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 FEASIBILITY OF IDENTIFYING WILDLAND RESOURCES THROUGH THE ANALYSIS OF DIGITALLY RECORDED REMOTE SENSING DATA

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By

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ABSTRACT

This report describes the research performed during the first funding year of this study which seeks to determine the feasibility of identifying and classifying wildland terrain features through the use of digitally recorded remote sensing data. Primary emphasis during this phase has been the discussion of the rationale for using automated interpretation techniques. The pattern recognition program developed by personnel at the Laboratory for Agricultural Remote Sensing, Purdue University, is examined for its applicability to wildland terrain data. These data consist of eighteen-channel optical-mechanical line scan imagery obtained in 1966 in cooperation with the University of Michigan Willow Run Labs.

Preliminary greyscale printouts received from L.A.R.S. reveal that, with accurate ground truth information, certain features show promise of being automatically identified and classified. The statistical aspects of wildland feature identification by automatic means is currently being studied with members of the L.A.R.S. staff. Results from these investigations will be reported upon in forthcoming progress reports and the 1969 annual progress report.

ACKNOWLEDGMENTS

This research project is being performed under the sponsorship of the National Aeronautics and Space Administration as part of the total research effort being performed for the Natural Resources Survey Program in Agriculture/Forestry. This sponsorship has enabled the preparation of material for a dissertation leading to an advanced degree in Forestry from the University of California, under the direction of Dr. Robert N. Colwell, Chief of the Forestry Remote Sensing Laboratory, Berkeley, California.

The cooperative efforts afforded by members of the Laboratory for Agricultural Remote Sensing (L.A.R.S.), under directorship of Mr. Robert MacDonald, is gratefully acknowledged for their assistance with the automated classification programs. Further close work with Dr. Roger Hoffer of the L.A.R.S. staff is anticipated in the near future with the objective of developing schemes for the identification and classification of wildland terrain features using the programs developed for agricultural purposes.

Acknowledgment is also given to Claire M. Hay who ably assisted with much of the preliminary analysis presented herein and who also prepared all of the maps and diagrams used in this study.

1.0 Introduction

1.1 General. Land managers in recent years have come to rely heavily on aerial photographs as valuable aids in the assimilation of information for decision-making processes. Two prime reasons for this are: (1) aerial film emulsions provide the potential user with a recognizable, permanent, and highly detailed record for subsequent interpretation; and, (2) aerial photographic missions quite often yield considerable amounts of information for relatively little time and expense when compared to detailed "on-the-ground" surveys.

However, while the amount of information obtainable from aerial photographs is very great, recent technological advances in sensor capability indicate that remote sensing data will be pouring forth from aircraft and earth-orbital satellite missions at such an increased rate in the near future that more efficient data handling and analysis procedures will be required. Several "automatic" techniques for the rapid reduction of photographic data for meaningful interpretation have been devised. Yet, some of the more promising sensors being developed for remote sensing applications are capable of recording not only radiant energy levels in the visible and near-infrared portions of the electromagnetic spectrum, but also energy levels in certain portions which are beyond the limits of film emulsion sensitivity (see Figure 1). The automated analyses of data obtained from these more "exotic" sensors are more readily facilitated since the reflected and/or emitted radiation levels exhibited by features of interest are most often electronically tape recorded. Remote sensing data recorded in this fashion are adaptable to a number of analytical formats: analog, digital, and picture-like "printouts" (Holter, 1968).

THE ELECTROMAGNETIC SPECTRUM

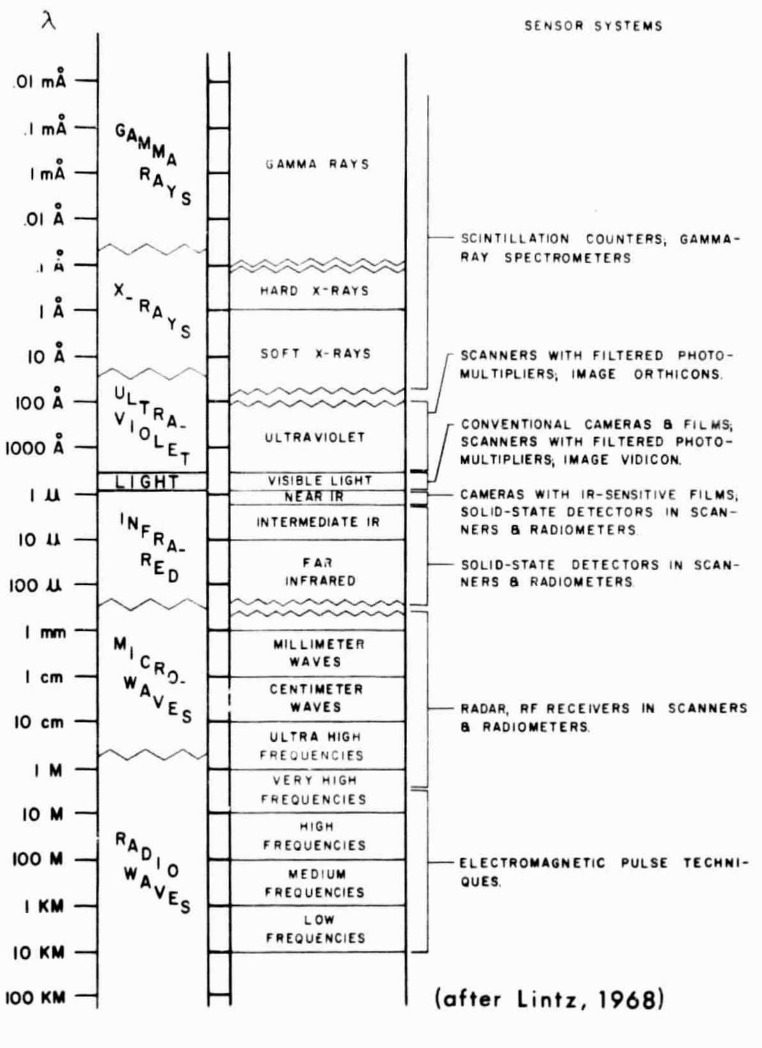


Figure 1. Portion of the electromagnetic spectrum for which remote sensing capabilities exist at the present state-of-the-art. The region of interest in this paper encompasses the range of radiant energy from a narrow band in the ultraviolet region to the thermal infrared region around fourteen microns.

It will be one purpose of this paper to discuss various data manipulations as they currently are applied to terrain feature indentification or classification, and to compare the results obtained by such means with those obtained by conventional techniques. Later sections will contain detailed discussions of the "pattern recognition" approach for feature classification developed by personnel at Purdue University's Laboratory for Agricultural Remote Sensing (LARS). The primary emphasis of this paper will be to determine the extent to which this LARS program can be successfully applied in the analysis and automatic classification of wildland features.

1.2 The Multiband Concept - Basic Considerations The radiant energy exhibited by terrain features and recorded by any particular sensor device is influenced by a number of factors which often vary in importance between sensor types. The interaction of radiant energy with matter results in one or more of the following phenomena: (a) the energy can be transmitted, (b) it can be reflected, (c) it can be absorbed, (d) it can be emitted (or re-emitted), (e) it can be scattered. These phenomena do not, in general, occur uniformly at all energy wavelengths. The importance of this basic premise has led to a formulation of the following statement:

> "Absorption, emission, scattering and reflection of electromagnetic energy by any particular kind of matter are selective with regard to wavelength, and are specific for that particular kind of matter, depending primarily upon its atomic and molecular structure". (Colwell, et al; 1963).

The significance of the above statement is demonstrated by a process known as "multiband spectral reconnaissance" (Colwell, 1961), whereby an optimum sensor bandpass or set of bandpasses can be selected such that the resultant target-to-background contrast might be maximized, or a unique combination of tone responses might be defined. Where these bandpasses fall within the range of film emulsion sensitivity (i.e., approximately 0.3 to 1.0 microns), then optimum film-filter combinations might be selected. Where bandpasses outside this range are suggested, then some kind of recording sensor other than a film emulsion must be used.

Before the optimum bandpass (or set of bandpasses) can be selected, however, some information about the variables affecting the radiant energy detected by the sensor must be examined. These variables include: sensitivity of the detector, filter transmission, illumination source and spectral characteristics (reflectance and emission) of the feature of interest. With the application of sensors at great altitudes above the terrain, the atmosphere becomes a selective filter which tends to limit total radiation to the sensor. Such factors as signal-to-noise ratios, uncontrolled detector "gain" variations, changes in solar angle (if that is the illumination source), and others can also contribute to variability in tone or signal response.

Figures 2 and 3 will serve as a simple demonstration of <u>photographic tone response</u> for an artificial target panel array of selected color chips. Figure 2 contains both a color illustration of the panel and a black-and-white print taken with an unfiltered panchromatic film emulsion. The illumination source for these two illustrations consisted of four 2750°K photoflood lamps directed in pairs from 45° on either side of the panel at a distance of three feet. Note, on the unfiltered black-and-white print, that the twelve color chips appear to fall into a few distinct tone density classes within which individual distinctions (or identifications) are nearly impossible to make. Black, brown, and violet all appear to have the same dark tone; cyan and blue are slightly

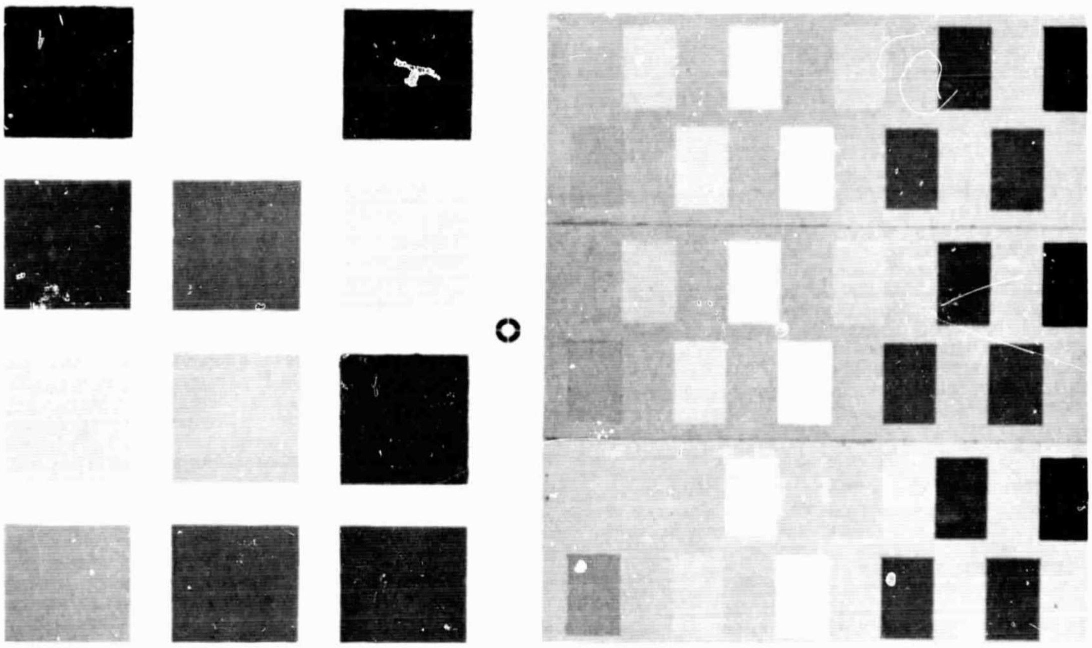


Figure 2a. A special panel array consisting of various colors and background materials is shown in the above print. The twelve colors on the left-hand side of the panel (including the black-and-white squares) were selected so as to include representative hues from a wide range of possible colors in the visible spectrum. The right-hand portion of the panel is presented to demonstrate the varying psycho-visual response of different background hues to identical, subtle green, yellow and brown hues which are common to many wildland terrain types. See Figure 2b for the greyscale tone response of these same color hues.

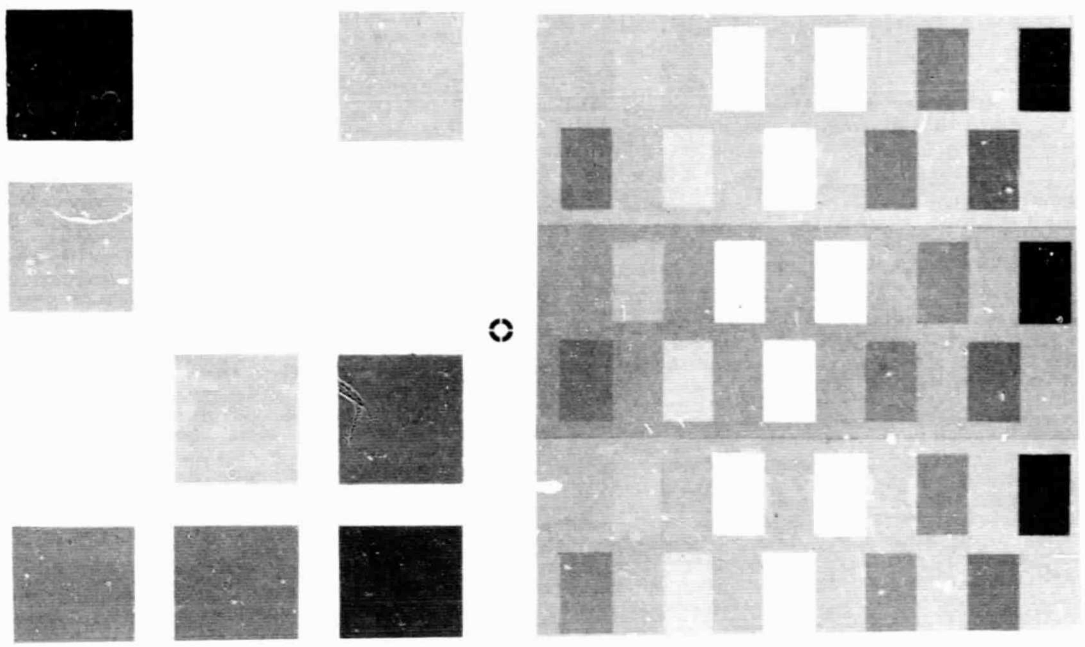
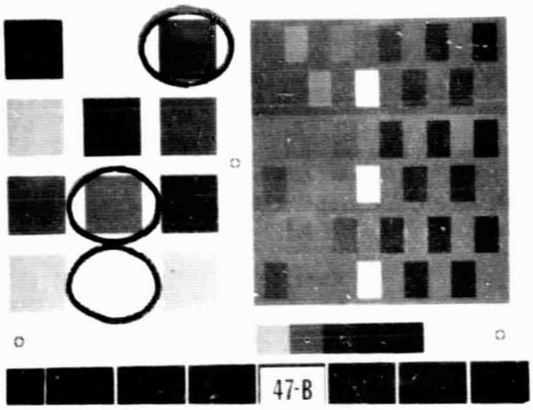
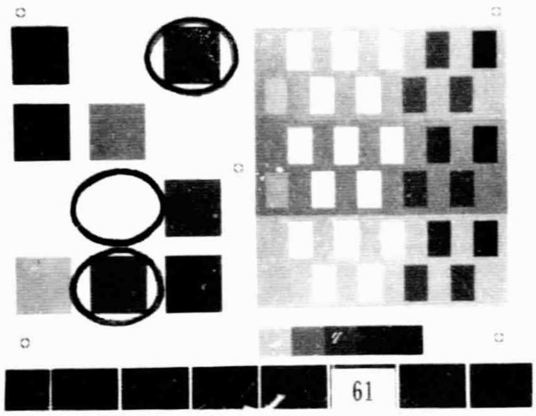


Figure 2b. Shown above .s the same color panel array observed in the preceding illustration. Here, it is seen photographed using a panchromatic black-and-white film emulsion without a limiting spectral filter (see Figure 3). Note that several of the color hues have very similar tone values (black and violet, the darkest; cyan, blue and brown, next darkest; red, magenta and green, next darkest; orange and chartreuse, lighter still; and white and yellow, the lightest tone). The importance of using and selecting the appropriate spectral filter to separate features which would otherwise exhibit similar tones is brought out in the text and in Figure 3.



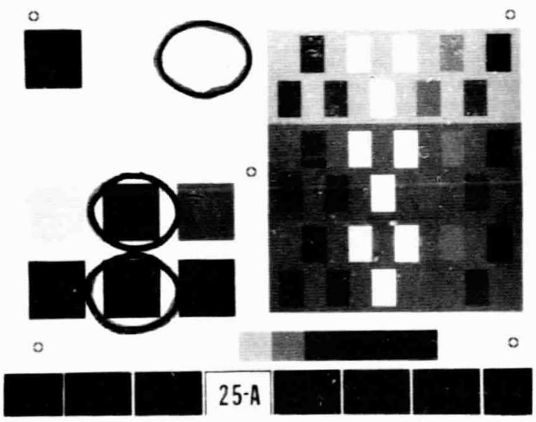
FILM-FILTER: Pan-47B

COLOR	TONE RESPONSE
Blue	Light
Green	Dark
Red	Dark



FILM-FILTER: Pan-61

COLOR	TONE RESPONSE
Blue	Dark
Green	Light
Red	Dark



FILM-FILTER: Pan-25A

COLOR	TONE RESPONSE
Blue	Light
Green	Dark
Red	Dark

Figure 3. Three commonly used film-filter combinations are shown above. By making tone response comparisons such as those noted above for separating the encircled blue, green and red color chips, all twelve of the colors in the panel array can be similarly classified, each as a unique color.

lighter in tone; red, magenta and green can be grouped in the next lighter tone class; orange and chartreuse, next; and white and yellow are lightest in tone. The result is that the color chips cannot be positively identified on the basis of this single tone response information since several choices occur within the classes in which they can be placed. When appropriate spectral filters are used in conjunction with the film type used to produce this black-and-white print, then varying tone responses are rendered as seen in Figure 3. This illustration clearly demonstrates that when three separate filters are used (for example, blue, green and red gelatin filters) the combination of tone responses defines and helps to identify each of the color chips.

An obvious question which the reader can now raise is why several black-and-white film emulsions, together with special filters, should be used when the color film emulsion alone, by virtue of its multi-layer construction, provides "multiband" photography directly in a single exposure. Numerous advantages of black-and-white photography can be pointed to in answering such a question, including: better spatial resolution capability of the black-and-white film, greater control over its exposure; greater opportunity to normalize the film density and greater flexibility in filter selection for special applications. However, it is not the purpose of this paper to debate the relative merits of color vs. black-and-white films. (For further information on this subject, as well as a list of suitable references, see Colwell and Lent, 1967). The principle of selectively filtering portions of the radiant energy spectrum in order to exploit contrasts or differences between objects of interest has been presented with the foregoing photographic example. Electronic recording sensors, too, can be selectively filtered, such that multi-channel data can be analyzed and features classified or identified by a unique, characteristic "signal response" similar to the photographic tone response.

2.0 Justification for Research

2.1 Current Needs The development of an ability to obtain remote sensing data and quickly reduce them to meaningful information is an important objective of many persons who are working in data processing and management positions. Owing to the tremendous amount of interest in remote sensing applications currently being expressed by the scientific community, and in view of present sensor state-of-the-art, several major problems are coming to the forefront. These include (a) the extent to which vast quantities of remote sensing data can be utilized in specific applications, and (b) the efficiency with which these data can be reduced to meaningful information for the land manager.

The first of these problems is highlighted by the current trend of acquiring for the image analyst more data than he can possibly handle. Extensive data acquisition programs threaten to saturate all of the present data handling capabilities of the entire remote sensing community. The primary objectives of such programs usually are the interpretation of data and the dissemination of vital information in order to (a) facilitate management decisions, and (b) point to promising areas for further investigation. Consequently, the image analyst could greatly benefit from some form of automatic data handling and analysis procedures.

With all of the information that is derivable from most remote sensing missions, much of the data remains unused and that portion which is used could perhaps be profitably employed in other related applications as well. Hence, the limiting factor commonly is the relatively small amount of time which the image analyst can afford in interpreting all of his data. Automated interpretation techniques would certainly reduce this problem.

The efficiency problem mentioned above can be relieved only after examination has been made of a number of techniques which might facilitate the reduction of remote sensing data to useful information. The land manager has a great responsibility to rapidly assess resource supply and demand in order to meet the needs of those utilizing the land. Current requirements call for the development of inventory systems which will allow wise management of resources that might otherwise be depleted. One very important resource which already is seriously depleted in many parts of the world is life-sustaining food. Approximately twenty percent of the two billion people in the developing countries are undernourished and sixty percent subsist on diets which are deficient in nutritional quality (Hindmarsh, 1967). Most attempts to alleviate this pressure for foodstuffs are aimed at making agricultural surveys and improving crop production routines. The advent of aerial photography has permitted manual interpretation of agricultural areas to be made so that sampling schemes could be devised which would speed up the process. Recent means of aiding the image analyst have been directed towards automating certain portions of his task in order to further reduce data handling time. The limits to which automation can be extended in the analysis of remote sensing data for agricultural surveys are evidenced by programs such as those established at the University of Michigan's Willow Run Laboratories (Institute of Science and Technology) and at Purdue University's Laboratory for Agricultural Remote Sensing (L.A.R.S.). Both of these programs will be discussed in later sections in relation to wildland inventories--especially the application of L.A.R.S.' "pattern recognition" approach to automated resource inventory.

2.2 Future Needs The gloomy prospect of maintaining sufficient food supplies in a world already filled with poverty and malnutrition even at present population levels threatens to reduce itself to complete chaos within the next few decades as these populations continue to increase. Populations in developing regions (viz., Asia, Africa and Latin America) are doubling nearly every twenty years, while those in developed regions double every fifty to ninety years (Hindmarsh, 1967). This increased pressure for food must be relieved by some means on a global basis. A recent report by the President's Science Advisory Committee guardedly concluded that the solution to the world's food shortage during the next twenty years is possible. But the report stipulates that it will require a major effort by developed and undeveloped countries (P.S.A.C., 1967).

The demand for other resources, too, will be felt in increasing amounts in coming years. Because resource demands will continue at high levels, emphasis on technological developments will be required to keep pace with these needs. This paper will explore the feasibility of identifying certain wildland resources employing digitally recorded remote sensing data and compare the results with conventional survey means as an alternate, more efficient procedure of extracting valuable information for the land manager. The promising "pattern recognition" technique employed by L.A.R.S. in inventorying crop types will be closely examined in order to determine its applicability for recognizing these vital wildland resources.

3.0 Review of Past and Present Related Work

3.1 General Approaches to Automated Picture Interpretation The field of automatic picture pattern classification is a relatively recent development, generally coinciding with aircraft and spacecraft data acquisition programs over the past two decades. Until recently, military-oriented applications commanded a major source of support for research in automated techniques to help solve such problems as target discrimination, recognition and classification (see, for example, Anon., 1962; G.A.C., 1962; Roetling, 1962; Cheng et al, 1968). The same concepts can often be applied for non-military "targets"; more and more effort is being devoted to the automated investigation of vital Earth resources.

A number of automated remote sensing interpretation techniques have been studied. Those which involve the interpretation or analysis of remote sensing data as they are being recorded, or following some form of mechanical pre-processing, can be called "direct" techniques. "Indirect" techniques are those which involve the scanning of pictorial formats. Either approach--direct or indirect--has its advantages and limitations.

Early work by Rosenfeld (1962) considered the problems of feature description in terms of single parameters, such as the amount of light passing through respective photo image points on a negative or positive film transparency, or the amount of light reflected at any given point from an opaque print. Tone frequency analysis and other aspects of tone signature analysis enabled some preliminary automatic terrain feature discrimination. The possibility of employing automatic interpretation techniques to aerial photographs for forest surveys was explored by Langley (1961); later (1965), he described a photo scanning system which allows for the digital storage of data on wildland features, based on their photographic tone densities. Information so stored can be manipulated in a variety of ways, to produce not only photo-like images, but also statistical and graphical computer printouts. Figure 4 illustrates a technique for presenting graphical computer data of photographic tone density by color-coding the digitized output. The black-and-white photo at the top of the illustration is a print made from a 35mm negative (film-filter combination: panchromatic film with a Wratten 25A filter). It depicts a vertical view of an array of simulated terrain features (different soil types and rock types of varying texture and composition) together with various colored panels. The illustration below the black-and-white print contains a pair a graphical computer printouts, color-coded to accentuate tone differences (density). The print on the left contains densities equally grouped into eight levels; that on the right, into sixteen equal levels (see Table 3.1 for density frequency analysis and color codes). Note that this type of presentation, which consists of scanning a transparency, assigning each video display "raster" element to one of sixty-four possible grey-scale categories, and storing the digital density equivalents in a computer memory, not only provides the image analyst with density frequencies, but also results in a map-like printout which indicates their geometric positions. For inventory purposes, this capability can be an important feature.

3.2 Willow Run Laboratories (University of Michigan) The principal reason for including a discussion of the Willow Run Laboratories here is that this facility's personnel, under sponsorship of Project MICHIGAN, has developed an "optical-mechanical" scanning system which enables the application of automatic data handling techniques. The scanning sensor device, which electronically records up to eighteen spectrally separate data "channels", was used for collecting wildland data in late May, 1966.

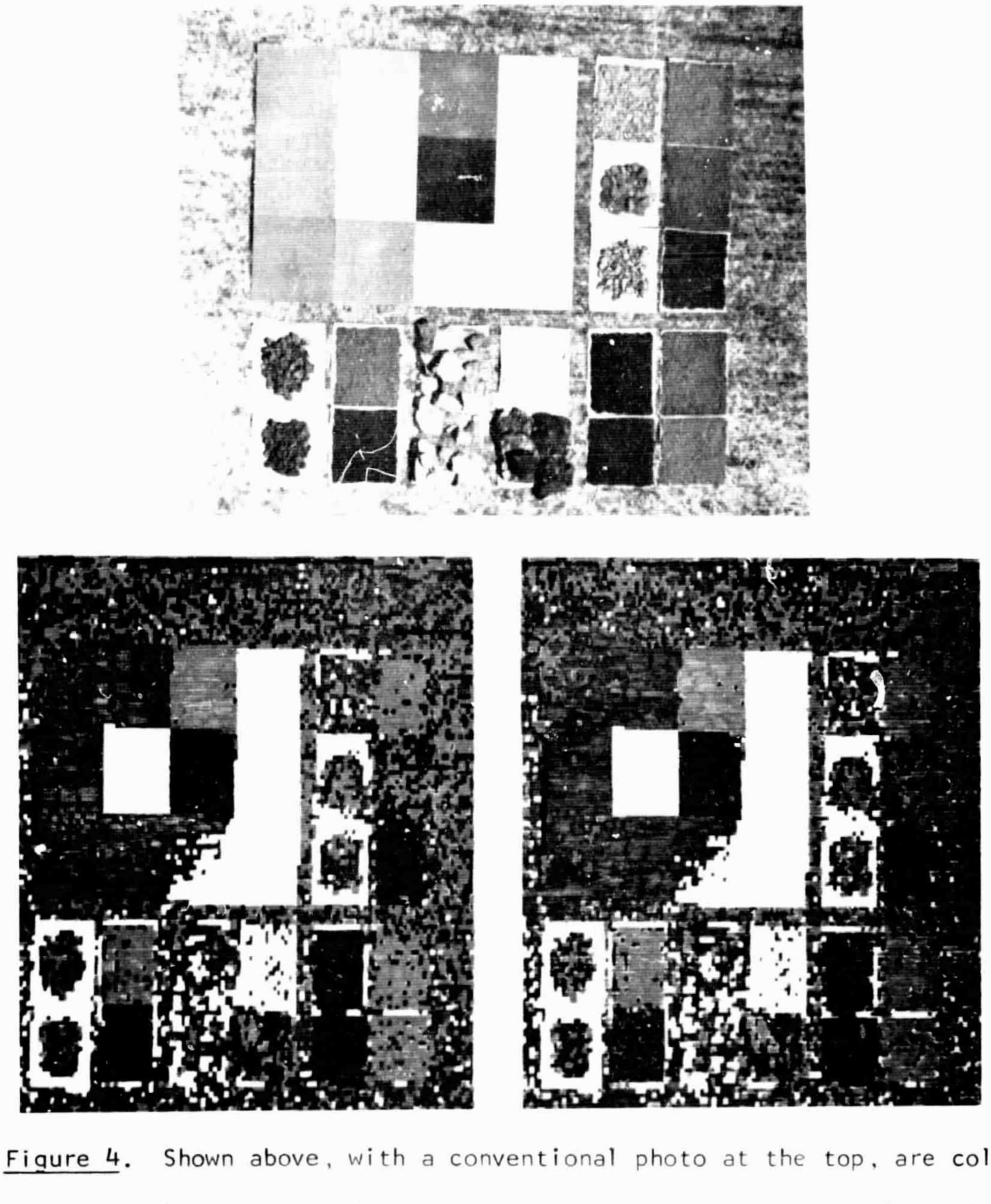


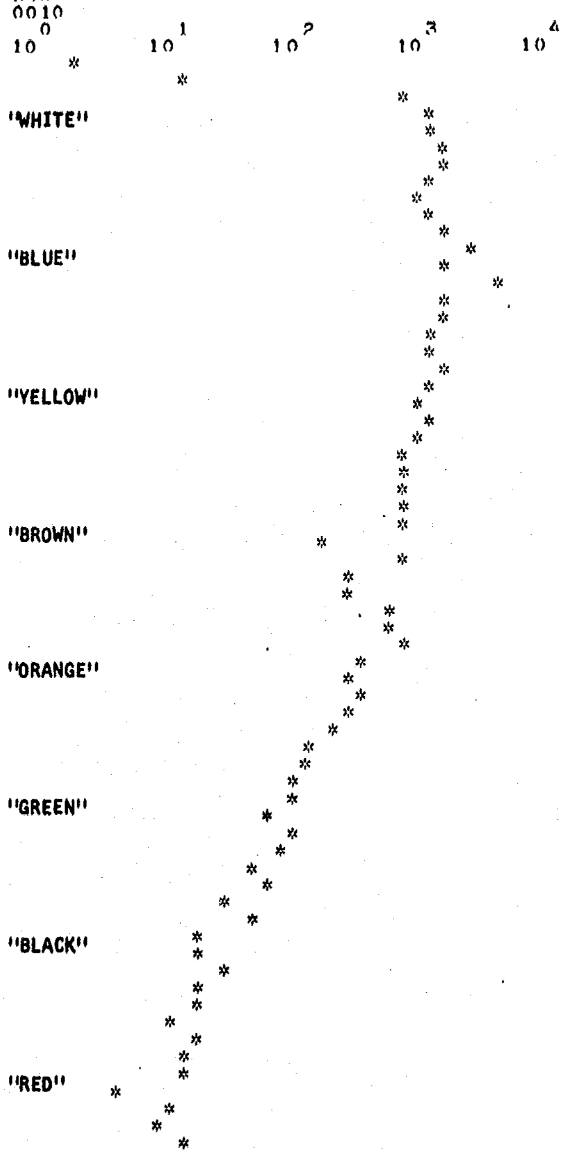
Figure 4. Shown above, with a conventional photo at the top, are color-coded graphic computer displays of tone density expressed in 8 equal-stepped categories (left) and 16 equal-stepped categories (right). The few differences observed between the two printouts are a function of the "sensitivity" of the algorithm used in compressing raster data for the resulting computer output. See Table 3.1 on the following page for color codes. (The black-and-white computer printouts from which the above displays were made are courtesy IBM, Gaithersburg, Md.).

Table 3.1 Tone Density Frequency Distribution for Figure 4.

VIDEO ANALYSIS

XO = 0016 YO = 0376
XF = 3755 YF = 3959
DX = 0015 DY = 0010

VIDEO	NO. OF PTS.	
0	4	
1	31	
2	1420	
3	2855	'WHITE'
4	3067	
5	4251	
6	3695	
7	3067	
8	1984	
9	3367	
10	3883	
11	5744	'BLUE'
12	4143	
13	7531	
14	4303	
15	4011	
16	3214	
17	3355	
18	4144	
19	3248	'YELLOW'
20	1786	
21	2634	
22	1720	
23	1439	
24	1023	
25	1190	
26	1039	
27	1039	'BROWN'
28	415	
29	963	
30	583	
31	587	
32	882	
33	919	
34	1007	
35	720	'ORANGE'
36	566	
37	727	
38	550	
39	483	
40	271	
41	306	
42	248	
43	226	'GREEN'
44	87	
45	171	
46	111	
47	82	
48	90	
49	60	
50	83	
51	43	'BLACK'
52	43	
53	63	
54	35	
55	39	
56	19	
57	35	
58	27	
59	27	'RED'
60	6	
61	16	
62	11	
63	31	



MEAN = 15.59
STANDARD DEVIATION = 09.63

Sixty-four tone density frequencies and eight levels of color codes for the graphical computer output of Figure 4 are listed in the above Table. The film-filter combination scanned in this video analysis was panchromatic-25A. (Printout courtesy of IBM Corp., Gaithersburg, Md.).

The major study effort reported upon in this paper employs this 1966 remote sensing data in an effort to determine the feasibility of automatically identifying various wildland features.

The schematic diagram of Figure 5 shows, in simplified form, the basic operation of the Michigan M-5 line scanner. This optical-mechanical line scanner, so named because of the rotating mirrors and special collecting optics, is a complex instrument compared to conventional cameras (Lowe, 1968). However, a number of reasons exist which justify or perhaps necessitate its use in certain remote sensing applications despite some obvious limitations. Some of these reasons are expounded upon below:

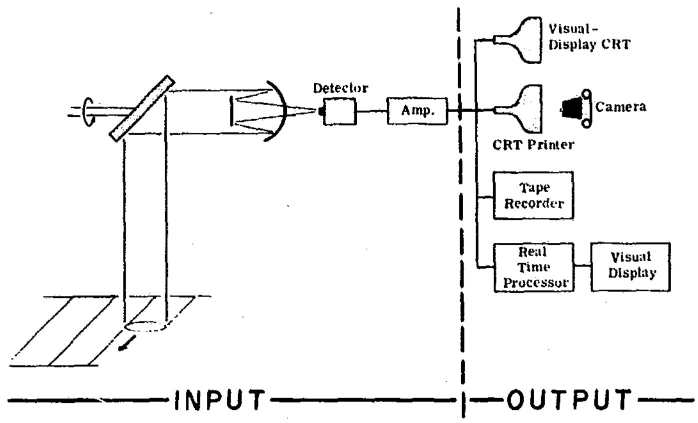
(a) The optical-mechanical line scanner can record data outside the photographic region. The capability of recording up to eighteen separate, but simultaneously sensed, terrain "signals" covering a spectral range from 0.32 microns to 14 microns, provides the image analyst with a powerful analytical tool. The multispectral nature of this device, which includes five thermal infrared data channels, enhances the analyst's ability to define various features on the basis of their characteristic "signatures" of reflected and emitted energy. It may be that certain features can only be uniquely defined by the inclusion of data from this non-photographic region.

(b) The output signal is in electrical form and can therefore be readily transmitted, recorded, analyzed or processed in a variety of formats. Levels of reflected and emitted energy emanating from terrain features are recorded on analog tapes. These tapes can then be processed in various ways as diagrammed in Figure 5. The data can be played directly through a cathode ray tube (CRT) to give the console operator a crude "birds-eye" view of the terrain below; tapes can be processed more leisurely in the lab by photographing the scan lines to produce a pictorial image of scene radiance. The continuous film strips formed in this way can be studied individually, channel by channel, or combined in groups of two, three or more channels for additive color enhancement experiments (see Appendix); in addition, the tape records can be converted from analog to digital format for subsequent statistical analyses.

(c) The scanner detectors generally have a wider dynamic range than photographic film emulsions. The optical-mechanical scanner detectors, encompassing a spectral sensitivity wavelength interval from 0.32 microns to 14 microns, have a tremendous range of radiant energy levels to record. Film emulsion, while only encompassing an approximate spectral sensitivity wavelength interval from 0.3 to 1.0 micron, does not possess the total flexibility inherent in the scanner's electronic amplification components. One of the most important factors in the application of object discrimination--whether interpreted by humans or machines--rests on the degree of contrast, if any, between the object of interest and its background (Lowe and Braithwaite, 1966). The greater dynamic range of scanner detectors enable subtle contrast differences to be electronically enhanced.

(d) The optical-mechanical line scanner can collect radiance data simultaneously in many wavelength channels. Based on the previous discussion in Section 1.2 on the merits of multispectral analysis for identifying terrain objects, the Michigan M-5 line scanner, with eighteen possible recording channels, possesses a great multispectral capability.

