USE OF REMOTE SENSORS IN HIGHWAY ENGINEERING IN KANSAS

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Many papers have been written concerning the domestic use of various types of remote sensors; however, few describe specific applications of remote sensors to highway engineering problems. The purpose of this paper is to describe the remote-sensing program conducted by the State Highway Commission of Kansas in cooperation with the Federal Highway Administration and to present the results of visual interpretation of the data collected. Descriptions are given of methods of collection and types of data, including frequency and type of ground observation data. Data collected on magnetic tape, to be reduced and analyzed by computer, are described; however, no findings are presented. Results of visual interpretation of data indicate that the combined use of color aerial photography and infrared imagery (8- to 14-μm, nighttime, high-altitude) renders the most distinctive evidence for detection, evaluation, and mapping of engineering soil groups.

•THIS investigation was conducted by the State Highway Commission of Kansas in cooperation with the Federal Highway Administration to determine the value of certain remote sensors when applied to highway engineering problems in eastern Kansas. Three engineering problems were investigated: evaluation of the condition of concrete pavement, detection of subterranean voids, and detection and mapping of engineering soil groups. The specific objectives were as follows:

1. Evaluate sensor data combined with aerial photography in the evaluation of concrete pavement performance and the detection of concrete stains;
2. Determine what combination of aerial photography and imagery would render a distinctive signature for various types of soils and materials;
3. Determine whether the cost of remote sensors can be justified at this stage of development for soil and materials mapping in Kansas; and
4. Determine the best combination of photography, within the capability of the State Highway Commission of Kansas, for soils and materials investigations.

This report describes the results obtained in the investigation for the detection and mapping of engineering soil groups.

CONTRACTORS

Four contractors were engaged to gather, reduce, and analyze remote-sensing data over one or more of the test sites.

1. Remote Sensing, Inc., Houston, Texas, was engaged by the State Highway Commission of Kansas to gather airborne remote-sensing data over the 5 test sites. The equipment included Wild RC-8 aerial camera, plus X panchromatic film; RS-14 dual-channel infrared scanner, 3- to 5.5-μm and 8- to 14-μm range; 13.3 GHz scatterometer; 13.7 GHz microwave radiometer; and Hasselblad 4-camera cluster for narrow-band photography. The infrared, scatterometer, and microwave-radiometer data were collected on magnetic tape. Imagery was available for the 8- to 14- and 3- to 5.5-μm infrared range.
2. Peter E. Chapman and Peter A. Brennan, Consultants, Reno, Nevada, were engaged by Remote Sensing, Inc., as subcontractors to gather spectral-reflectance data

to compile spectral albedo curves in order to select film-filter combinations for the Hasselblad camera cluster for use in soil discrimination. An ISCO model spectroradiometer was used to take values in a 2-phase operation that included the visible range (380 to 750 nanometers) and near infrared (750 to 1,550 nanometers).

3. Resources Technology Corporation, Houston, Texas, was engaged by the Federal Highway Administration to reduce and analyze the remote-sensing data collected over all sites on magnetic tapes by Remote Sensing, Inc.

4. Under separate contract, the Federal Highway Administration engaged the Willow Run Laboratories, University of Michigan, Ann Arbor, to obtain multispectral data over 3 of the test sites. Results of this facet of the investigation will be released by the Federal Highway Administration. Some of the results obtained by the University of Michigan on the computer analysis of one of the test sites are reported in this Record by Wagner.

TEST SITES

Five test sites were selected. Test sites 1, 2, and 3 were used for concrete pavement evaluation; test site 4 was used for the detection of subterranean voids; and test site 5 was used for the detection and mapping of major engineering soil groups.

This report will only discuss the results obtained for the detection and mapping of major engineering soil groups. Consequently, the subsequent discussions will be limited to the investigations of site 5.

Test site 5 is a 27- by 1-mile segment of land in Jefferson County, Kansas. The area is characterized by interbedded Pennsylvanian limestone and shale overlain by Kansan glacial drift; residual soils are prominent along valley walls of major drainage channels. Loessial type of soil caps the high terrain in the northern area, and alluvium is encountered in the Kansas River valley on the south end of the site as well as in the valleys of major drainage channels throughout the area.

PREVIOUS WORK IN AREA

A construction materials inventory of Jefferson County by photo interpretation was completed by the State Highway Commission of Kansas in 1968, and several preliminary soil surveys have been conducted along centerlines of major highways in the corridor area. No extensive engineering soil mapping has been accomplished in the area by ground-survey methods or with remote sensor and aerial photography. The Soil Conservation Service of the U.S. Department of Agriculture has mapped approximately 80 percent of the corridor area for agricultural purposes.

