Multispectral Data Interpretation for Engineering Soils Mapping

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The application of multispectral remote sensing to engineering soils mapping was investigated along a 60-mile test flight in Indiana. The multispectral data included 15-channel imagery and 4 types of aerial photographs (black and white, infrared black and white, color, and color infrared). The study showed the color film to be the best for mapping soils and soil conditions. A cost analysis showed the color film to be the most economical because the interpretation time was less and the results more reliable. The multispectral data were analyzed by visual methods, by densitometry, and by use of a computer. The computer analysis proved to be efficient and practical. The spectral response of some engineering soils are discussed, and digital computer maps are shown as examples of automatic classification for the multispectral data. A special feature in the computer analysis assists in selecting the optimum combinations of channels. Options in the computer programs permit development of separate map displays showing various soils and soil conditions of interest to the engineer. The spectral response concept is valid for soils mapping, but adequate ground control is necessary to assist in the automatic analysis. Vegetative cover is a limiting factor.

•THE EVALUATION of remote sensing methods and types of aerial films as a source of data for civil engineering purposes has been investigated only in the last few years. This paper describes the results of research conducted on the evaluation of these techniques in order to produce engineering soils maps for site selection studies. The research project was cosponsored by the U.S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads, and the Indiana State Highway Commission. The work was executed at the Airphoto Interpretation and Photogrammetry Laboratory of the School of Civil Engineering, Purdue University (14). The automatic analysis of multispectral data on computer was done at the Laboratory for Applications of Remote Sensing (LARS), Purdue University. This research is an extension of the work initiated in 1965 by Harold T. Rib and R. D. Miles (5, 6).

DATA COLLECTION

A test site was selected early in 1967 in south central Indiana along state Route 37. The area was selected on the basis of variability of earth materials and land forms. Figure 1 shows the route selected. It is a 70-mile section of a proposed highway from Indianapolis to Bedford, Indiana.

Intermediate scale aerial coverage with black and white Kodak Plus-X panchromatic film was obtained April 11, 1967, by personnel of the Indiana State Highway Commission (ISHC) plane. This produced 1:12,000 scale photography of the entire route for planning data collection procedures and the multichannel flights.

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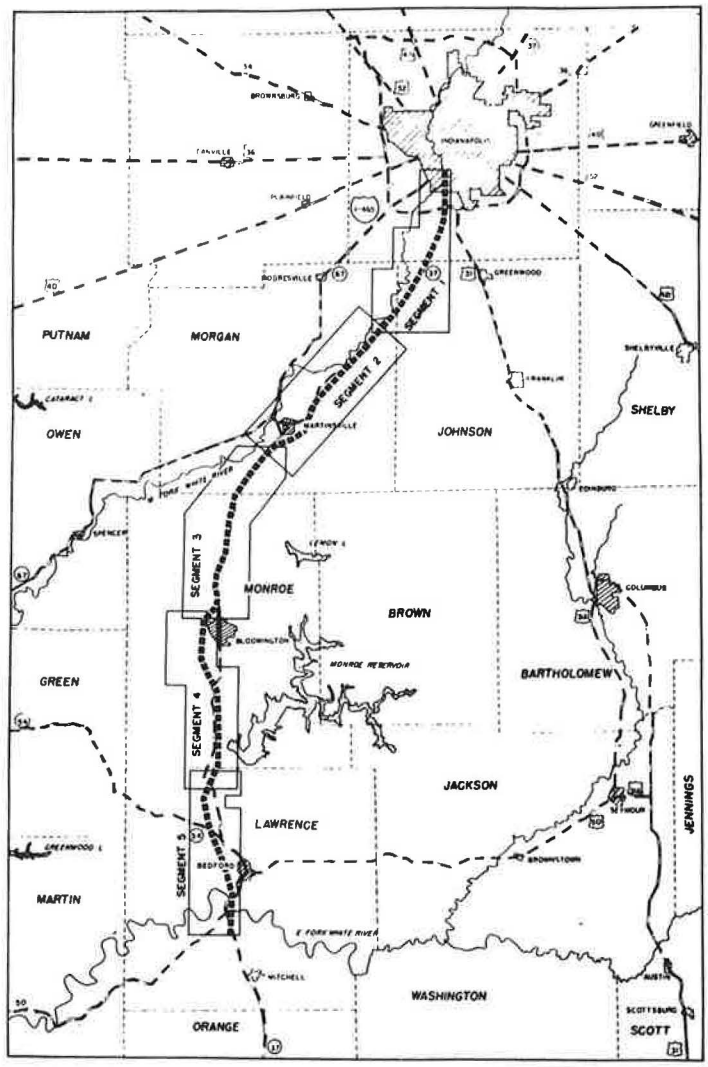


Figure 1. Mosaic areas along study route.

The multispectral imagery was obtained on contract by personnel of Willow Run Laboratories, University of Michigan. Permission was obtained from the Office of Naval Research and the Army Electronics Command to use the Project Michigan M-5 scanner. The multichannel data collection flight took place on April 28, 1967. The aircraft, operated by personnel of the Willow Run Laboratories, flew over the designated area collecting information in 15 different bands of the electromagnetic spectrum as given in Table 1.

Personnel of the Indiana State Highway Commission obtained the aerial photography for this project. They used a 6-in. focal length Wild RC-8 aerial camera mounted in a single engine aircraft. Table 2 gives the series of flights, films, filters, and other conditions pertinent to the photography and imagery.

Prior to aerial flights, several days were spent in the field collecting data concerning (a) moisture conditions of soils, (b) direct temperature readings on soils, and (c) apparent temperature of soils and rocks by means of an infrared radiometer. The

maximum information obtained in one day was on April 28, 1967, when the scanner was used to collect the multispectral imagery at 2 different altitudes. Also, ISHC personnel obtained 3 rolls of Ektachrome MS aerographic film.

A regional engineering soil map was prepared at a scale of 1:20,000 using USDA aerial photographs. This mosaic provided information on regional distribution of land forms and parent materials. After receiving the prints, films, and imagery, mosaics were assembled and engineering soil maps were prepared. Nineteen different photo-maps were prepared by interpretation of black and white, color, or color infrared films and prints.

TABLE 1

SPECTRAL BANDS FOR IMAGERY OF INDIANA PROJECT

Spectrum	Band Number	Band Width (microns)
Ultraviolet	UV	0.32-0.40
Visible (violet)	1	0.40-0.44
Visible (blue)	2	0.44-0.46
Visible	3	0.46-0.48
Visible (blue-green)	4	0.48-0.50
Visible	5	0.50-0.52
Visible (green)	6	0.52-0.55
Visible	7	0.55-0.58
Visible (yellow)	8	0.58-0.62
Visible (red)	9	0.62-0.66
Visible (red)	10	0.66-0.72
Near infrared[a]	11	0.72-0.80
Near infrared	12	0.80-1.00
Middle infrared	IR4	4.50-5.50
Far infrared	IR8	8.00-13.5

[a]The near infrared up to approximately 1.5 microns is also called reflective infrared.

ENGINEERING SOILS MAPS FROM AERIAL PHOTOGRAPHS

This investigation involved the evaluation of the incremental information obtained by use of different aerial photos and sensor data. The first set of maps was produced from the 1:20,000 scale aerial photographs by standard photo-interpretation techniques and show land form-parent material distribution. The maps portray an area about 3 to 5 miles wide by 70 miles long and were reproduced as photo-maps as shown in Figure 2. These maps show land forms, and profiles, test holes, the location of special large scale maps (example: map 2.2.2), and the areas studied by the use of the LARS computer approach (example: area 5).

The tentative route is indicated by a black and white, narrow dashed strip. The special maps are indicated by white brackets, the computer-interpreted areas by

TABLE 2

PHOTOGRAPHY AND IMAGERY DATA SHEET

Date and Instruments	Alt. (ft)	Time Start	Time End	Speed	F-Stop	Mean Terrain (ft)	Approx. Scale	Film Types
April 11, 1967 RC-8 (6 in.)	6,700	—	—	—	—	700	1:12,000	Plus-X pan (1 roll)[d]
April 28, 1967 Scanner[a]	3,200	10:55[b]	11:38[b]	—	Cone	700	1:28,800	Multispectral
April 28, 1967 Scanner[a]	1,600	11:48[c]	12:35[c]	—	Cone	700	1:14,400	Multispectral
April 28, 1967 RC-8 (6 in.)	2,400	9:55	12:18	200	6.8	700	1:6,000	No. SO-151 (3 rolls) No filter
May 18, 1967 RC-8 (6 in.)	2,400	9:50	12:35	200	8.0	700	1:6,000	Plus-X (1 roll) No. 8442 (blank) No filter
May 19, 1967 RC-8 (6 in.)	2,400	9:40	12:00	200	6.8	700	1:6,000	No. 8442 (3 rolls) No filter
May 22, 1967 RC-8 (6 in.)	2,400	12:40	13:06	200	6.8	700	1:6,000	No. 8443 (2 rolls)[d] Antivignetting
May 24, 1967 RC-8 (6 in.)	2,400 2,400	10:05 11:35	10:32 13:42	— —	8.0 8.0	700	1:6,000	No. 8443 (2 rolls)[d] Infrared BW (4 rolls)
May 25, 1967 RC-8 (6 in.)	2,400	11:00	11:30	—	8.0	700	1:6,000	Plus-X (1 roll)[d] (rerun)

[a]Multispectral scanner M-5, Project Michigan, Willow Run Laboratories, University of Michigan.
[b]Going north.
[c]Going south.
[d]Exposed with an antivignetting filter.