Two general approaches to object discrimination by multispectral analysis have been suggested by researchers. One approach is to do extensive spectral analyses (i.e., measurements of reflectance and emittance



(after Lowe, 1968)

Figure 5. Schematic diagram of an optical-mechanical line scanning system. Theoretically, any number of separate recording "channels" can be built into the scanner by using beam-splitting optics and appropriate detectors. The Michigan M-5 line scanner used in obtaining the 1966 data had eighteen channels coupled to four detectors and their accompanying amplifiers. On the input side of the above diagram, the basic operation is shown which consists of focusing the incoming radiations on a detector where an electronic signal is generated and amplified to recording levels. The rotating mirror, together with the forward motion of the aircraft, enables a scan line to be "painted" adjacent to the previous scan line. The aircraft speed is geared to the rotation rate of the mirror, thereby accounting for the appropriate advance to insure complete contiguous coverage. Some of the Michigan M-5 line scanner parameters used in collecting the 1966 data include the angular resolution = 0.0033 radians,* scan rate = 60 revs/sec., and ground travel per scan = 200 feet/sec. (Hasell, 1968). On the output side of the diagram, several ways of using the recorded signals are suggested and discussed briefly in the text.

*By authority of DOD memorandum (dated 21 Dec. 1967) on classification of infrared imaging devices, the M-5 scanner and its imagery were declassified.

characteristics) of the object of interest and of its background such that specific filtered wavelengths which optimize the chance for discriminating the object from its background can be prescribed prior to the remote sensing mission. The other approach is to develop a capability within the sensor system to record a large number of bandwidths covering as wide a spectral interval as possible in order to statistically analyze and select those bands exhibiting the greatest tonal or radiometric differences between the object and its background. Both approaches have been used in recent studies, each depending on the specific objectives of the research problem (see Colwell et al, 1965 and Dakin et al, 1968, for representative studies on approach #1; see Section 3.4 for numerous references on approach #2).

3.3 Laboratory for Agricultural Remote Sensing (L.A.R.S., Purdue University) Personnel at L.A.R.S. have been actively engaged in agricultural remote sensing studies for a number of years under sponsorship of the National Aeronautics and Space Administration. Foremost in their programs has been the goal of investigating remote sensing techniques requiring little or no human participation to reduce these agricultural data to useful information. The most promising of these programs is based on the technique of applying "pattern recognition" concepts to the relative amplitudes and configurations of electromagnetic radiation exhibited by various objects for the purpose of automatically reducing the data to a more useful form. By early 1966, the staff at the University of Michigan's Willow Run Laboratories had developed the eighteen-channel optical-mechanical line scanner and magnetic tape data recording system. This development eliminated Purdue's need to rely on multispectral remote sensing data obtained by two separate, unrelated systems;

namely, cameras and single-channel scanners. The prospect of obtaining and analyzing vast quantities of densitometer readings from film records obtained from cameras and scanners was eagerly replaced with that of handling data recorded directly on analog tapes which could be prepared for computer processing. The capability offered by Michigan's M-5 multi-channel scanner greatly enhanced the "automated" aspects of Purdue's efforts.

The program objectives expressed by personnel at L.A.R.S. are the following (Anon., 1966):

(a) To determine the extent to which selected major crops of the corn belt region, such as corn and soybeans, can be differentiated on the basis of multispectral response signatures at various times during the growing season;

(b) To determine the amount of variation and to identify the major sources of variation in the multispectral response signatures of selected soil conditions and major crop species of the corn belt at various times during the growing season; and

(c) To determine and prescribe methods for gathering "ground truth" information that will allow prediction of multispectral response signatures obtained by remote multispectral sensing techniques.

Several interrelated study areas are involved at L.A.R.S. to achieve these objectives. These include: biophysical studies designed to learn more about variations in plant and soil reflectance spectra; remote multispectral sensing studies designed to determine the feasibility of using an optical-mechanical scanner sensor for agricultural surveys; and, data handling and pattern recognition studies to determine the economic value of developing a system to automatically identify and classify important agricultural crops and conditions. This last study area is a crucial one in terms of the problems related to adapting the Michigan data to the Purdue pattern recognition approach. It is also of crucial concern to the present investigation discussed herein regarding the feasibility of adapting the Purdue pattern recognition approach to wildland surveys.

Hoffer (1967) presented a review of Purdue's earlier work, detailing some of the initial efforts to develop automated means for recognizing characteristic response signatures of various crops and soils. It was concluded that under certain conditions of crop maturity, remote multispectral sensing techniques could provode a means of identifying crop species such as wheat, oats, corn and soybeans. Because of the variation in response exhibited by the crop species in different wavelength intervals, it was possible to propose statistical procedures which might automatically discriminate species from one another. Within-species variations were considerable and recommendations to minimize them were presented.

"Pattern recognition", as defined by L.A.R.S. (Cardillo and Landgrebe, 1966), resembles somewhat the photo interpretive techniques developed for identification keys and suitable operational tests of performance. The important distinction which is brought out by L.A.R.S. in comparing photo interpretation with pattern recognition is that photo interpretation is generally better suited for problems of "... higher sophistication involving lower data quantities,...", whereas pattern recognition is better suited to the reverse set of conditions. The type of pattern recognition favored in the Purdue program involves the making of statistical decisions based on multiple radiance signatures. Features which tend to fall into "density functions" as a result of characteristic reflectance phenomena can have "likelihood ratios" computed for them which express the relative probabilities of unclassified points belonging to a particular category of interest vs. some other category. Considerable sampling of crop type responses are necessary to develop the parameters which define the joint probability distribution functions. Certain assumptions are made with regard to obtaining the probability density functions, including an assumption that the sample sizes are sufficiently large to characterize (statistically) the feature in question. Briefly, the steps involved in implementing a feature recognition program using the Purdue procedure include:

1. Acquiring optical-mechanical scanner imagery over the total area of interest where ground truth data have been collected. This is done to the extent necessary for insuring that adequate categories of feature variability and conditions are represented;

2. Converting the analog records into a compatible digital format for processing by L.A.R.S.' computing hardware facilities;

3. Selecting computer "training samples" from the converted digital data which has the detailed ground information so that feature signatures can be determined; and

4. Processing the entire imaged area by computer programs which have been designed to display the imagery either as a function of radiance levels, or in map-like printouts of the feature of interest against a blank background of other features (see Figure 6).

A review of the statistical aspects of the pattern recognition approach used by the L.A.R.S. staff is included in the Appendix. Early published results from L.A.R.S. (Landgrebe, 1967), while admittedly very

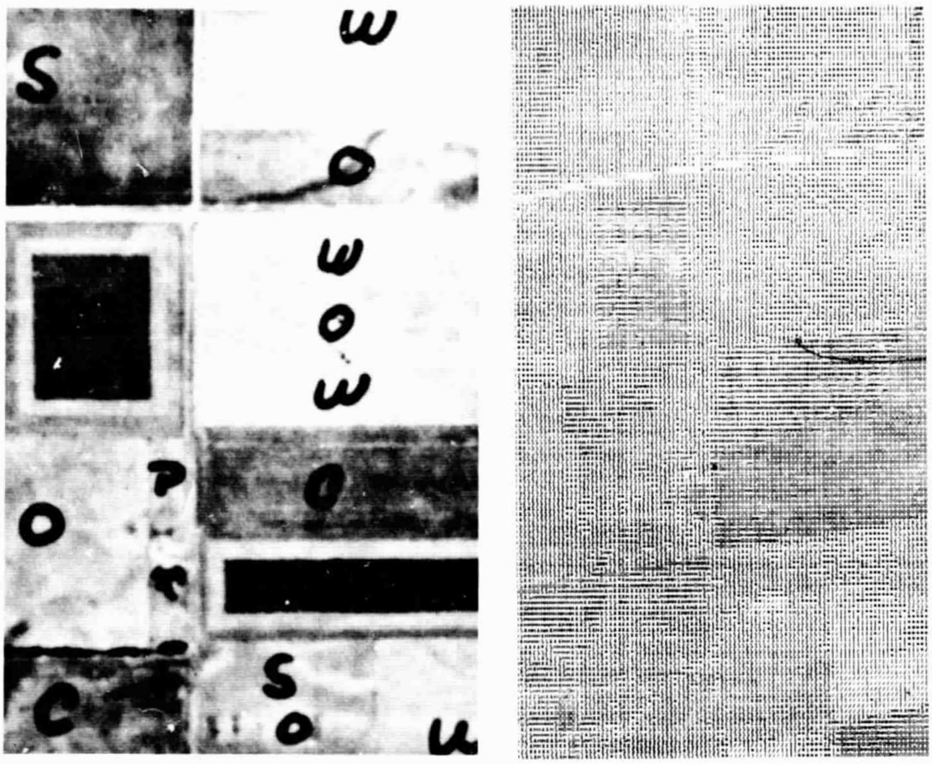


Figure 6a. Examples of agricultural classification by automated means is shown in the above and following illustrations (Figure 6b). A conventional black-and-white aerial photo showing the coverage obtained by the optical mechanical line scanner is presented with each figure for reference. Ground truth is marked on this photo: "W" denotes wheat and, for the included computer printouts, represents the feature to be discriminated against all other features (O = oats, S = soybeans, RC = red clover, C = corn and P = pasture. The example of printout shown above (top right) represents a preliminary greyscale output, wherein the signal responses for a particular channel of data (0.62-0.66 microns) were coded to correspond with analogous tone densities. Curvature across the line of flight is noted in this output and is caused by the relative "ground motion" and recorder speeds. Each raster element depicted above represents, for the 2000' flying altitude, approximately 10 square meters. Figure 6b represents three preliminary attempts at automatically classifying wheat. In the first example of computer printout (top right), a single channel of data was used (0.72 to 0.80 microns). All signals falling within a particular voltage interval as that exhibited by wheat "samples" were printed "W" and all others were left blank. The three main wheat fields were correctly classified, but obviously some errors occurred. In the next attempt at improving this classification (lower left), four channels of data were combined to better define the wheat signal and to consequently eliminate some of the error occurring with the use of only a single channel. Note that while much of the error has been eliminated, a few signals are still incorrectly classified as wheat. In the last example (lower right) the first authentic attempt at automatically classifying wheat, based on simple statistical probability distribution function (Gaussian) and the same four channels employed for the previous classification were again used. Note that the best classification has been obtained with this example.

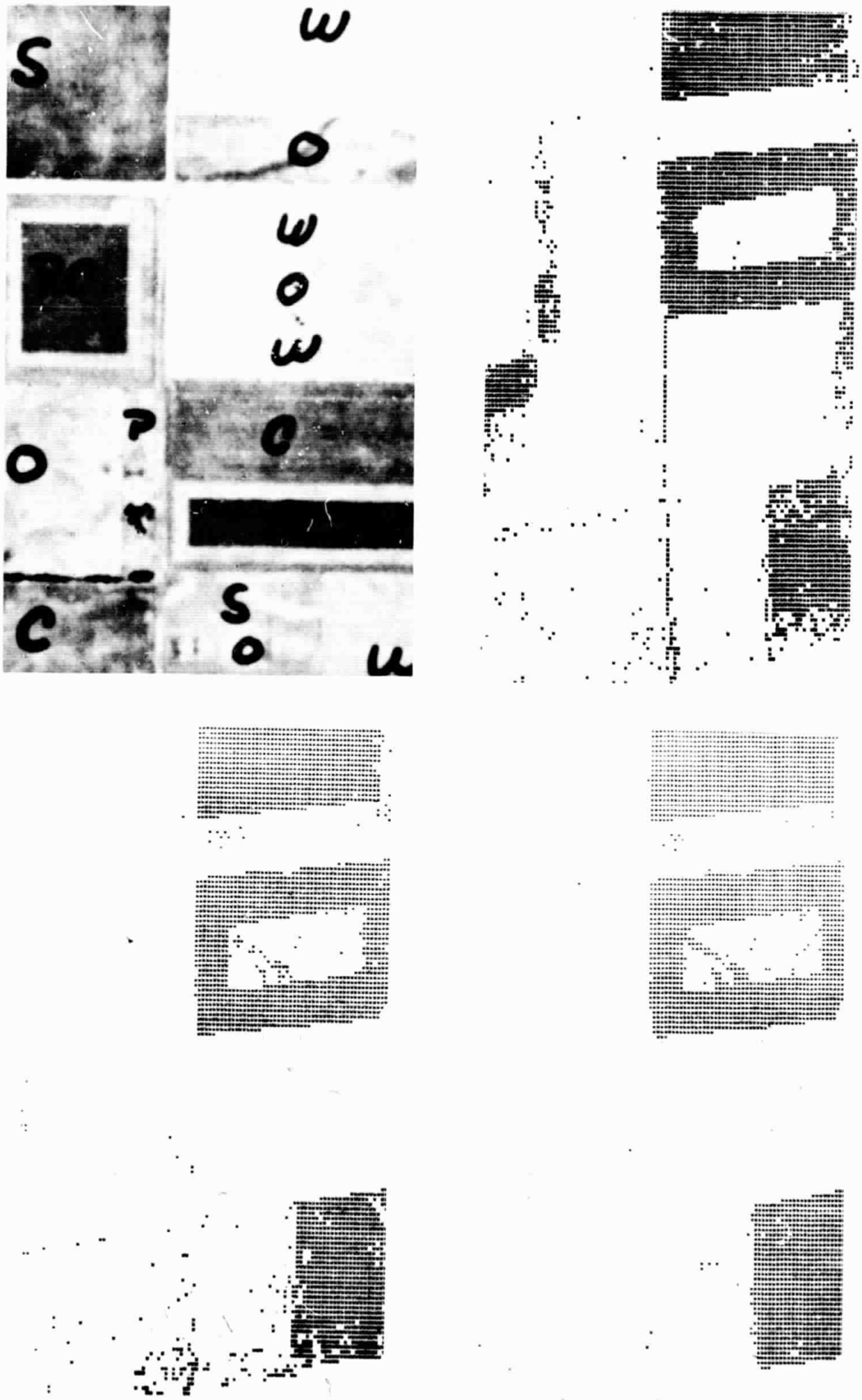


Figure 6b. Remaining examples of automated classification of wheat are shown above and discussed on the preceding page.

unsophisticated, demonstrated the automatic classification of wheat using first one channel of data and subsequently four combined channels. The processing capability has since been improved to twelve channels of "visible and near-infrared" data. The presumption in the early stages of work was that an improvement in classification could be expected by the information derived from additional channels of data. At a recent NASA briefing in Houston, Landgrebe (1968) presented interesting data which showed that "errors" in classification decreased drastically when three, four, or five channels of data were analyzed, but that with the addition of more and more channels, the error factor did not continue to decrease but rather gradually increased, suggesting that the new information was confounding the classification scheme.

3.4 Related Additional References A number of related references are listed below that were not included in the previously cited material concerning work performed at Michigan and Purdue. They are included now because they may be of interest and assistance to the reader who might be interested in developing a program using one of the many automatic interpretation approaches available to him. These references are listed alphabetically by author:

Christensen, R. 1968. A general approach to pattern discovery. Tech. Report #20, Dept. of Physics, University of California, Berkeley.

Dalke, George W. 1966. Implementation of pattern recognition techniques as applied to geoscience interpretation. Computer Contribution #7, State Geological Survey, University of Kansas, Lawrence, Kan.

Dalke, George W. Automatic processing of multi-spectral images. CRES Tech. Report #61-16, University of Kansas, Lawrence, Kansas.

Dalke, George W. 1967. Multi-image correlation systems study for MGI: phase I. Tech. Report. Contract No. DAAK 02-67-C-0435. CRES, University of Kansas, Lawrence, Kansas.

Dobrin, M. B. 1968. Optical processing in the earth sciences. I.E.E.E. Spectrum. pp 59-66.

Doverspike, G. E., F. M. Flynn and R. C. Heller. 1965. Microdensitometer applied to land-use classification. Photogrammetric Eng. 31(2): 294-306.

Gates, David M. 1964. Characteristics of soil and vegetated surfaces to reflected and emitted radiation. In: Proc. 3rd Symposium on Remote Sensing of Environment. University of Michigan, Ann Arbor, Michigan.

Gibbons, F. R., J. N. Rowan and R. G. Downes. 1968. The role of humans in land evaluation. In: Land Evaluation. Papers of a CSIRO symposium organized in cooperation with UNESCO. 26-31 August. Macmillan of Australia.

Hawkins, J. K. and C. J. Munsey. 1963. Automatic photo reading. Photogrammetric Engineering 29(4):632-640.

Hawkins, J. K. and C. J. Munsey. 1964. Photographic techniques for extracting image shapes. Photographic Science and Engineering 8(6):329-335.

Hawkins, J. K. and C. J. Munsey. 1967. Image processing by optical techniques. Jour. Optic. Soc. of America 57(7):914-198.

Hoffer, R. M., R. A. Holmes and J. R. Shay. 1966. Vegetable, soil and photographic factors affecting tone in agricultural remote multispectral sensing. In: Proc. 4th Symposium on Remote Sensing of Environment. University of Michigan, Ann Arbor, Mich. pp 115-134.

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

Holter, Marvin, R. and W. C. Wolfe. 1959. Optical-mechanical scanning techniques. In: Proc., Institute of Radio Engineers. September. pp 1540-1550.

Langley, Philip G. 1962. Computer analysis of spectrophotometric data as an aid in optimizing photographic tone contrast. In: Proc., U. S. Army E.R.D.L. Symposium on the Detection of Underground Objects, Materials and Properties. Ft. Belvoir, Va. pp 103-115.

Limperis, T. 1964. Target and background signature study. In: Proc., 3rd Symposium on Remote Sensing of Environment. University of Michigan, Ann Arbor, Mich. pp 423-434.

McLachlan, D. 1962. The role of optics in applying correlation functions to pattern recognition. Jour. Opt. Soc. of Amer. 52(4):454-459.

Nunnally, Nelson R. 1968. A comparison of microdensitometry and TV waveform analysis as expressions of observed landscape patterns on radar. Tech. Report #6 for ONR (Geog Br) Task NR389-151. Contract No. NR 4761(00) 6pp.

Rosen, C. A. 1967. Pattern classification by adaptive machines. Science 156(3771):38-44.

Rosenfeld, Azriel. 1962. An approach to automatic photographic interpretation. Photogrammetric Engineering 28(4):660-665.

Rosenfeld, Azriel. 1968. Automated picture interpretation. In: Land Evaluation. Papers of a CSIRO symposium organized in cooperation with UNESCO. 26-31 August. Macmillan of Australia.

Rosenfeld, Azriel. 1968. Picture processing by computer. Tech. Report No. 68-71. Contract No. NR 5144(00). Computer Science Center, University of Maryland, College Park, Maryland.

Steiner, Deiter and H. Haefner. 1965. Tone distortion for automated interpretation. Photogrammetric Engineering 31(2):269-280.

Steiner, Deiter and T. Gutermann. 1966. Russian data on spectral reflectance of vegetation, soil and rock types. Final Tech. Report. Contract No. DA-91-591-EUC-3863/01-652-0106. Department of Geography. University of Zurich, Switzerland.

Swain, Philip H. and D. A. Germann. 1968. On the application of man-machine computing systems to problems in remote sensing. L.A.R.S. Information Note #051368. Purdue University, West Lafayette, Ind.

Tobler, W. R. 1966. Spectral analysis of spatial series. Paper presented at the 4th Annual Conference on Urban Planning: Information Systems and Programs, Berkeley, California.

Schulman, F. D., W. Gilman, J. V. Sharp and R. L. Christensen. 1964. Optimized digital automatic map compilation system. Final Tech. Report. Contract No. DA-44-009 AMC-111(X), U.S.A.E.G.I.M.R.A.D.A.

Willow Run Laboratories (IST) 1968. Proposal for multispectral sensing and processing for agriculture. Submitted to ARS, USDA. 29 May 1968. University of Michigan, Ann Arbor, Michigan.

Witmer, Richard E. 1967. Waveform analysis of geographic patterns recorded on visible and infrared imagery. Tech. Report #4 for ONR (Geog Br) Task NR 387-034. Contract No. NR 4761(00) 225pp.

4.0 The N.A.S.A. Bucks Lake Forestry Test Site Study Area

4.1 Location and General Description The official N.A.S.A. Forestry Test Site (viz., Test Site #20), located in Plumas County, California, is shown in Figure 7. This site, covering about 120 square miles of diverse terrain conditions and uses, ranges from 3800' elevation at Meadow Valley to 7200' elevation at the highest point. The entire area has been mapped recently for geological structures by personnel at the University of Nevada under a separate N.A.S.A. contract (Slemmons, Tafuri and Ballew, 1966).

Timber is one of the primary economic resources in the Meadow Valley Working Circle; five major tree species are found in this mixed-conifer region: Ponderosa pine (*Pinus ponderosa*), White fir (*Abies concolor*), Douglas fir (*Pseudotsuga menziesii*), Sugar pine (*Pinus lambertiana*), and Incense cedar (*Libocedrus decurrens*). Other tree species of interest in this area include Jeffrey pine (*Pinus jeffreyi*), Red fir (*Abies magnifica*), Lodgepole pine (*Pinus contorta*), and a number of hardwood species including California Black Oak (*Quercus kelloggii*). Other vegetation in the area is quite diverse, reflecting in turn the great diversity of soil types present. Many varieties of brush species are present and while they may be commercially unexploitable, they nevertheless represent important resources in terms of watershed protection, wildlife forage and habitats, understory seedling habitats, and to a certain extent, soil indicators. Water resources are another important feature in this area. A hydroelectric storage reservoir is provided by Bucks Lake itself which can be regulated by power needs. Numerous other lakes and streams in the area provide for recreation resources in the form of fishing, boating, waterfowl hunting, hiking and swimming. Meadow sites, located at

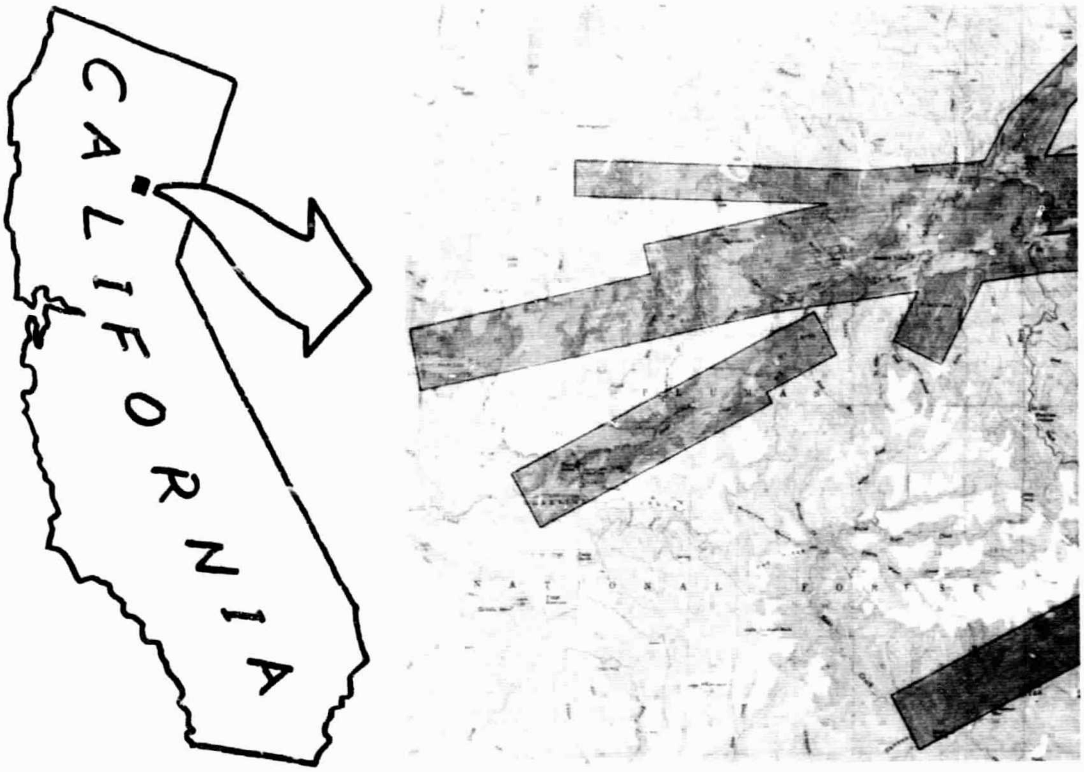


Figure 7. A portion of the N.A.S.A./Forestry Test Site is illustrated by the above map showing its northern California location. Areas which were scanned and recorded during the 1966 mission using the Michigan M-5 optical-mechanical line scanner are outlined. Both early morning and late afternoon flights are included on the map. Only the data obtained in late afternoon were analyzed in this paper, however, since they appeared to have better signal records than those of the early morning flight. The strip of recorded imagery along the southern edge of Bucks Lake was selected for intensive study from which "training samples" could be isolated and used for distinguishing similar terrain types in the other imaged areas.

the lower elevations near Meadow Valley, provide grazing for domestic animals to a certain extent during the Spring and early Summer months. Further resources exist in this area and detailed photographic studies have been conducted by personnel at the University of California for the N.A.S.A./U.S.D.A. Forestry Remote Sensing Laboratory, Berkeley, California which demonstrate the usefulness of photography and other imagery for making preliminary resources evaluations of an area (see Carneggie, 1966; Lauer, 1967; Draeger, 1968).

4.2 Coverage Obtained of the Bucks Lake Forestry Test Site by the 1966 University of Michigan Multichannel Line Scanner Mission

Approximately sixty miles of flight lines--outlined in Figure 7--were imaged of the Bucks Lake Area during the 1966 mission with the C-47 borne Michigan M-5 multichannel line scan radiometer. This imagery was collected on two separate flights and at two very different times of day. Table 4.1 lists some of the flight information for data collected over the Bucks Lake Test Site:

Table 4.1: Summary of 1966 Multichannel Scanner Flight Data of the Bucks Lake Test Site

Date	No. Tapes: 7 Channels/ 14 Channels	Approximate Overflight Time (start)	Altitude Above Terrain	Surface Weather Condition
5-19-66	1/1	1700	2000'	Clear, 21°C
5-20-66	3/3	0630	2000'	Clear, 18°C
9-20-68*	1/1	1100	3500'	Clear

*Imagery was recently collected over the Bucks Lake Test Site with the Michigan optical-mechanical line scanner under contract to a southern California aerospace company; the flight lines are not plotted in Figure 7 because they are not yet known to the author. The two 1968 flight lines, which total twenty-four air miles of imagery, are mentioned here because of their potential usefulness in making comparisons with identical areas flown in 1966. Communication with the project monitor in charge of the 1968 data has been made and a means for cooperative effort established.

All five of the fourteen-channel analog tapes have been duplicated at the Willow Run facility and sent to L.A.R.S. for A/D conversion and subsequent processing. Figure 8a illustrates a portion of the flight line along the southern tip of Bucks Lake (see Figure 7) derived from the filmstrip printouts of all eighteen channels of line-scan data. The spectral wavelength interval for each strip is indicated in the upper left corner. This particular strip of terrain was selected from which "training samples" could be chosen. Ground truth information is most intensive for this portion of the data.

4.3 Detailed Description of Important Terrain Features

The features of interest in the study area selected for "training samples" readily fell into several broad categories of classification. Initial efforts in automated interpretation for this study were directed toward making these primary distinctions; more refined distinctions were attempted with several types where it was deemed important to do so. The broad categories for classification used in this study were: Timber, Brush, Water, Bare/Rock, Meadow, and Other (e.g., cultural features). Each of these categories is discussed in detail with illustrative material where it is required. Figure 8b consists of a diagrammetric "spot-map" indicating the location of the ground photos of these terrain features which comprise Figure 9 through Figure 14.

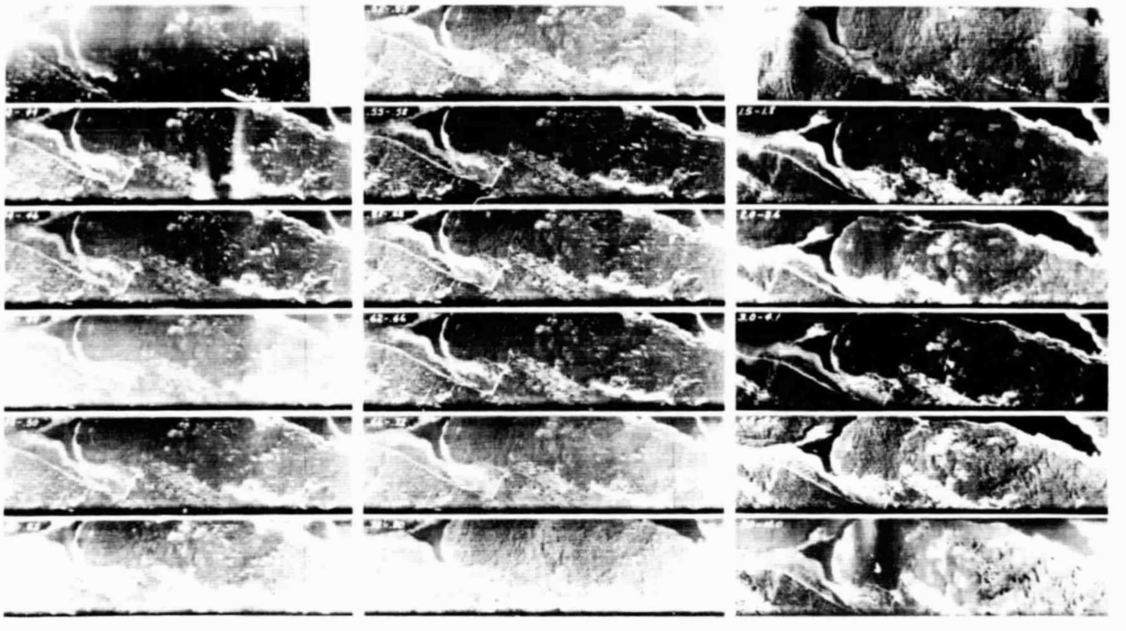


Figure 8a. Eighteen channels of filmstrip printout are illustrated above. These were derived from the CRT display of data at the southern tip of Bucks Lake (see Figure 7). The wavelength interval is indicated in microns in the upper left corner of each printout. While all eighteen channels are presented here, it should be noted that only twelve of the channels of data (i.e., those in the visible and photographic IR region of the spectrum) are suitably compatible for analysis with the L.A.R.S. pattern recognition program. This is because the five thermal IR channels and the one UV channel are not adequately synchronized with the remaining data channels to allow consistent addressing of specific data points. Each of the twelve synchronized channels appears in the Appendix with overlays of significant features.

GROUND PHOTOS SPOT MAP for figures 9 through 19

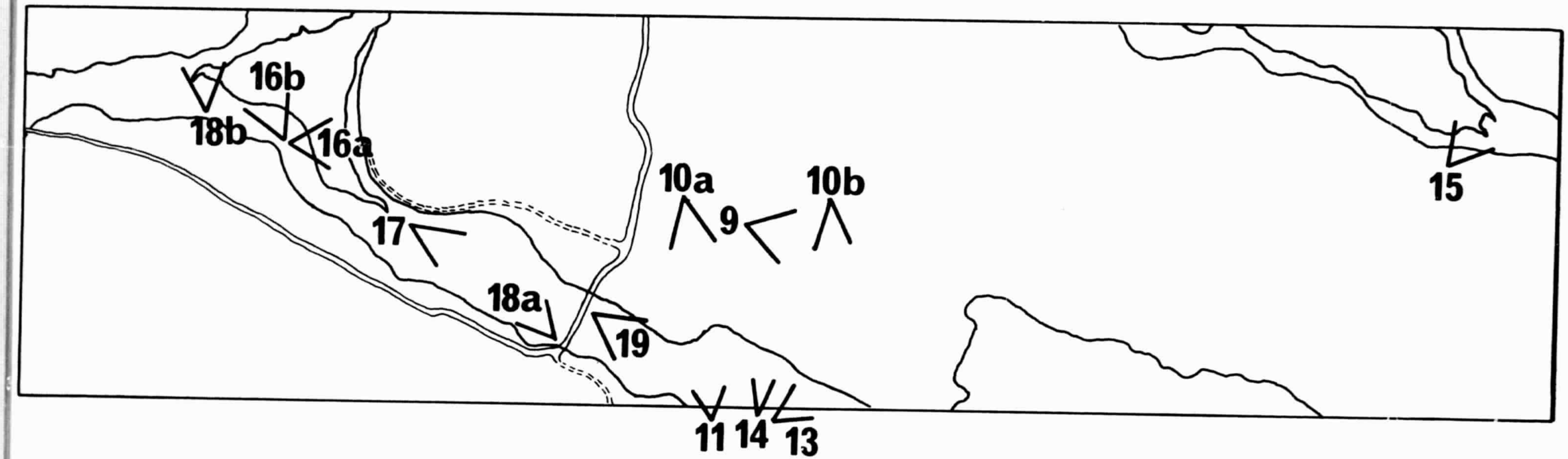


Figure 8b. Locations of terrain features of interest which were photographed on the ground are shown in the above diagram. These sites were deemed typical in appearance (reflectance) for these various types throughout the entire Bucks Lake Test Site. Figure 12 is not located in the above diagram since it was selected for a site which appears a few miles to the east of the area shown above. Line scan printouts are included with this figure, however, so that its appearance can be noted.

Figure 9. Category: Timber

The above illustrations are representative of some of the commercial timber sites in the Meadow Valley Working Circle. These particular stands are composed predominantly of White fir (Abies concolor) and show evidence of previous and current logging operations. When such stands are unlogged they appear relatively dense from an aerial viewpoint, with few unnatural openings. Their dense and pointed crown structure, combined with the low sun angle at time of data recording, results in a coarse textured, mottled appearance as seen on both the line scan filmstrip printout and conventional photography. Individual tree canopies are observed to blend together more in the thermal IR channels (e.g., see 8-14 micron channel in Appendix).

Figure 10a. Category: Timber/Brush

Where openings exist in timbered sites, the resultant terrain signal recorded by the line scan sensor can vary considerably, depending on such factors as slope, size of opening, condition of opening, etc. In the above ground photo illustration, the openings within the gently sloped timber stand contain a dense cover of Bracken fern (Pteridium aquilinum) which is usually a reliable indicator of a favorable timber growing site (i.e., a relatively deep soiled, well-drained mesic condition). The ground cover composition is rarely such that this vegetation type can be recorded individually in hopes of breaking it out into a classification category, however. Because of the low sun angle at time of data recording during the 1966 mission, shadows resulted in line scan data that indicated less reflectance and/or cooler conditions than that of the tree canopies themselves. At a higher sun angle (and therefore greater insolation intensities) this condition would have reversed itself).

Figure 10b. Category: Timber/Brush

The above photo illustration reveals a timber-brush composition (and consequently a signal recording) different from that of Figure 10a. This site is much steeper than the previous site; the ground condition is more diverse, being composed of several brush species (principally Ceanothus spp.) and bare areas. A water basin appears in the foreground above, indicating a stream or spring nearby. By referring to any of the line scan data channels appearing in the Appendix, one can determine that spatial resolution is too poor to enable accurate identification of a water body of this size. Terrain conditions similar to these appearing in the foreground can be observed in the timber stand on the far ridge, at a reduced scale.

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Figure 11. Category: Timber/Meadow

Numerous meadow sites, intermixed with commercial and non-commercial timber stands, exist in the study area. Shown above is a typical timber/meadow site located near the southeast tip of Bucks Lake. Several timber species are commonly found on such sites, including hardwood types, though only two coniferous species are evident above: namely, White fir and Lodgepole pine. The particular site exhibited above is relatively dry at the surface, although subsurface moisture is present. Lodgepole pine is indicative of moist sites. Some Willow (Salix spp.) is seen on the right hand portion of the photo. The meadow itself has a very smooth and uniform texture on the line scan filmstrip printouts (see Appendix). Some very high infrared reflectance is noted particularly in the .72-.80 micron channel of data.

Figure 12. Category: Brush

The appearance of dense brushfields as seen on line scan data prints is illustrated by the bottom two images of this figure. A ground photo of the same region is shown at the top. These brushfields contain a variety of different species; however, the brushfields cannot be distinguished on the line scan prints as other than smooth, uniform textured areas (for a tone signature analysis of these data, see Draeger, 1968). Clearings in the brushfields have been artifically made to prepare the area for tree planting. Note that these brush conversion operations have a characteristic appearance on all of the above illustrations. The site is favorable for timber growing and can be made to produce a commercial stand of timber with proper management practices.

Figure 13. Category: Brush/Timber

Dense stands of manzanita (Arctostaphylos spp.) can be seen in the above illustration along the ridge top. White fir is present on the lower slopes and Lodgepole pine can be seen in the foreground lowlands. This terrain and that of the following illustration can be examined on the enlarged line scan prints included in the Appendix. The views are oriented looking from the center bottom of the print in a northeasterly direction for the scene above, and in a northwesterly direction for the following scene (see Figure 14).