DATA COLLECTION

Planning Photography

On March 17, 1969, black-and-white panchromatic photography was flown at a scale of 1:18,000. It was used to plan the remote-sensing mission and to conduct initial landform classification. Color Ektachrome was flown in August 28, 1969, at scales of 1:2,000 and 1:10,000, and color infrared was flown on October 5, 1969, at the same scales. This photography was used to study the area with differing vegetative conditions and to assist in the initial landform classification.

Ground Reconnaissance

Ground reconnaissance of the test site was completed by January 1970. Soils in each major landform were evaluated according to color (Munsell color notations), grain size, plasticity indexes, and parent material. Within the various landforms, more than 100 stations were selected as sites for collecting ground-observation data and for taking ground-reflectance readings. The latter would be used to select film-filter combinations for narrow-band photography.

Ground-Reflectance Readings

On March 14 and 15, 1970, consultants Chapman and Brennan took ground-reflectance readings using an ISCO model SR spectroradiometer. Sky and ground readings were taken at each station. Readings were taken at 0.025-μm increments between 0.4 and 0.75 μm (visible range) and at 0.05-μm increments between 0.8 and 1.0 μm (near-infrared range). Readings were taken on existing dry ground, and soil-moisture samples were taken at each station. Subsequently, the ground was saturated, and readings were taken to ascertain the decrease in soil-reflectance ability due to wet conditions.

The purpose of the narrow-band photography was to enhance the contrast between major engineering soil groups. Reflectance readings were taken primarily on soils formed in the Kansas River alluvium; however, readings were taken on glacial and loessial soils and residual soils derived from Pennsylvanian bedrock. These soil types were referred to as upland soils. Alluvial and upland soils were evaluated separately, inasmuch as the respective landforms were easily differentiated on aerial photography.

Figure 1 shows reflectance data for representative readings for alluvial-soil units. Figure 2 shows reflectance data for representative readings for upland-soil units. The greatest albedo spread occurred in the red and near infrared; however, several of the curves crossed in the yellow, green, and blue portion of the spectrum. Although reflectance was less and the albedo spread between major soil groups was reduced on wet samples, the greatest albedo difference still occurred in the red and near-infrared portion of the spectrum.

Most soil-mapping problems were anticipated in the alluvial soils, and most reflectance readings were concentrated in this area. The variation in reflectance within the same alluvial soil type is shown in Figure 3. The albedo spread among the soil types was great enough so that no overlap occurred at any wavelength.

Inasmuch as the greatest albedo spread occurred in the red and near infrared, the film-filter combinations were selected to concentrate the narrow-band photography in this portion of the spectrum. Figure 4 shows film and filter selection for each of the Hasselblad cameras.

Collection of Remote-Sensing Data

On March 23, 1970, the daytime remote-sensing mission was flown by Remote Sensing, Inc. A Fan Jet Falcon aircraft was used and was equipped with an aerial metric camera, a dual-channel infrared scanner, a 13.3-GHz scatterometer, a 13.7-GHz microwave radiometer, and a 4-camera cluster of Hasselblad cameras. Data were collected at 1,000 ft and 5,000 ft above terrain. At approximately the same time, color Ektachrome and color infrared photography was flown by the State Highway Commission of Kansas at altitudes of 1,000 and 5,000 ft above the terrain. A Wild RC-8 aerial camera and a Cessna 206 aircraft were used.

In the early morning hours of March 24, the nighttime remote-sensing mission was flown. Radiometer, scatterometer, and infrared data were collected on magnetic tape at altitudes of 1,000 and 5,000 ft above the terrain. Table 1 gives the data collected.

Ground-Observation Data

Eight 2-man crews gathered ground-observation data prior to, during, and immediately after the day remote-sensing mission, and 3 crews collected data during the night flight. During the day mission, 6 crews collected surface and subsurface (13-in. depth) soil-moisture samples, recorded surface and subsurface (13-in. depth) soil temperatures, and took ground color photographs at designated stations. More than 200 soil samples and 100 ground photographs were taken. Personnel from the Federal Highway Administration took ground radiometer (8- to 14-μm range) readings at designated stations. A ground-resolution target was placed in the center of the flight line in order to evaluate the quality of the aerial photography.

Except for ground photography, similar but lesser amounts of data were collected during the night mission. Five rotating amber beacons were stationed along the flight line of the test site to guide the aircraft. Aluminum foil targets, 10 by 10 ft, were placed at the beacon stations to provide control points for the radiometer data.

Figure 1. Representative reflectance readings for alluvial soils.

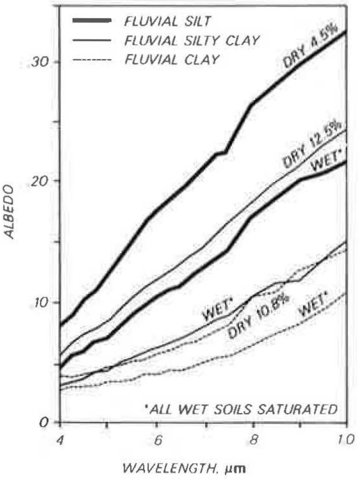


Figure 2. Representative reflectance readings for upland soils.