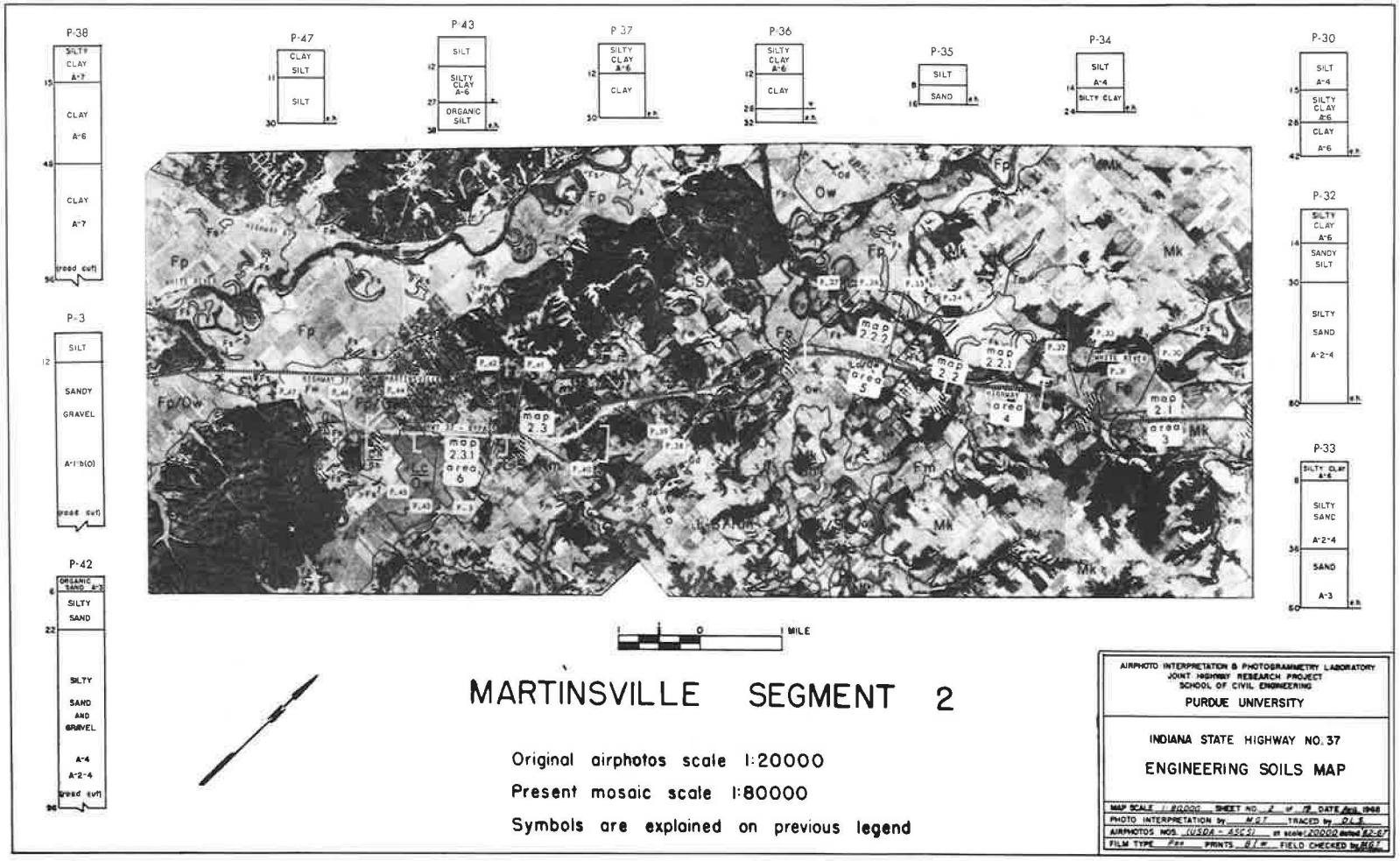


Figure 2. Example of regional engineering soils map.

hatched brackets, and the test holes and soil profiles by white labels designated P followed by a number. The land forms are marked by continuous black lines and labeled with black symbols. The range and township lines, section corners, and section numbers are indicated in white numbers and letters.

The symbols used on all the photo-maps are shown in Figure 3 (1, 2). The symbols are divided into 5 different parts to indicate land form, soil textural class, drainage class, depth to bedrock class, and slope class. Examples are given in the legend shown in Figure 3.

The land form-parent material maps were developed to provide a regional concept of physiography and materials distribution. These maps assist in the preparation of

INDIANA STATE HIGHWAY NO 37

ENGINEERING SOILS MAPS

LAND FORM - PARENT MATERIAL CLASSIFICATION

LAND FORM CLASSIFICATION

A Unconsolidated Material Land Forms

FLUVIAL LAND FORMS

Fp Flood plain and major drainage ways
Fm Minor drainage ways and narrow stream valleys
Fs,Fd Swales and depressions on flood plains
Fo Oxbows and meander scars on flood plains
Fk Muck in depressions on flood plains
T Terraces ; T_L - Low terraces
A Alluvial fans
C Colluvial deposits

GLACIAL LAND FORMS

Gw Ground moraine of Wisconsin age
Gi Ground moraine of Illinoian age
Rm Ridge moraine
Mk Kame moraine (Wisconsin)
K Kame
E Esker
Gd Depression; Gk kettle

GLACIOFLUVIAL LAND FORMS

Ow Outwash and valley train deposits (Wisconsin)
Oi Outwash and valley train deposits (Illinoian)
Od Depressions on outwash

LACUSTRINE LAND FORMS

Lc Lacustrine plain
Ld Depression on lacustrine plain

EOLIAN LAND FORMS

S Dunes (Includes silt mounds)
L Loess plain

RESIDUAL SOIL LAND FORMS

R/Sh Residual soils over shale and siltstone plain
R/Ls Residual soils over limestone plain

B Consolidated Material Land Forms

SEDIMENTARY ROCK LAND FORMS

Sh Shale and/or siltstone plain
Ls Limestone plain

Sinkholes
Limestone quarry

SOIL TEXTURE CLASSIFICATION

1 Sands and gravels
2 Silty to clayey sands and gravels
3 Fine sands
4 Silty soils
5 Silty elastic soils
6 Clays
7 Clays (high plasticity)
8 Organic

DRAINAGE CLASSIFICATION

p Poor (0-3 feet to ground water table)
i Imperfect (3-6 feet)
g Good (over 6 feet)

DEPTH TO BEDROCK CLASSIFICATION

1 Less than 3 feet to bedrock
2 3 to 10 feet to bedrock
3 More than 10 feet to bedrock

SLOPE CLASSIFICATION

f Flat (0-3%)
m Moderate (3-10%)
s Steep (over 10%)

KEY TO SYMBOLS

For all the symbols used, the first part is related to the land form, the second to the material texture, the third to the drainage condition, the fourth to the depth to bedrock, and the fifth to the slope condition.

EXAMPLES

Fp46p3f The land form is a flood plain (Fp) with parent material of silts and clays (46). Drainage is poor (p) with the water table between 0 and 3 feet most of the year. Depth to bedrock (3) is greater than 10 feet. The over-all topography is flat (f); all slopes are below 3%.

L/R/Sh Loess (L) and/or ( ) residual soil (R) over siltstone and shale (Sh)

$\frac{LR}{Sh}$

Figure 3. Legend for photo-maps.

detailed, large-scale engineering soil maps. The regional map is required unless county engineering soil maps are available.

A series of detailed engineering soils maps were prepared on various photo-mosaics to evaluate film type. The first maps were prepared from the black and white prints, the second from the color prints, and the third from the color infrared transparencies. Two scales were used on the final engineering soils photo-maps as shown in Figures 4 and 5. The same type of map was produced from each film type.