Figure 14. Category: Brush/Timber. Another view looking across the lowland meadow in Haskins Valley to the timbered ridge in the background. Moist sites in the meadow are indicated by the predominance of large willow (Salix spp.) stands as seen in the foreground, as well as the scattered Lodgepole pine trees in the meadow. The willow here resembles brushfields in texture when viewed on the line scan prints in the Appendix. High near-infrared reflectance can be seen on several channels of data where large willow thickets exist (see channels 12 and 13).

Figure 15. Category: Brush/Bare Soil

A dense brush cover above the shoreline of Bucks Lake is seen in this illustration. A considerable amount of whitethorn (Ceanothus cuneatus) is present on this slope above a very bright reflecting granitic shoreline. This area can be compared with its corresponding tone response on the line scan imagery enlargements in the Appendix; the area seen above appears at the extreme upper right-hand corner. The roadcut just above the waterline is also distinguishable on most of the data channels. Again, note the smooth textured appearance of this brushy slope and how closely it resembles that of the other brushfields in the region, even though it is considerably different in species composition from them.

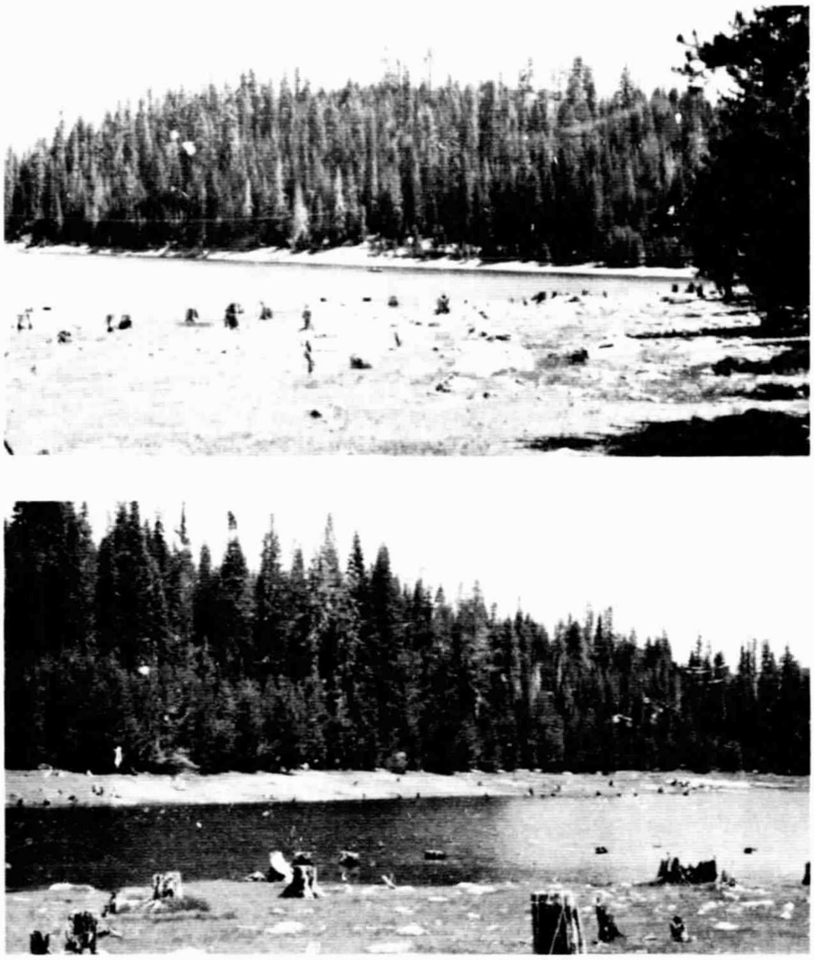


Figure 16. Category: Water/Timber

Large water bodies are readily identified on the line scan prints. In the above two illustrations, the importance of this area as a recreational site and a storage reservoir is indicated. Mixed timber species can be seen in the top photo (a) and distinguished on the basis of crown shape and color differences; in the lower photo (b) signatures of young stands of timber can be compared with those of taller stands. The shoreline in this region of the lake (i.e., the southernmost extremity of Bucks Lake) contains grasses and forbs which results in a different sensor record than that obtained over bare shoreline.

Figure 17. Category: Bare Rock. The bright reflecting feature seen on the first eleven channels of line scan prints (along the stream entering the south tip of Bucks Lake) is illustrated in the above panoramic ground photo. Gravels and cobbles form a terrain feature along the stream flowing through the meadow area which is readily distinguished in these first eleven channels; however, this feature "vanishes" completely in channel #12. The bright patches at the lower right edge of line scan data for this channel are easily distinguished from bare rock and are known to be snow patches.

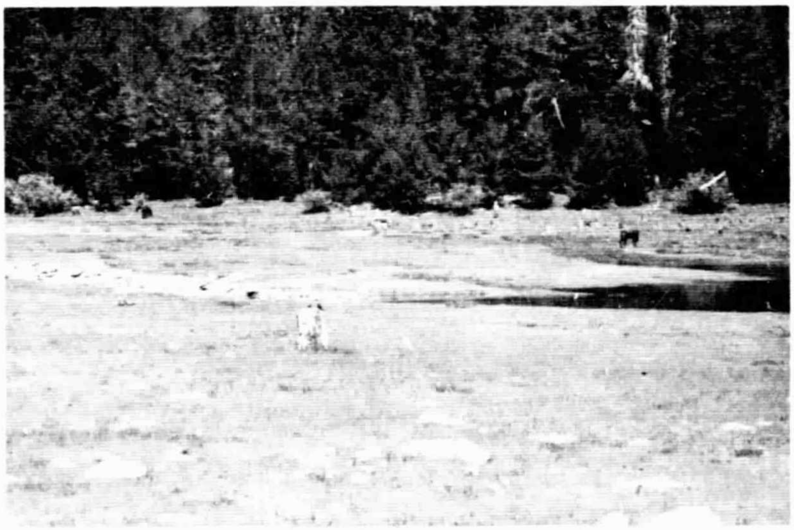


Figure 18. Category: Meadow

The two illustrations above, obtained within a mile of each other, depict differences in cover composition. These differences are most likely attributable to different moisture regimes in the two sites. The top photo (a) depicts a site which is considerably less moist than that depicted in the lower photo (b). In the lower photo, the presence of domestic livestock highlights a potential importance of forage as a valuable resource.

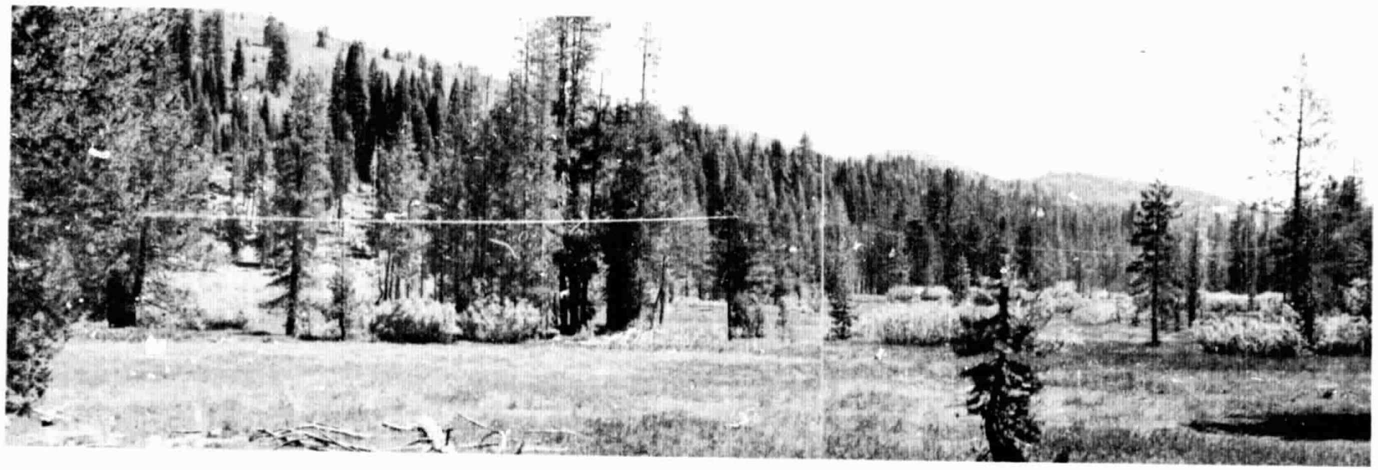


Figure 19. Category: Mixed Types. In this last illustration of terrain features to be automatically distinguished and classified, most of the types presented in the previous photo views are shown above in one panoramic scene. The variability associated with differences in slopes, differences in vegetative densities, the effect of moisture on species composition, the textural pattern associated with different vegetative communities, etc., are all suggested in this one ground photo. The preceding terrain feature photos have been included in this paper in order to familiarize the reader (short of a personal visit) with the region of study and the various terrain features of interest.

5.0 Procedure For Automatic Terrain Feature Classification

5.1 Preliminary Investigations. Some preliminary work was done on multispectral tone signature analysis using film densities obtained over wildland features in the Bucks Lake Test Site. Various terrain features were stratified into different categories and tone density values were measured from negatives of both conventional aerial photography and the Michigan line scan filmstrips. These initial efforts were performed in an attempt to evaluate these "indirect" techniques and compare different data sources for automating certain portions of the overall data analysis task. Figure 20 outlines specific areas within the Bucks Lake Forestry Test Site from which extensive densitometer data were collected. The procedure for this tone density analysis consisted of the following steps:

a) Obtaining the multi-channel imagery. Site #1, outlined in Figure 20, depicts the area of coverage of a selected strip of line scan data from which densitometer values could be measured upon the filmstrip negatives. All eighteen channels of data were subsequently measured on the 1966 film records of this strip. Site #2, outlined in the upper right hand corner of Figure 20, depicts the area of coverage obtained through the use of a specially designed four-lens multispectral camera developed by personnel at Long Island University. This latter mission was flown in the summer of 1967; the data derived from that mission represents the current state-of-the-art in terms of calibrated multispectral photography. Four film-filter combinations were flown. A single film emulsion (nine-inch wide roll magazines) was used throughout the photographic experiment in conjunction with special spectral filters which enabled the recording of bandwidths in the blue, green, red, and near-

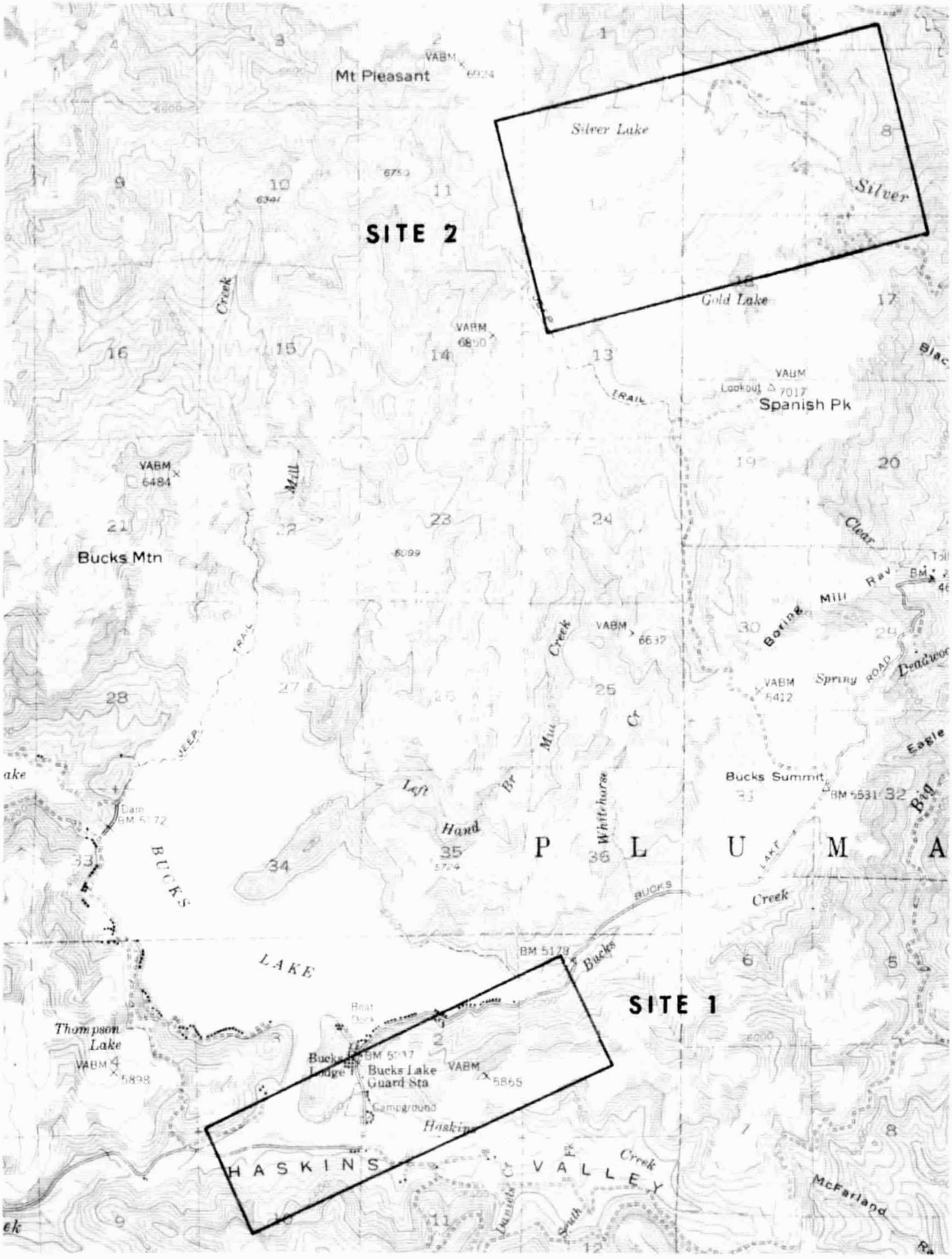


Figure 20. Portion of the Bucks Lake Test Site showing location of two areas for which film emulsion densities were analyzed. Data from Site #1 were measured from 18-channel scanner imagery; data from Site #2 were measured from multispectral photography obtained from a specially designed 4-lens camera developed by personnel at Long Island University.

infrared (photographic) portions of the electromagnetic spectrum Black-and-white infrared film was used in order to obtain sensitivity in the near-infrared part of the spectrum. Each of the other band records relied upon standard Wratten gelatin type filters used in conjunction with a special IR cutoff filter which nullified the high sensitivity exhibited beyond the 700 millimicron range.

b) Selecting terrain features of interest for identification and classification. Within each of the two test sites shown in Figure 20, several terrain features were selected for densitometer measurement. For the strip of line scan data designated as Site #1, some fifteen different terrain types were measured:

Site #1 Terrain Types

1. Water bodies
2. Granitic shoreline
3. Conifer stand (mixed)
4. Conifer stand (Lodgepole pine)
5. Brush Stand (S aspect)
6. Brush/Timber mix
7. Snow patches
8. Bare/Brush mix
9. Brush stand (N aspect)
10. Streambed gravels
11. Paved roads
12. Riparian vegetation
13. Meadow vegetation (moist)
14. Meadow vegetation (dry)
15. Vegetated shoreline

For the aerial photography covering the area designated as Site #2 in Figure 20, eleven terrain types were selected for measurement, namely:

Site #2 Terrain Types

1. Water bodies
2. Granitic outcrop
3. Hardwood stand (Black oak)
4. Meadow vegetation (moist)
5. Meadow vegetation (dry)
6. Hardwood stand (White alder)
7. Brush stand (open)
8. Talus slope
9. Brush stand (dense)
10. Conifer stand (dense, young)
11. Conifer stand (dense, old)

c) Measuring tone densities from these two sources of data. The procedure for measuring tone densities directly from the film negatives involved the use of a Welch Densichron. The 18-channel film strips were of such size (i.e., 35mm wide) as to made measurement considerably more difficult. In fact, with the available aperture sizes, which ranged from 1.0 microns to 3.5 microns, it was deemed impossible to obtain accurate measurements of terrain type #11: Paved roads. Because of the heterogenous character of many of the terrain features--in both Site #1 and Site #2--as large an aperture size as possible was used in measuring densities in order to gain a more typical density value of the feature as it appears on the negative. If smaller size apertures were used, the chance of obtaining densities which were more indicative of shadows or adjacent features would be increased. This method of analyzing terrain features is therefore presented as one in which considerable variability exists as a function, not so much of the data itself, but of the variability attributable to human judgment. The negatives measured for Site #2, because they were larger in format and had greater spatial resolution, enabled values to be obtained which were more reliable, since features could be more distinctly defined and measured.

d) Calculating correlations between the data channels and between the film-filter combinations. To determine the relative similarity of tone responses exhibited between the line scan data channels or between the four film-filter combinations, a simple Pearson's correlation coefficient was calculated. This statistic shows how the tone density for the various terrain features is related between the different negatives. A high correlation coefficient indicates a high degree of similarity in relative density responses between the respective terrain features recorded on each data channel or film-filter combination. Note that a constant, or near constant, factor in one set of tone densities which are being correlated with another, does not change, appreciably, the correlation coefficient. Consequently, a high Pearson's correlation coefficient can result, though graphically the two sets of data points may appear to be quite unrelated. This is important to realize, especially if such an analysis were to be performed with "uncalibrated" data, since a shift in the photo development process (or an uncontrolled shift in analog recorder gain settings) can result in data records which are displaced from their true values. Table 5.1 lists the Pearson's correlation coefficient calculated for each possible pair of data channels for Site #1 terrain features.

The spectral bandwidths of the 18-channel data are listed below for reference to Table 5.1.

Channel #1:	0.32 - 0.38u	Channel #10:	0.62 - 0.66u
Channel #2:	0.40 - 0.44u	Channel #11:	0.66 - 0.72u
Channel #3:	0.44 - 0.46u	Channel #12:	0.72 - 0.80u
Channel #4:	0.46 - 0.48u	Channel #13:	0.80 - 1.0u
Channel #5:	0.48 - 0.50u	Channel #14:	1.5 - 1.8u
Channel #6:	0.50 - 0.52u	Channel #15:	2.0 - 2.6u
Channel #7:	0.52 - 0.55u	Channel #16:	3.0 - 4.1u
Channel #8:	0.55 - 0.58u	Channel #17:	4.5 - 5.5u
Channel #9:	-.58 - 0.62u	Channel #18:	810 -14.0u

The data from which the correlation coefficients were derived are listed in the Appendix. Table 5.2 lists Pearson's correlation coefficients for the photographic tone densities measured at Site #2. Film-filter combinations used to photograph this site were: IR-47B, IR-58, IR-25A and IR-89B. The first three combinations also had special "IR cutoff" filters for proper scene recording necessary to carry out the objectives of the experiment. Three sets of correlations were computed for Site #2

Table 5.1

Pearson's Correlation Coefficient for 18 Channels of Data

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1/	1.0	.92	.95	.99	.98	.96	.95	.92	.93	.95	.98	.70	.68	.60	.62	.55	.75	.66
2/		1.0	.97	.94	.96	.99	.99	.99	.99	.99	.94	.59	.60	.77	.83	.74	.80	.70
3/			1.0	.96	.98	.98	.98	.97	.96	.96	.96	.70	.67	.68	.75	.64	.62	.47
4/				1.0	.99	.98	.97	.95	.95	.97	.99	.75	.74	.77	.79	.69	.79	.71
5/					1.0	.99	.99	.97	.96	.98	.99	.72	.71	.74	.80	.69	.73	.61
6/						1.0	.99	.99	.99	.99	.98	.68	.68	.78	.80	.69	.76	.68
7/							1.0	.99	.99	.99	.98	.68	.68	.83	.84	.74	.76	.65
8/								1.0	.99	.99	.96	.68	.68	.86	.83	.75	.77	.68
9/									1.0	.99	.95	.60	.60	.81	.79	.69	.74	.66
10/										1.0	.97	.64	.64	.81	.80	.69	.77	.71
11/											1.0	.75	.74	.86	.82	.79	.67	.73
12/												1.0	.97	.20	.42	19	.11	.09
13/													1.0	.35	.61	.41	.08	.40
14/														1.0	.87	.32	.73	.69
15/															1.0	.92	.71	.67
16/																1.0	.85	.76
17/																	1.0	.92
18/																		1.0

data. Terrain types were first grouped into vegetated and non-vegetated categories; a third set of correlations is listed for the combined groups.

Table 5.2

Pearson's Correlation Coefficients for Site #2 Terrain Types

Set I: Non-Vegetated Category (Terrain types #1, #2 and #8)

IR-47B	IR-58	IR-25A	IR-89B
1.0	0.94	0.93	0.81
	1.0	0.99	0.96
		1.0	0.97
			1.0

Set II: Vegetated Category (Terrain types #3, 4, 5, 6, 7, 9, 10 and 11)

IR-47B	IR-58	IR-25A	IR-89B
1.0	0.90	0.72	0.08
	1.0	0.73	0.24
		1.0	0.26
			1.0

Set III: Combined Terrain Types

IR-47B	IR-58	IR-25A	IR-89B
1.0	0.92	0.88	0.21
	1.0	0.92	0.03
		1.0	0.20
			1.0

The data from which these correlation coefficients were derived are reproduced in the Appendix.

Some elementary comments can be made about the data presented in Table 5.1 and 5.2 and how they relate to automated terrain classification schemes. First, it should be pointed out that data sampling to determine a feature's tone density is highly dependent upon human judgment and variability. The technique of measuring specific data points, as was performed for the analysis presented herein, is very time-consuming. A technique for automatically scanning pre-determined transects on the film is possible which will yield data such as those seen in Figure 21. Here again, the procedure is relatively slow and the amount of data converted to potential information is exceedingly high. Video scanning systems are available which increase tremendously the scan time, and generally reduce the total data conversion. Figure 4 contains an example of this technique.

Second, it can be seen from these rudimentary data that information derived from the near-infrared (photographic) and thermal infrared portions of the electromagnetic spectrum is of considerable use in distinguishing certain terrain types. The low correlation coefficients calculated between these data channels (or the one film-filter combination) and their counterparts in the visible part of the spectrum indicates the strong disparity of tone responses. The high correlations between data channels (and the three film-filter combinations) in the visible portion of the spectrum seem to suggest that tone densities of wildland terrain features do not differ significantly between these bands. This may be due to the density measuring technique and the data smoothing effect of the Densichron aperture sizes used. The tone density response exhibited by live healthy foliage accounts for a considerable amount of density differences between the visible and infrared data records.

The scanning microdensitometer data records (such as those in Figure 21) can be readily converted to digital data for subsequent analysis similar to the type of records upon which the L. A. R. S. data handling system operates. However, the original imagery would require considerable scanning time to approximate that of reducing analog radiance records to digital format.

5.2 Application of L. A. R. S. Pattern Recognition Program to Wildland Features. Several problems were anticipated and possible solutions to them considered in preparing to use the L.A.R.S. pattern recognition program for the identification and classification of various wildland resources.

First, the features to be identified and classified from a wildland environment were judged to be more complex in structure and appearance to the "sensor's eye" than agricultural crop types. These agricultural resources (and their related features such as bare ground and irrigation ditches) are sufficiently uniform structurally from point to point within cultivated units that variations in the radiant signal--whether it be recorded on film emulsion or magnetic tape--are generally less than those expected from uncultivated terrain. When the signal variation for a particular feature is small, the likelihood of its being discriminated from other neighboring features (or backgrounds) is increased. While detailed in situ ground feature spectra were not recorded for analytical purposes in this paper (primarily because it is felt that such spectra generally are not

Figure 21. On the following four pages are separate illustrations of aerial photographs with an optical density scan trace presented below each. These aerial photographs, obtained by personnel at Long Island University using an optically matched 4-lens multispectral camera, allow digital data to be collected, indirectly, of various terrain types present along the scan line. The scanned trace was performed automatically using a General Aniline Scanning Microdensitometer with graphical readout. Note that such traces yield a tremendous amount of data when digitized; some form of "curve smoothing" is necessary to define a typical signal response from any particular feature (the "Lake" has been highlighted for reference).

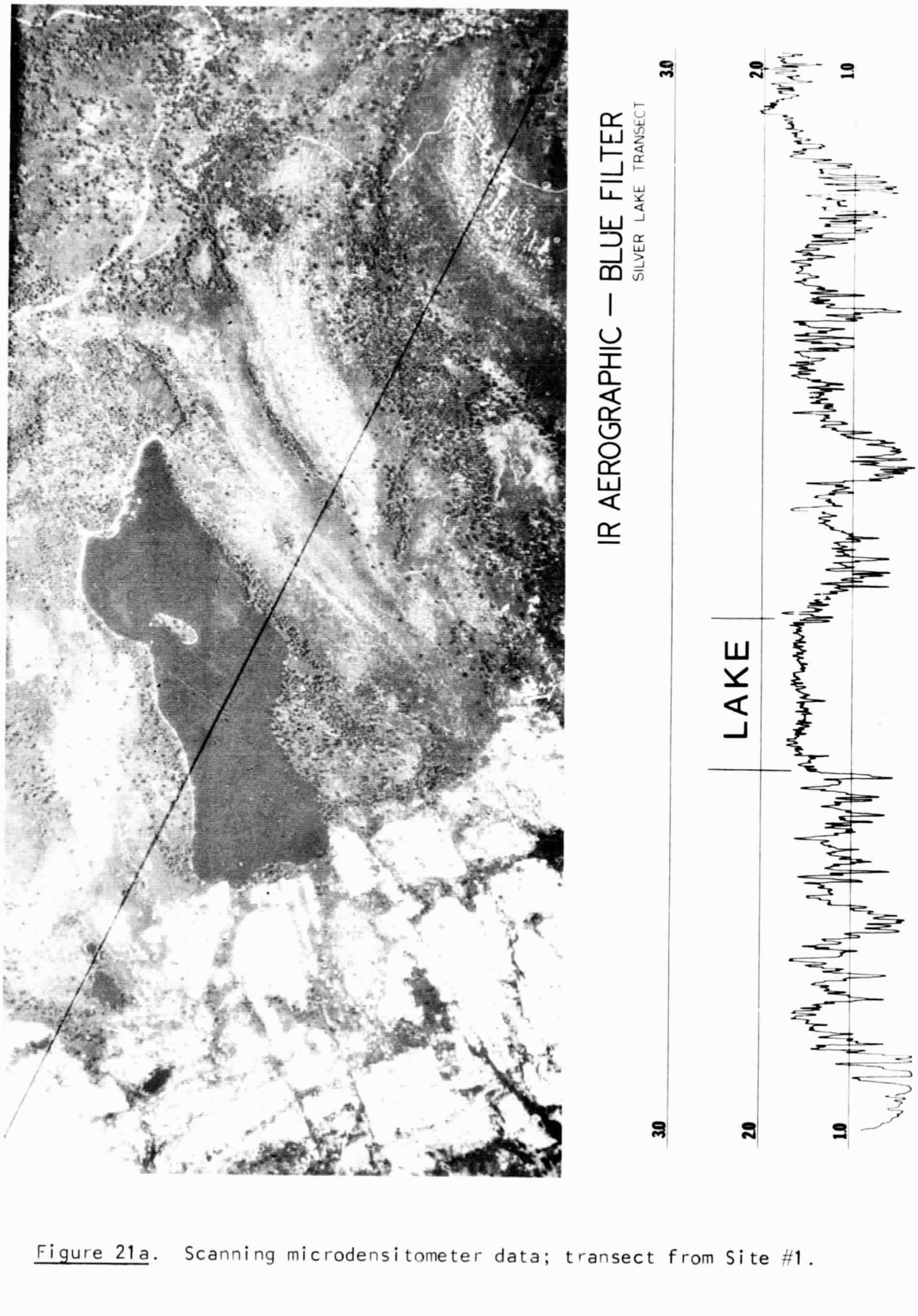


Figure 21a. Scanning microdensitometer data; transect from Site #1.

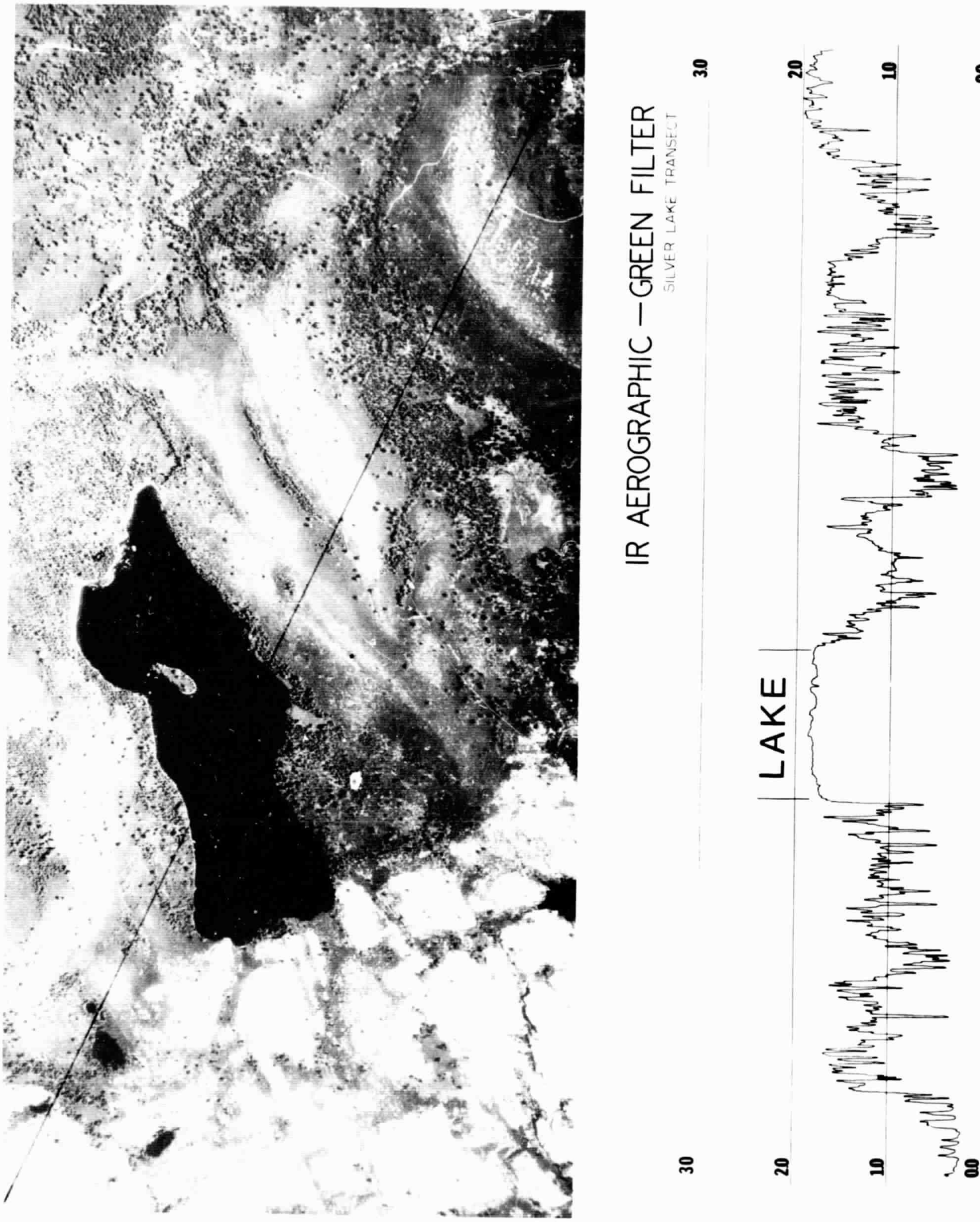


Figure 21b. Scanning microdensitometer dat; transect from Site #1.

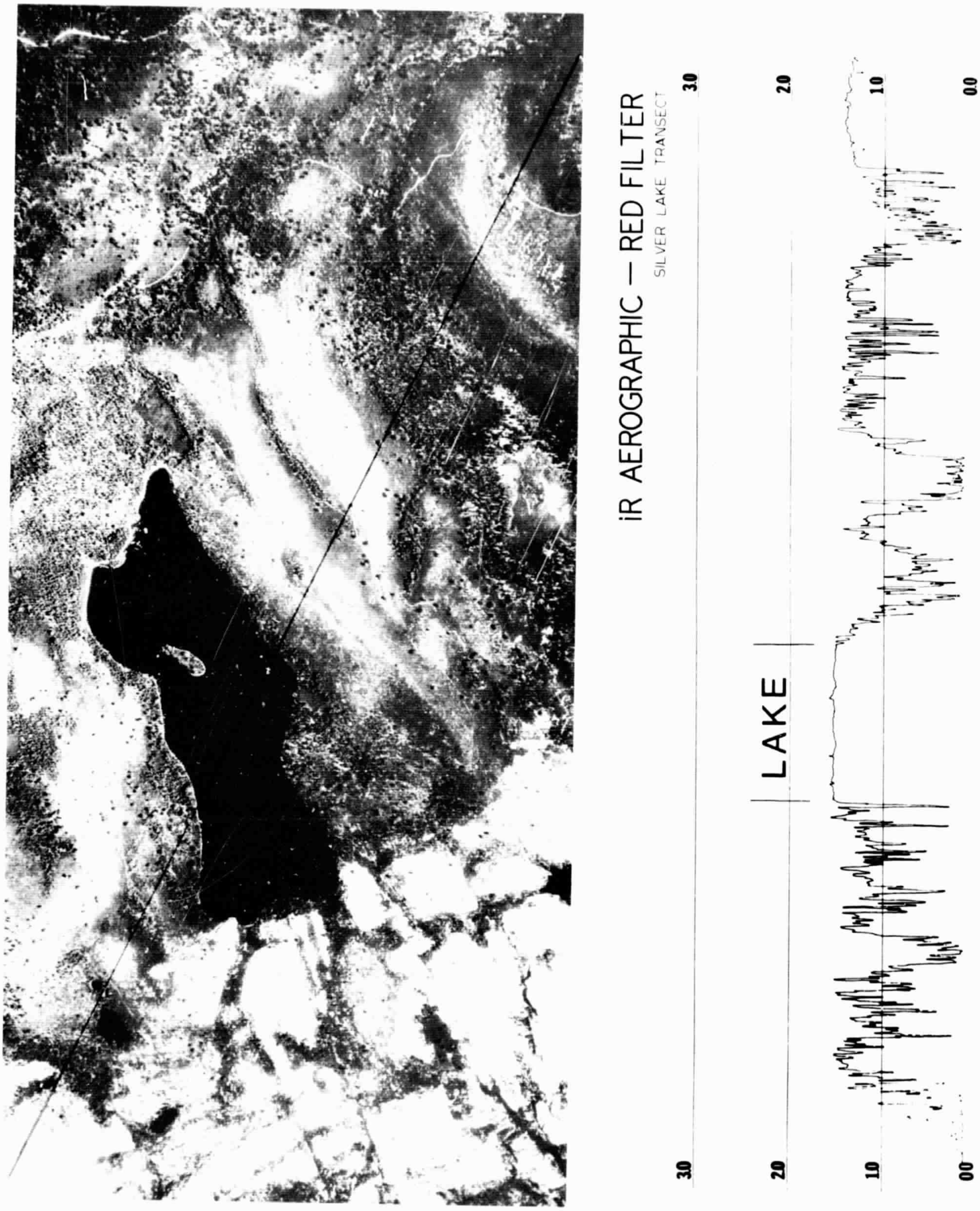


Figure 21c. Scanning microdensitometer data; transect from Site #1.

