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THE USE OF CIR AND AIRBORNE MULTISPECTRAL SCANNER TECHNIQUES FOR WETLAND SOILS MAPPING OF HIGHWAY CORRIDORS

ALICE E. REDFIELD
Dames & Moore

KENNETH S. THOM
General Electric Company, Space Division

I. ABSTRACT

This paper summarizes the results of an investigation aimed at evaluating the potential advantages of state-of-the-art airborne remote sensing for highway siting and planning tasks, specifically in wetlands areas.

The basic objectives of the study were to develop methodologies using remotely sensed data for mapping wetlands soils and drainage, to evaluate the relative merits and usefulness of the various methods developed, to generate a selection of output products from the remote sensor data for display to highway planners and photointerpreters, and to provide recommendations for implementation of remote sensing techniques in the highway planning and siting process. To accomplish these objectives, remote sensor and ground truth data were acquired for selected test sites in Florida, Michigan, and Minnesota. One of several test sites in Michigan has been selected as representative of the study objectives and methodology.

II. SITE DESCRIPTION

The Michigan test site is in the northern portion of the Lower Peninsula, approximately 150 miles north-northwest of Detroit along Interstate 75 in Roscommon County, 3 miles northwest of Maple Valley and 5 miles east of Houghton Lake (Figure 1). The site is within the Eastern Lake section of the Central Lowland Province, an area of maturely dissected and glaciated ridges and lowlands characterized by moraines, lakes, and lacustrine plains. Pleistocene glacial materials, as much as several hundred feet thick, mantle the bedrock and have modified most of the present surface. The level to gently sloping areas are composed primarily of outwash and till, whereas the more rolling areas are characterized by morainal deposits. Relief is generally less than 10 feet. Streams drain into Houghton Lake.

Soils at the test site are classified into three broad types. Sandy soils occur largely on moraines and some outwash plains. Clay soils, or moderately retentive subsoils, are associated with till plains and ground moraines. Organic soils, peat, and muck are common in low-lying, poorly drained areas.

Vegetation is mostly second growth resulting from timber operations and numerous burnings. The original vegetation can be grouped into four classes as follows: deciduous forests on sandy, well-drained soils; mixed hardwood-coniferous forests on somewhat poorly drained soils; and conifers and reeds in poorly drained swamp areas.

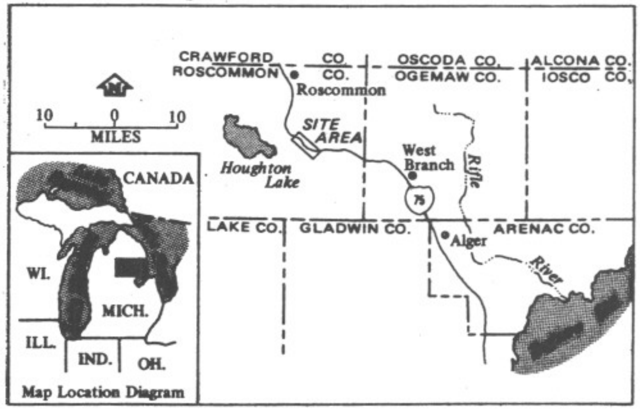

Figure 1. Location of Michigan Test Site.

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III. DATA ACQUISITION

A. COLOR INFRARED PHOTOGRAPHY

Color infrared photography was acquired over the Michigan test site during the summer and fall of 1978 using a 6-inch focal length, 9-inch X 9-inch frame mapping camera and EK 2443 false color reversal film. The summer photography was obtained on July 24, 1978 when vegetation was in leaf. The fall photography was flown on October 28, 1978 when deciduous vegetation was in the process of losing its leaves. Both sets of color infrared photography were flown at an altitude of 2400 feet, which resulted in a nominal photographic scale of 1:4800, or one inch equals 400 feet. The flightlines for the summer and fall color infrared photography were laid out in a northwest-southeast direction roughly parallel to Interstate 75. Forward overlap was set at 60 percent, providing optimum stereoscopic viewing of adjacent frames in the flightline sequence.