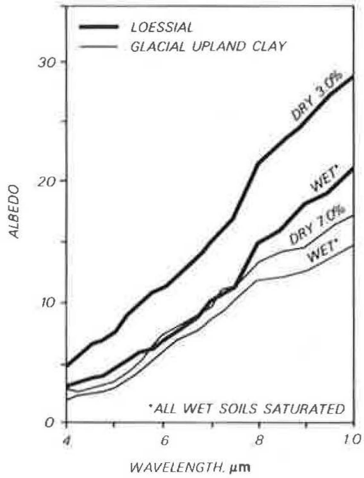


Figure 3. Variation of reflectance of major alluvial soils.

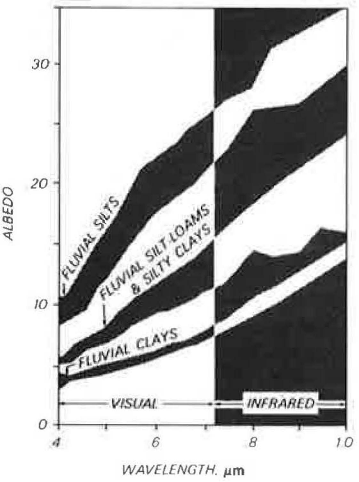


Figure 4. Film-filter selection for narrow-band photography.

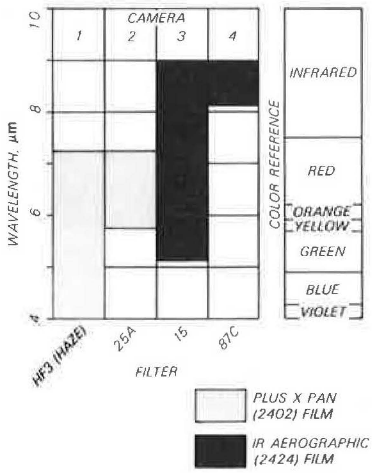


Table 1. Remote-sensing data gathered over test site 5.

Data	Date	Altitude or Scale
Black and white panchromatic photography	3-17-69	1:18,000
Color Ektachrome photography	7-28-69	1:10,000 and 1:2,000
Color infrared photography	9-5-69	1:10,000 and 1:2,000
Black-and-white panchromatic photography	3-23-70	1:10,000 and 1:2,000
Color Ektachrome photography	3-23-70	1:10,000 and 1:2,000
Color infrared photography	3-23-70	1:10,000 and 1:2,000
Narrow-band photography 70 mm, 0.4 to 0.72 µm	3-23-70	1:8,000 and 1:32,000
Narrow-band photography 70 mm, 0.58 to 0.72 µm	3-23-70	1:8,000 and 1:32,000
Narrow-band photography 70 mm, 0.52 to 0.9 µm	3-23-70	1:8,000 and 1:32,000
Narrow-band photography 70 mm, 0.8 to 0.9 µm	3-23-70	1:8,000 and 1:32,000
Infrared 8- to 14-µm imagery, day	3-23-70	6,000 and 1,000 ft
Infrared 3- to 5.5-µm imagery, day	3-23-70	6,000 and 1,000 ft
Infrared 8- to 14-µm imagery, night	3-24-70	6,000 and 1,000 ft
Infrared 3- to 5.5-µm imagery, night	3-24-70	6,000 and 1,000 ft
13.3 GHz scatterometer data on magnetic tape, day	3-23-70	6,000 and 1,000 ft
13.7 GHz radiometer data on magnetic tape, day	3-23-70	6,000 and 1,000 ft
13.3 GHz scatterometer data on magnetic tape, night	3-24-70	6,000 and 1,000 ft
13.7 GHz radiometer data on magnetic tape, night	3-24-70	6,000 and 1,000 ft

DATA ANALYSIS

The scope of this discussion is limited to the results obtained by the State Highway Commission of Kansas from the visual analysis of photography and imagery taken over test site 5 in Jefferson County. Data collected on magnetic tapes over all sites are being reduced and analyzed by contractors engaged by the Federal Highway Administration under separate contract. A final report to be released jointly by the State Highway Commission of Kansas and the Federal Highway Administration will present final results of this aspect of the research project.

Planned Method of Operation

For this study, the interpretation and mapping efforts were concentrated in 3 separate areas that represented the different geological conditions in the test site. Initial interpretation of the soils was accomplished on stereopairs of black-and-white panchromatic photography at a scale of 1:5,000. Soil maps were prepared in pencil in order that modifications could be made as other forms of data were analyzed. Color and color infrared photography were then analyzed along with narrow-band photography. Infrared imagery (8- to 14-micrometer range) was analyzed last. Available Soil Conservation Service information was used to assist in the interpretation in a portion of each test section.