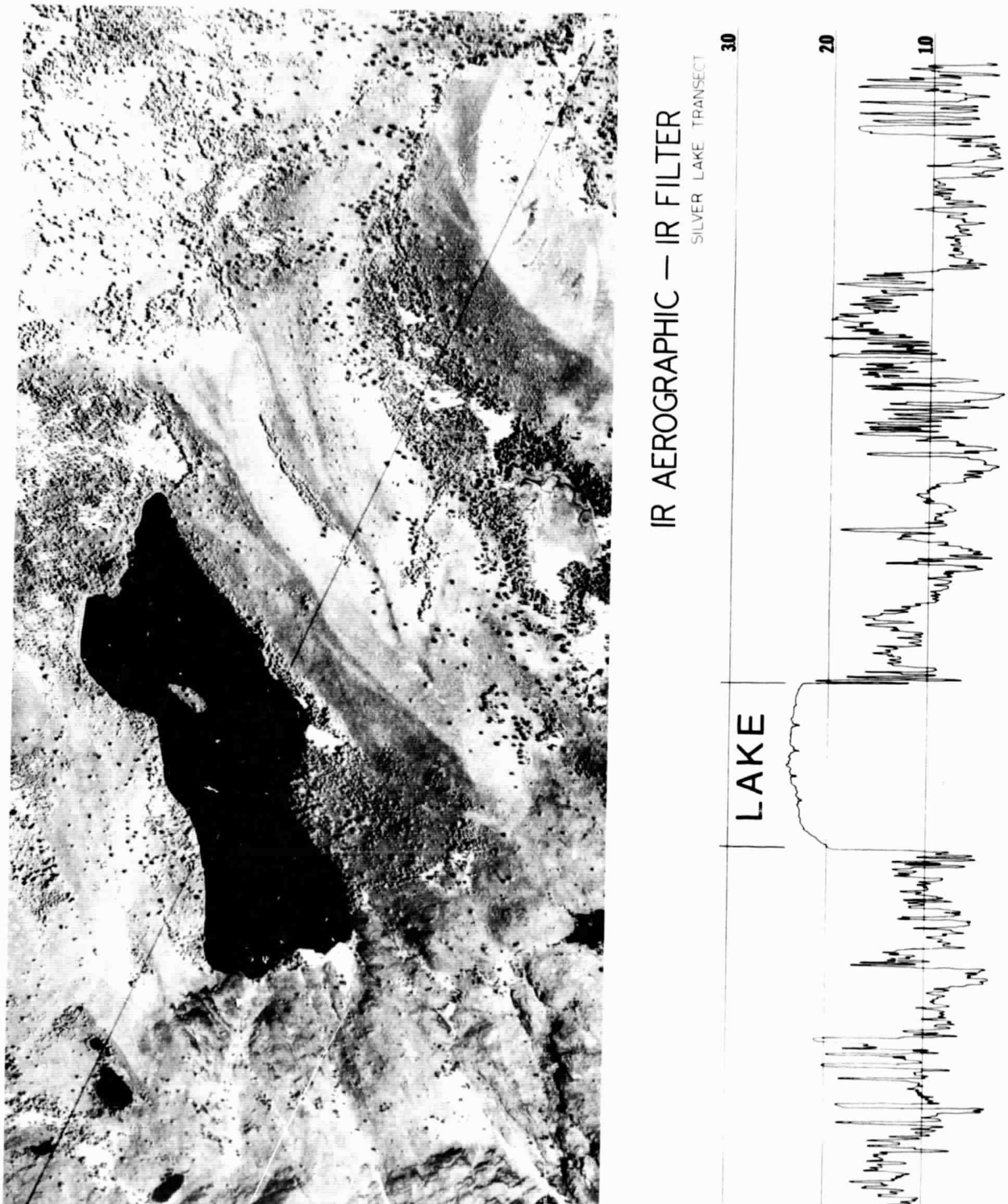


Figure 21d. Scanning microdensitometer data; transect from Site #1.

meaningfully obtainable with current measuring devices), it was observed that feature reflectance variation exhibited by the scanning micro-densitometer data presented in Figure 21 was relatively high. Figure 22 contains a flight line diagram of line scan coverage upon which the wildland features of interest have been superimposed. These feature delineations were made from type maps derived from conventional color aerial photography flown two weeks after the 1966 Michigan line scan mission.

Second, it was further observed, by examining the photographic portion of Figure 21, that not only were the individual terrain features generally intermixed and rather complex in structure but also their reflected signal response appeared to be significantly influenced by topographic characteristics. Consequently, the stratification of wild-land resource types within the area of study included categories which incorporated topographic relief. Figure 23 depicts this stratification based on topographic categories.

Finally, it was felt that, owing to the late afternoon time of data collection and recording, sun angle would significantly influence reflectance characteristics. Therefore, this last stratification based on aspect was included in the analysis. Figure 24 depicts this information diagrammatically; also included in the lower portion of Figure 24 is a composite stratification of all three of the foregoing category maps. It clearly shows the complex nature of the combination of terrain types, topographic relief and aspect stratifications. Figure 25 shows one channel of line scan data from the 1966 mission with three clear acetate overlays which were used in the selection of training samples.

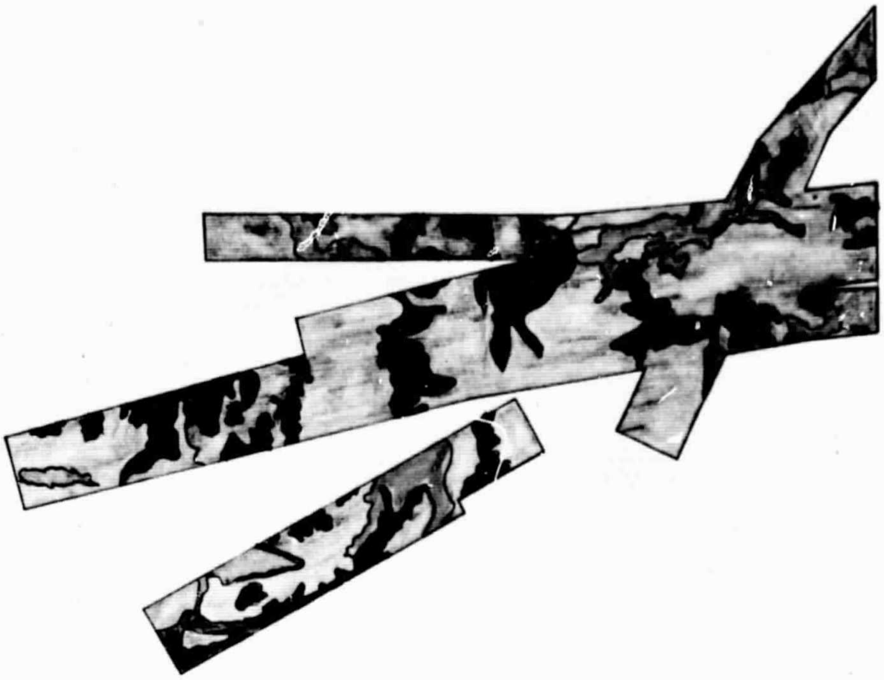


Figure 22. Terrain type delineations are noted in the above diagram of the 1966 Michigan line scan data. These type delineations were made from high altitude conventional color aerial photography obtained within two weeks of the 1966 mission. Six types have been delineated and color coded above.

Type I - Brush, oak. Coded red and comprises 12% of flight lines.

Type II - Coniferous forests. Coded grey and comprises 63% of area.

Type III - Understocked area. Coded orange and comprises 11% of area.

Type IV - Bare ground, rock. Coded yellow and comprises 7% of area.

Type V - Water bodies. Coded blue and comprises 4% of area.

Type VI - Meadow, riparian. Coded green and comprises 3% of area.

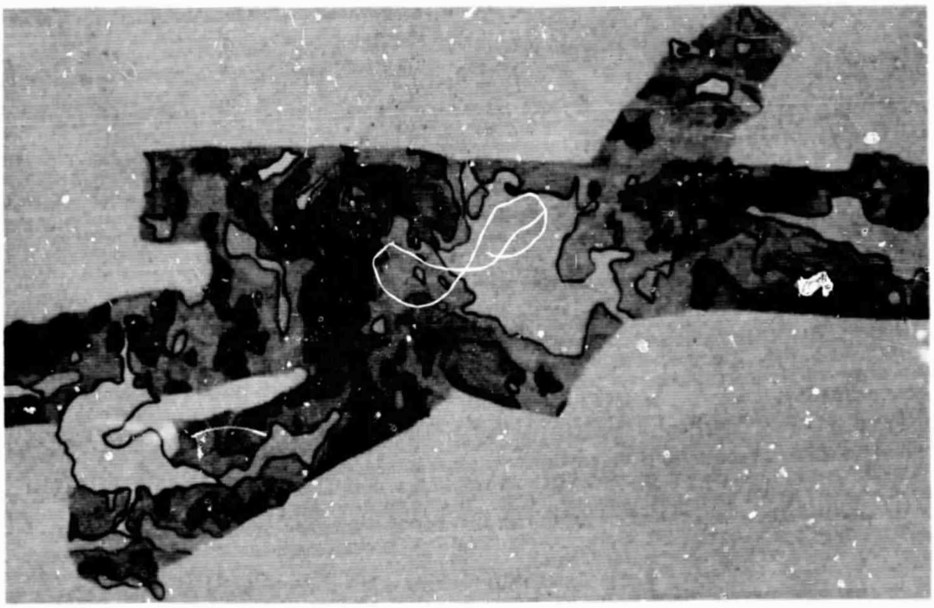
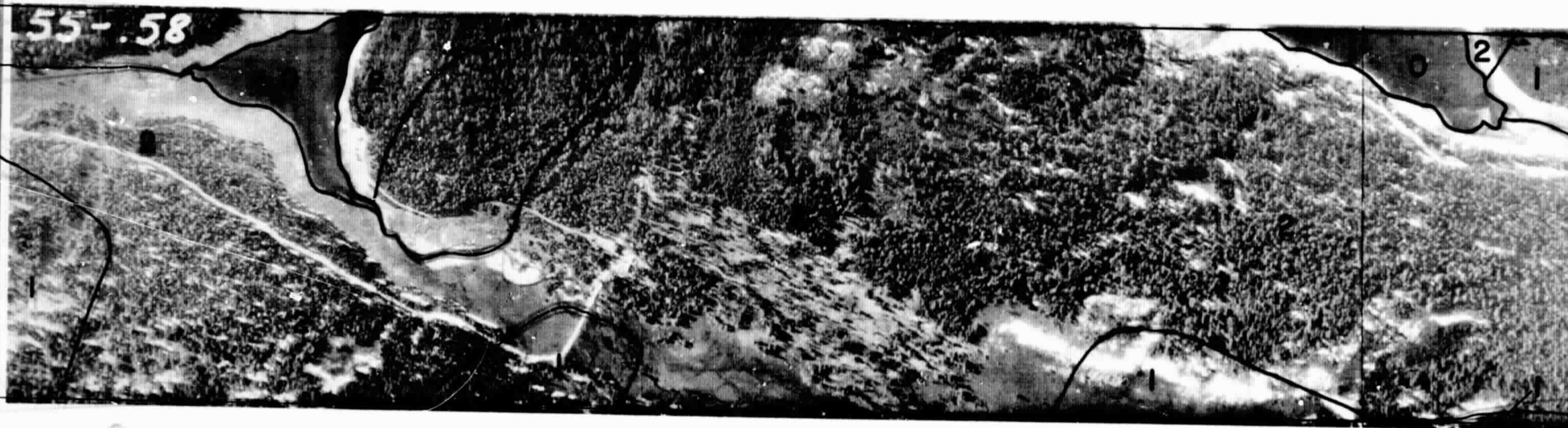


Figure 23. Topographic stratifications are noted in the above color coded diagram. These stratifications were made from topographic maps employing a dot grid system for coding regions of equal slope. The categories are:

(water bodies)	Grey	0° slope	4% of area
	Blue	$0 - 6^{\circ}$ slope	22% of area
	Green	$6 - 15\%^{\circ}$ slope	43% of area
	Yellow	$15 - 25\%^{\circ}$ slope	27% of area
	Red	$25 - 35^{\circ}$ slope	3% of area
	Violet	$35 - 40^{\circ}$ slope	less than 1% of area

Figure 24. The two diagrams above complete the stratification of types and characteristics within the flight lines of recorded data. The top diagram denotes east-west aspects as mentioned in the text; the lower diagram represents a composite of the three stratifications (terrain types, topographic relief and aspect) specially coded in three digit labels to correspond to the three stratifications.

SLOPE ASPECT



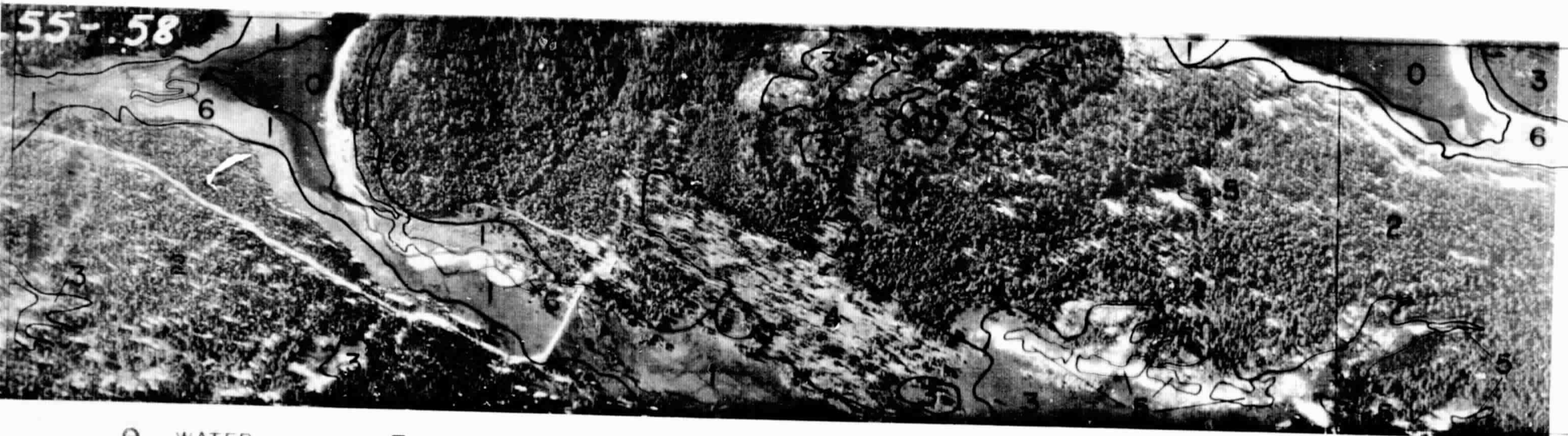
0 WATER 1 EAST 2 WEST

SLOPE CLASSES

0	WATER	3	15° to 25°
1	0° to 6°	4	25° to 35°
2	6° to 15°		

05-A

VEGETATION TYPES



0	WATER	3	BRUSH	6	BARE GROUND
1	MEADOW	4	TIMBER & BRUSH		
2	TIMBER	5	SNOW PATCHES		

65-B

6.0 Results.

6.1 First Computer Printouts of Feature Classification. The first computer printouts of digitized line scan data were received from L.A.R.S. on December 17, 1968. Two strips of data were digitized comprising approximately 300 seconds of recorder imagery. Three channels of data were printed of each strip for viewing purposes and for the selection of subsequent training samples. These channels were: channel 1 (.40 - .44 microns), channel 9 (.62 - .66 microns), and channel 11 (.72 - .80 microns). Figure 26 contains two of these output channels (viz., channels 9 and 11) from a portion of the total digitized data. While no attempt at identification of various terrain features was possible with this first printout effort, it is apparent from viewing the greyscale output of Figure 26 that the regions where ground truth information is available can be readily scanned following the appropriate selection of training samples.

These greyscale preliminary printouts--so-called because printer codes are selected which approximate equivalent radiance levels--were printed with eleven density levels. The total range of radiance in digital format can be expressed from 0 to 256 in sixteen intervals. The intervals chosen for the greyscale printouts are arbitrarily selected after "viewing" the data during A/D conversion. The channels selected for printout in this fashion have been found from previous work to best simulate the tone responses which might be viewed photographically. The combination of visible channels with the near infrared channel provides the added feature of cross referencing when a particular point or terrain feature is not adequately separated on the basis of printer density in one channel or another.

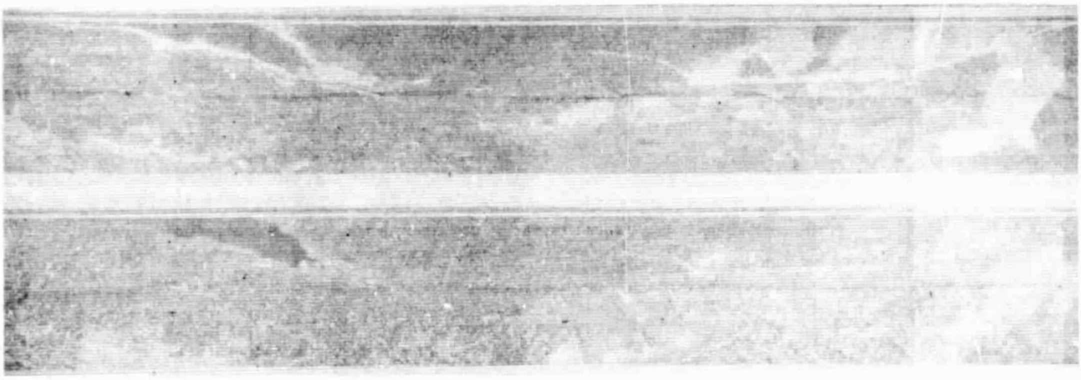


Figure 26. Two computer printed channels of linescan data are illustrated above, following an arbitrary selection of digital codes used for printing the relative radiance levels of terrain features. The two channels shown above are: upper, channel 9 (.62 - .66 microns) and lower, channel 11 (.72 - .80 microns). Note, by comparing these computer printed illustrations with the filmstrip printouts of Figures 8a and 12, that certain features can be located with reasonable accuracy. Since ground truth was obtained with care to location of the various species and other features, the coordinate location of representative signal responses from them can be analyzed and statistical tests performed to identify and classify similar features in other portions of the flight. The selection of training samples and the subsequent performance of the statistical tests are currently being conducted with members of the L.A.R.S. staff and the results will appear in upcoming progress reports and in the 1969 annual report.

6.2 Continuing Analysis. The continuing efforts to determine the feasibility of automatically identifying and classifying wildland features from digitally recorded data will consist of the selection of training samples from the two strips of preliminary printouts and the test of these training samples against known fields of data. The training samples will consist of four or five samples per terrain feature; each sample contains approximately one hundred contiguous data elements in square or rectangular plots. These training samples are currently being selected and the information about their location within the digital printouts will be transmitted to L.A.R.S. for subsequent coding and processing. Several trips to the Purdue facility are anticipated in the near future to work directly with members of the staff, principally Dr. Roger Hoffer. The results of these further studies of identification and classification will be presented in the upcoming quarterly progress reports and 1969 annual progress report.

7.0 Conclusions.

From the discussions shared with members of the L.A.R.S. staff, and after studying the preliminary greyscale printouts, it is felt that reasonable success in automatically identifying and classifying the various terrain features found in the Bucks Lake Test Site can be achieved. The analog data recorded in the late afternoon 1966 mission appear to be sufficiently "clean" to enable the L.A.R.S. pattern recognition program to be tested. It still remains to be seen whether the effects of topographic relief and aspect will be as significant as anticipated. Should these variables prove to be important enough to include in the total analysis, the burden of providing adequate ground truth will be increased tremendously from that of merely identifying features of interest. An administrator of NASA recently commented: "In the areas of agriculture, forestry and geology the principle need now is for improved identification of the signature of various species". (Newell, H. E., 1968). While this is certainly a true statement, it should be emphasized that the obtaining of the signature by recorded techniques plays an important role in the eventual identification of that signature--especially when automated means are required to reduce the data to meaningful information.

8.0 Literature Citations.

Following are the literature citations specifically referenced in previous sections of this paper. They are arranged alphabetically by section heading.

SECTION 1.0

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

Colwell, Robert N., W. Brewer, G. Landis, P. Langley, J. Morgan, J. Rinker, J. Robinson and A. Sorem. 1963. Basic matter and energy relationship involved in remote reconnaissance: Report of Subcommittee I, Photo Interpretation Committee. Photogrammetric Engineering 29(4):761-799.

Colwell, Robert N. and Jerry D. Lent. 1967. A test of the concept and practical applications of multiband reconnaissance. Final Report on NASA Grant NGR/05-003-080. 75 pp.

Holter, Marvin R. 1968. Private communication, 6 August 1968.

Lintz, Joseph, Jr. 1968. Overview of remote sensing. In: Proceedings of Remote Sensing of the Environment, 807.4. Two-week short course, August 5-16, 1968. University of California, Los Angeles. 1-49 pp.

SECTION 2.0

Hindmarsh, A. E. 1967. The world food problem. Lockheed Missiles and Space Co., Sunnyvale, Calif. 24 pp.

President's Science Advisory Committee. 1967. The World Food Problem. 3 Volumes. Washington, D.C.

SECTION 3.0

Anonymous. 1962. Principles of a natural image computer. DDC publication # AD 421667. Washington, D.C.

Anonymous. 1966. Unpublished rough draft of preliminary report to NASA, prepared by staff at L.A.R.S., Purdue University, Lafayette, Indiana.

Cheng, G. C., R. S. Ledley, D. K. Pollack, A. Rosenfeld. 1968. Pictorial pattern recognition. Thompson Book Co., Washington, D.C. 521 pp.

Colwell, Robert N., G. A. Thorley, W. C. Draeger, D. T. Lauer. 1965. A multispectral photographic experiment based on a statistical analysis of spectrometric data. Final Report, NASA Grant NGR/05-003-080. 138 pp.

Dakin, D. R., C. D. Bartky, P. G. McManigal, D. G. Piper. 1968. Aerial photographic energy model. Tech. Report AFAL-TR-68-136. 195 pp.

Goodyear Aircraft Corp. 1962. Electronic correlation techniques for target recognition. Final Report GER-10449. Akron, Ohio.

Hoffer, Roger M. 1967. Interpretation of remote multispectral imagery of agricultural crops. L.A.R.S. Research Bulletin No. 831. Purdue University, Lafayette, Indiana.

Landgrebe, David A. 1968. Progress report of research presented to NASA officials. NASA/MSC Houston, Texas. 17 September 1968.

Landgrebe, David A. and Staff. 1967. Automatic identification and classification of wheat by remote sensing. L.A.R.S. Information Note 21567, Research Progress Report 279. Purdue Univ., Lafayette, Indiana.

Langley, P. G. 1961. Can forest photo-interpretation be automated? In: Proceedings, American Society of Photogrammetry, Columbia River Section. 17-24 pp.

Langley, P. G. 1965. Automating aerial photo-interpretation in forestry--how it works and what it will do for you. In: Proceedings, American Society of Photogrammetry, Detroit, Michigan 172-177 pp.

Lowe, Don S. 1968. Line scan devices and why use them. In: Proceedings of 5th Symposium on Remote Sensing of Environment. University of Michigan, Ann Arbor, Michigan. 77-101 pp.

Lowe, Don S. and John G. N. Braithwaite. 1966. A spectrum matching technique for enhancing image contrast. Applied Optics 5(6):893-898.

Roetling, P. G. 1962. Study of spatial filtering by optical diffraction for pattern recognition. DDC publication # AD 275817. Washington, D.C.

Rosenfeld, Azriel. 1962. Automatic recognition of basic terrain types from aerial photographs. Photogrammetric Engineering 28(1):115-132.

SECTION 4.0

Carneggie, David M. and R. N. Colwell. 1966. The use of high altitude color and spectrozonal imagery for the inventory of wildland resources: volume III, the soil, wat', wildlife, and recreation resource. Final Report for Earth Resources Survey Program OSSA/NASA. 42 pp.

Carneggie, David M., W. C. Draeger and D. T. Lauer. 1966. The use of high altitude color and spectrozonal imagery for the inventory of wildland resources: volume I, the timber resource. Final Report for Earth Resources Survey Program, OSSA/NASA. 41 pp.

Draeger, William C. 1968. The interpretability of high altitude multispectral imagery for the evaluation of wildland resources. Annual Progress Report for Earth Resources Survey Program OSSA/NASA. 71 pp.

Lauer, Donald T. 1967. The feasibility of identifying forest species and delineating major timber types by means of high altitude multispectral imagery. Final Report for Earth Resources Survey Program, OSSA/NASA. 108 pp.

Slemmons, David B., W. Tafuri and G. Ballew. 1966. Geology of the Bucks Lake, California NASA remote sensing test site. Tech. Report #5, NGR 29-001-015. MacKay School of Mines, University of Nevada, Reno, Nevada. 13 pp.

SECTION 7.0

Newell, H. E. 1968. Current program and considerations of the future for earth resources survey. In: Proceedings, 5th Symposium on Remote Sensing of Environment. University of Michigan, Ann Arbor, Michigan. 69-76.

9.0 Appendix

9.1 Statistical Aspects of the L.A.R.S. Pattern Recognition System.

"Pattern recognition", as discussed in the text, embodies a realm of study which has several approaches. The approach employed at L.A.R.S. involves a decision making operation which classifies a pattern on the basis of comparisons of feature characteristics with those of a reference set of patterns. The reference set of patterns, as used in this study, is defined by the judicious selection of "training samples" chosen within various terrain features of interest.

Generally, the pattern recognition designer must often use subjective rationale in the selection of characteristics which define a particular feature. This rationale is usually based upon prior experience with the particular terrain types within which he is working. On the basis of these selected characteristics, the problem of determining the "best" decision or classifying schemes are subsequently examined. The input for the pattern recognition program is the particular pattern (set of radiance signals within data channels used in the analysis) to be identified and classified. The output from the pattern recognition program is a set of coded sheets which correspond with the best-decision printouts of features examined. The statistical aspects which lead to these best decisions should be such that modifications are possible in order to insure a flexible system.

Let C_1 be the radiant output (i.e., Characteristic) of a particular feature recorded in Channel 1, C_2 in Channel 2, ..., C_n in Channel n where n in this study is a maximum of twelve. The ordering of these features forms a measurement vector $C = (C_1, C_2, ..., C_n)$ and on the basis of this measurement vector, the decision is made as to which terrain feature vector it most closely resembles. There are many ways the actual decision can be arrived at with respect to determining which category a particular pattern most closely resembles; the statistical decision making function described herein, which, for lack of information regarding a better one, is based on probability density functions. For each category of interest, a set of likelihood ratios can be computed, which indicate the relative probabilities that a set of characteristics in question belongs to the category of interest rather than to any of the alternatives. For example, if $X_1, X_2, \ldots, X_N$ constitute a feature sample from a multivariate normal distribution, the maximum likelihood estimates of the mean and covariance matrix can be shown to be the sample mean and the sample covariance matrix. This would apply to each feature of interest being examined. The decision rule for classification is determined if the conditional probability of X given X from the feature of interest is largest. Stated in equation form,

$$L_{feature(i)}(X) = -(X - M_{feature(i)})^T \cdot C^{-1}_{feature(i)} \cdot (X - M_{feature(i)}) - Log_e \cdot \left| C_{feature(i)} \right|$$

where M is the mean, and T denotes "transpose".

The decision is made in favor of category "i" over category "j" if,

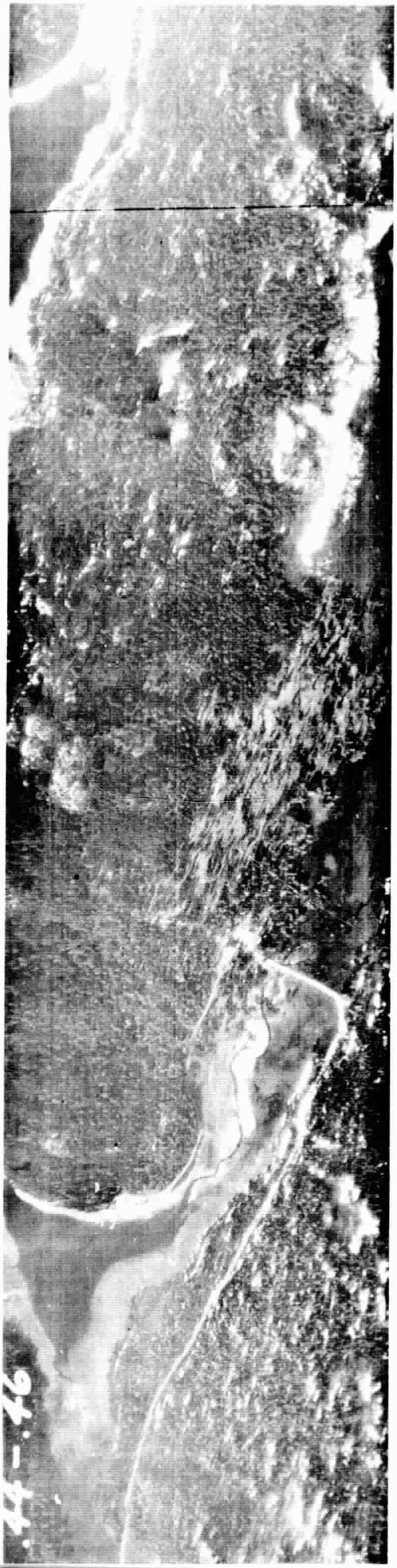
$$L_{feature(i)}(X) > L_{feature(j)}(X), \text{ etc.}$$

A more complete discussion of this decision making process and the rationale behind it can be found, along with some agricultural crop classification results, in a previously cited reference (Anonymous, 1966).

9.2 Enlargements of 18-Channel Line Scan Filmstrips From a Portion Of The 1966 Mission. Photo enlargements of the eighteen channels of imagery comprise the following eighteen pages of illustrations. These are the same prints that appear in Figure 8a.

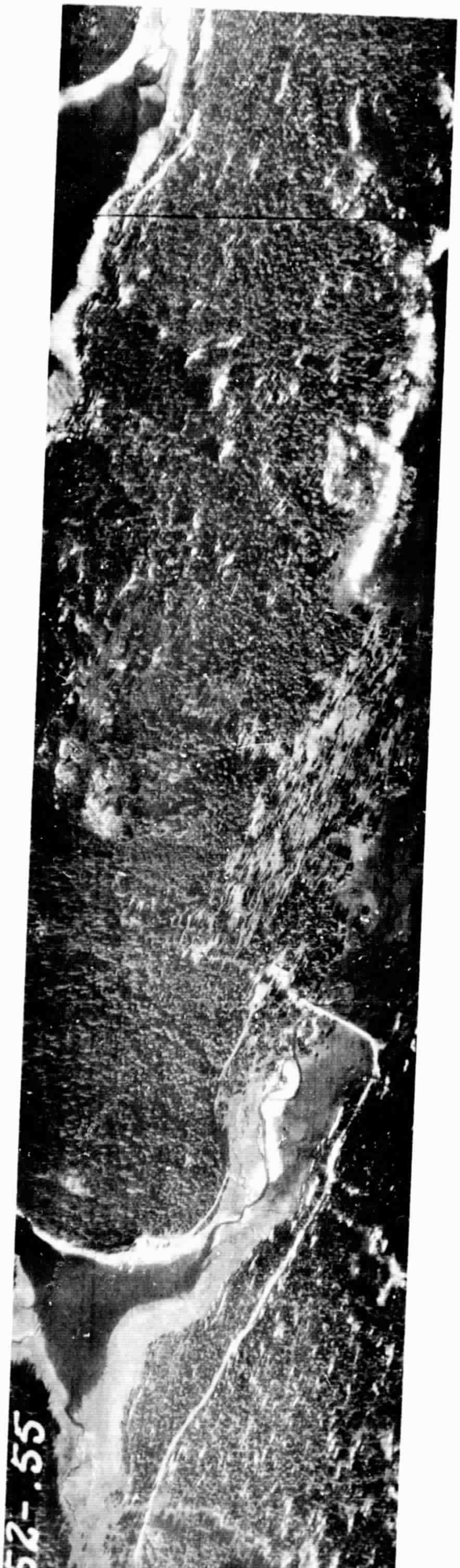

32-38


40-11


44-46


48-50


50-52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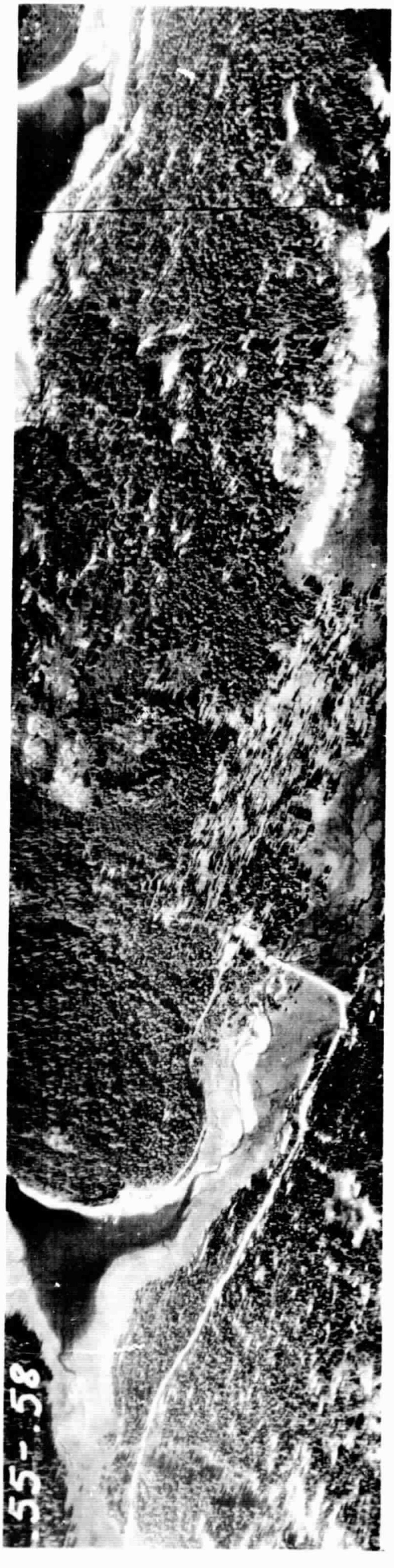
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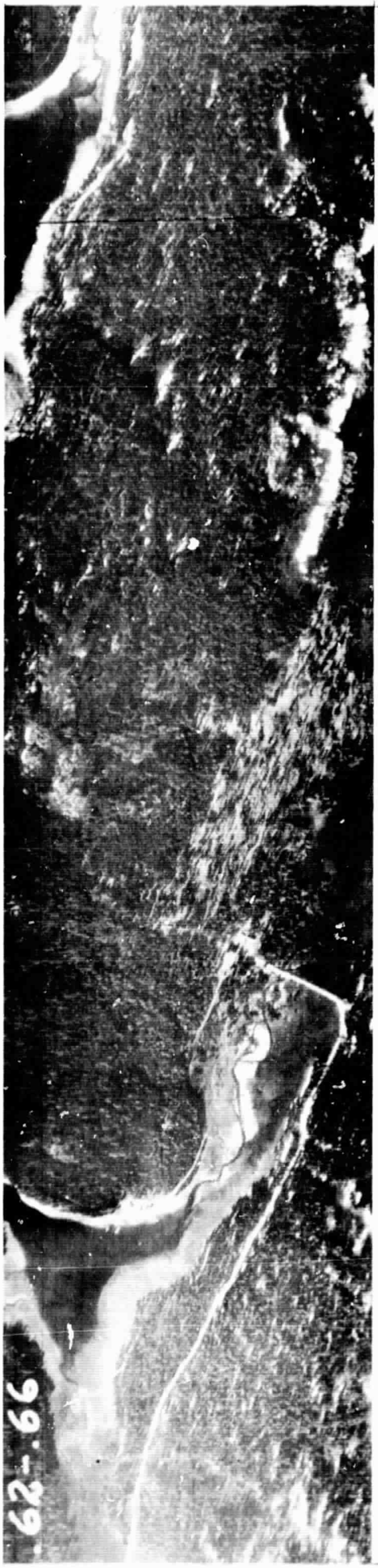
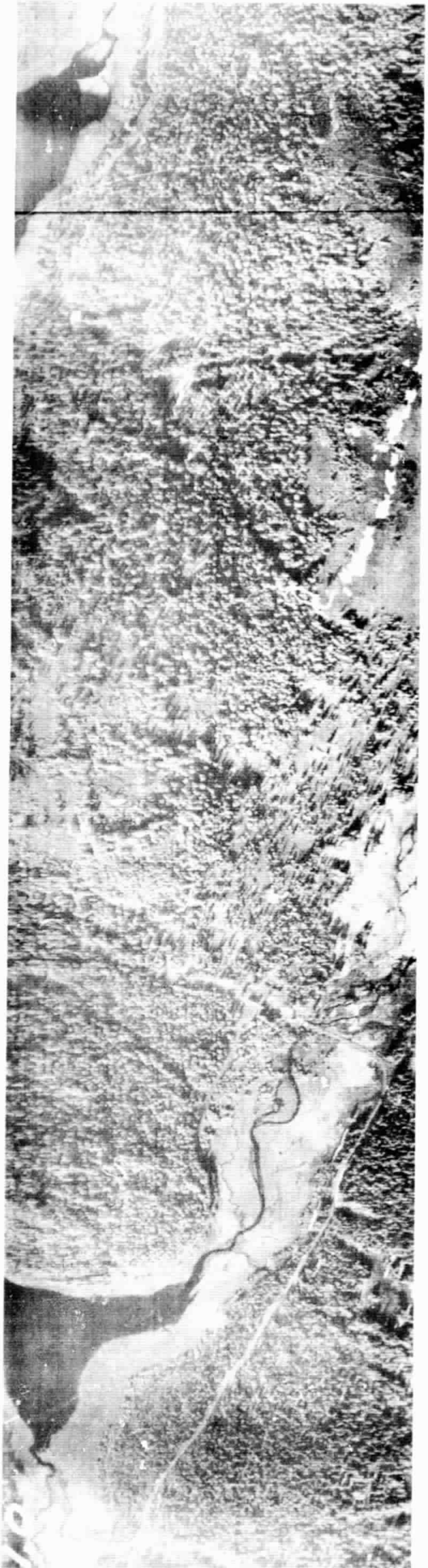
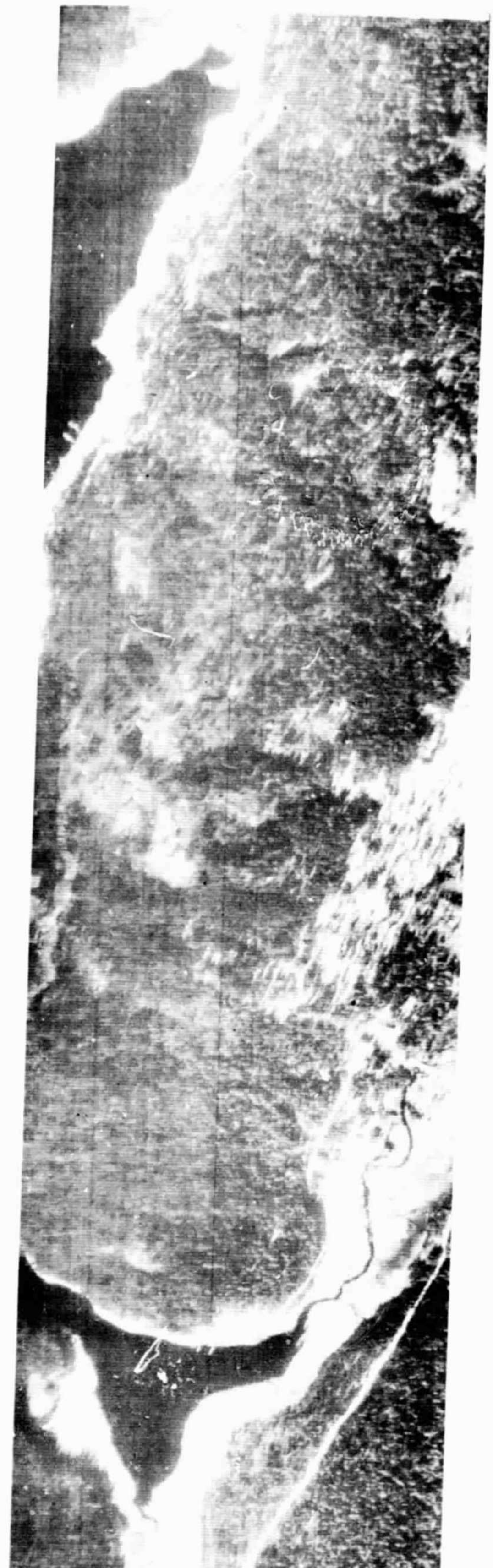
58-62