When comparing the maps produced from black and white and color aerial photographs, only minor differences were found. These differences primarily concerned the location of soil boundaries. This is explained by the fact that engineering soils mapping has been developed on the basis of land form-parent material relationships, and not on intrinsic colors of the soils. However, color is an asset for mapping engineering soils in that soil boundaries are located with greater precision and the interpretation is more accurate. The color assisted in locating and identifying muck basins, depressional conditions with various degrees of moisture, and minor land forms. Sinkholes in limestone terrain were detected more readily on color, and land forms under the leafless trees were more easily identified. With color, a greater number of soil features such as silt mounds and subsoil revealed by plowing were located and explained. Soils in several instances were readily distinguished on the basis of color. The red residual clay developed from limestone and the light yellow-grey silt in minor drainageways were identified by correlation of natural color with the photograph.

The color infrared was compared to black and white and color films. The main advantages of this film were concerned with accurate location of vegetation and bare soil (or bare rock) areas. The color infrared indicated the relative moisture conditions of the soils better than the natural color. The film was more difficult to interpret than natural color, partly because of a lack of experience in viewing objects recorded in this region of the spectrum.

The filter used with the color infrared film was a Wratten 12. The Wratten 12 filter, as compared with the Wratten 15, caused the color to shift toward the blue, the vegetation to purple-red instead of red, and the bare soil areas to hues of blue instead of green. The age of the film may also have affected the color infrared rendition. Aging is a critical aspect of color infrared and may be a factor in color as well as black and white. The effect of not aging the film is more obvious on the color infrared.

It was found that color infrared transparencies yield more information than color film or prints on soil surface drainage conditions, wet zones, and the like. It was found that on the bare soil areas the blue color darkened as the moisture increased. This was independent of soil type and color, except that light-colored soils had a tendency to be of a lighter blue.

Muck pockets and highly organic soils were not as easily detected on color infrared as compared to color. Highly plastic red clays in the limestone plains were rendered in different hues of green and different color values, depending on their reddishness and their moisture content. When considering color balance shift, these clays should show hues of greenish yellow to yellow for the light brown-red soils and the deep red clay soils respectively. Color and color infrared were of equal value in the identification of red clays developed as residual soil.

In this project a large number of photo-mosaics were prepared (28 separate 2- by 4-ft panels), and the time required for interpretation was carefully recorded. This allowed a measure of interpretation time differences in terms of film types and scales. The results indicated less time per unit area on color photos (at a given scale) than for any other type. They showed also that less time is required for the smaller scale photography per unit area, but much less detail was obtained. The comparative photo-interpretation times are given in Table 3. The gain in interpretation time for natural color varied between 23 and 40 percent when compared to black and white photos.

This economy of time is also reflected in the cost study that was conducted during this project. All costs and time of execution for each phase of the work were carefully recorded. The personnel of the Indiana State Highway Commission provided information on the costs for flying, processing, and printing photographic materials and costs of reduction and printing of the photo-maps. Costs for interpretation times, field

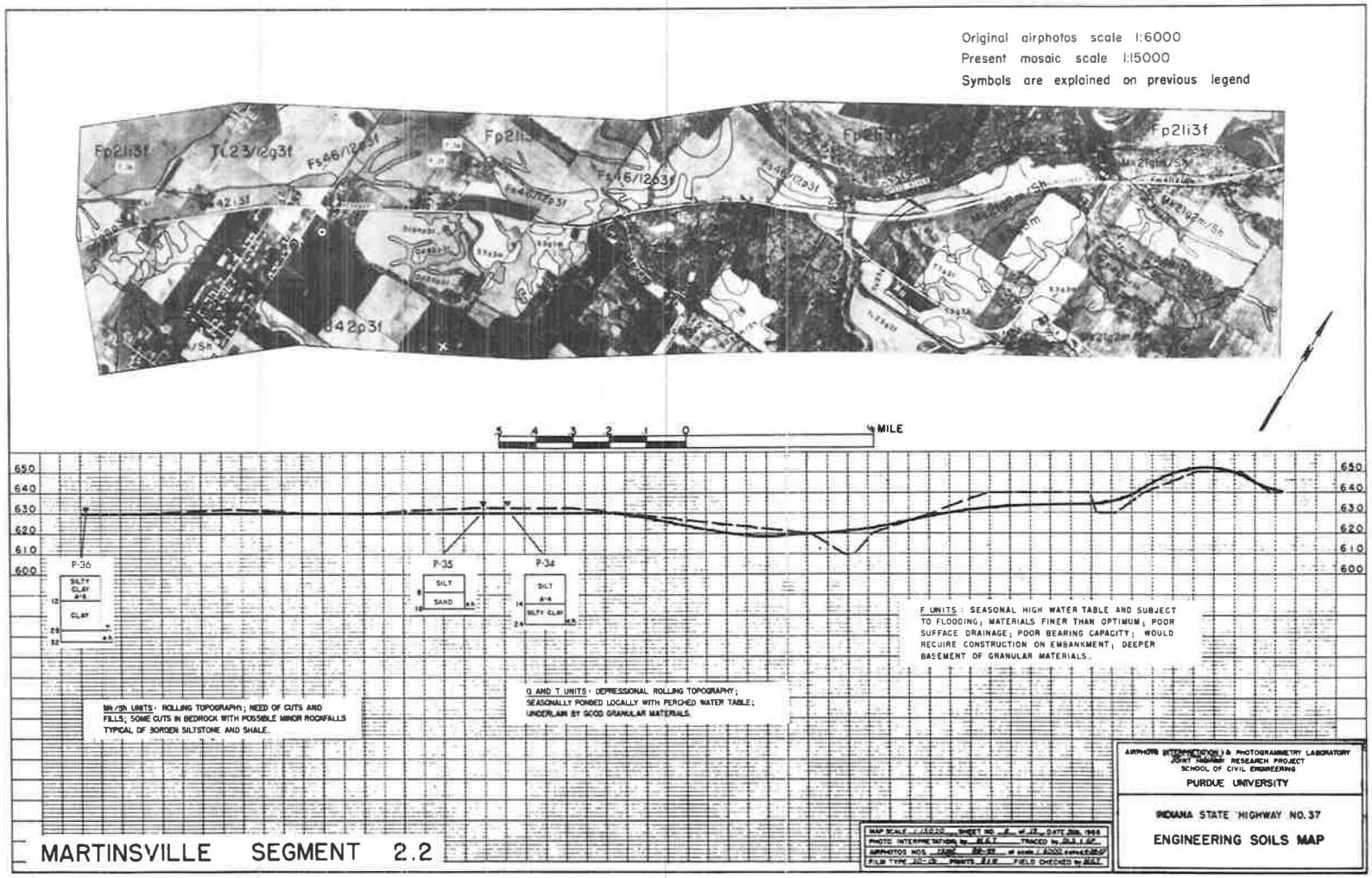


Figure 4. Example of engineering soils map.