The quality of the summer color infrared photography was excellent, both in terms of spatial and spectral resolution. Ground resolutions were estimated to be on the order of 0.5 to 1.0 foot. Although the fall photography had similar spatial resolution, spectral quality was considered only fair because low sun angle resulted in extensive shadowing and partially underexposed (darker) image scenes.

B. MULTISPECTRAL SCANNER IMAGERY

Multispectral imagery was acquired of the Michigan test site with the Bendix modular multispectral scanner, which uses a diffraction grating to split ground reflectance into 11 spectral bands. Acquisition flights were flown on October 4, 1977 and August 8, 1978, at an aircraft altitude of 2000 feet resulting in a ground resolution of 6 feet per pixel. Flightlines were approximately parallel to Interstate 75 in a generally northwest-southeast direction (magnetic heading of 320° to 355°). For both flight dates, imagery over the site was obtained on high density digital tapes in four swaths, then converted to computer compatible tapes. Imagery from both flights was uniformly good. Scanner response to spectral reflectance remained constant along each swath but appeared to change slightly between swaths, possibly due to drift in sensor calibration or sun angle changes.

IV. GROUND TRUTH

Ground truth over the Michigan test site consisted of representative borings supplemented by a 1924 county soils survey map which presented an overview of general soils conditions at the test site (Figure 2). The ground truth was considered to be adequate for assessing the capabilities of color infrared photography and multispectral scanning techniques for mapping wetland soils and drainage characteristics within the study area. However, the test borings were made on either what is now the median strip between highway lanes, or in poorly drained areas caused mainly by the local "damming effects" of the highway embankments. Consequently, the value of the test borings was not as good as had been expected, particularly with regard to the evaluation of natural surface conditions in the immediate area of the boring. From the areal or regional geomorphic context, however, the borings are within wider flood plains and related low-lying areas, many of which are characterized by poor natural drainage conditions and fine-textured surficial soils.

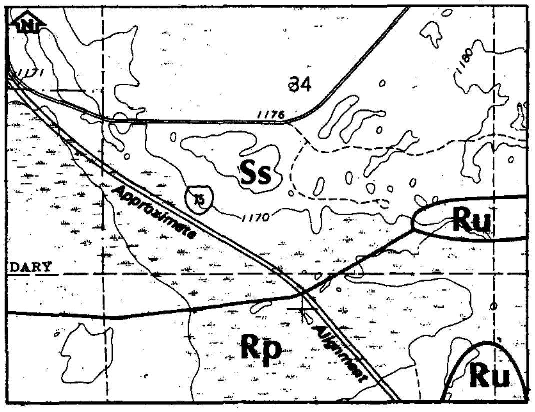
V. INTERPRETATION OF COLOR INFRARED PHOTOGRAPHY

A. CONVENTIONAL PHOTOGRAPHIC ANALYSIS

Stereoscopic triplets from both seasons were selected over the test site where ground truth data were available. Borings were then located on their respective photo frames. Locations were necessarily approximate since descriptions of reference points were not specific and/or some reference points could not be identified on the aerial photographs.

The color infrared positive image frames were interpreted stereoscopically on a light table using a standard 0.9X mirror stereoscope. Delineation of soil moisture characteristics, as discussed below, was made on mylar overlays registered to the individual image frames. Summer and fall images were interpreted independently in an effort to determine differences in interpretability and whether additional information could be obtained from seasonal coverage.

Interpretive results were based on observable, stereoscopic characteristics, including pattern elements



MAP UNIT	LANDSCAPE POSITION	UNIFIED SOIL CLASSIFICATION (DEPTHS)	DRAINAGE CAPABILITY (IN/HR)	SOIL MOISTURE (IN/HR)	DEPTH TO WATER TABLE
Rp Rifle peat	Nearly level--filled lakes	PT 0 to 42 inches	Very poorly drained (5 to 10)	0.5	Surface
Ss Saugatuck sand	Level and depressional areas and gentle surrounding slopes	SP-SM 0 to 22 inches (cemented 14 to 22 inches) SP 22 to 24 inches	Somewhat poorly to poorly drained (10), except hardpan (0.2 to 0.8)	0.03	6 inches
Ru Rubicon sand	Nearly level to gently sloping	SP÷SM 0 to 48 inches	Well to moderately well drained	0.02	42+ inches

Figure 2. Soil Survey and Associated Units at the Test Site.

related to landforms, drainage, texture, and vegetation, and spectral characteristics, including color/hue and vegetation and soils reflectance.