62-66


66-72

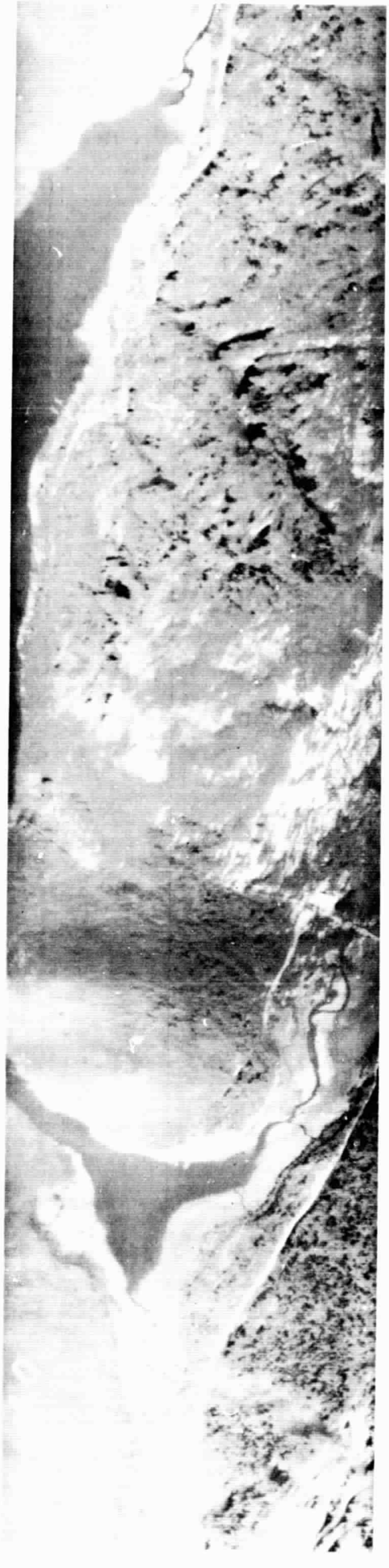

72-80




1.5-1.8


20-2.6

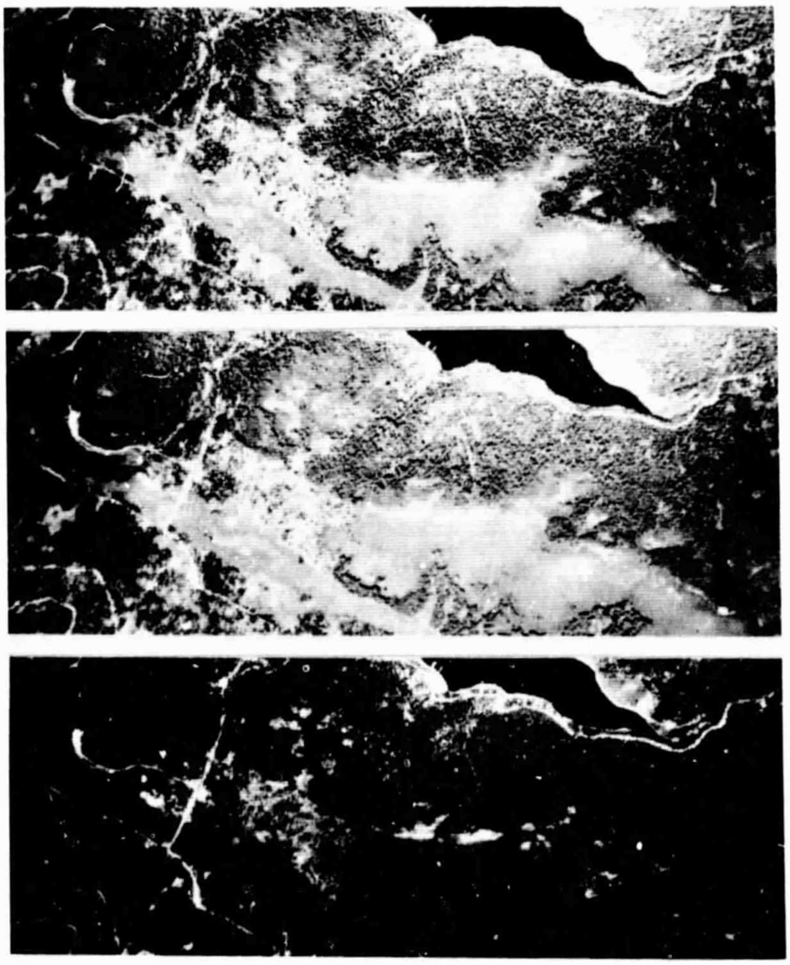

4.5-5.6



9.3 Examples of Additive Color Enhancement. A technique for enhancing conventional panchromatic aerial photographs was mentioned in the text as a possible means of facilitating the photo interpreter's task. This technique - additive color enhancement - will be briefly described and a few examples presented to demonstrate its potential in a wildland environment. Its relationship to automated interpretation lies in the human's ability to combine data in superimposed form that will enhance a particular feature much the same as an automated system can screen multispectral data and decide from a number of alternatives which types of features are present.

The technique used to obtain the examples presented in this section consists of projecting two or more black-and-white simultaneously exposed transparencies of the same area through separate but contiguous projecting lenses, each containing a pre-selected color filter. The result of superimposing the projected images in common registration are shown below. These particular examples were derived from aerial photographs exposed through an optically and geometrically calibrated 4-lens multispectral camera developed by personnel at Long Island University. They were combined and photographed in a special viewer to produce these enhanced images.

The area shown in these enhanced examples corresponds to Site 1 seen in Figure 20 on page 49. Four possible spectral records could be combined: one in the blue, one in the green, one in the red, and one in the photographic infrared. The top example was obtained by using only two photographic spectral records, namely, the red record and IR record. The red record was projected through a Wratten K3 (Yellow) filter while the IR record was projected through a Wratten 47B (Blue) filter. Note that high contrasts between vegetated and non-vegetated features is highlighted in this example. The middle example was obtained by using all four photographic spectral records: the blue record was projected through a Wratten 47B (Blue) filter, as was the green record; the red record was projected through a Wratten 25A (Red) filter; and the IR record was projected through a Wratten 58 (Green) filter. Note that this example too highlights the contrasts between vegetated and non-vegetated features. These contrasts do not seem to be as obvious as the first example, however. The bottom example is a simulation of color infrared film and was obtained by using three spectral records: green, projected through a blue color filter; red, projected through a green color filter; and, IR projected through a red filter. The color saturation is so high in this example that textural differences exhibited by different vegetation types are somewhat masked.

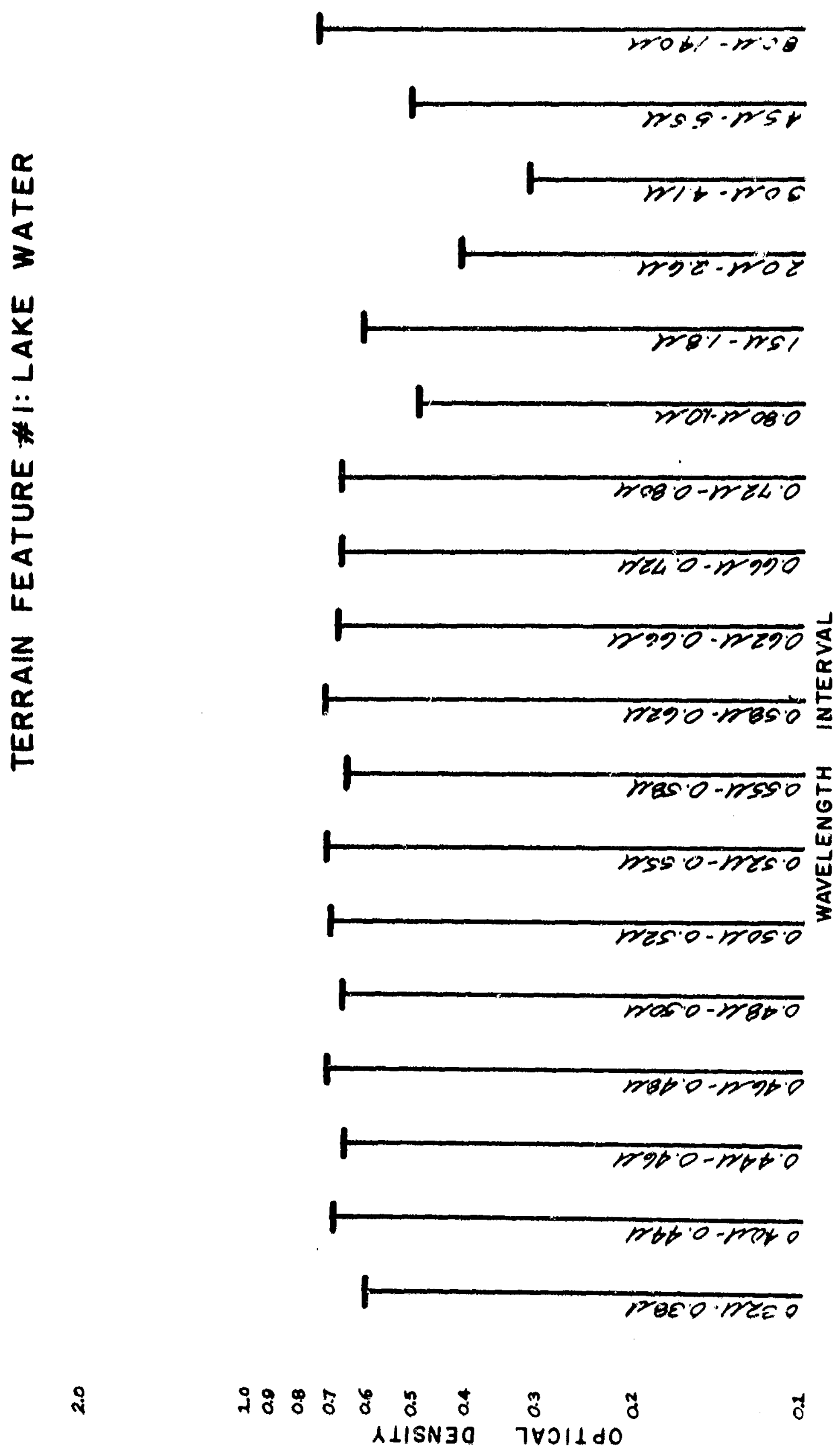


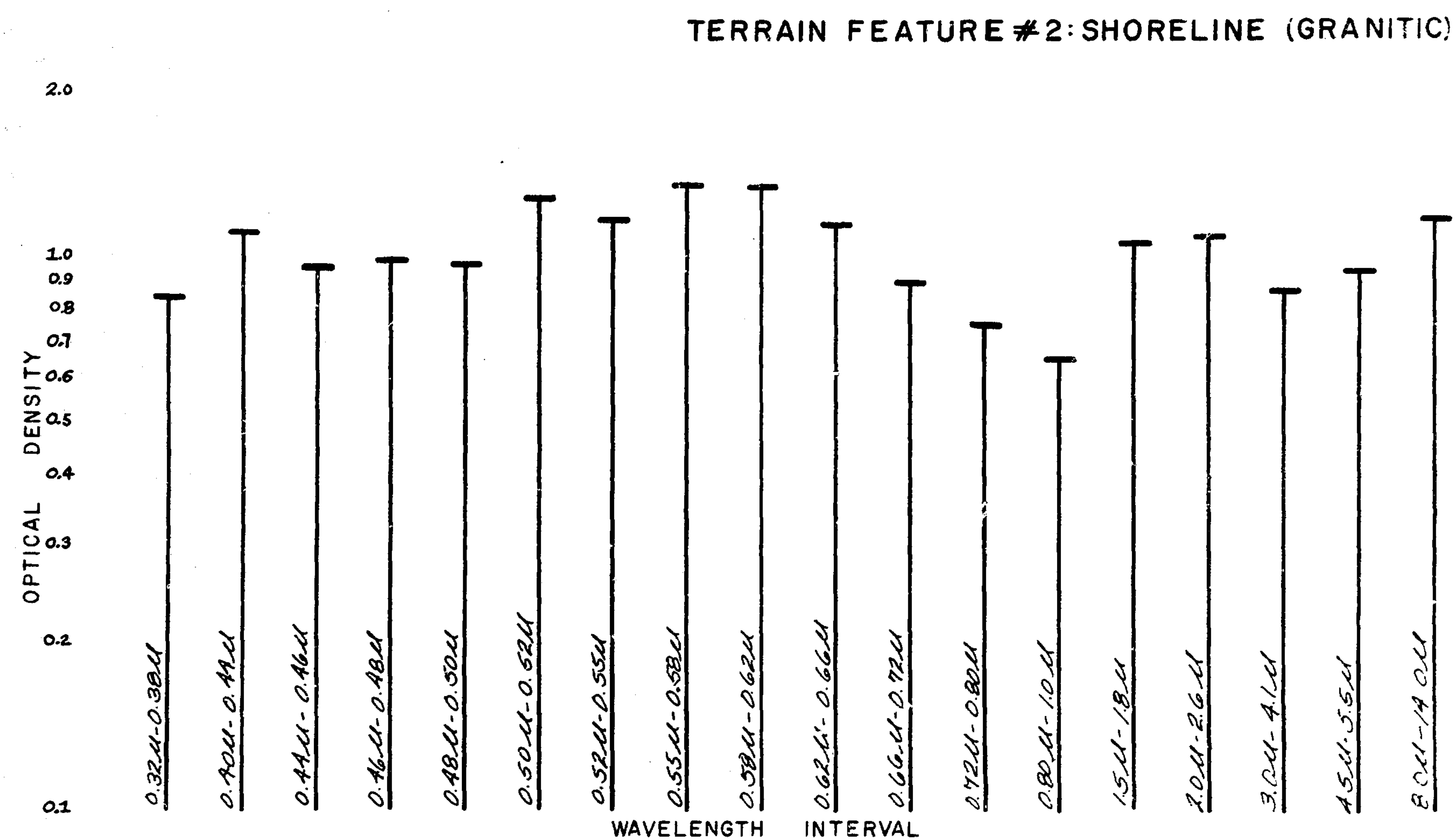
9.4 Raw Data Used In Calculating Correlation Coefficients Between Different Channels of Imagery And Different Film-Filter Combinations. Two sets of data are included in this section. The first consists of optical density values measured from the 18-channel line scan imagery using a Welch Densichron. The area of interest corresponds to Site 1 seen in Figure 20 on page 49. Some fifteen terrain types were selected for measurement in each of the eighteen channels; type 11 (roads) was considered too difficult to accurately measure in certain instances and consequently blanks appear in the data sheets. Similar difficulty occurred with other types at less frequent intervals. In addition to the density measurement data sheets, histograms plotting both terrain feature versus optical density and wavelength interval versus optical density are included for Site 1. Only the density measurements were included for the area which corresponds to Site 2 seen in Figure 20. These measurements were made using the negatives for the illustrations which appear in Figure 21 a - d.

Area measured *Site #1 - optical densities*

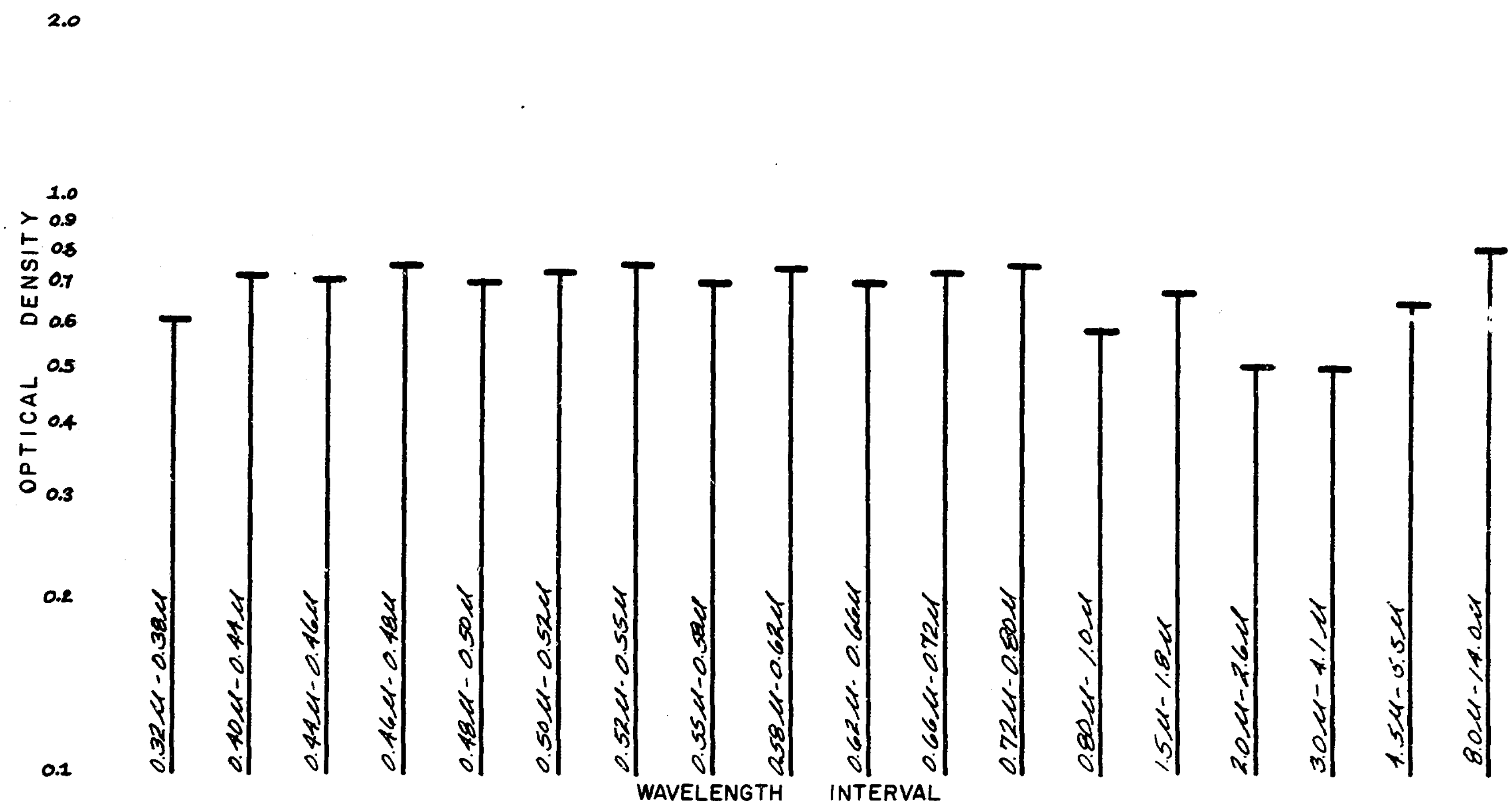
TERRAIN TYPES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	WAVELENGTH INTERVALS
1	.62	.85	.62	.58	.47	.56	1.82	.71	.67	.95	0.67	.47	.57	.49	.71	.32μ - .38μ
2	.71	1.22	.74	.76	.78	.85	1.62	.98	.83	1.29	.97	.73	.73	.74	.71	.40μ - .44μ
3	.68	.97	.73	.74	.72	.74	1.53	.80	.72	1.20	—	.70	.75	.72	.80	.44μ - .46μ
4	.73	1.00	.77	.74	.66	.78	1.60	.87	.77	1.01	—	.74	.74	.75	.84	.46μ - .48μ
5	.68	.98	.72	.71	.65	.75	1.66	.81	.73	1.67	—	.67	.69	.71	.80	.48μ - .50μ
6	.72	1.30	.75	.75	.76	.82	2.00	.98	.82	1.35	—	.75	.77	.76	.95	.50μ - .52μ
7	.73	1.18	.77	.82	.76	.88	1.75	.96	.86	1.30	—	.79	.82	.80	1.00	.52μ - .55μ
8	.67	1.37	.72	.78	.80	.87	2.00	1.08	.82	1.45	—	.80	.88	.84	1.07	.55μ - .58μ
9	.74	1.36	.76	.80	.75	.86	1.82	.97	.85	1.37	—	.78	.78	.77	1.08	.58μ - .62μ
10	.70	1.16	.72	.74	.71	.80	1.60	.90	.78	1.14	—	.72	.71	.72	.93	.62μ - .66μ
11	.69	.90	.75	.74	.71	.77	1.36	.85	.79	0.95	—	.72	.74	.76	.86	.66μ - .72μ
12	.69	.76	.77	.74	.77	.77	1.14	.80	.75	0.80	—	.89	.90	.86	.76	.72μ - .80μ
13	.50	.66	.59	.58	.65	.69	1.05	.68	.67	0.64	—	.77	.77	.72	.61	.80μ - 1.0μ
14	.63	1.08	.69	.67	—	.92	—	.93	.85	1.07	—	.78	.89	.89	1.08	1.5μ - 1.8μ
15	.44	1.10	.53	.51	—	1.14	—	.88	.74	1.26	—	—	—	.75	.85	2.0μ - 2.6μ
16	.33	.88	.52	.45	—	1.05	—	1.08	.84	1.20	—	.69	.66	.72	.84	3.0μ - 4.1μ
17	.53	.95	.66	.56	—	.76	—	1.15	.88	1.02	—	.61	.57	.66	.88	4.5μ - 5.5μ
18	.76	1.19	.82	.64	—	.98	—	1.26	1.02	1.03	—	—	—	.68	1.00	8.0μ - 14.0μ

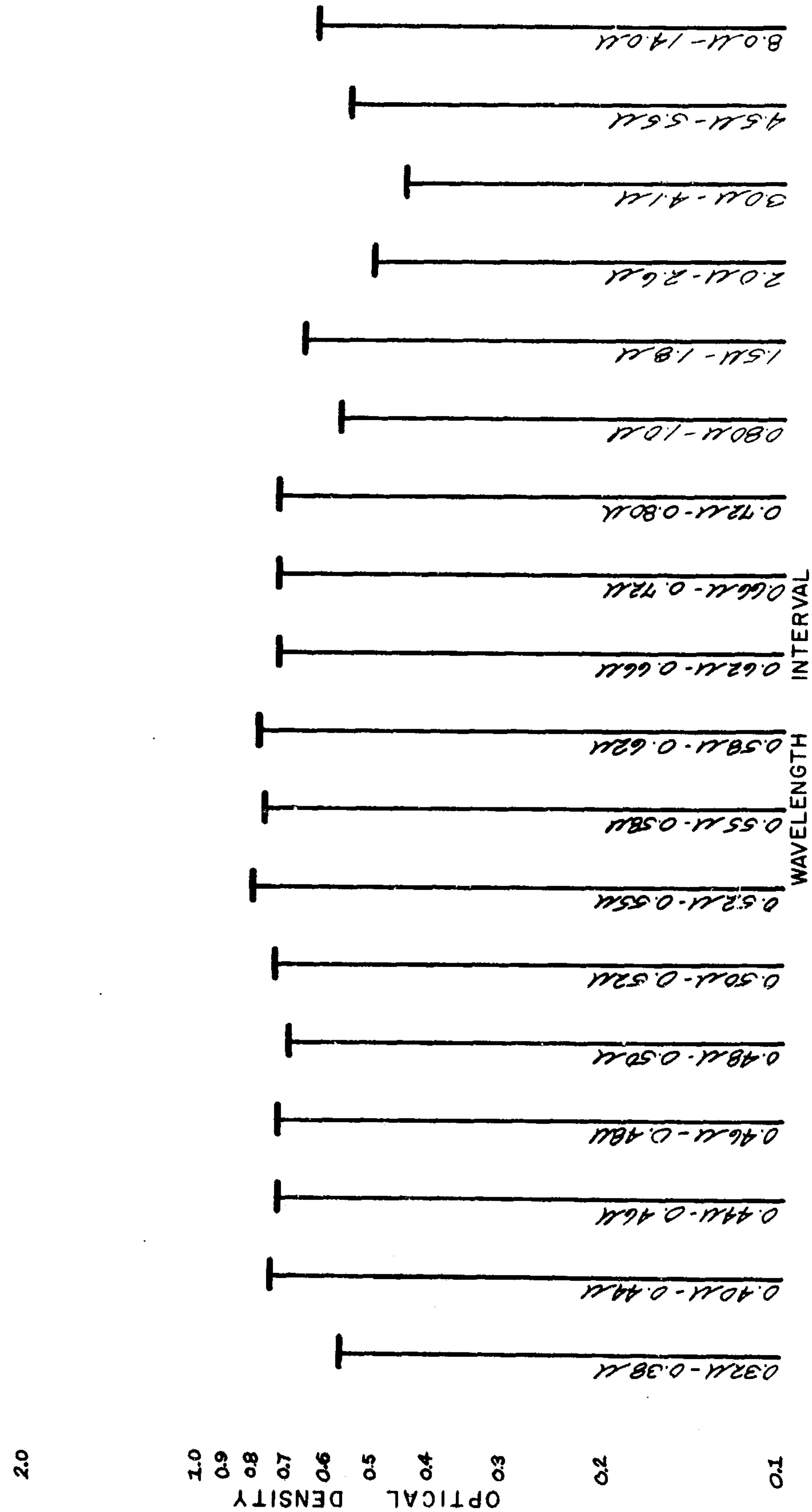

TERRAIN FEATURE #1: LAKE WATER
WAVELENGTH INTERVAL
OPTICAL DENSITY
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
2.0
0.32μ-0.38μ
0.40μ-0.44μ
0.44μ-0.46μ
0.46μ-0.48μ
0.48μ-0.50μ
0.50μ-0.52μ
0.52μ-0.55μ
0.55μ-0.58μ
0.58μ-0.62μ
0.62μ-0.66μ
0.66μ-0.72μ
0.72μ-0.80μ
0.80μ-1.0μ
1.5μ-1.8μ
2.0μ-2.6μ
3.0μ-4.1μ
4.5μ-5.5μ
8.0μ-14.0μ


TERRAIN FEATURE #2: SHORELINE (GRANITIC)
OPTICAL DENSITY
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.32μ-0.38μ
0.40μ-0.44μ
0.44μ-0.46μ
0.46μ-0.48μ
0.48μ-0.50μ
0.50μ-0.52μ
0.52μ-0.55μ
0.55μ-0.58μ
0.58μ-0.62μ
0.62μ-0.66μ
0.66μ-0.72μ
0.72μ-0.80μ
0.80μ-1.0μ
1.5μ-1.8μ
2.0μ-2.6μ
3.0μ-4.1μ
4.5μ-5.5μ
8.0μ-14.0μ
WAVELENGTH INTERVAL

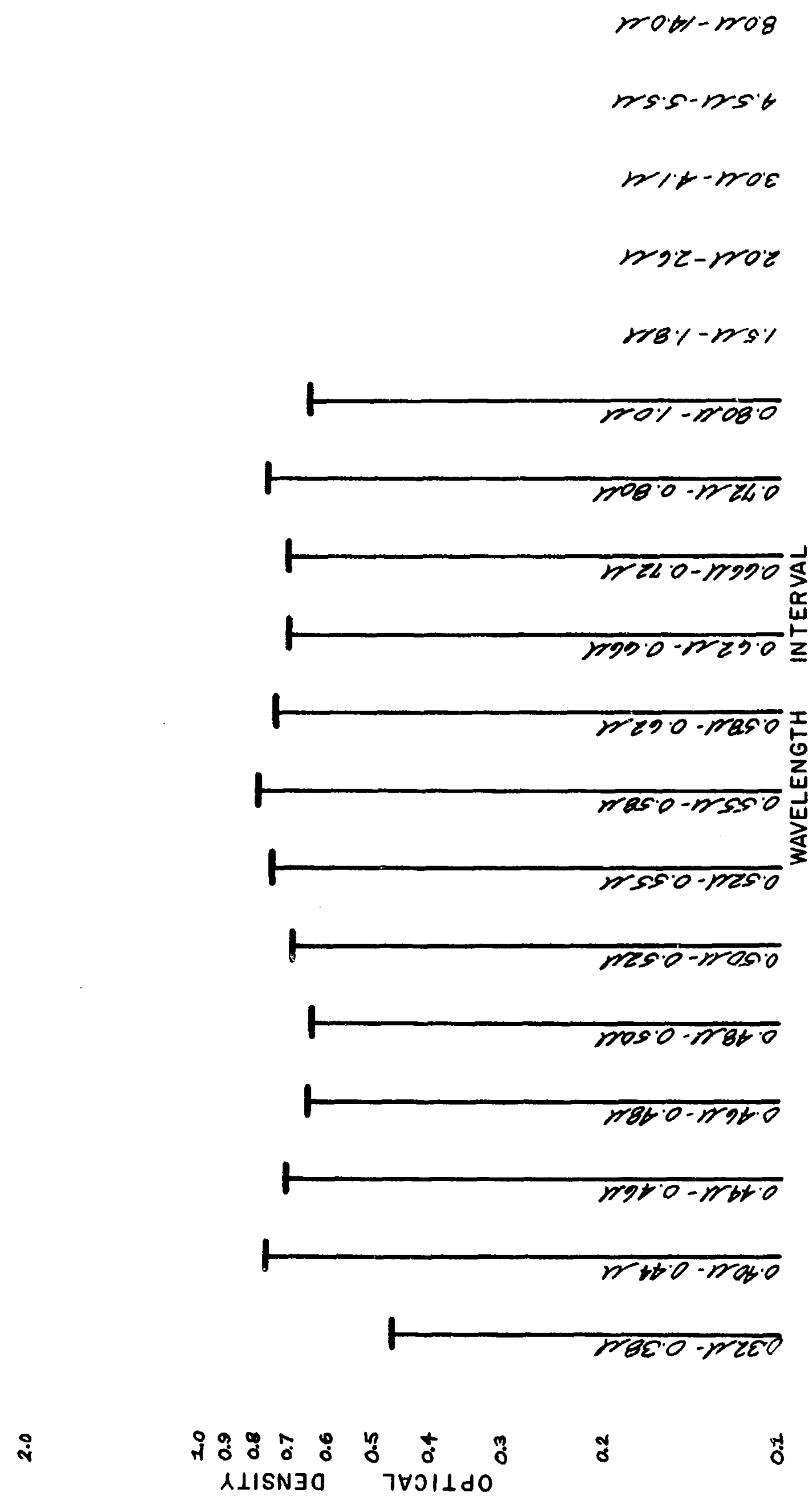
TERRAIN FEATURE #3: CONIFERS (WHITE FIR)



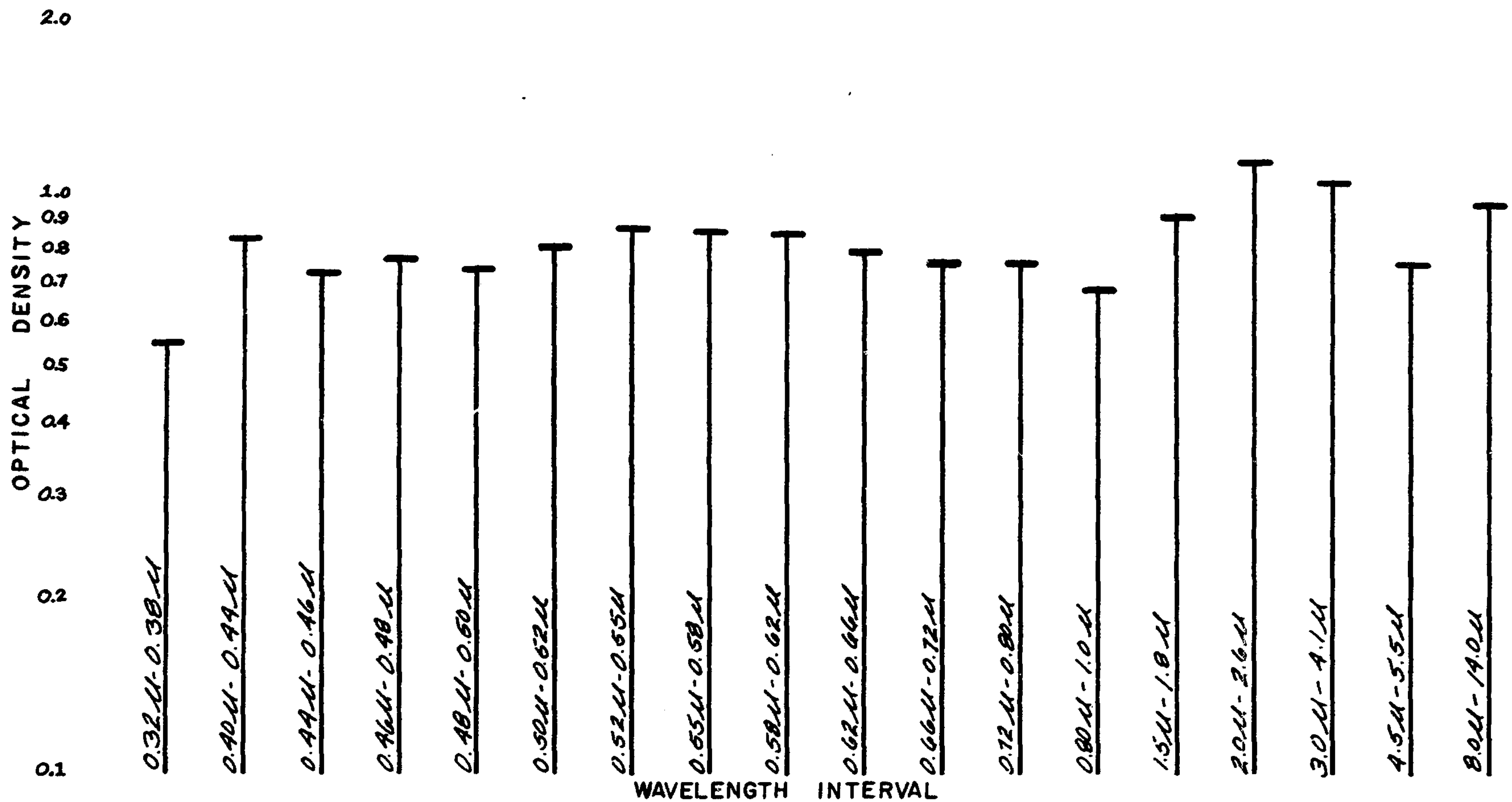
TERRAIN FEATURE #4: CONIFERS (LODGEPOLE PINE)