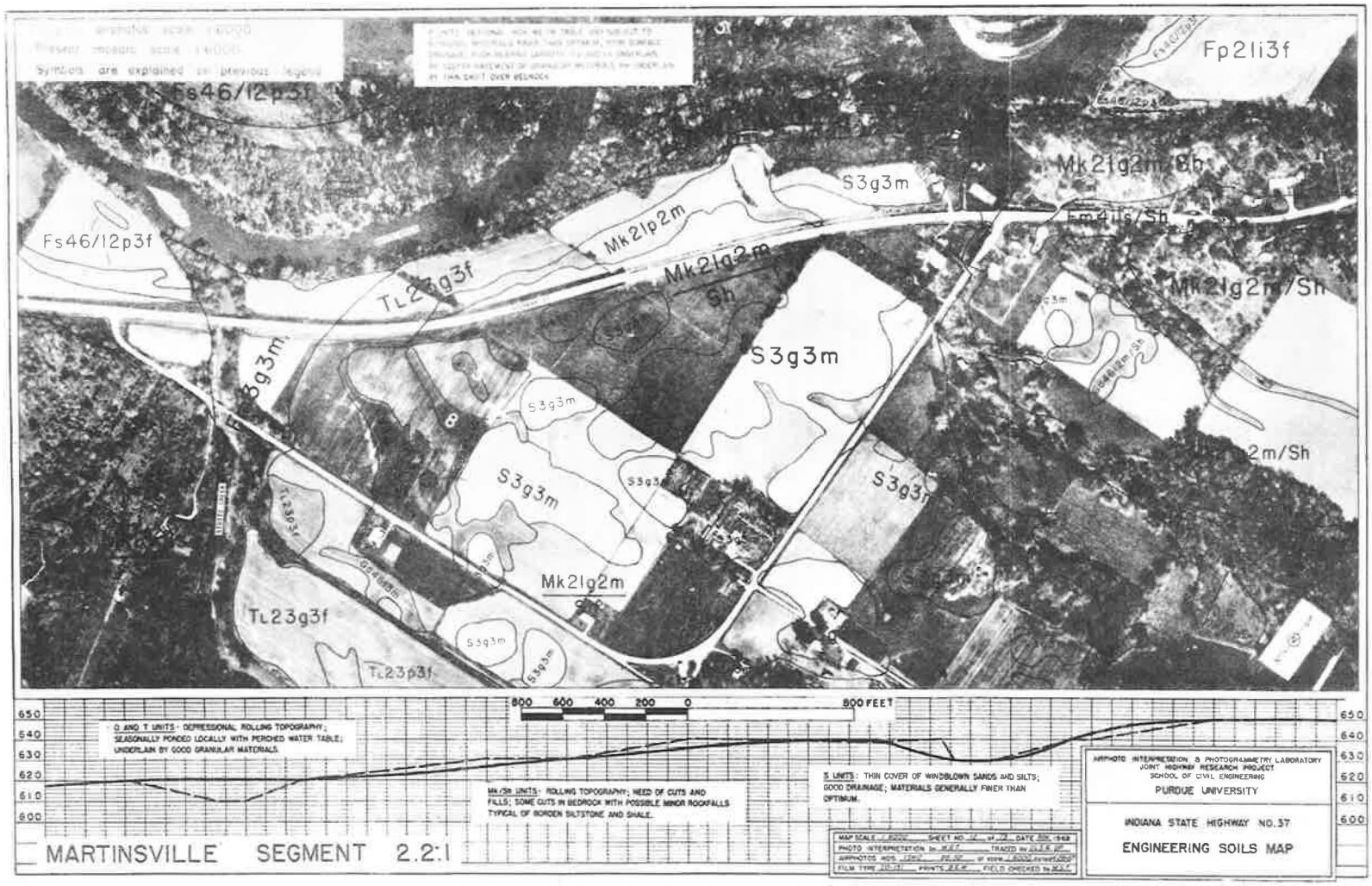


Figure 5. Example of large-scale engineering soils map.

TABLE 3

COMPARATIVE PHOTO-INTERPRETATION TIMES

Photo-Map No.	Scale (sq mi)	Area (sq mi)	P.I. Total Time (hours)	Normalized P.I. Time (hours/sq mi)
1 to 5	1:20,000	350.00	120.0	0.34
(9 photo-maps)	1:12,000	134.00	44.0	0.33
1.1	1:4,800	2.48	3.0	1.21
2.1	1:4,800	2.46	2.25	0.915
2.2	1:4,800	2.32	6.5	2.80
2.3	1:4,800	2.46	4.0	1.62
3.1	1:4,800	2.02	5.0	2.48
4.1	1:4,800	2.17	3.5	1.61
2.2.1	1:4,800	0.85	4.0	4.71
2.2.2	1:4,800	0.825	4.5	5.45
2.3.1	1:4,800	0.85	4.0	4.71
2.3(C)	1:4,800	2.02	2.5	1.24 (23.4 percent)
3.1(C)	1:4,800	1.70	2.5	1.47 (40.8 percent)
4.1(C)	1:4,800	1.80	2.0	1.11 (31.0 percent)
2.2.1(C)	1:4,800	0.72	2.0	2.78 (41.0 percent)
2.2.2(C)	1:4,800	0.85	2.75	3.24 (40.5 percent)

checking, sampling, and drafting of maps were noted. Costs used for soil testing were provided by personnel of the ISHC Materials and Testing Division.

The cost analysis is given in Table 4. These costs were based on the 70-mile route under study and the mapping of all the sections of this route as indicated. It is based on costs for film purchased in the spring of 1967. The other items are based on prices during the period of 1967 to 1969. The black and white photography (BW) at a scale of 1:20,000 was for a corridor 5 miles in width and 70 miles long. All other photography was for a single flight line.

The item "Prints" indicated in parentheses is the additional cost of color prints from transparencies. This shows that the color transparencies and color infrared transparencies if prints are included are more expensive than the others. The cost of field checking and sampling was approximately 30 percent less when using color photography. This was based on an evaluation of the actual borings made to assist in the interpretation of the black and white film and the estimated number that could be eliminated if color photographs were used. Figures in this table should not be quoted out of

TABLE 4

COMPARATIVE COST STUDY OF ENGINEERING SOIL MAPS OBTAINED FROM AERIAL SURVEYS

Item	BW Prints 1:20,000	BW Prints 1:12,000	BW Prints 1:4,800	Color Prints 1:4,800	Color Transparencies 1:4,800	Color Infrared Transparencies 1:4,800
1. Flying	N.A.	0.70	1.26	1.26	1.65	1.65
2. Films	N.A.	0.81	1.92	11.34	8.24	9.43
3. Chemicals	N.A.	0.02	0.04	2.72	1.03	1.03
4. Prints	3.76[a]	0.24[b]	0.73[c]	8.36[c]	None[c] 18.00[d]	None[c] 18.00[d]
5. Processing-printing	N.A.	0.33	0.98	3.93	2.29	2.29
6. Mosaics (uncontrolled)	1.57	1.89	3.29	3.29	3.29	3.29
7. Photo interpretation	2.14	2.05	11.70	8.40	8.40	8.40
8. Field checking and sampling	12.25	12.25	12.25	8.75	8.75	8.75
9. Soil samples testing	41.80	41.80	41.80	28.00	28.00	28.00
10. Photo-maps tracing	4.10	4.72	6.31	6.31	6.31	6.31
11. Reduction and printing	1.71	3.41	6.83	6.83	6.83	6.83
Total unit cost	67.33	68.22	87.19	89.19	74.79 92.79[d]	75.98 93.98[d]

[a]For a 5-mile wide corridor, 70 miles long.
[b]For a 9,000-ft wide strip, 70 miles long.
[c]For a 3,600-ft wide strip, 70 miles long.
[d]Additional cost when color prints are used in addition to the positive transparencies.

Note: Amounts in dollars per linear mile.

their context, because these costs did not include capital expenses, depreciation, taxes, and other related items. For example, the cost for processing-printing of the color prints is the cost of the processing of the color negative from which the prints were made. The cost for prints of the color prints is the cost of materials and labor as contracted by a commercial firm. The cost for BW 1:12,000 prints is only for materials; the cost for labor is included as a separate item.

Table 4 also gives a comparison in overall mapping costs using color or black and white at the same scale. It shows a very small increase in cost when using color prints prepared from color negative film. The reduction in interpretation time and amount of sampling when color is used tends to offset the higher cost of the color prints.

It was found that color is the best single source of information for engineering soil mapping when atmospheric conditions are good. The best combination of 2 films is color and color infrared. This combination enables the interpreter to determine the relative moisture conditions of the soils and the intrinsic color of the soils. The black and white infrared film was of little value for engineering soils mapping, with the filtering that was used.

The optimum scale was found to be 1:12,000 when the interpretation is not to be reported on standard engineering plans and profiles. If reported on plans and profiles, the scale should be at least 1:6,000, or as large as 1:2,400 depending on the scale used for the particular project.

Time of interpretation was found to increase rapidly with an increase of the photo scale. The use of color was found to decrease the time of interpretation from 20 to 40 percent, at a scale of 1:4,800.

ENGINEERING SOILS MAPS FROM MULTISPECTRAL DATA

The multispectral information on the study route was obtained in 2 single flight lines, one flown north to south at an altitude of 3,200 ft, the other flown south to north at an altitude of 1,600 ft. The imagery was obtained in 15 different bands of the electromagnetic spectrum as given in Table 1.

The purpose of this discussion is to present the results of 3 different approaches used to interpret the multispectral imagery. The 3 approaches are (a) interpretation by visual examination using conventional air-photo interpretation methods with the additional concept of a spectral signature of materials, (b) densitometric measurements to establish signatures of materials, if possible, and (c) the automatic method of multispectral data classification developed by the Laboratory for Applications of Remote Sensing at Purdue University. In each case the purpose was to determine the method most applicable for the production of soils maps useful to civil engineers in site selection studies.

Interpretation by Visual Inspection—The visual examination involved the following techniques: (a) examination of the original 70-mm negative film strips on a light table with and without magnification, and (b) examination and interpretation of contact prints and enlarged (2 diameter) prints made from the negatives.

It was determined that the maximum number of bands that could be handled and examined simultaneously in a convenient manner was six and ideally only four. Attempts were made to visually examine 12 bands simultaneously, but the information obtained on the first few bands was forgotten by the time the 10th, 11th, or 12th band was being examined.