Stereoscopic viewing enhanced subtle variations in local topography and landform expression and assisted in the delineation of different vegetation types having similar spectral characteristics, but identifiable differences in height, shape, and density.

Circular, oval, or elongate flat depressions and linear or dendritic, nearly level flood plains, particularly when associated with standing water, were indicative of poorly drained soils. Dense vegetation and dark tone also reflected conditions of high soil moisture. Well-drained soils were generally characterized by grainy textures and light tonal and high reflectance signatures. These soils occupied gently rolling to undulating plains with locally steep slopes, and were characterized by less dense vegetation, often large-crowned deciduous trees such as oak. Poorly to moderately drained soils generally exhibited intermediate tones and were found topographically between low, poorly drained and higher, well-drained soils. Erosion and gullying were also used as aids in determining soil texture. Standard stereoscopic interpretation of drainage densities was initially considered; however, the large scale of the imagery precluded accurate drainage density discernment. The key observables, arranged in tables, formed the basis for subsequently classifying the types of soils and wetland units at the test site.

In addition to evaluating soil moisture and permeability characteristics, the remote sensor investigation resulted in the evaluation of engineering characteristics, with emphasis on determining soil consistency and relative soil compactness (relative density). Soil consistency relates specifically to fine-grained materials, chiefly silts and clays whereas relative soil compactness refers to coarse-grained materials, namely sands and gravels. An attempt was made to classify the consistency of the various fine-grained soils units in terms of anticipated resistance to penetration. Those units, for example, interpreted to be "soft" soils would probably indicate a penetration resistance of 2 to 6 blows per foot. "Medium stiff" soils would have a penetration resistance of 7 to 12 blows per foot. Soils with a penetration resistance in excess of 12 blows per foot would be classified as "stiff" soils.

With regard to relative soil compactness, loose soils would have a penetration resistance of 0 to 25 blows per foot. Medium dense soils would range from 26 to 75 blows per foot. Dense soils would have a penetration resistance in excess of 75 blows per foot. Correspondingly, those soils interpreted to be "soft" or "loose" would have fairly low bearing capacities which would, in turn, have an impact on road design and construction capabilities.

Soil consistency and relative compactness characteristics were inferred on the basis of microlandform, drainage, textural, and erosion features, as identified from the stereoscopic interpretation of the color infrared photography.

B. INTERPRETIVE RESULTS

The Michigan test site contained wetlands soils and drainage conditions typical of soils units in the northeastern part of Michigan. The test site had a manmade lake in the northeast quadrant of the interpreted frames, and a channel, with a wide, swampy flood plain, traversing the lower half of the frames east to west; sets of culverts allow water to pass under the highway. On the summer imagery, one of the wettest areas of the frame was a channel west of the highway. There was no significant difference in the areal extent of the wet units on the summer and fall imagery. However, the northern portion of the highway median appeared to be drier in the summer. The black, smooth signature of standing water was visible in ditches parallel to the highway and connecting the culverts. Other wet units on both the summer and fall scenes were topographically low and had extremely dense vegetation indicating very high soil moisture, but probably no standing water.

All three borings used for ground truth were in areas interpreted as having high soil moisture. Boring A, west of the highway and slightly north of the northernmost culvert, was in a dense, scrubby area on the edge of the swamp. Both the summer and fall images interpreted A as a soft silt and clay, the summer unit indicated some sand, with high soil moisture. The log for boring A showed 6 inches of dark organic material, underlain by soft, wet sand and silt; depth to water was 1 to 2 feet.