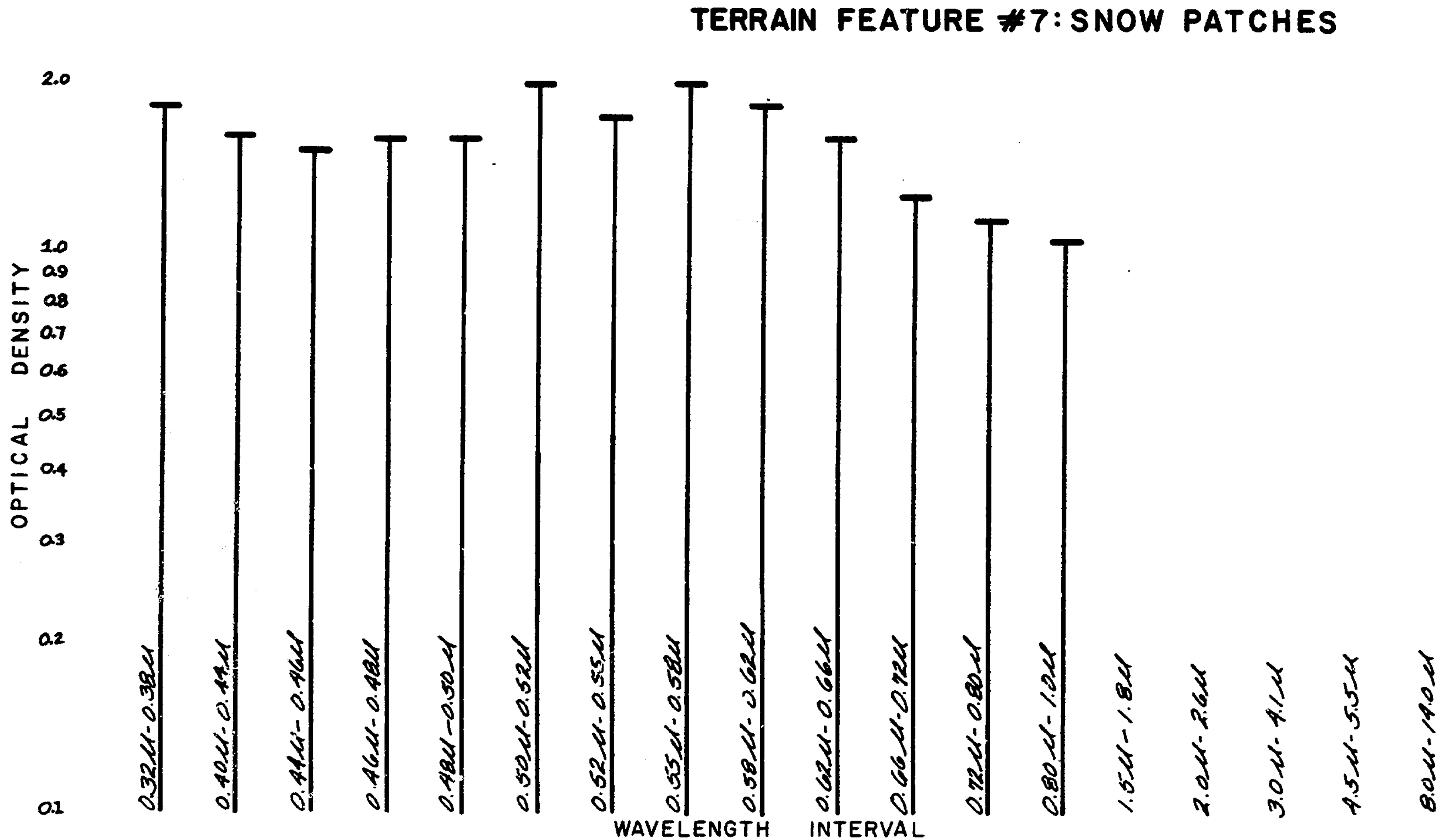


TERRAIN FEATURE #5: BRUSH (SOUTH ASPECT)

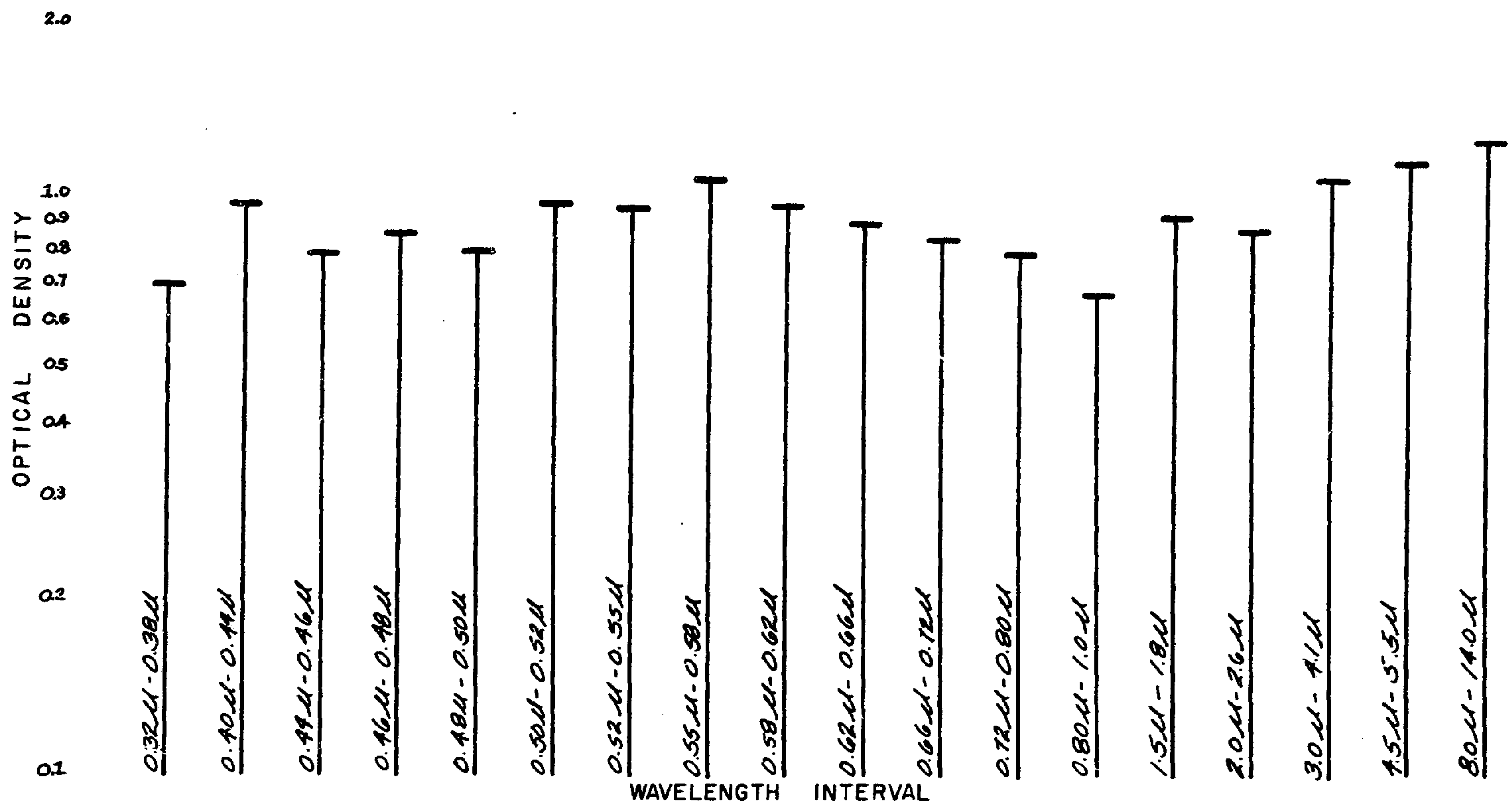


TERRAIN FEATURE #6: CONIFER–BRUSH MIXTURE

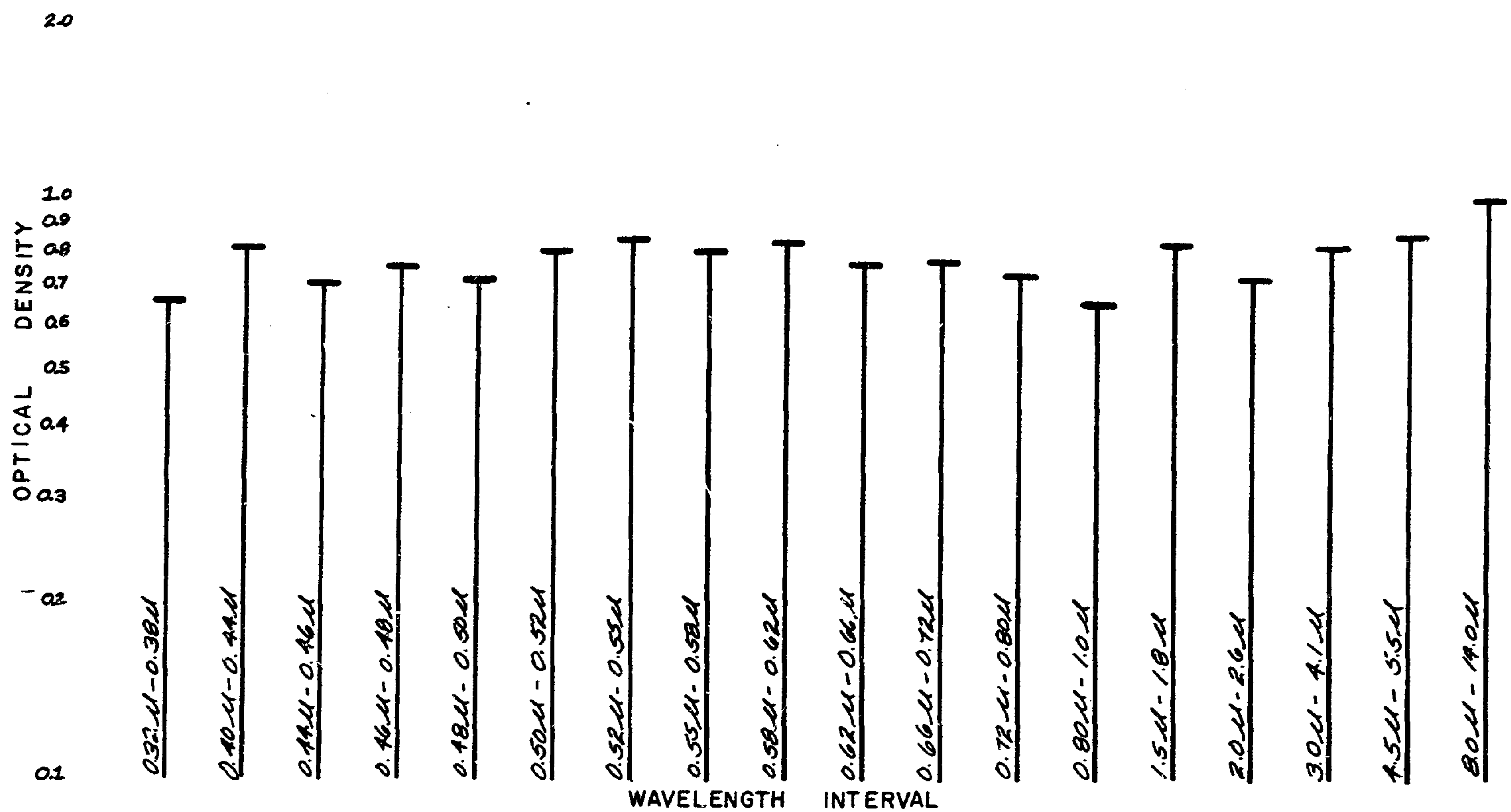



TERRAIN FEATURE #7: SNOW PATCHES
OPTICAL DENSITY
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.32μ-0.38μ
0.40μ-0.44μ
0.44μ-0.46μ
0.46μ-0.48μ
0.48μ-0.50μ
0.50μ-0.52μ
0.52μ-0.55μ
0.55μ-0.58μ
0.58μ-0.62μ
0.62μ-0.66μ
0.66μ-0.72μ
0.72μ-0.80μ
0.80μ-1.0μ
1.5μ-1.8μ
2.0μ-2.6μ
3.0μ-4.1μ
4.5μ-5.5μ
8.0μ-14.0μ
WAVELENGTH INTERVAL

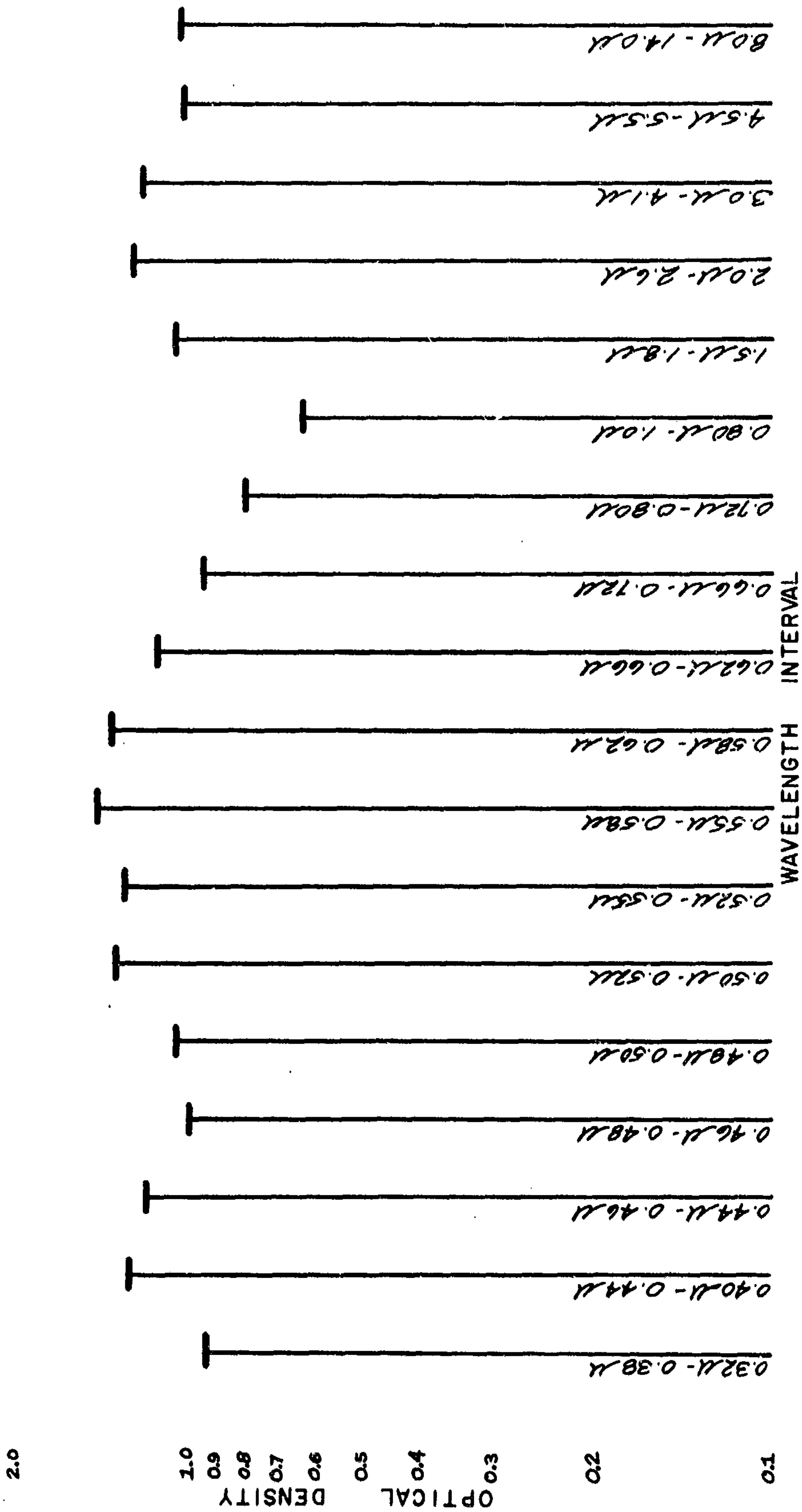
TERRAIN FEATURE #8: LOGGING SITE



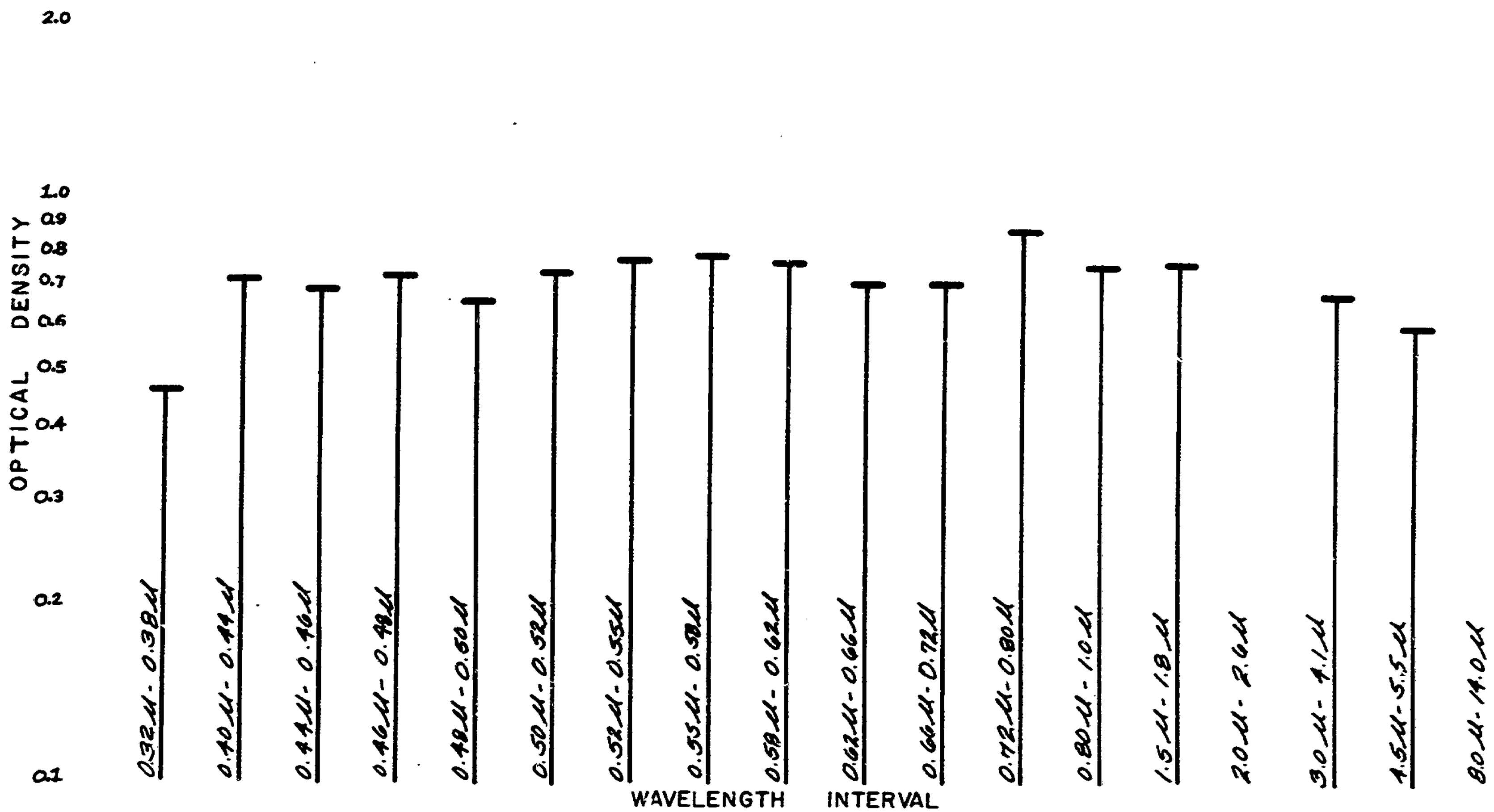
TERRAIN FEATURE #9: BRUSH (NORTH ASPECT)



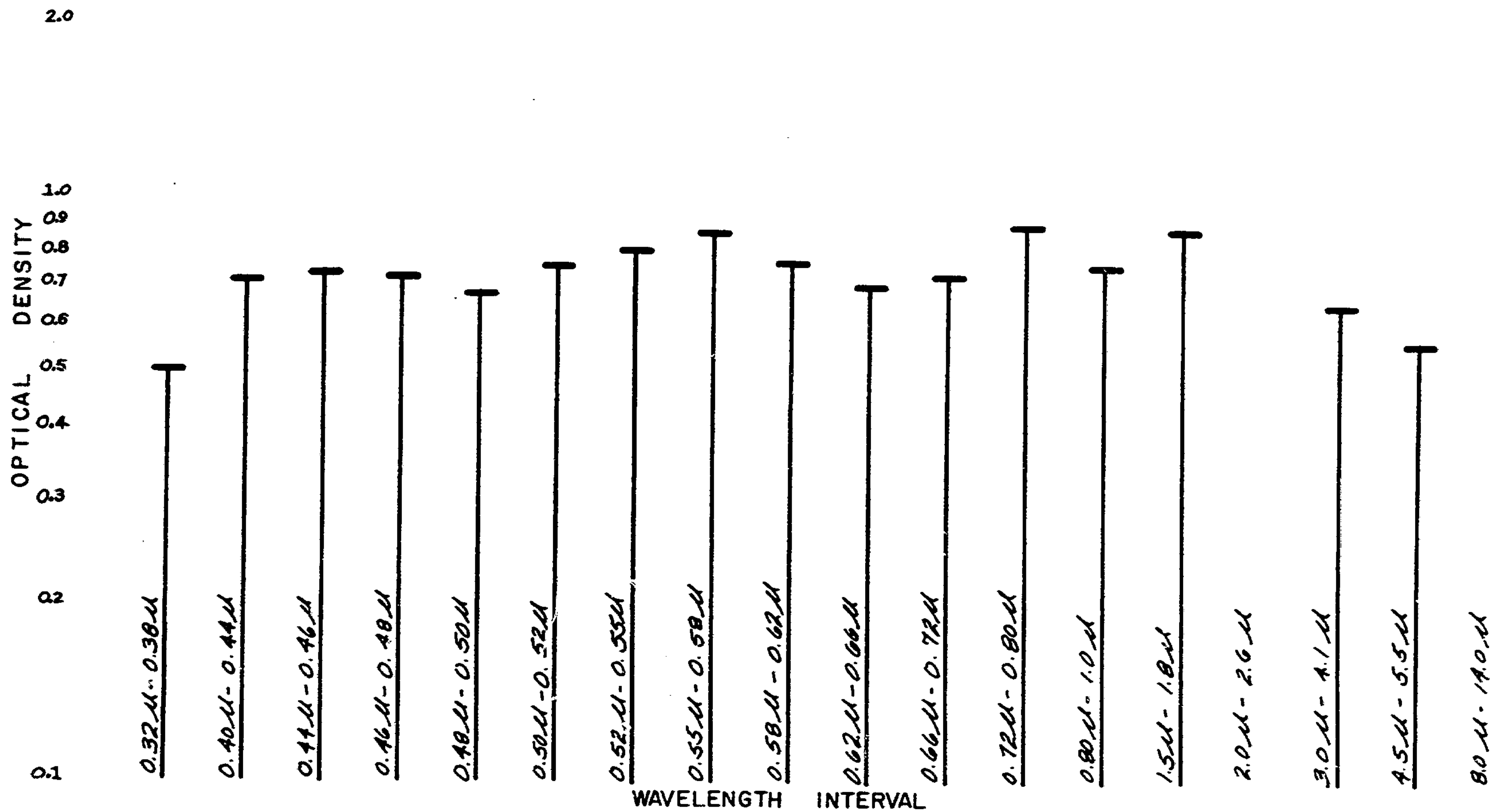
TERRAIN FEATURE #10: STREAM GRAVEL



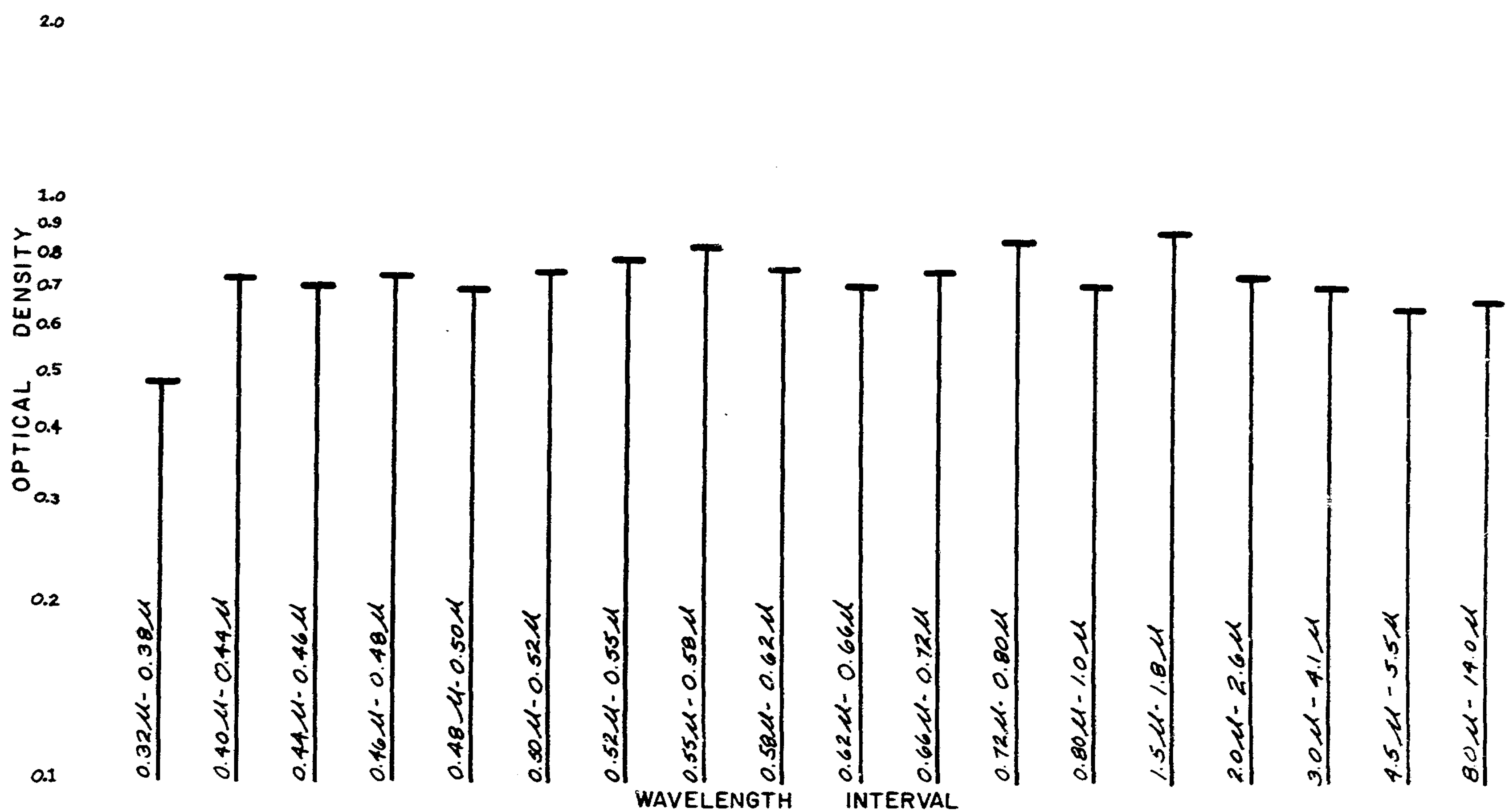
TERRAIN FEATURE #12: RIPARIAN VEGETATION



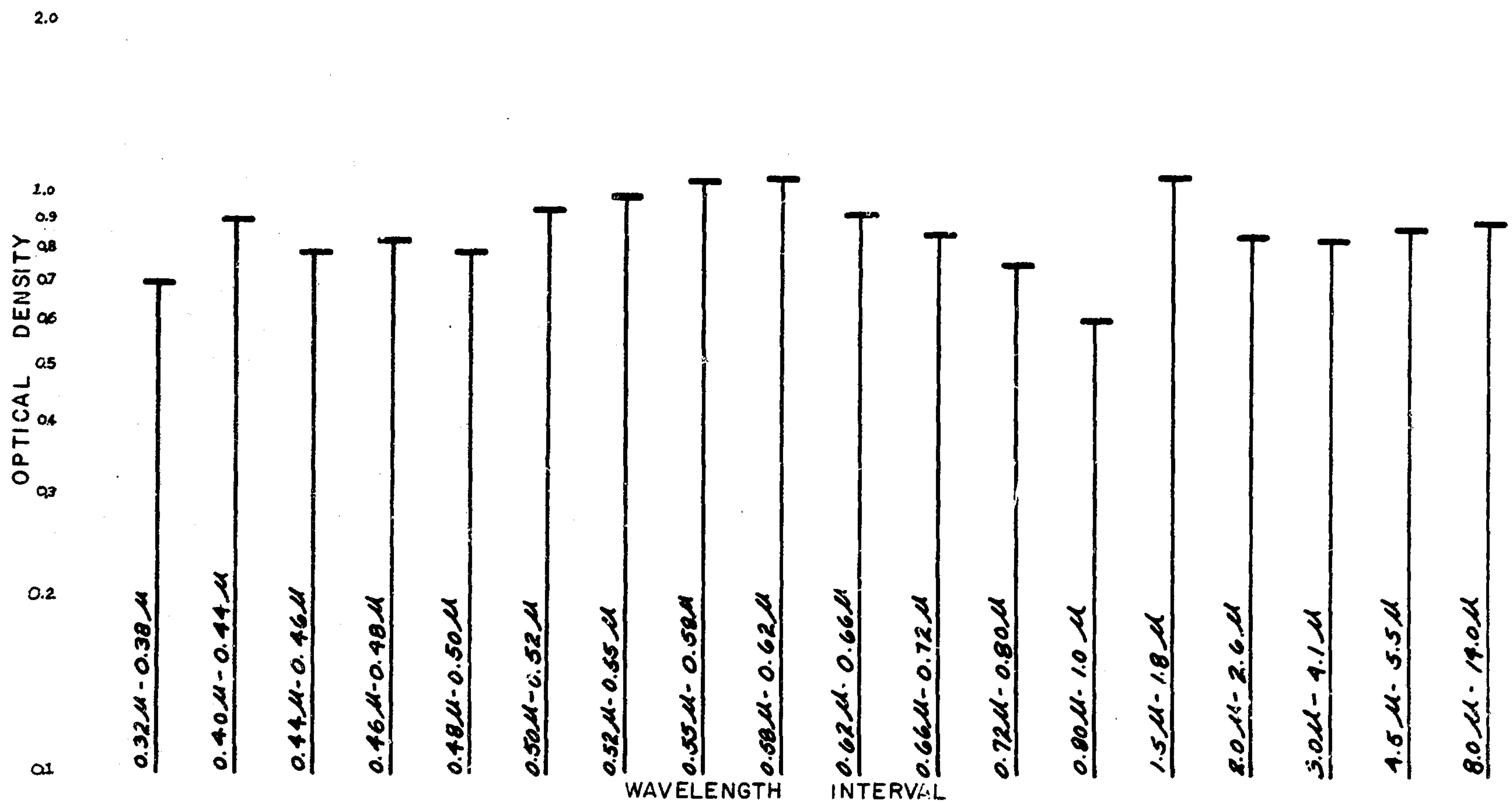
TERRAIN FEATURE #13: MEADOW (GRASSES)

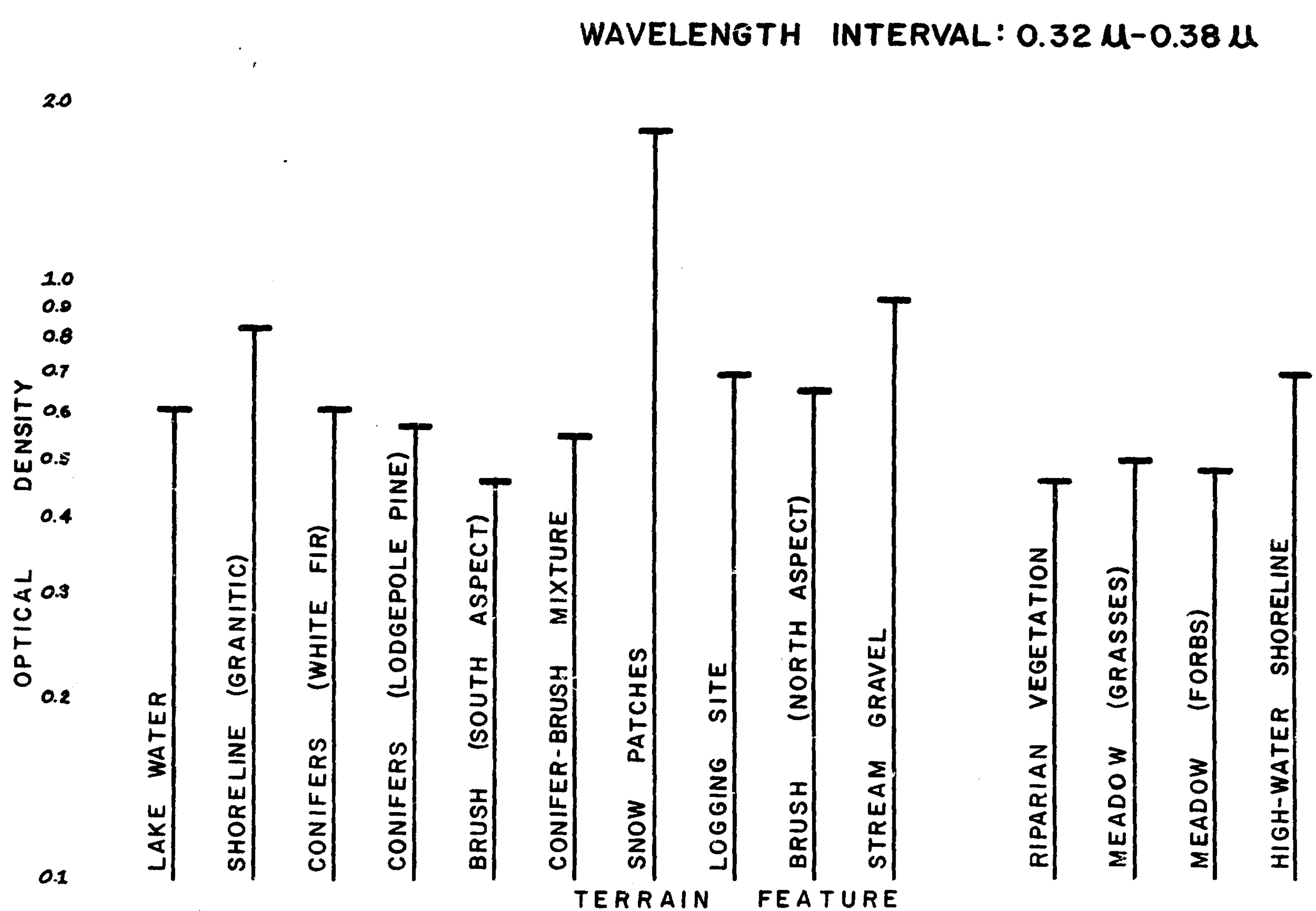


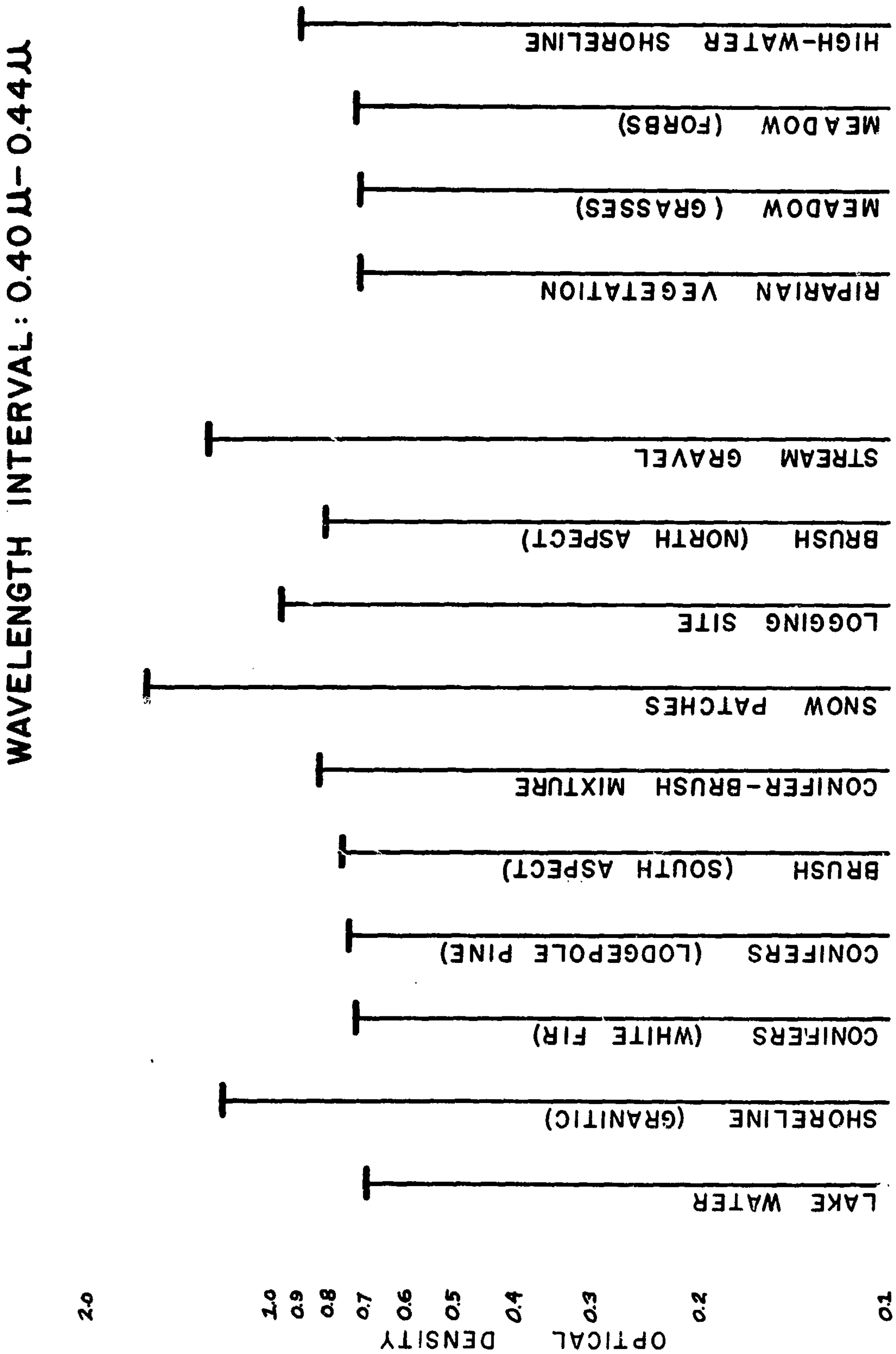
TERRAIN FEATURE #14: MEADOW (FORBS)