This visual examination enabled the sorting of bands that were very closely related and thought to be essentially similar. The following 6 bands were determined to be most valuable for further examination:

Band	Microns
Thermal infrared	8.0-13.5
Reflective infrared	0.8-1.0
Red	0.62-0.66
Green	0.52-0.55
Blue	0.40-0.44
Ultraviolet	0.32-0.38

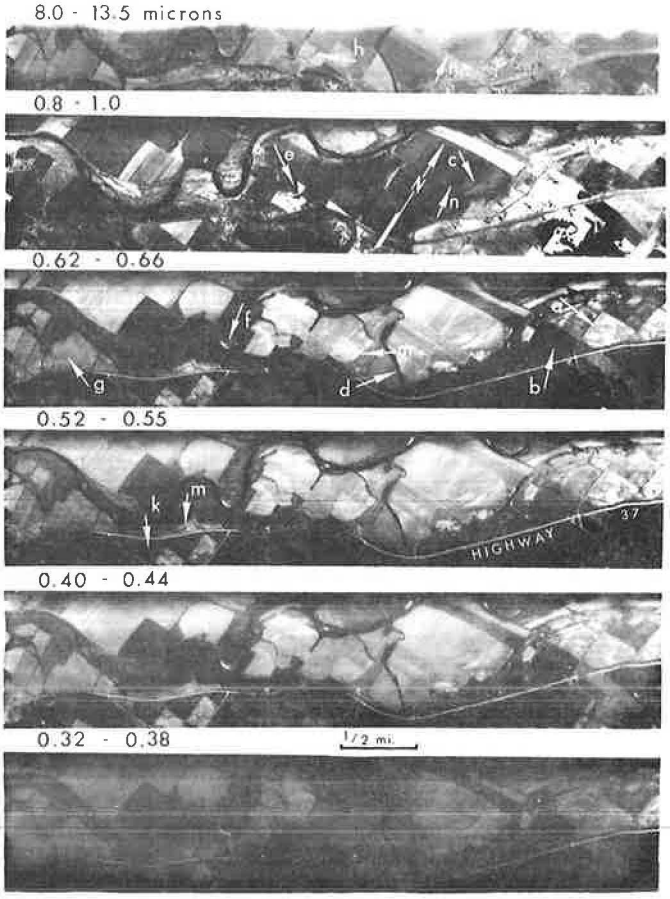


Figure 6. Example of multispectral imagery (area 4).

Figure 6 shows an example of the imagery produced in the wave-length regions. These are reproductions of the high-altitude imagery (3,200 ft) at a scale of 1:28,800 (1 in. = 2,400 ft). The low-altitude imagery (1,600 ft) at a scale of 1:14,400 (1 in. = 1,200 ft) was also examined but is not illustrated.

This figure shows the 6 bands considered to be most informative and shows 2 main land forms: a flood plain and a glacial moraine. Several bare soil conditions, drainage conditions, and various soil tones can be observed. A careful examination of each band revealed the following:

1. The thermal infrared band—The thermal infrared (8.0-13.5 μ) band was particularly useful in detecting surfaces that were relatively hot and emitting strongly and surfaces that were relatively cool. Water bodies and vegetation are considered relatively cool and show as dark areas or items on the imagery. Most soil areas were a similar intermediate grey tone except for a few special features normally due to drainage condition or moisture condition. Item h on Figure 6 is a soil drainage feature that could not be detected at all on the other bands nor on the photography, even on the color infrared. Tonal variations in this band will change over a 24-hour period in a drastic way as the surface temperature of materials changes and eventually may result in tonal inversions on imagery obtained at night. This may be of value in evaluating the causative factor.

2. The reflective infrared band—The reflective infrared (0.8-1.0 μ) imagery was very useful in determining areas of vegetation, e, in contrast to bare soil, c, areas. On this band, water bodies are very dark and uniform in tone, bare soils, c, and road systems are intermediate grey tones, wet soils are dark grey, and the crops and vegetation are very light grey to white. Coniferous trees are medium grey to dark.

3. The visible red band—The red (0.62-0.66 μ) imagery was found to be most useful for soil studies. Soil contrasts were shown better on this band than any other except the 0.52-0.55 μ band. In the red band, water bodies are dark, and soils are of various shades of grey from light, f, to medium dark, a. Bare dry soils are light, m on Figure 6. Wet soils are darker, c and n on Figure 6. Vegetation is dark. It is important to note that the tone inversions for soils and vegetation occur in the 0.8-1.0 and 0.62-0.66 micron bands. These 2 bands in combination yield extremely significant information as discussed in the section on automatic classification.

4. The visible green band—The visible green (0.52-0.55 μ) imagery is quite similar to the previous one but soils were not as distinct; however, the important soil features recorded on the 0.62-0.66 μ band were present. For instance the mottled tones of the ground moraine, a, and current scars, m on Figure 6, still show.

5. The visible blue band—The visible blue (0.40-0.44 μ) band is definitively not as interesting in terms of soil mapping. Much of the contrast between dark and wet soils and light colored soils is gone, c, m, and n on Figure 6. Because of a reduction of the overall contrast and the greater reflectance of pavement materials in this range, the road systems show much better. Water bodies are all of the same dark grey tone and cannot be distinguished from the vegetation.

6. The ultraviolet band—Only a few features show as bright tones on the 0.32-0.38μ band. Certain ultraviolet reflectors are recognized such as roofs, concrete pavements, some bituminous concrete pavements (because of the aggregates), limestone quarries, and river sand bars, f on Figure 6.

General Conclusions Based on the Visual Inspection—There is a change in reflectance as revealed by color of soil evidenced in bands 0.8-1.0, 0.62-0.66, and 0.52-0.55 μ and in a subdued manner in the 0.40-0.44 μ band. If an appreciable change in the drainage of soils or if a highly saturated zone occurs, the 8.0-13.5 μ band reveals a different temperature regime in comparison to the surrounding soils that are warmer.

The different bands treated separately are not as significant as when grouped, such as contrasts shown on the 0.8-1.0 μ and 0.62-0.66 μ bands. From the visual examination the following conclusions were drawn:

1. The best combination of imagery was obtained by grouping the 8.0-13.5 μ, the 0.8-1.0 μ, the 0.62-0.66 μ, and either the 0.40-0.44 μ or the 0.32-0.38 μ bands.
2. Soil contrasts were best detected on the 0.62-0.66 μ and 0.52-0.55 μ bands.
3. Water bodies showed best in the 8.0-13.5 μ and 0.8-1.0 μ bands. The 0.8-1.0 μ band appeared to be the best because of contrasts of the high reflectance of vegetation and the strong absorption of water in that band.
4. The imagery suffered from lack of resolution even for the low altitude imagery.
5. No information about the topography was obtainable either directly or indirectly from the imagery. Topography is an important element in engineering soils mapping by remote sensing techniques. It is obvious that multispectral imagery cannot replace aerial photography. It should be considered as a supplement to aerial photography.
6. Certain soil features and soil conditions are enhanced and more easily detected on the imagery than on aerial photography.

Recommendations for Visual Analysis of Multispectral Imagery—From the experience gained through this investigation, the following recommendations are made for future projects involving multispectral imagery:

1. The scale on the final imagery should be larger than 1:12,000, ideally between 1:10,000 and 1:6,000.
2. The geometric distortion or "sigmoid" distortion necessitates the use of the central two-thirds of the imagery for practical purposes. This is tolerable but attempts should be carried further to develop equipment for distortion-free restitution.

3. To use the far infrared 8.0-13.5 μ band to the maximum, the imagery should be obtained both during the daytime and at night in the hours before dawn. This would allow much better insight on infrared behavior and emissivity of materials.

Interpretation by Densitometric Measurements—In an attempt to study the validity of the spectral signature concept, a series of density measurements of the multispectral imagery was obtained. The approach involved the measuring of the transmission density on a calibrated transmission densitometer (1-mm aperture) for items of interest on the imagery. The density reading was normalized against a standard grey scale. Each of the imagery sections in each band and the respective calibration grey scale level were made comparable. Figure 7 shows the results for the 0.66-0.72 μ and 0.80-1.00 μ bands of a sample area (area 1-A). All the prime density levels that appear on these figures were normalized against a standard grey scale. Most of the changes in reflectance levels are due to changes in vegetative cover (i, n, t, v on Figure 7).