Boring B, in the median, was interpreted as sandy, silty, and clayey with high soil moisture. The log for boring B showed 6 inches of coarse sand above 6 inches of sand, peat, and roots underlain by 2 feet of clay above 2 feet of sand; depth to water was 6 inches.

Boring C, east of the culvert under the northbound lane, was an area of high soil moisture on both the summer and fall image. The log for boring C showed 6 inches of loose sand above 6 inches of dry, dense peat, underlain by 4 feet of wet peat and silt; depth of water was 3 feet.

Comparison with the Soil Survey of Roscommon County (1924), a portion of which is shown in Figure 2, revealed that the entire image frame covered a portion of the Saugatuck sand, a somewhat poorly to poorly drained unit occurring in level and depressional areas and on gentle surrounding slopes. Although this agreed with borings B and C, the location of the test site with respect to the soils map was not precise. Neither the highway nor the manmade lake appear on the 1:24,000-scale topographic quadrangle (1963) covering the area. The topo map shows a swamp approximately where it was delineated on the image frames. Therefore, the interpretation of color infrared photography over the test site resulted in the enhancement of the small scale soils map, whereby a number of local units within the Saugatuck sand were delineated.

In contrast, small, dry, sand areas, topographically higher than the surrounding terrain, were evident on both the summer and fall imagery. The soils had a grainy appearance and high spectral reflectance characteristics. Large-crowned, moderately spaced trees, probably oak, were prominent on the highest, driest areas near the lake; smaller mixed deciduous trees were moderately spaced on the well-drained ridges above the flood plain. No borings were located in these areas which were also included in the Saugatuck sand unit in the Roscommon County Soil Survey.

VI. INTERPRETATION OF MULTISPECTRAL SCANNER DATA

A. IMAGE 100 SYSTEM

Interpretation of the scanner data was performed using the Image 100 computer based digital image processing system designed by the General Electric Company. A DEC PDP-11 series computer, with standard peripherals, was used as the system process controller.

Prior to actual interpretation, the scanner data was manipulated to a format suitable for entry into the Image 100. The Image 100 system was conceived to operate upon data from the multispectral scanner (MSS) on the Landsat spacecraft. Although the Bendix modular multispectral scanner (MMS) and the Landsat MSS are similar in principle, their outputs are significantly different. The Image 100 works with up to four spectral bands of data in an array 512 pixels wide by 512 lines long. Further, the input signal must be formatted such that the spectral bands are interleaved on a line by line basis. The computer compatible tapes (CCTs) - generated from the scanner high density digital tapes - contained 11 spectral bands in an array 825 pixels wide by approximately 2000 lines long. Also, the spectral band data was interleaved on a pixel by pixel basis.

Reformatting of the data was performed in two steps. First, the total contents of the CCT were read by the computer and placed into mass storage. After this process was completed, the operator selected four of the 11 spectral bands for any segment of 512 by 512 within the original 825 by 2000 array. The computer then extracted the appropriate pixels from mass storage, placed them in the band interleaved by line format and generated a product tape, which acted as the input to the Image 100.

Selection of the appropriate 512 by 512 segments was a relatively straight-forward two step process. First a single band segment was generated by compressing the imagery by a four to one factor in the length (along track) direction, selecting the central 512 pixels in the width (across track) direction, and displaying the result on the Image 100 screen. The imagery was then compared with the ground truth data and the photography to obtain the geographic relations. This allowed determination of a starting pixel number and starting line number necessary to produce a 512 by 512 segment having a one-to one length to width ratio which covered the test site. Following this determination, three product files were placed on the product tape. Each file contained imagery of the segment of interest with bands 1-4 on the first file, 5-8 on the second file, and 9-11 on the third file.

Selection of the four bands best suited for use in the interpretation phase was done using two techniques. First, histograms of the intensity distributions for each band were generated. As expected, histograms from adjacent bands were quite similar and it was determined that to obtain the best differentiation, the four bands to be used should be selected from the following groups: bands 1-4, bands 5-8, bands 9-10, and band 11. To confirm this decision and to assist in the final selection, shade prints of density slices of each band were prepared for segments from the test site.