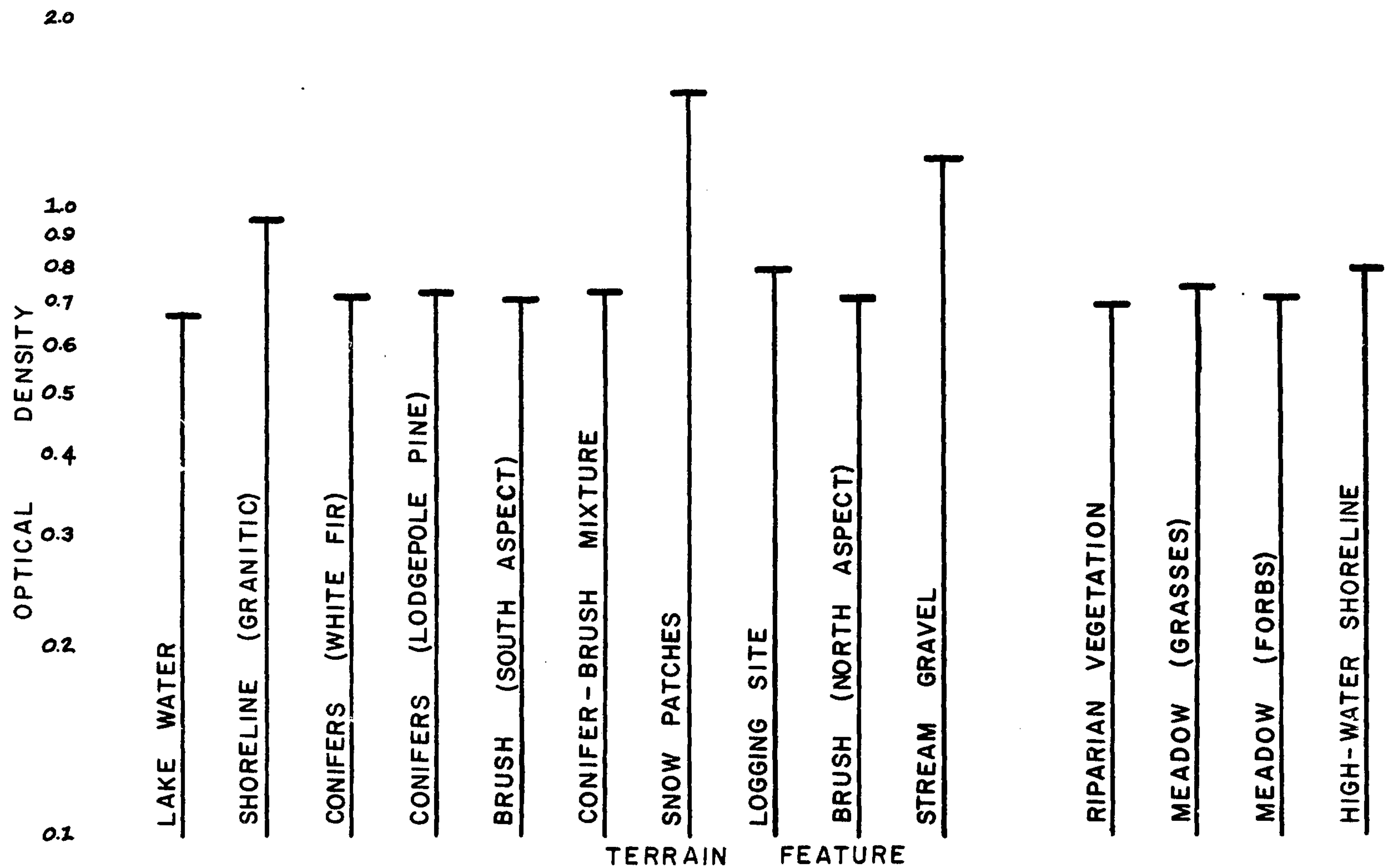
TERRAIN FEATURE #15: HIGH-WATER SHORELINE

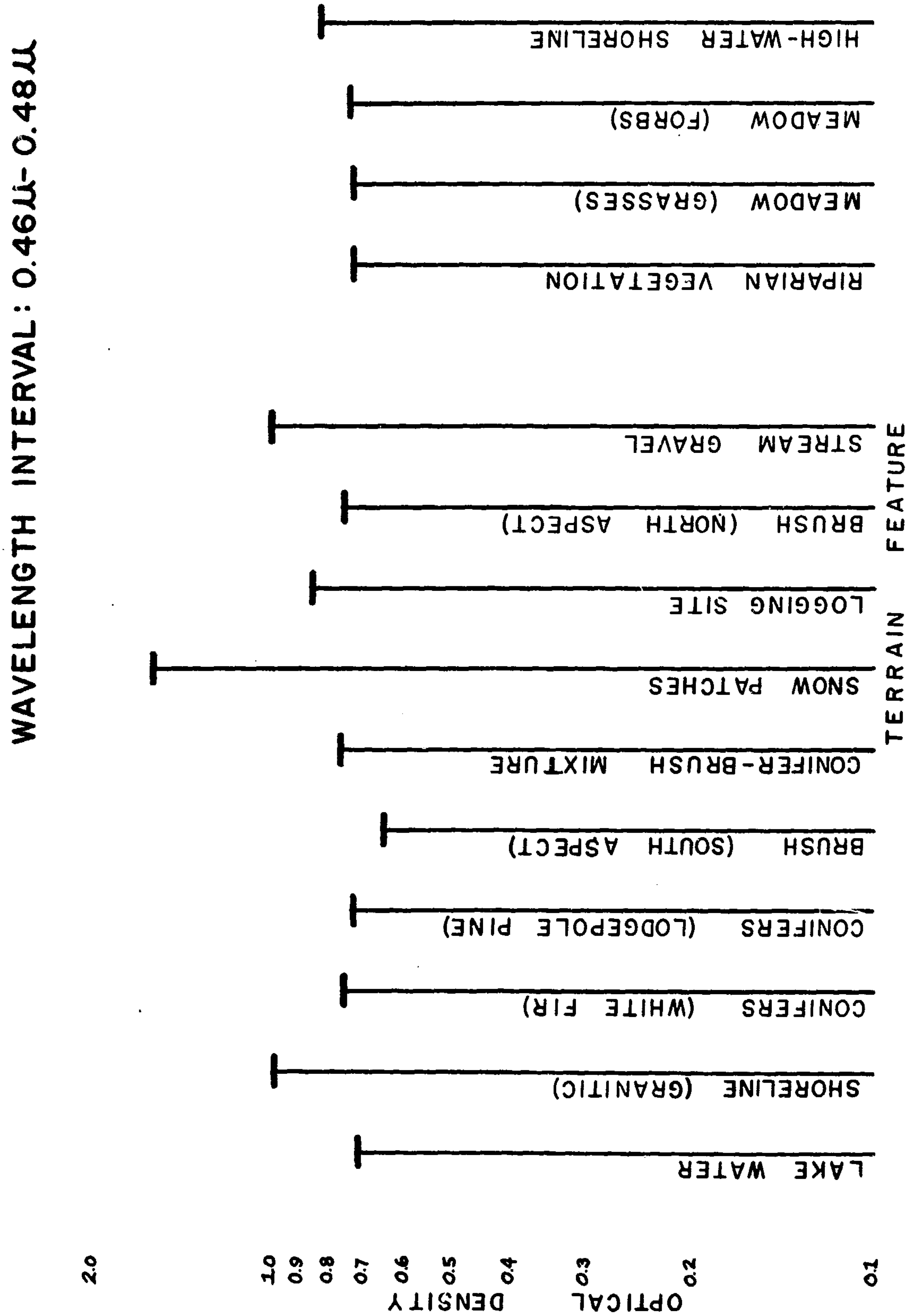



WAVELENGTH INTERVAL: 0.32 μ-0.38 μ
OPTICAL DENSITY
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
LAKE WATER
SHORELINE (GRANITIC)
CONIFERS (WHITE FIR)
CONIFERS (LODGEPOLE PINE)
BRUSH (SOUTH ASPECT)
CONIFER-BRUSH MIXTURE
SNOW PATCHES
LOGGING SITE
BRUSH (NORTH ASPECT)
STREAM GRAVEL
RIPARIAN VEGETATION
MEADOW (GRASSES)
MEADOW (FORBS)
HIGH-WATER SHORELINE
TERRAIN FEATURE

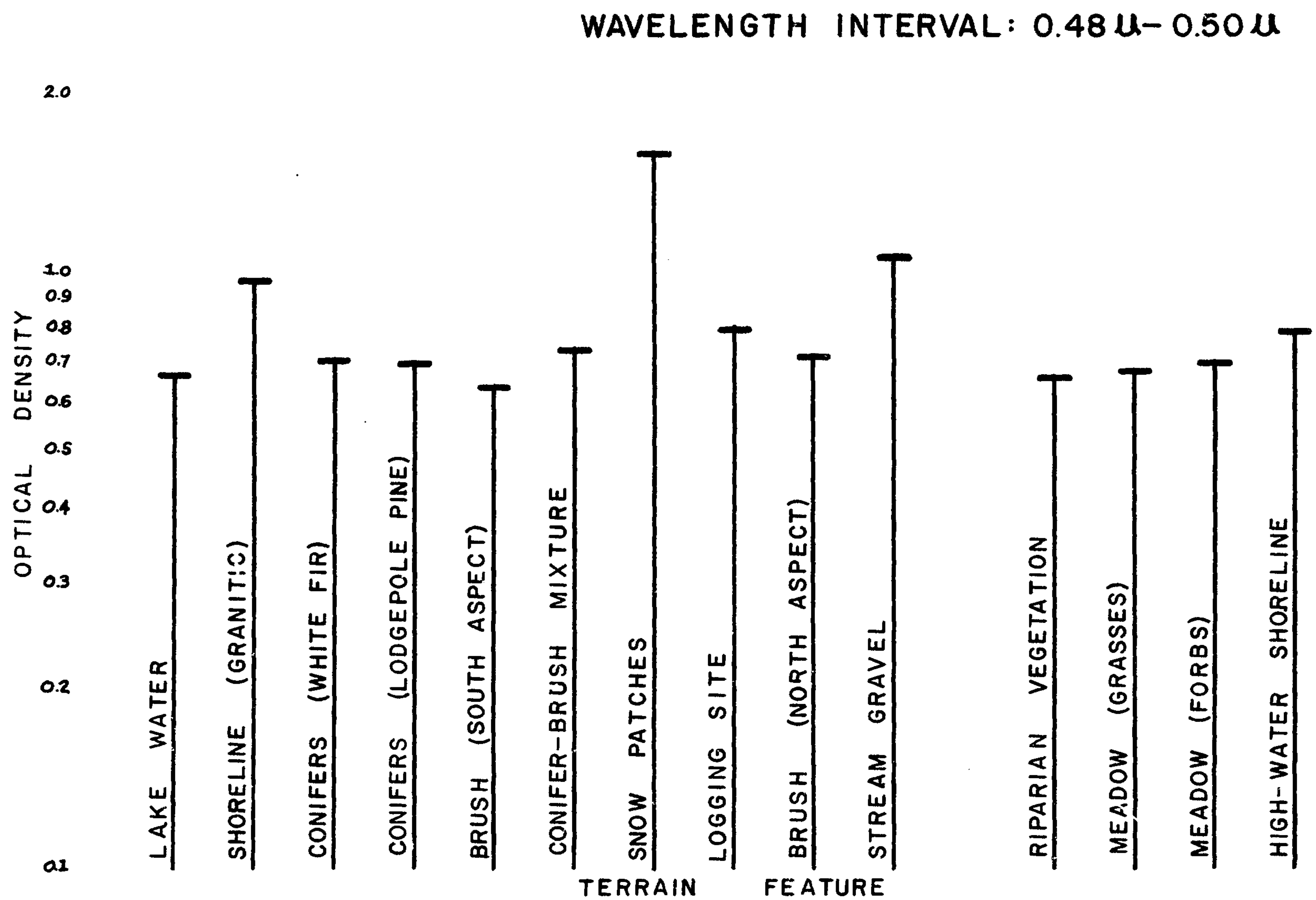

WAVELENGTH INTERVAL: 0.40μ-0.44μ
TERRAIN FEATURE
LAKE WATER
SHORELINE (GRANITIC)
CONIFERS (WHITE FIR)
CONIFERS (LODGEPOLE PINE)
BRUSH (SOUTH ASPECT)
CONIFER-BRUSH MIXTURE
SNOW PATCHES
LOGGING SITE
BRUSH (NORTH ASPECT)
STREAM GRAVEL
RIPARIAN VEGETATION
MEADOW (GRASSES)
MEADOW (FORBS)
HIGH-WATER SHORELINE
OPTICAL DENSITY
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

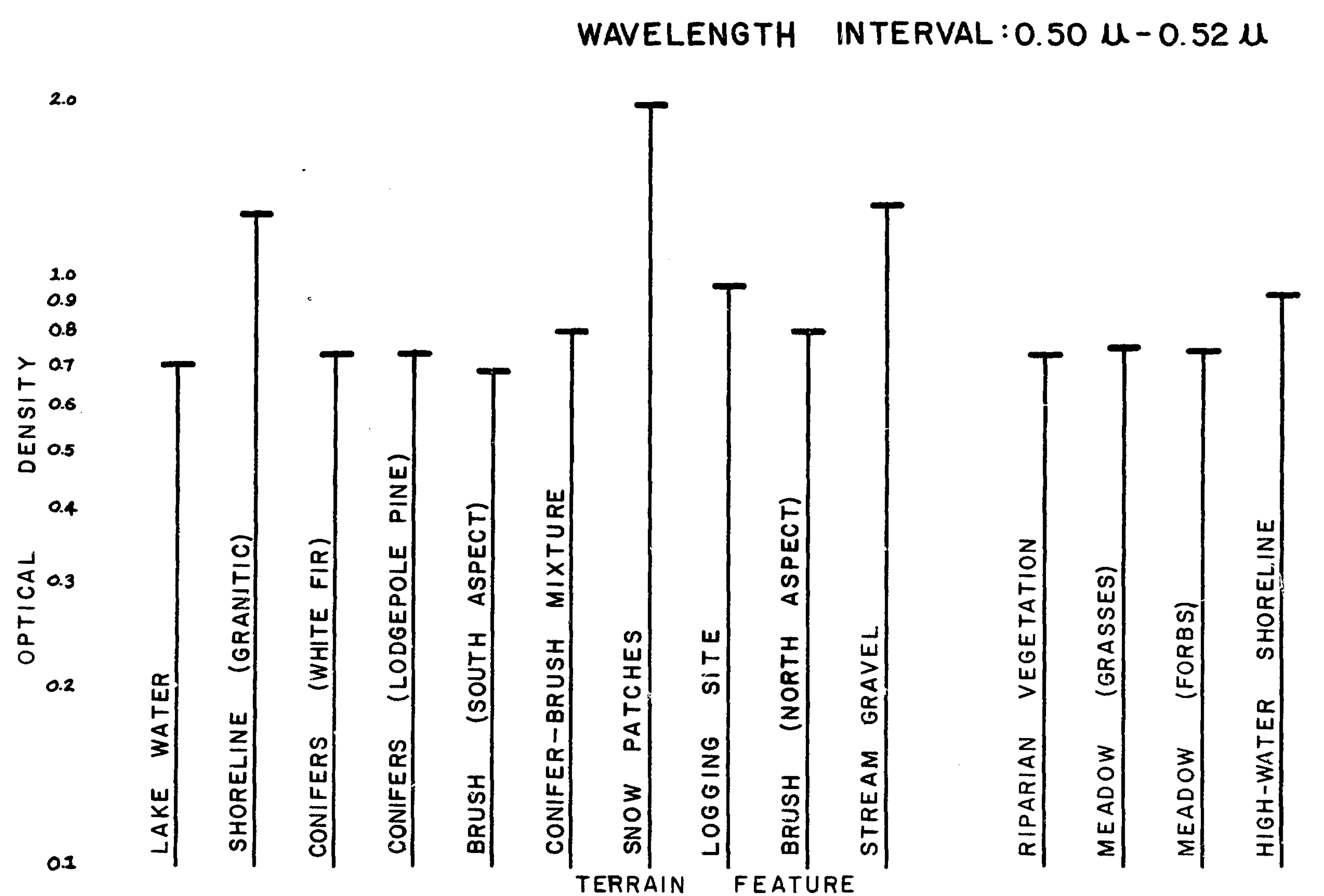
WAVELENGTH INTERVAL : 0.44μ-0.46μ

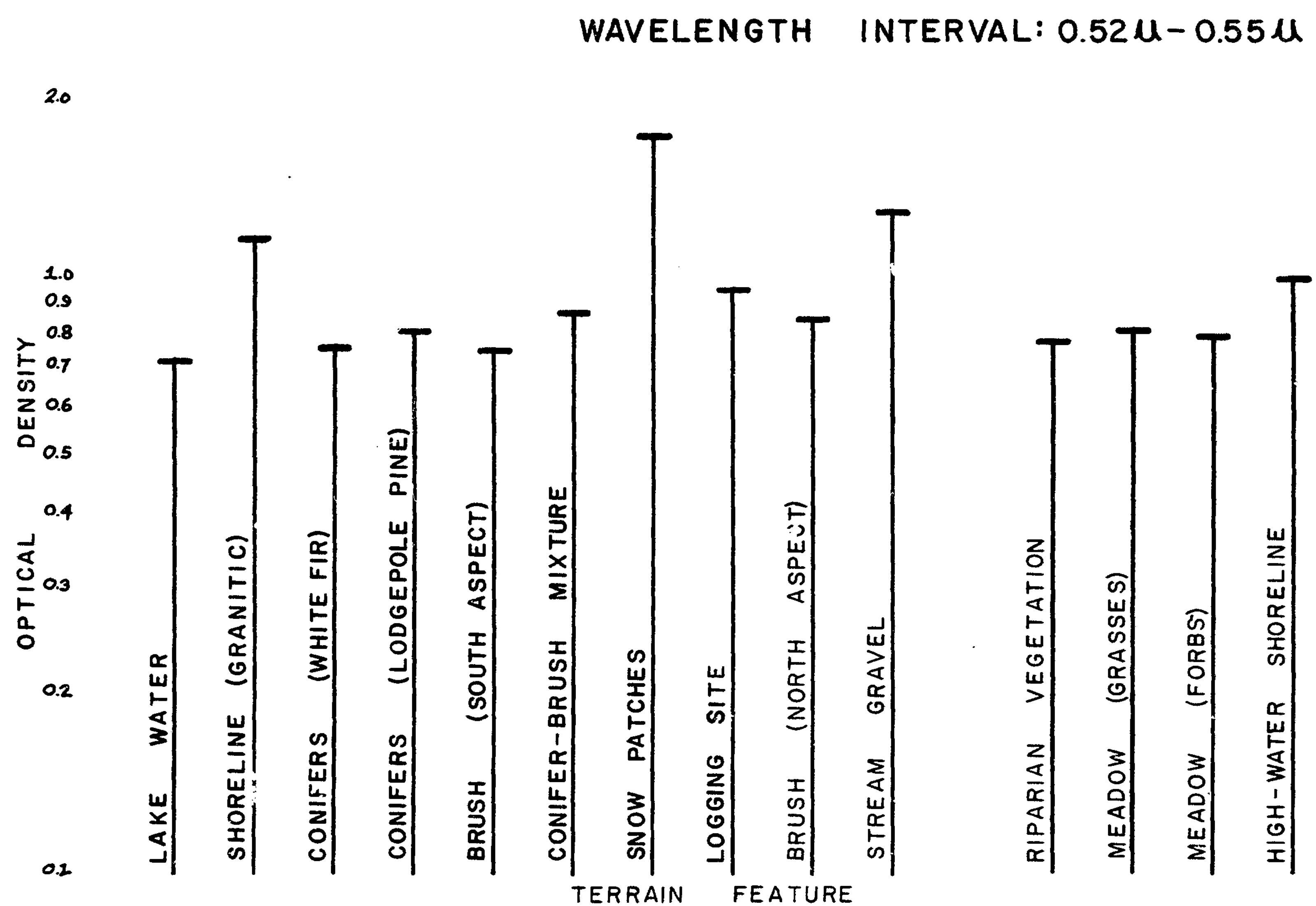


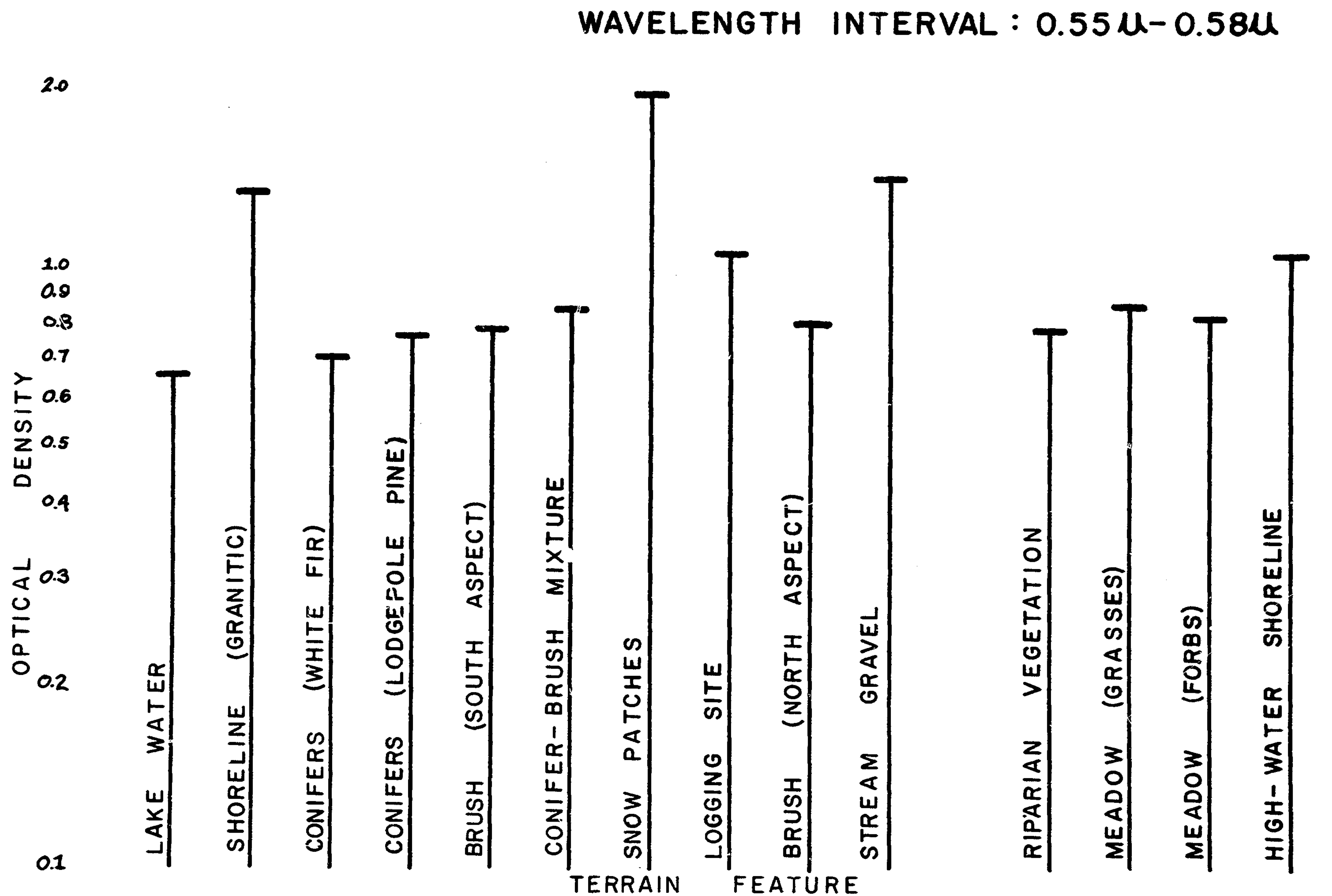


WAVELENGTH INTERVAL: 0.46μ - 0.48μ
TERRAIN FEATURE
LAKE WATER
SHORELINE (GRANITIC)
CONIFERS (WHITE FIR)
CONIFERS (LODGEPOLE PINE)
BRUSH (SOUTH ASPECT)
CONIFER-BRUSH MIXTURE
SNOW PATCHES
LOGGING SITE
BRUSH (NORTH ASPECT)
STREAM GRAVEL
RIPARIAN VEGETATION
MEADOW (GRASSES)
MEADOW (FORBS)
HIGH-WATER SHORELINE
OPTICAL DENSITY
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
2.0

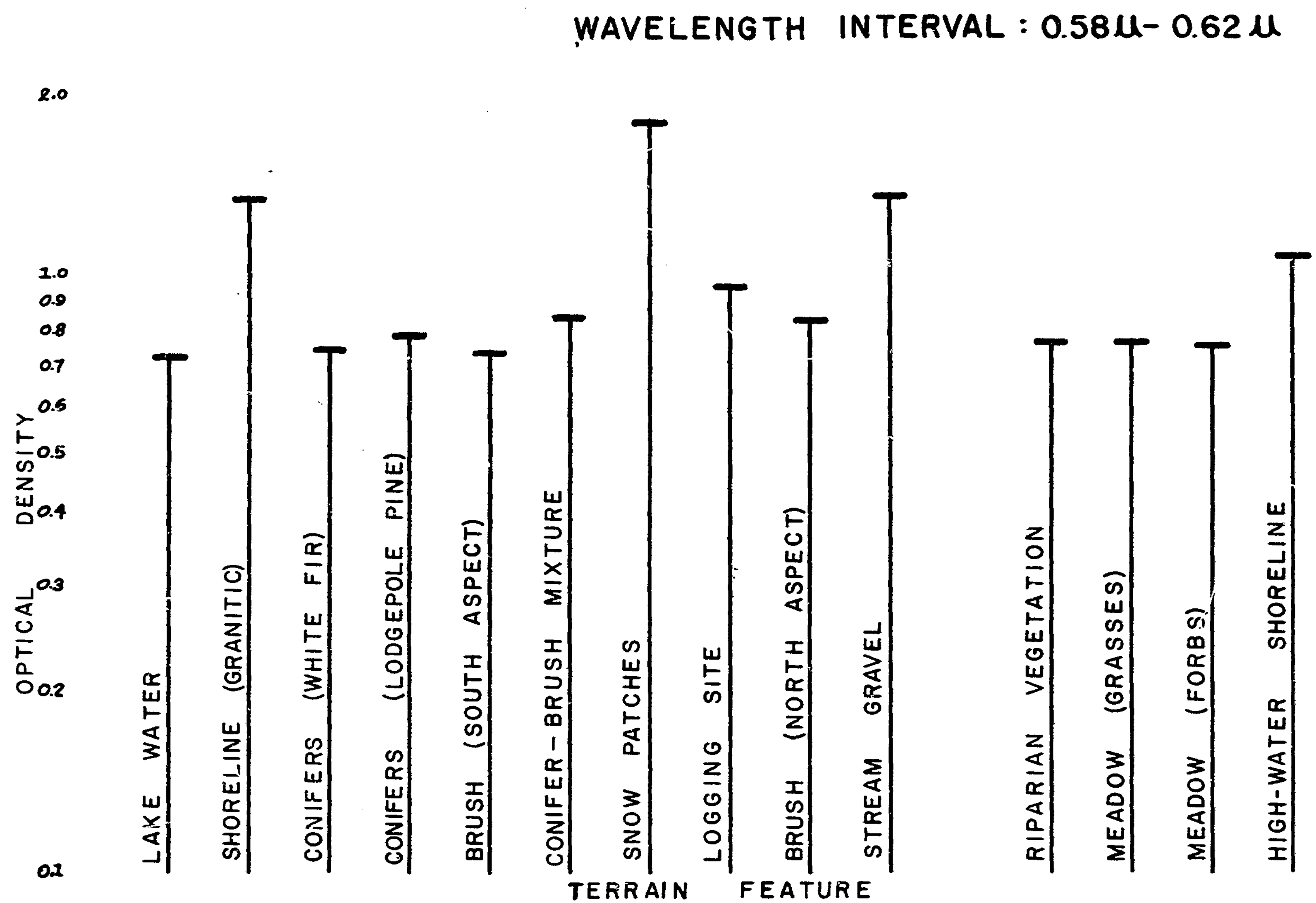

WAVELENGTH INTERVAL: 0.48 µ – 0.50 µ
OPTICAL DENSITY
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
LAKE WATER
SHORELINE (GRANITIC)
CONIFERS (WHITE FIR)
CONIFERS (LODGEPOLE PINE)
BRUSH (SOUTH ASPECT)
CONIFER-BRUSH MIXTURE
SNOW PATCHES
LOGGING SITE
BRUSH (NORTH ASPECT)
STREAM GRAVEL
RIPARIAN VEGETATION
MEADOW (GRASSES)
MEADOW (FORBS)
HIGH-WATER SHORELINE
TERRAIN FEATURE

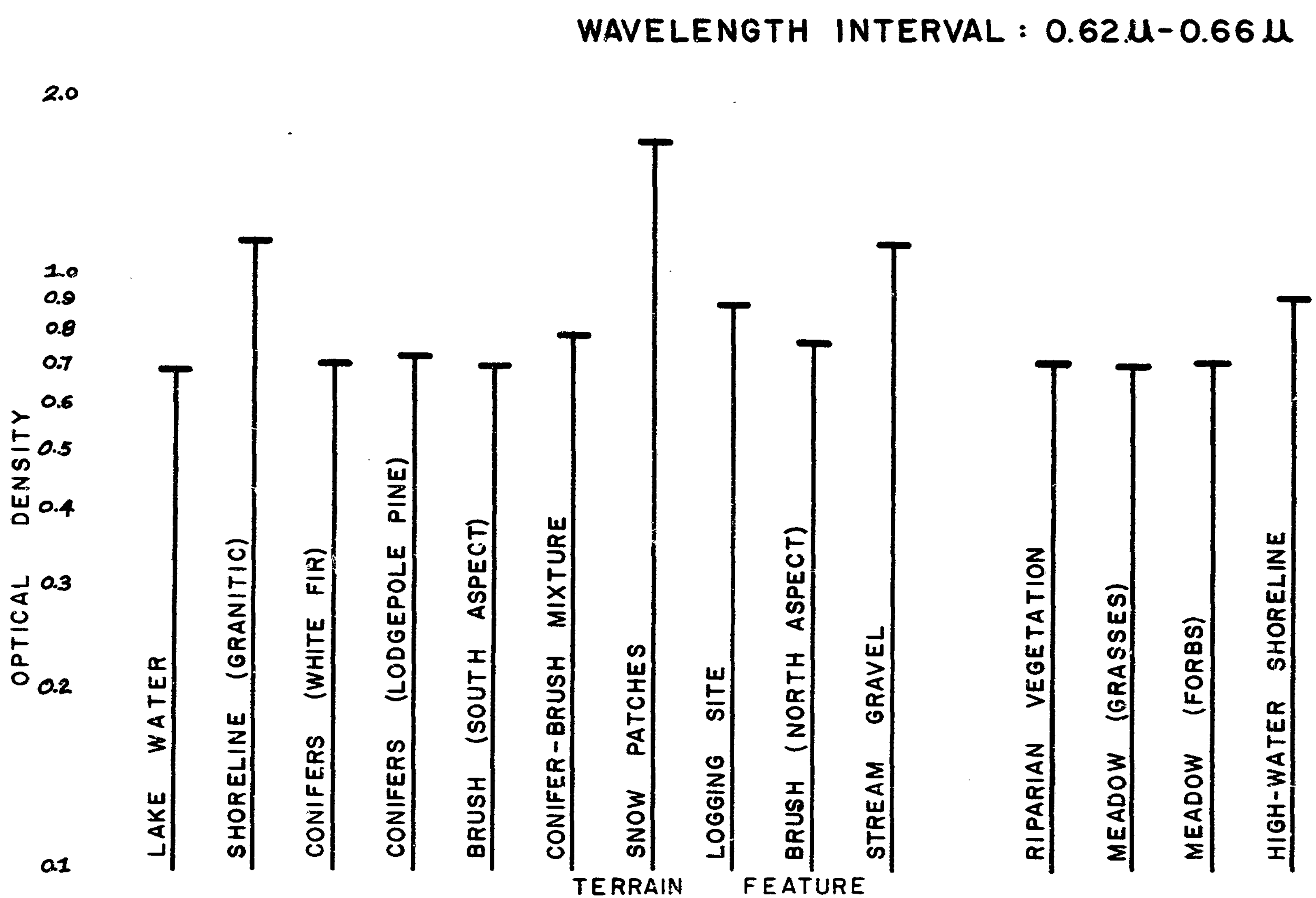

WAVELENGTH INTERVAL: 0.50 μ - 0.52 μ
OPTICAL DENSITY
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
LAKE WATER
SHORELINE (GRANITIC)
CONIFERS (WHITE FIR)
CONIFERS (LODGEPOLE PINE)
BRUSH (SOUTH ASPECT)
CONIFER-BRUSH MIXTURE
SNOW PATCHES
LOGGING SITE
BRUSH (NORTH ASPECT)
STREAM GRAVEL
RIPARIAN VEGETATION
MEADOW (GRASSES)
MEADOW (FORBS)
HIGH-WATER SHORELINE
TERRAIN FEATURE