Fields d and g were dark, wet silty soil area as revealed by ground truth. The multispectral response for these fields as shown in Figure 8 are similar in terms of relative intensity within one band to the nearest 0.15 unit of normalized density. Figure 8 also shows the multispectral signatures for 2 contrasting terrain types. Fields h and t represent an area of dry, pale yellow-brown silt and an area of wet muck. These extremes were selected to emphasize the contrast in spectral signatures. The signature for the dry soil (Fig. 8) shows a very high response in most bands except the middle and far infrared, while the signature for the wet muck shows the overall low returns except for the far infrared, which is affected by water content. The relative

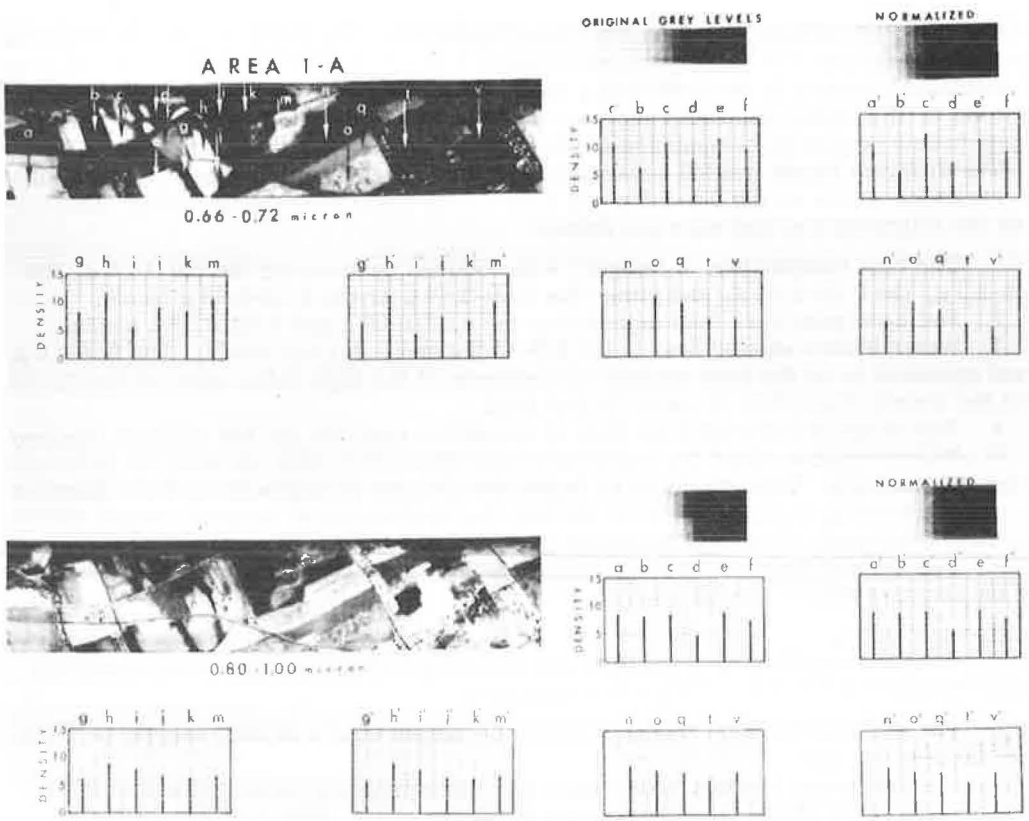


Figure 7. Normalized signatures by densitometric measurements.

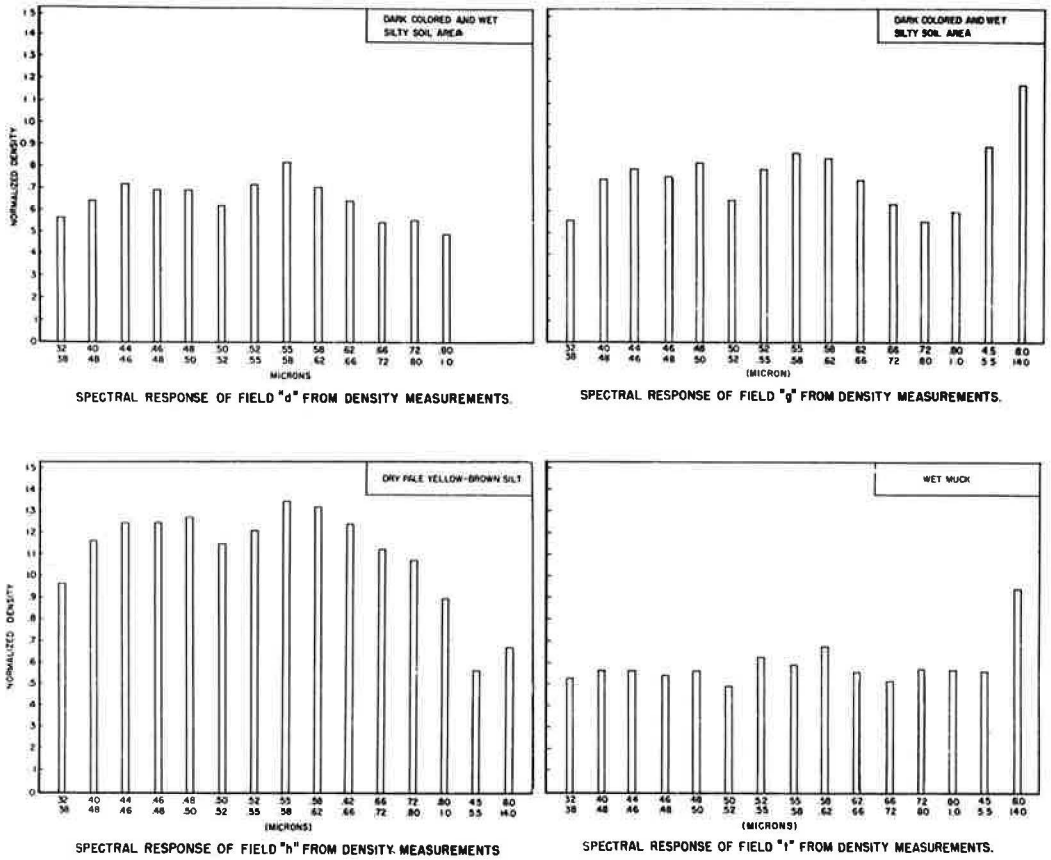


Figure 8. Spectral signatures from normalized density measurements.

responses shown in Figure 8 can be compared. They show that 3 different materials with different engineering characteristics in terms of texture and moisture content have different spectral signatures. These results and other measurements made during the research confirmed that the concept of multispectral signature of first surfaces is a valid premise in remote sensing. This correlates with Rib's research on this subject (5, 6).

This research showed the problems associated with the densitometric approach. It is slow and cumbersome. Long strips of imagery have to be searched. It is a tedious job to measure the densities point by point and to normalize and plot the results. If the data can be adapted for use in conjunction with a computer, there is really little point in using this approach and its use is not encouraged except for very special reasons.

AUTOMATIC CLASSIFICATION OF MULTISPECTRAL DATA BY COMPUTER

A system of computer programs has been developed over the past 3 years by the Laboratory for Applications of Remote Sensing for purposes of analyzing remote multispectral data for various agricultural applications. The studies include automatic crop identification and mapping, and studies of relative crop moisture and disease of crops as well as other related agricultural applications. This research effort is sponsored by the National Aeronautics and Space Administration in conjunction with the U.S. Department of Agriculture and Purdue University. LARS serves as a focal point for