Two groups of soils scientists and photointerpreters independently inspected the shade prints for the Michigan test site. Both groups concluded that the most interpretive information could be obtained by utilizing imagery from bands 2, 6, 10, and 11 (spectral bands 0.44-0.49, 0.62-0.66, 0.97-1.05, and 8.0-12.0 micrometers, respectively). Therefore, the scanner data interpretations were performed using only those four bands. Figure 3 is a representative reflective infrared scanner image over the test site.

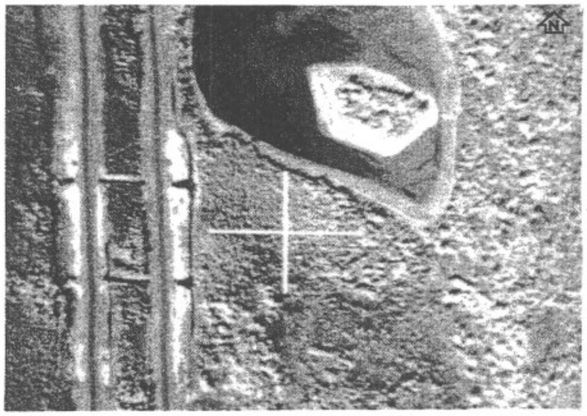


Figure 3. Reflective Infrared Scene from Image 100.

B. CLASSIFICATION TECHNIQUES

The extraction of thematic information from multispectral imagery was accomplished by the statistical measurement of radiometric properties of the test area in conjunction with the operator's visual and statistical interpretation of the data. Two principal analysis functions performed during system operation were "training" and "classification," defined below.

<u>Training</u>. Multispectral analysis is predicated on the fact that like features in a scene have similar spectral properties. To perform analyses, the user must inform the machine as to which features (water, soil, vegetation, etc.) are of interest; the machine then extracts the multidimensional spectral properties of the selected feature.

Classification. When the spectral properties of the feature are found, the Image 100 system scans the total image (pixel-by-pixel) and determines if the spectral properties of each pixel correlate with those of the feature of interest. The result of the classification process is a map in which each pixel is identified by a class type (or theme).

C. INTERPRETIVE TECHNIQUES

Since the system is user interactive, a variety of interpretive techniques was available to enhance the extraction of useful information from the raw data. Two of these techniques, single-cell signature acquisition and feature space partitioning, were used in this project to generate spectral signatures and thematic data.

Single Cell Signature Acquisition. The single cell method involves "one dimensional training." The Image 100 cursor, controlled by a joystick, is located over a training area and a set of one-dimensional histograms (1 histogram per spectral band) is acquired. Upper (maximum) and lower (minimum) limits selected for each histogram define the spectral signature (parallelepiped) for a given target (category). The resulting theme is then compared with available ground truth, and errors of commission and/or omission are evaluated. If modifications are required, the size of the training area can be changed and/or the boundaries of histograms modified. If desirable, new training areas can be selected and the process repeated.

Feature Space Partitioning Classifier. The feature space classifier utilizes a non-parametric approach based on parallelepiped techniques. The basic principle of the technique requires that the system operator, interacting with a thematic display of classification results, scattergram graphics, and histogram displays, selects upper and lower spectral bounds of land cover classes. The classification is performed on a two-axis projection defined as two spectral bands, ratios of bands, or other combination of data space using only the selected bounds and is independent of the spectral distribution of class statistics between these bounds.

D. INTERPRETIVE RESULTS

This test site had wide variations in soil moisture conditions lying in close proximity. Areas of standing water were first delineated with the manmade lake and the wet culverts being easily differentiated. Areas of very high soil moisture were alarmed by signature extention beyond the bounds of the color infrared interpretation and then corroborated by inspection of additional color infrared frames. Next a signature was developed for dry, bare soils based on the embankments paralleling the highway. When extended, this signature accurately reflected the dry areas in the photointerpretation and also delineated strips of land surrounding the manmade lake and island in the lake. Comparison with other photographic frames confirmed the correctness of this interpretation. Training on areas west of the interstate highway resulted in a generally accurate reproduction of photointerpreted classes when extended to other areas of the test site.

