range Expt. Sta., Berkeley, California.

West, A. J. 1957. Studies conducted on the influence of forests on snow during the past 60 years. Professional Paper, University of California, School of Forestry.

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.

Wilson, R. C. 1967. Space photography for forestry. Photogrammetric Engineering 33(5):483-491.

Vermer, J. 1966. Objective comparison of film-filter combinations for photo interpretation. Symposium Commission VII. SIP Paris.