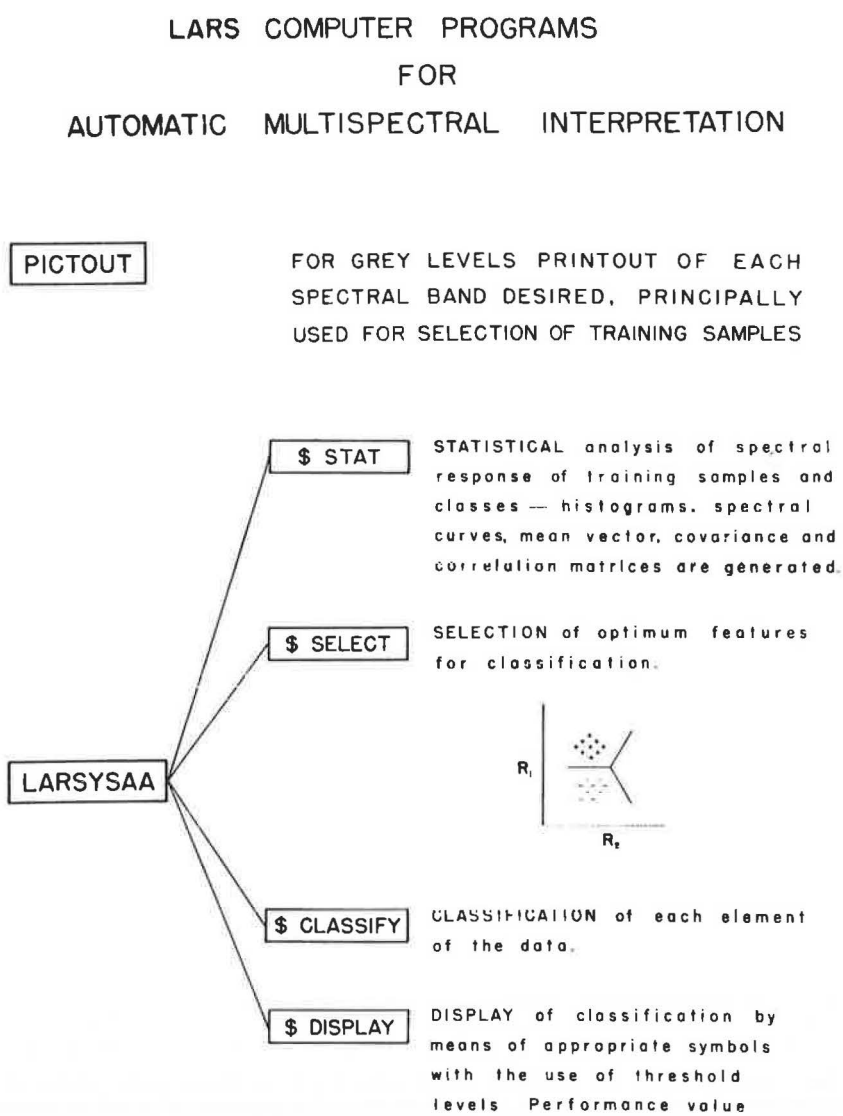
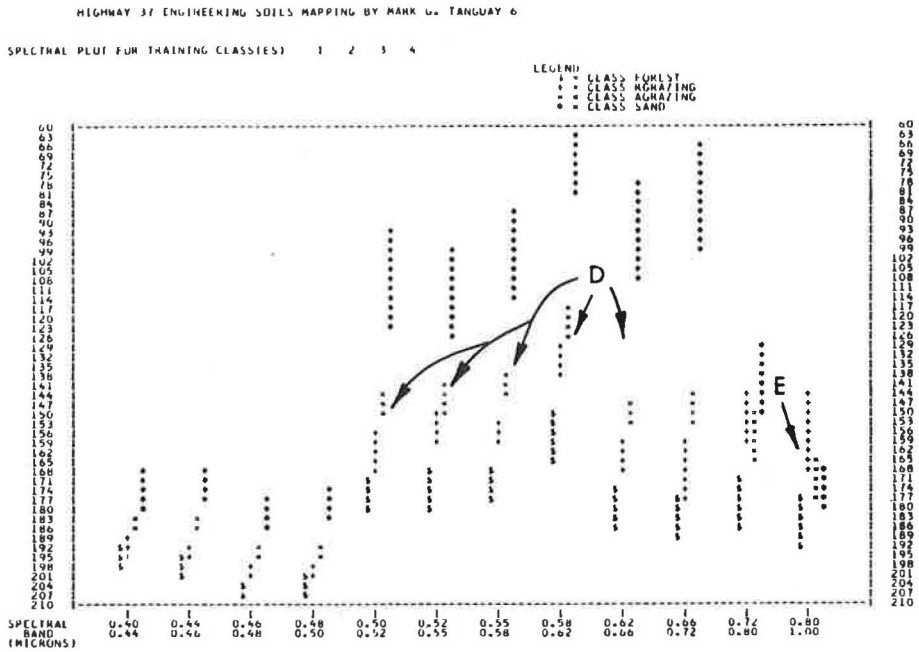


Figure 9. Computer programs for classification of scanner data.

research into the applications of modern remote sensing techniques for the benefit of national and state programs in natural resources.

Two LARS computer programs, LARSYSAH and LARSYSAA, were used to determine if the automatic classification procedures developed for agricultural purposes could be applied to engineering soils mapping. The facilities at LARS were made available to this Joint Highway Research Project to investigate the potential for engineering applications.

The LARS programs are shown in Figure 9. The approach involves a spectral pattern recognition technique in which training samples are used as a basis for classification. The computer is "trained" to recognize all areas having similar spectral signatures and to automatically classify these unknown areas into one of the categories designated by the researcher. The PICTOUT programs reproduce the multispectral data



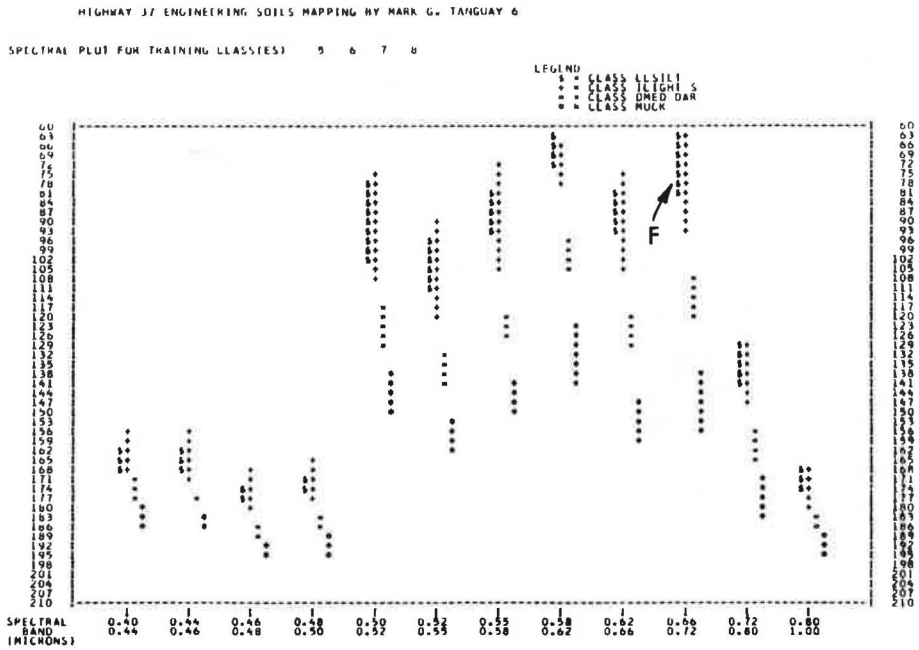


Figure 10. Spectral plots for 8 training classes.

as computer printouts similar to the imagery film strip. The imagery grey levels are represented by printer characters. This program also produces histograms of the grey levels for each band. One or several bands of the grey scale printouts can be used to select training samples.

Training samples should be conceived of as a set of spectral data, representative of a given ground object or ground feature and identified on the computer printouts by a system of coordinates. The material represented by a set of training samples is referred to as a "class."

The theory and development of LARSYSAA is discussed in the literature by Swain et al. (7), Landgrebe et al. (8), Landgrebe and Phillips (9), and others in LARS publications (10, 11, 12).

Once the training samples and their coordinates are selected, the statistics are obtained on the reflective characteristics of each class. The statistics include the mean vector of each class and the covariance correlation matrices. Histograms of each sample and/or class and their spectral response graphs can also be printed to assist the researcher in verifying the quality of each training sample and each class. To determine if the classes are easily separable, an option prints a series of combined spectral plots for the training classes. Figure 10 shows 8 classes. In the upper half, point D indicates that the 4 classes would be equally well distinguished in the 5 bands indicated by the arrows. In the 0.80-1.00 μ band, 3 classes would be similar (point E), and class AGRAZING is difficult to distinguish from class SAND.

In the lower half of Figure 10, point F indicates that 2 classes are difficult to distinguish in the 0.66-0.72 μ band. The class LLSILT (for very light-colored silt) has the same response as the class ILIGHTS (for intermediate light-colored silt). The other 2 classes have lower responses and are distinguishable. By visual inspection of the statistics, these 2 classes, LLSILT and ILIGHTS, obviously show similar response. The training samples for these 2 classes could be grouped under one class.

Examples of automatic multichannel data classification are shown in Figures 11 and 12. They indicate potential applications for engineering soil classification. Figure 11 shows 6 maps and a photo-mosaic for area 1-A. The 6 maps were produced by using the 12-channel (visible range) scanner data. They do not include the ultraviolet or the thermal infrared.