The signatures developed by scanner data classification were somewhat broader than the relatively detailed differentiation obtained by using the combination of stereo, textural, and tonal variation for the color infrared interpretation. Attempts were made to further subdivide the broader classifications of the scanner imagery. In many cases, these subdivisions were successful and the results correlated reasonably well with the photointerpretation. However, an excessive amount of computer time was required and the additional detail obtained could not justify the expenses incurred, should these techniques be translated into an operational environment.

VII. ANALYTICAL RESULTS

The stereoscopic analysis of color infrared photography was extremely valuable in the interpretation and mapping of wetland soils in the Michigan Basin. The accuracy of the analysis has been demonstrated by the degree of correlation achieved, both in the delineation of soil boundaries and in the classification of the various soils units. In specific instances, the color infrared interpretation provided more detail than was otherwise obtainable from existing ground truth data alone. As a result, it was felt that the interpretive approach used in this investigation could be a cost-effective method for the assessment of basic soils and wetlands conditions in environmentally sensitive, and often inaccessible, areas.

Major conclusions reported as a result of the remote sensor interpretation of the Michigan test site were as follows:

1. Stereoscopic viewing of subtle topographic and vegetation density variations, in association with tonal, textural, and spectral reflectance characteristics, provided an excellent means for accurately inferring wetland soils and drainage conditions.

2. Stereoscopic viewing greatly assisted in discriminating amongst different vegetation species which had similar tonal or textural signatures, but could be distinguished by subtle height differences not easily discernible by monoscopic or spectral viewing alone.

3. Coniferous forests, occupying broad alluvial channels and bog areas, correlated well with poorly drained swampy areas containing layers of peat and muck. Conversely, well-drained soils were associated with sandy areas and large-crowned deciduous trees.

4. Circular and oval-shaped depressions exhibiting dense vegetation were generally associated with softer, saturated soils.

5. It was possible to make qualitative inferences with regard to the extent and distribution of surficial soils types, depths (shallow versus deep), soil moisture/drainage characteristics (high, medium, low, dry) and compactness, based on key landform associations, textures, colors, and spectral reflectance characteristics. However, it was not possible to differentiate local areas where variations in subsurface soils are known to occur, i.e., sand grading into clay at 6-foot depth, using surrogate indicators such as discernible vegetation differences.

6. To make efficient use of drilling time in practical applications, borings locations should be selected from the aerial photography, in undisturbed areas along the highway right-of-way, to augment the generalized soils units derived from the photointerpretation.

7. Although local variations in wetland soils conditions, specifically extent of surface water, were observed on corresponding frames of summer and fall photography over a particular area, this type of seasonal overflight coverage did not provide an increased interpretive capability with regard to better defining the wetland soils and drainage conditions at the site. This was due to two factors: (a) the majority of the fall color infrared photography was underexposed (dark) and had extensive shadows, greatly limiting the useability of this imagery; and (b) the summer and fall coverage sample was probably not as optimum as an early spring and summer-fall coverage program, particularly with regard to discerning variations in wetland soils conditions. The fall photography, however, was useful for interpreting subtle topographic and micro-relief variations, particularly in local areas where the ground could not be seen on the corresponding summer imagery due to dense deciduous vegetation cover.

8. The scale of the color infrared photography could be reduced by more than a factor of two and still provide the same, or greater, level of detail than was available with the existing 1-inch equals 400 feet (1:4800) photo scale. In addition to providing more ground coverage per image frame, a smaller image scale would allow the interpreter to stand back, so to speak, and differentiate between patterns of adjacent landform associations, such as subtle variations in topographic expression, drainage, size and shape, and texture - all of which are considered important observables in wetland soils and drainage mapping.