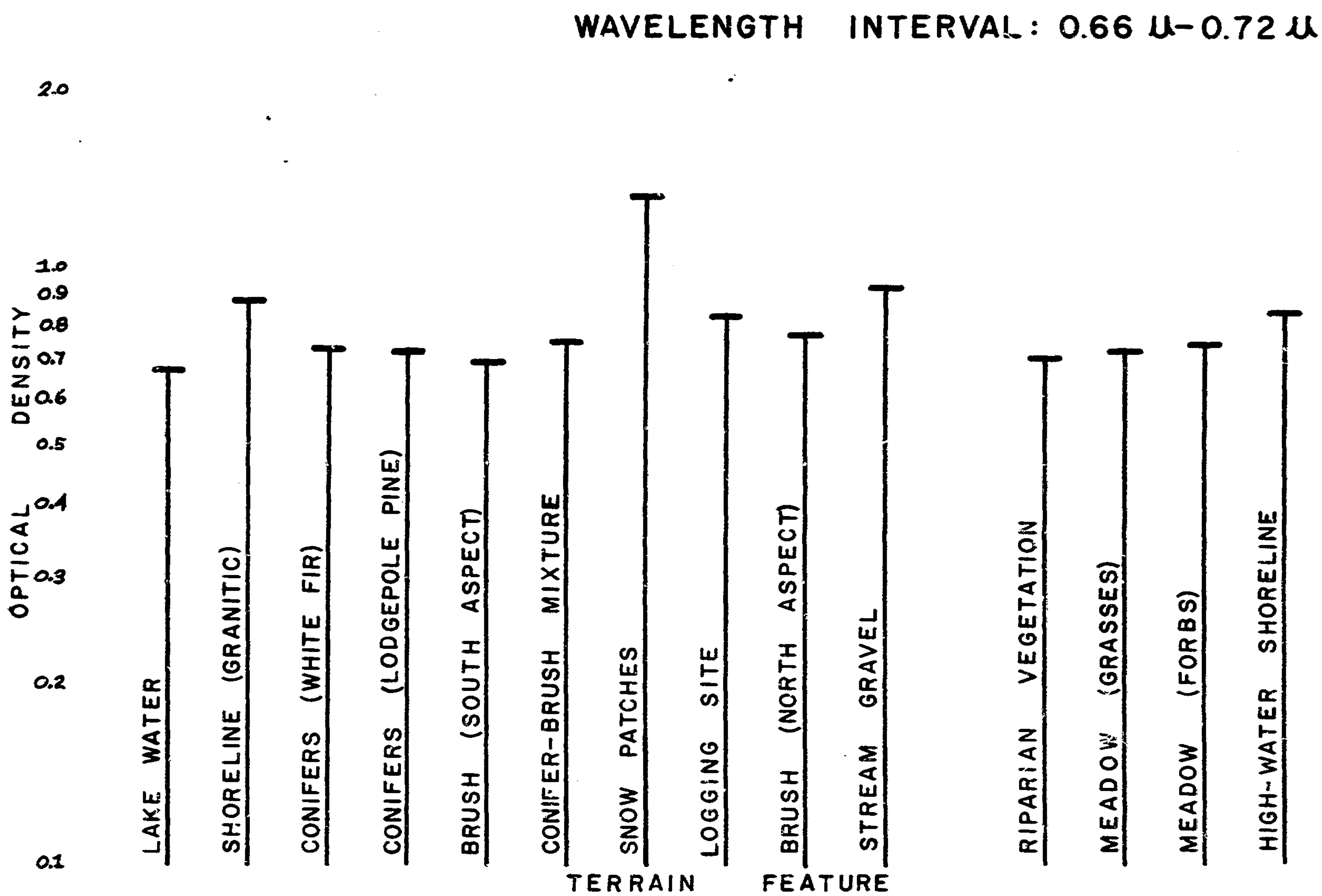

WAVELENGTH INTERVAL: 0.52μ-0.55μ
OPTICAL DENSITY
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
LAKE WATER
SHORELINE (GRANITIC)
CONIFERS (WHITE FIR)
CONIFERS (LODGEPOLE PINE)
BRUSH (SOUTH ASPECT)
CONIFER-BRUSH MIXTURE
SNOW PATCHES
LOGGING SITE
BRUSH (NORTH ASPECT)
STREAM GRAVEL
RIPARIAN VEGETATION
MEADOW (GRASSES)
MEADOW (FORBS)
HIGH-WATER SHORELINE
TERRAIN FEATURE

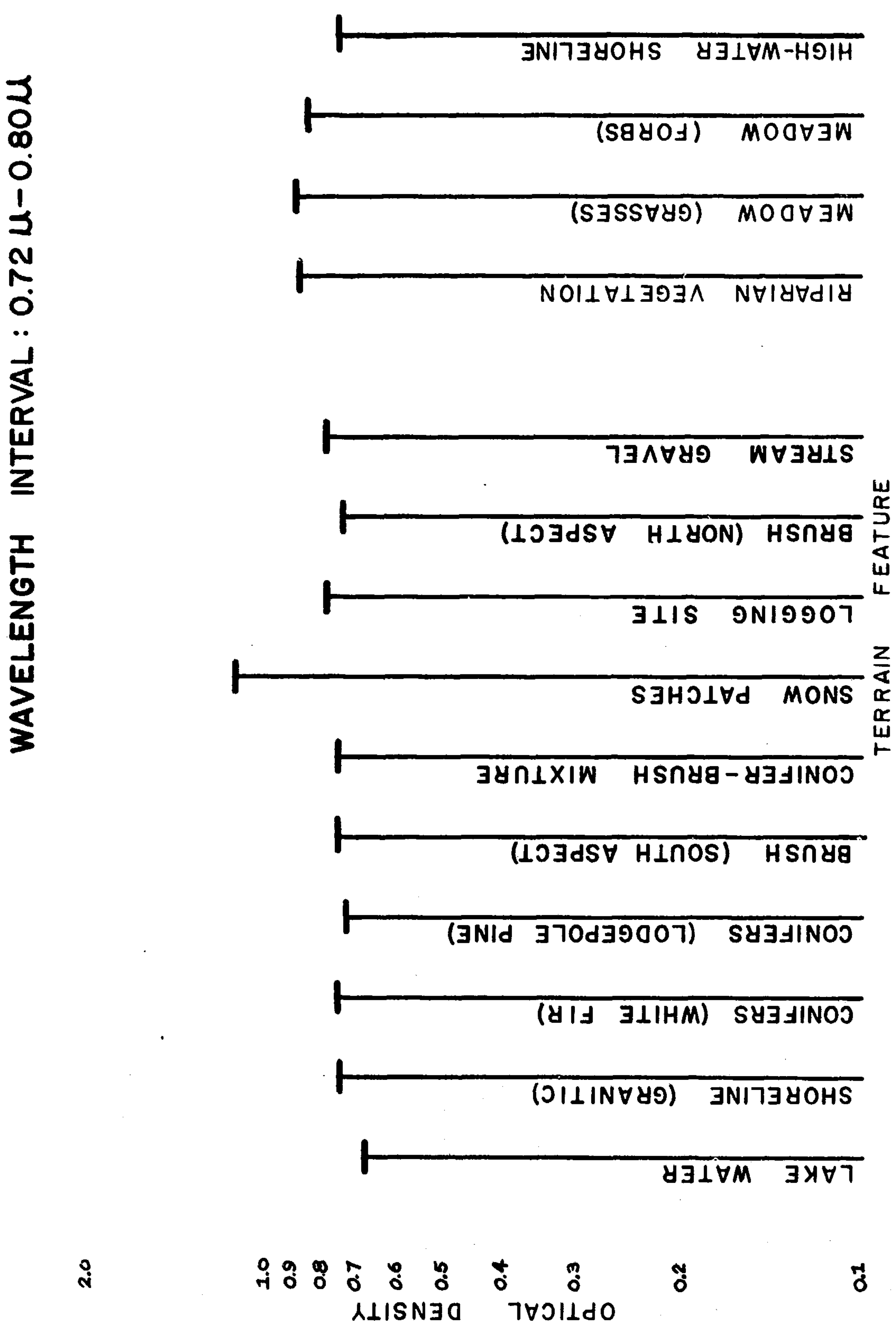


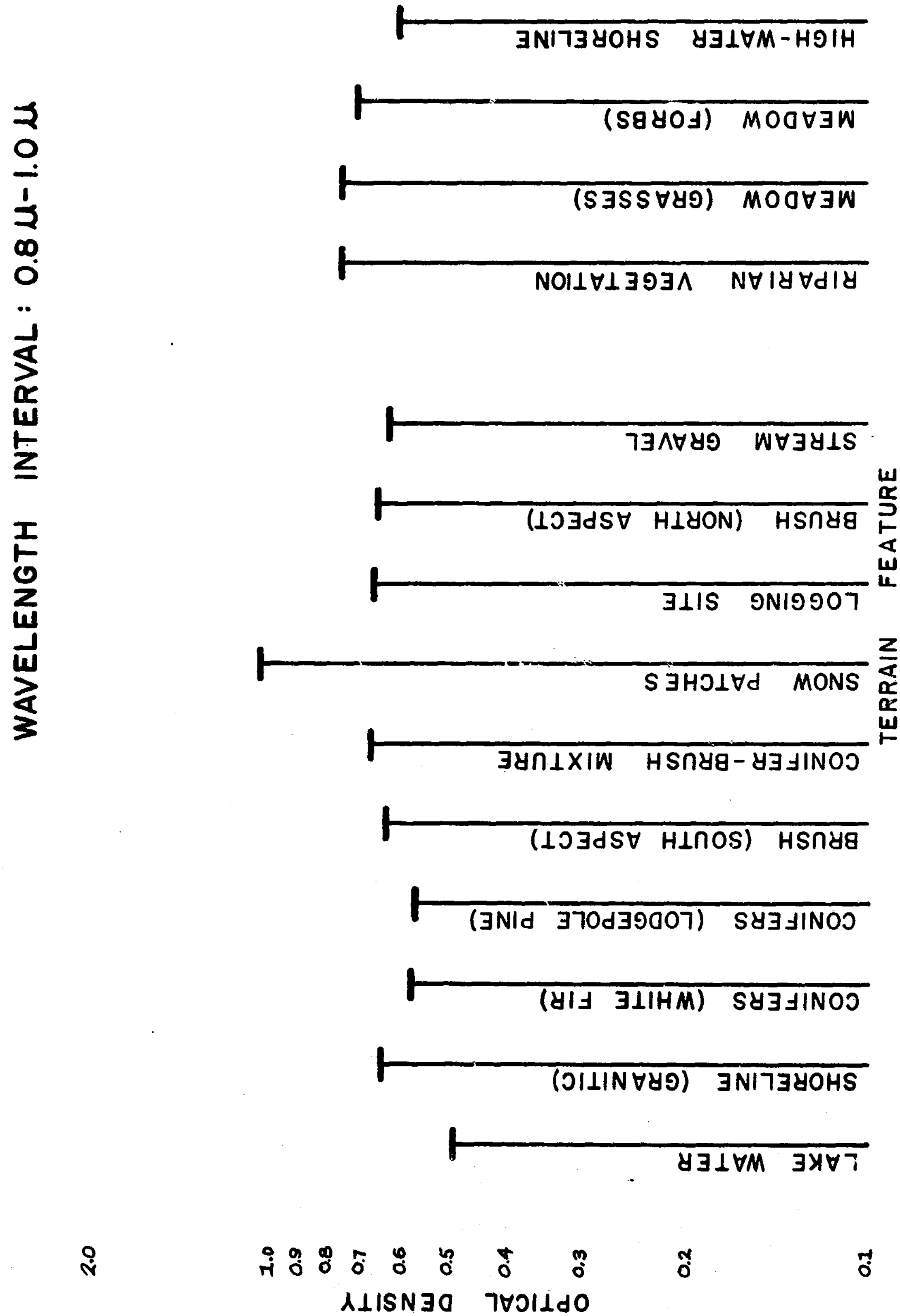
WAVELENGTH INTERVAL : 0.55µ-0.58µ
OPTICAL DENSITY
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
LAKE WATER
SHORELINE (GRANITIC)
CONIFERS (WHITE FIR)
CONIFERS (LODGEPOLE PINE)
BRUSH (SOUTH ASPECT)
CONIFER-BRUSH MIXTURE
SNOW PATCHES
LOGGING SITE
BRUSH (NORTH ASPECT)
STREAM GRAVEL
RIPARIAN VEGETATION
MEADOW (GRASSES)
MEADOW (FORBS)
HIGH-WATER SHORELINE
TERRAIN FEATURE

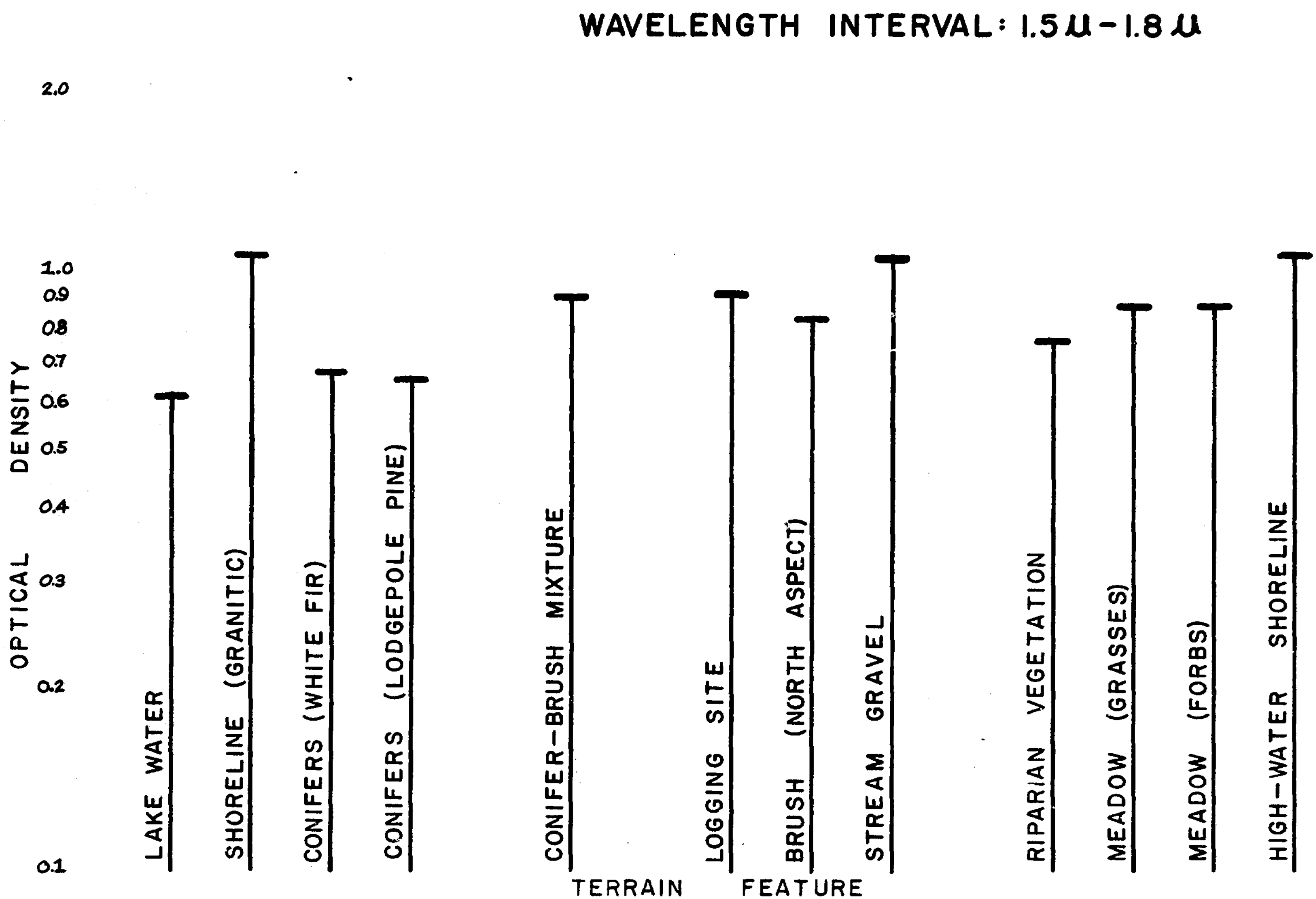

WAVELENGTH INTERVAL : 0.58μ - 0.62μ
OPTICAL DENSITY
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
LAKE WATER
SHORELINE (GRANITIC)
CONIFERS (WHITE FIR)
CONIFERS (LODGEPOLE PINE)
BRUSH (SOUTH ASPECT)
CONIFER-BRUSH MIXTURE
SNOW PATCHES
LOGGING SITE
BRUSH (NORTH ASPECT)
STREAM GRAVEL
RIPARIAN VEGETATION
MEADOW (GRASSES)
MEADOW (FORBS)
HIGH-WATER SHORELINE
TERRAIN FEATURE

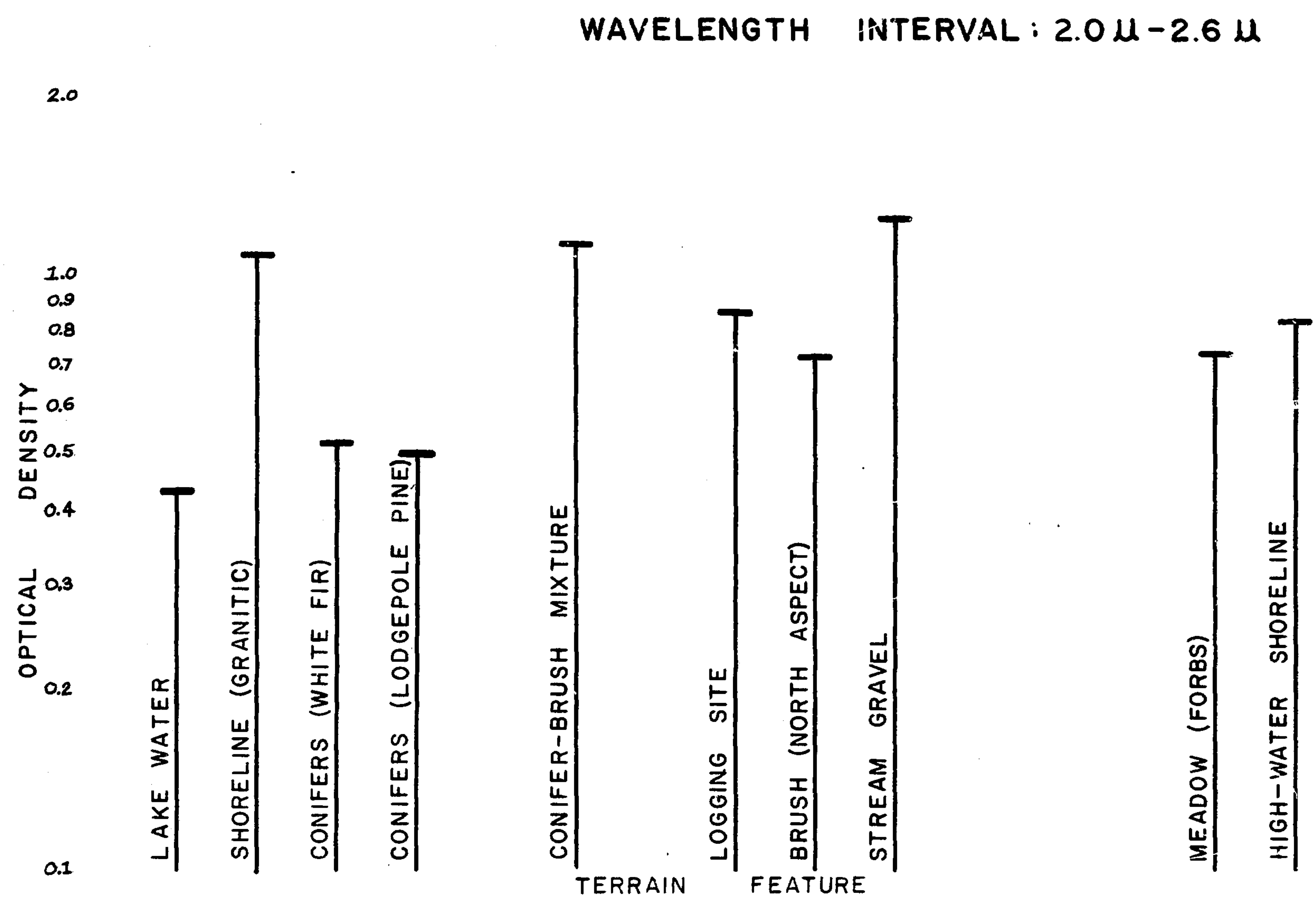

WAVELENGTH INTERVAL : 0.62μ-0.66μ
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
OPTICAL DENSITY
LAKE WATER
SHORELINE (GRANITIC)
CONIFERS (WHITE FIR)
CONIFERS (LODGEPOLE PINE)
BRUSH (SOUTH ASPECT)
CONIFER-BRUSH MIXTURE
SNOW PATCHES
LOGGING SITE
BRUSH (NORTH ASPECT)
STREAM GRAVEL
RIPARIAN VEGETATION
MEADOW (GRASSES)
MEADOW (FORBS)
HIGH-WATER SHORELINE
TERRAIN FEATURE

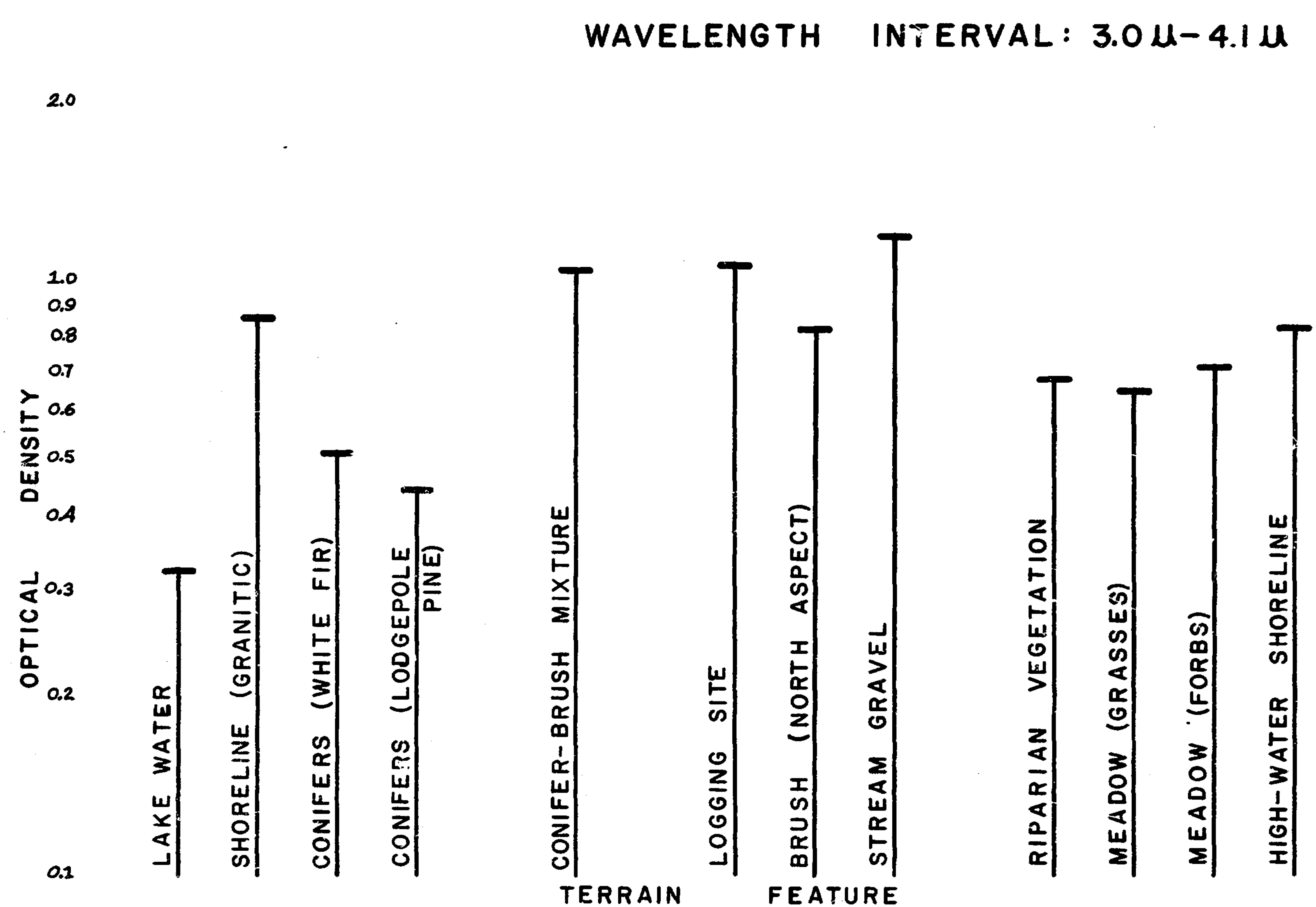

WAVELENGTH INTERVAL: 0.66 µ–0.72 µ
OPTICAL DENSITY
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
LAKE WATER
SHORELINE (GRANITIC)
CONIFERS (WHITE FIR)
CONIFERS (LODGEPOLE PINE)
BRUSH (SOUTH ASPECT)
CONIFER-BRUSH MIXTURE
SNOW PATCHES
LOGGING SITE
BRUSH (NORTH ASPECT)
STREAM GRAVEL
RIPARIAN VEGETATION
MEADOW (GRASSES)
MEADOW (FORBS)
HIGH-WATER SHORELINE
TERRAIN FEATURE


WAVELENGTH INTERVAL: 0.72 µ-0.80 µ
HIGH-WATER SHORELINE
MEADOW (FORBS)
MEADOW (GRASSES)
RIPARIAN VEGETATION
STREAM GRAVEL
BRUSH (NORTH ASPECT)
LOGGING SITE
SNOW PATCHES
CONIFER-BRUSH MIXTURE
BRUSH (SOUTH ASPECT)
CONIFERS (LODGEPOLE PINE)
CONIFERS (WHITE FIR)
SHORELINE (GRANITIC)
LAKE WATER
TERRAIN FEATURE
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
OPTICAL DENSITY

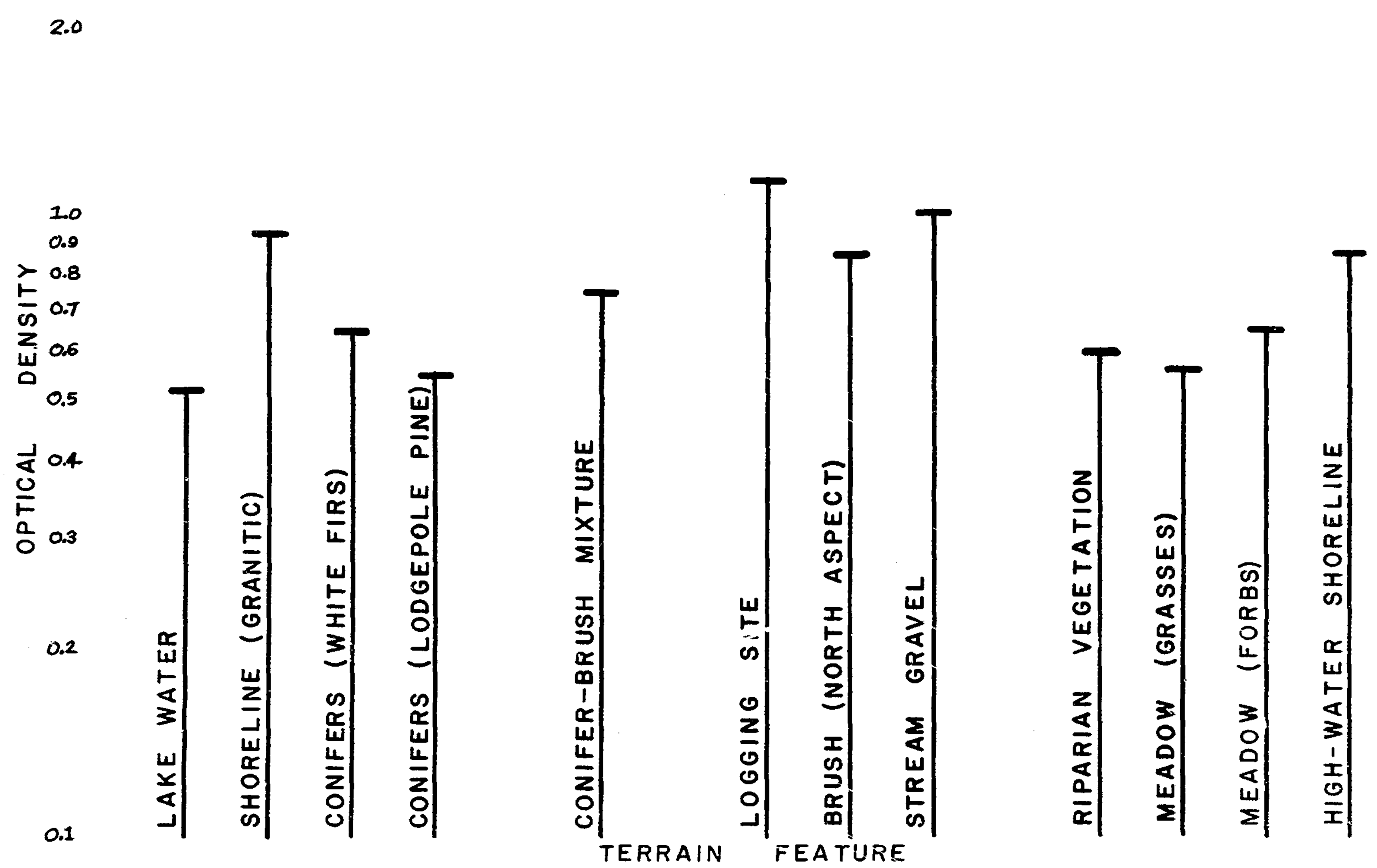

WAVELENGTH INTERVAL : 0.8µ-1.0µ
TERRAIN FEATURE
LAKE WATER
SHORELINE (GRANITIC)
CONIFERS (WHITE FIR)
CONIFERS (LODGEPOLE PINE)
BRUSH (SOUTH ASPECT)
CONIFER-BRUSH MIXTURE
SNOW PATCHES
LOGGING SITE
BRUSH (NORTH ASPECT)
STREAM GRAVEL
RIPARIAN VEGETATION
MEADOW (GRASSES)
MEADOW (FORBS)
HIGH-WATER SHORELINE
OPTICAL DENSITY
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
2.0

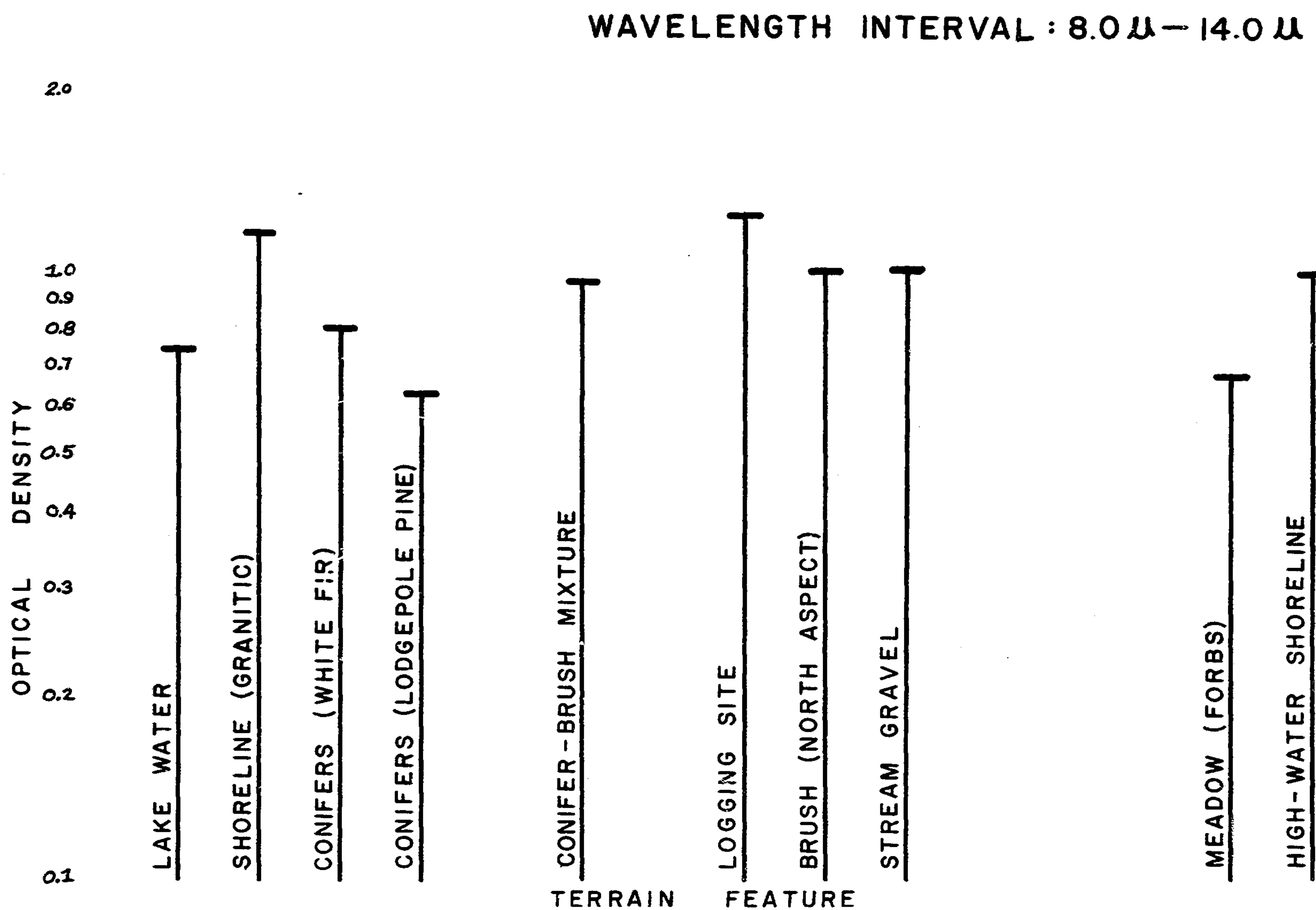

WAVELENGTH INTERVAL: 1.5µ-1.8µ
OPTICAL DENSITY
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
LAKE WATER
SHORELINE (GRANITIC)
CONIFERS (WHITE FIR)
CONIFERS (LODGEPOLE PINE)
CONIFER-BRUSH MIXTURE
LOGGING SITE
BRUSH (NORTH ASPECT)
STREAM GRAVEL
RIPARIAN VEGETATION
MEADOW (GRASSES)
MEADOW (FORBS)
HIGH-WATER SHORELINE
TERRAIN FEATURE


WAVELENGTH INTERVAL: 2.0µ-2.6µ
OPTICAL DENSITY
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
LAKE WATER
SHORELINE (GRANITIC)
CONIFERS (WHITE FIR)
CONIFERS (LODGEPOLE PINE)
CONIFER-BRUSH MIXTURE
LOGGING SITE
BRUSH (NORTH ASPECT)
STREAM GRAVEL
MEADOW (FORBS)
HIGH-WATER SHORELINE
TERRAIN FEATURE


WAVELENGTH INTERVAL: 3.0μ–4.1μ
OPTICAL DENSITY
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
LAKE WATER
SHORELINE (GRANITIC)
CONIFERS (WHITE FIR)
CONIFERS (LODGEPOLE PINE)
CONIFER-BRUSH MIXTURE
LOGGING SITE
BRUSH (NORTH ASPECT)
STREAM GRAVEL
RIPARIAN VEGETATION
MEADOW (GRASSES)
MEADOW (FORBS)
HIGH-WATER SHORELINE
TERRAIN FEATURE

WAVELENGTH INTERVAL : 4.5µ - 5.5µ




WAVELENGTH INTERVAL : 8.0 μ — 14.0 μ
OPTICAL DENSITY
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
LAKE WATER
SHORELINE (GRANITIC)
CONIFERS (WHITE FIR)
CONIFERS (LODGEPOLE PINE)
CONIFER-BRUSH MIXTURE
LOGGING SITE
BRUSH (NORTH ASPECT)
STREAM GRAVEL
MEADOW (FORBS)
HIGH-WATER SHORELINE
TERRAIN FEATURE

Area measured Site #2 - optical density

TERRAIN TYPES

	1	2	3	4	5	6	7	8	9	10	11	PHOTOGRAPHIC SPECTRAL RECORD
1	.97	2.00	.88	1.03	1.28	.95	1.39	1.90	.93	1.19	.74	"BLUE"
2	.14	1.36	.27	.43	.44	.43	.86	.82	.24	.61	.12	"GREEN"
3	.13	2.00	.17	.30	.43	.27	1.17	1.14	.77	.60	.14	"RED"
4	.10	.60	1.11	1.37	.78	1.45	.79	.27	.48	.70	.26	"IR"

9.5 Acetate Overlays. Four individual acetate overlays, similar to those included in Figure 25 on page 65, are included in the manila envelop which follows. They are provided, unbound, for use with any of the other photo enlargements contained in section 9.2 of this Appendix. In addition to the three overlays contained in Figure 25, a composite overlay in black is included which summarizes the information contained in the three separate overlays.