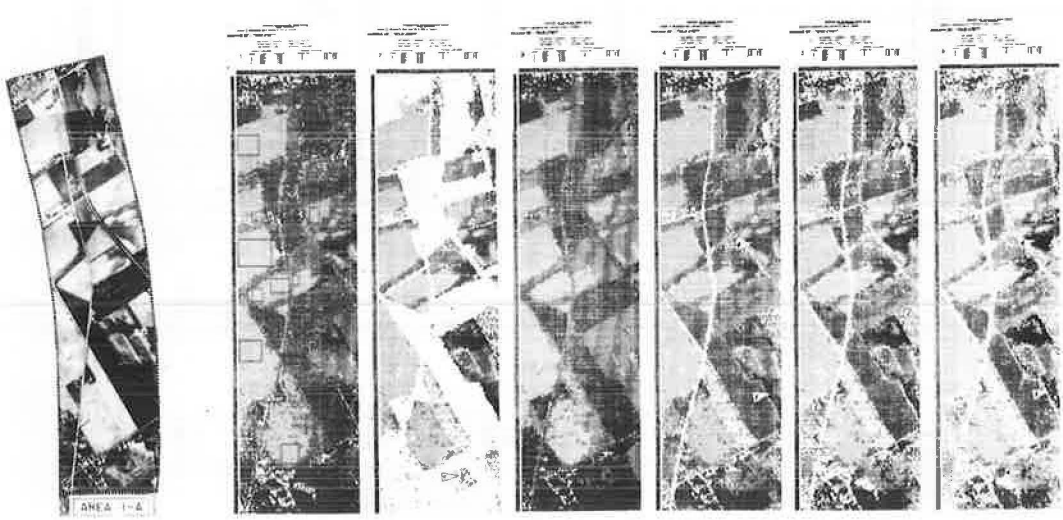


Figure 11. LARSYSAA printouts for general classification (map 1), 3 soils (map 2), soils, crops, forest, and roads (map 3), and examples of thresholding (maps 4, 5, and 6).

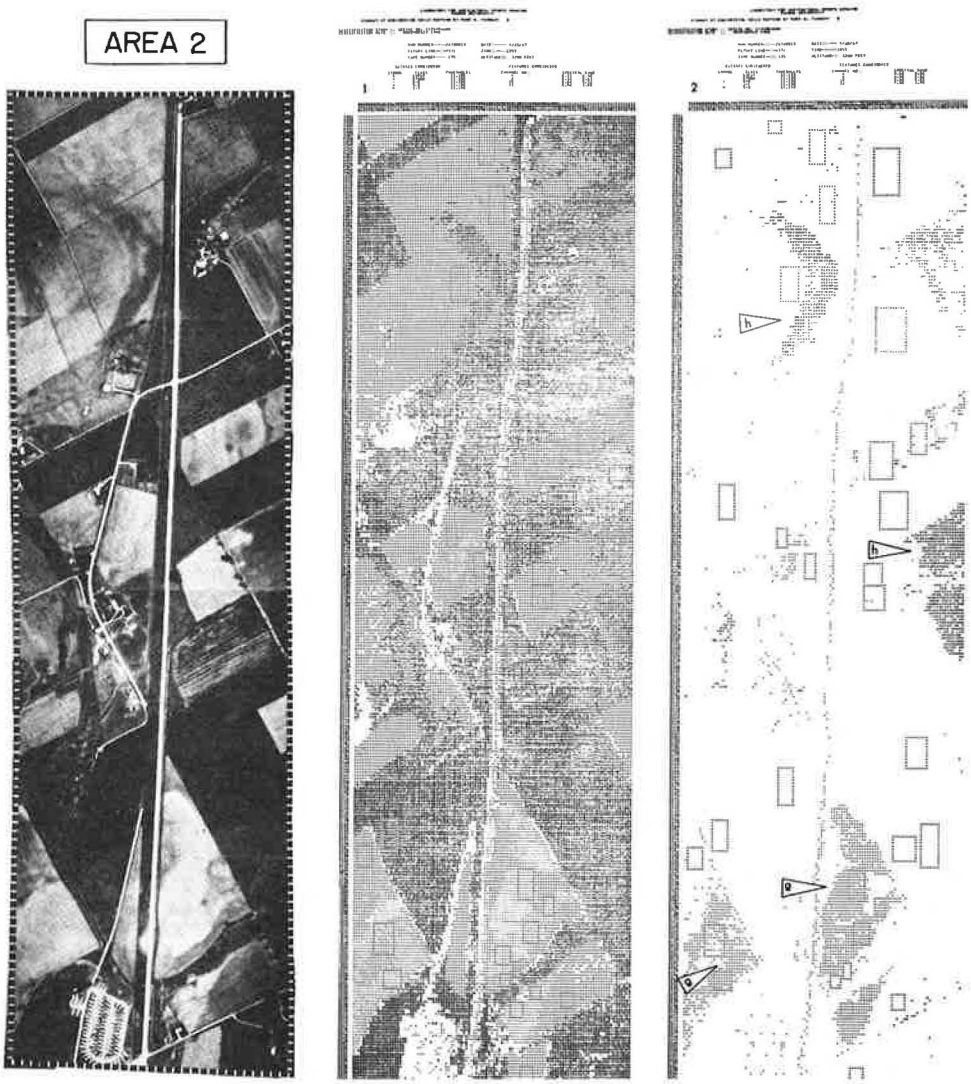


Figure 12. Printouts delineating 2 soil types.

Map 1 of Figure 11 shows a general classification of 7 classes for area 1-A: 3 different soil conditions as well as crops, forests, water, and roads. Map 2 shows the areal distribution of soils. It shows the location of light-toned soil, SOILD, the medium dark soil, SOILW, and wet dark-colored soil, SOILWW. Map 2 readily shows the distribution of the dark wet ground. The ground conditions of each soil class were verified in the field. This last soil class would require special treatment if an engineering facility were developed.

Map 3 of Figure 11 is a general interpretation of all the data. It illustrates a different character enhancement to locate the classes of materials. Maps 4, 5, and 6 show the effect of different threshold levels. The use of thresholds is made possible in the $ DISPLAY processor. A high threshold level is restrictive, and only the data points having very close spectral resemblance are displayed. A low threshold value is useful to display, in this case, all the light-toned soils of an area that may vary

slightly in spectral signature but are similar for engineering purposes. On the other hand, a high threshold value is useful in locating potentially troublesome areas as is the case for the SOILWW class, d and f. No training sample was taken for the area marked e, but this muck area was classified in the class for adverse soils, SOILWW. This shows the potential of this automatic classification based on spectral reflectance but also the need for ground control.

The maps of Figure 12 show other potential uses of this multichannel approach. The printout on the right side (map 2 for area 2) shows soils of engineering significance. The areas designated with the plus sign, g, indicate kame moraine. This portion of the moraine is underlain by sands and gravels as revealed by ground-checking. Special training samples were selected to show the location of these granular materials. The letter h points out a meander scar filled with highly organic soil as revealed by ground truth. This depressional soil condition would require special treatment or should be avoided. It is emphasized by overprinting by the letter M and by blanking out all other soils except the kame moraine.

In summary, the automatic computer classification as implemented by the LARS system and as tested in this research project is an important advance in automatic interpretation. This method of using training samples and a computer can produce, very rapidly, sets of soil maps useful to the engineer. The method can detect and classify reflectance of surfaces that indicate main soil classes, drainage conditions, muck area, and bare rock areas. The final interpretation and overall significance has to be assessed by an engineer competent in soils evaluation. The information will assist in planning boring programs.

CONCLUSIONS

This research project is concerned with the use of different aerial films and multispectral imagery as a source of data engineering soils mapping. Based on the results obtained for a 70-mile highway project in Indiana, conclusions are as follows:

1. In terms of developing annotated aerial photographs as detailed engineering soils maps, color photography is the best and most reliable source of information. Natural color photography enabled the mapping of a greater number of soil areas and soil conditions but did not allow full assessment of all soil conditions.
2. The combined use of color prints and color infrared transparencies is the best combination of 2 sources of remotely gathered information. This combination provided information on relative moisture conditions of soil areas.
3. Multispectral imagery obtained in 15 bands, UV to IR, provided some information on soils and soil conditions as a supplement to aerial photography.
4. If the multispectral data are to be processed by computer, the maximum number of bands should be obtained. The automatic classification of terrain features can be based on the optimum set or combination of bands.
5. If the imagery is to be analyzed by visual means, the minimum number of bands should be four and the maximum six. The 4 bands include the far infrared (8.0-13.5 μ), the reflective infrared (0.8-1.0 μ), the red (0.60-0.66 μ), and the green (0.52-0.55 μ). The 6 bands should include the 4 bands just named plus the blue (0.40-0.44 μ) and the ultraviolet (0.32-0.38 μ). The number of bands is restricted because of the inherent limitation of the human mind to analyze a very large number of images.
6. The best method of examination and interpretation of multispectral imagery is accomplished by automatic classification using a computer. The methods developed at the Laboratory for Application of Remote Sensing are applicable. The computer programs permitted (a) classification of the land surface in terms of vegetation, water, and various visible soil reflectance groups; and (b) delineation of unique soil conditions on a single map, emphasizing the distribution of adverse soil conditions.
7. The limitations of multispectral imagery for engineering soils mapping include vegetation masking the spectral data on soils and the lack of pertinent information about the topography.
8. Engineering soils plans and profiles, prepared from color aerial photographs, can be incorporated in soil surveys for highway projects. By this method boring sites

can be located to obtain more representative samples. The added expense of color is offset by the more reliable information obtained and the shorter period of time required for interpretation.

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