VIII. CONCLUSIONS AND RECOMMENDATIONS

In addition to the analytical results there were issues related solely to the technologies tested in this study. In terms of transferring the technology to highway planners there were at least two considerations:

1. Does the technique yield consistent, cost-effective analytical data?

2. Has the feasibility of the analytical method been established?

The multispectral scanning radiometer has three advantages over film. First, it makes more accurate measurements of color. This only represents an advantage _if_ the information sought is in the color domain. Second, if one required thermal measurements they must be acquired by a separate sensor and even if both systems are on the same aircraft the axis of rotation problem between the camera and the thermal sensor is magnified. Third, the scanner data is collected inherently in computer compatible form. Photography can certainly be scan converted, and if need be, color separated and scan converted. However, one virtually must give up perhaps the most valuable attribute of photography, spatial resolution. It is possible of course to enlarge the photo so that the scanning aperture does not degrade resolution but such solutions are very costly and would lead one to purchase or lease a scanner for even a modest data acquisition task. The pertinent question, however, was whether computer-aided analysis was essential. It was clear from the analytical methodology that adequately trained personnel do not require this support.

There was the separate issue of the importance of the thermal band. If a case could be made for the use of this band, then the case for the scanner was much strengthened as previously discussed because of the inherent registration between the bands. Since this was one of the important goals of the study, a review of the findings is appropriate. It was suspected that the thermal band would provide unique information on the state of surface and near surface moisture conditions. Studies by the Remote Sensing Institute of South Dakota State University have amply documented the use of the thermal scanner for the detection and mapping of near surface aquifers. They show that three conditions must prevail for the mapping of near surface aquifers:

1. Pre-dawn data acquisition;

2. Surface winds less than 3 knots; and

3. Relative humidity less than 30 percent.

It is obvious that in order to compare the value of the thermal band to the visible spectrum, the first of the above conditions cannot apply. Thus there was the more modest goal of surface or near surface moisture condition determination. It was found, however, that in the color infrared photography it was possible to:

1. Infer surface and near subsurface moisture from vegetation species composition and density, textural and spectral reflectance characteristics;

2. Infer soils groups from landform associations and vegetation species composition; and

3. Group the exposed soils into poor, moderate, and well-drained classes on the direct evidence of soil reflectance.

There was no additional information from the thermal band.

Finally the most successful technology and the one recommended for use by highway planners in wetlands areas was color infrared photography. It is obvious from the analytical text that the single most valuable attribute in the identification of the vegetation communities was the stereo view. This rules out the scanner on a practical basis. It is possible to design a stereo scanner but exceedingly difficult to use on a platform as unstable as an aircraft. The second most valuable attribute of color infrared photos was their ability to discriminate between plant communities and surface soil colors. Although this can be done equally well with the scanner, there was no significant improvement in this capability using the scanner. Finally, color infrared photography is widely available, and using the analytical methodology outlined in the text, it is expected that highway planners can perform the required survey of a proposed route in a wetlands area and get first order information about the proposed site that will minimize undesirable environmental impact.

This research was sponsored by the U.S. Department of Transportation, Federal Highway Administration, Washington, D.C.

IX. LIST OF SOURCES

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ALICE E. REDFIELD is a Remote Sensing Specialist with Dames & Moore, Washington, D.C. Miss Redfield has applied remote sensing imagery in support of projects such as transmission line and highway corridor investigations, siting studies, land use assessments, terrain analyses, and resources inventories.

Miss Redfield received a Bachelor of Arts degree in physics from Goucher College in Towson, MD, and a Master of of Library Science from Emory University in Atlanta, GA. She has completed the Harvard Continuing Education Seminar on the Use of Remote Sensing for Terrain Analysis and the Forest Photogrammetry Short Course at Virginia Polytechnic Institute.

KENNETH S. THOM is a Program Manager for Hardware Systems at the GE Space Division's facility in Lanham, Maryland, and has responsibility for the design and development of a variety of ground-based data and image processing equipment. Prior to this assignment, he was a member of a team of natural science specialists who assisted NASA in the conduct of the Landsat Investigation Program and also performed a wide variety of studies in agriculture, geology, marine resources, etc., utilizing Landsat and other remote sensing data sources. Mr. Thom holds a BSEE from Drexel University and has done graduate work in electrical engineering at Stevens Institute of Technology.