Each map unit designation included 6 items:

1. Landform classification,
2. Surface soil classification according to the Unified Soil Classification System,
3. Composite soil texture according to State Highway Commission of Kansas classification system,
4. Depth to bedrock,
5. Depth to groundwater table, and
6. Slope.

Once interpretation of data was completed and the soil maps completed, soil samples were taken in each major soil map unit on a statistical basis. The field sample data along with Soil Conservation Service information were to serve as a standard to evaluate the soil mapping process.

Interpretation and Correlation of Data

The detailed analysis and results of this phase of the study with the supporting data are included in an interim report by Stallard and Myers (1). The results and conclusions are summarized here.

Remote-Sensing Data

Broad landform relations were delineated on conventional black-and-white photography, particularly at the smaller scale. Soil groups were differentiated with varying degrees of accuracy through the use of clues provided by drainage patterns, land use, tonal contrasts, and slope changes. Narrow-band photography (no stereovision) provided similar information and added some contrasts in vegetation. Best tonal contrast was observed on photographs taken in the 0.58- to 0.72-μm band, which utilized a Wratten 25A filter.

Color photography (color transparencies) provided modifications to features delineated from the interpretation of black and white, especially on boundaries of soils that became more shallow downslope. Soil color changes were useful to place boundaries in areas where no tonal contrasts were evident on black-and-white photography. In bare fields, color photography contributed a great deal of detailed information concerning soil depths and types. Color was extremely helpful in differentiating residual limestone soil (a reddish color), unweathered glacial drift (a mottled-reddish color), and loessial soils that capped high terrain.

Color infrared photography provided contrasts similar to those provided by conventional color photography. In areas where contrasts on bare soils were useful in mapping, the color rendered a more distinct boundary. However, marked contrasts may be seen in differences in the growth of vegetation, particularly in different types of crops.

Marked differences were observed between the day and the night infrared imagery (8- to 14-μm range). The day imagery shows contrasts attributable to differences in vegetation and soil conditions (Fig. 5). Some very interesting contrasts were observed on the night imagery in one of the test areas (Oskaloosa), inasmuch as they did not coincide with any delineations or patterns observed on any of the other types of photography or imagery. Thermal units detected tend to indicate depths to bedrock or to the groundwater table, which acts as a strong thermal reservoir in areas of most intense radiation. This tentative conclusion is based on field drilling and probing that was accomplished along lines A-A′, B-B′, and C-C′ shown in Figure 5. An example of one of the profiles, B-B′, is shown in Figure 6.

Elsewhere in the test site, the nighttime imagery was influenced primarily by farming practices, or the quality of imagery was so poor that little interpretation was possible. The quality of imagery in the 3- to 5.5-micrometer range was too poor to be used.

Verification of Data

Verification of the interpreted map unit designations was performed by comparison to the field soil data collected for this purpose. Mapping accuracies, expressed as the percentage correct, were evaluated for the first 5 of the 6 items that constitute the map unit designation. These items were interpreted from remote-sensing data. Slope designations (item 6), which were taken from USGS topographic maps, were not considered in this analysis.

A good degree of accuracy (average 91 percent) in the interpretation of landforms (item 1) was achieved in all study areas. A varying degree of success was achieved in use of the interpretative modifiers (items 2 to 5) in different study areas. The low degree of success for item 2 (average 37 percent) might be attributed to the lack of familiarity with the Unified Soil Classification System. More success was achieved with item 3 (Kansas classification system); the average accuracies were 83, 87, and 38 percent for the 3 test areas. The low accuracy in one of the areas may be attributed to the fact that this area was characterized by alluvial soils that are highly erratic. A fair-to-good degree of accuracy was achieved in the interpretation of item 4 (average 84 percent) but especially so in the area where the soil mantle was relatively thin (average 96 percent). The detailed comparisons are given in the report by Stallard and Meyers (1).

The significance of the type and the amount of information conveyed to the user cannot necessarily be evaluated by percentage. Although some users may desire 100 percent accuracy, the objectives of the soils investigation must be achieved with a realistic expenditure of time and money. In addition, the type and the amount of information presented on a soils map are limited to the type and the amount of information the interpreter can extract from the photography and imagery. In essence, the soils map should reflect what the user needs and what the interpreter can provide. Soils mapping in Kansas for highway engineering purposes requires 3 items that may be inferred from aerial photography and remote-sensing imagery. They are depth to bedrock, depth to groundwater table, and major changes in soil material types. Generally these factors cannot be determined directly, but inferences and deductions must be made based on surface manifestations and data extracted from imagery. Usually information on these factors will be given as a range of values. Although not precise enough for design purposes, such information provides the location, soils, and design engineers with an excellent insight into the terrain being investigated for a prospective project.

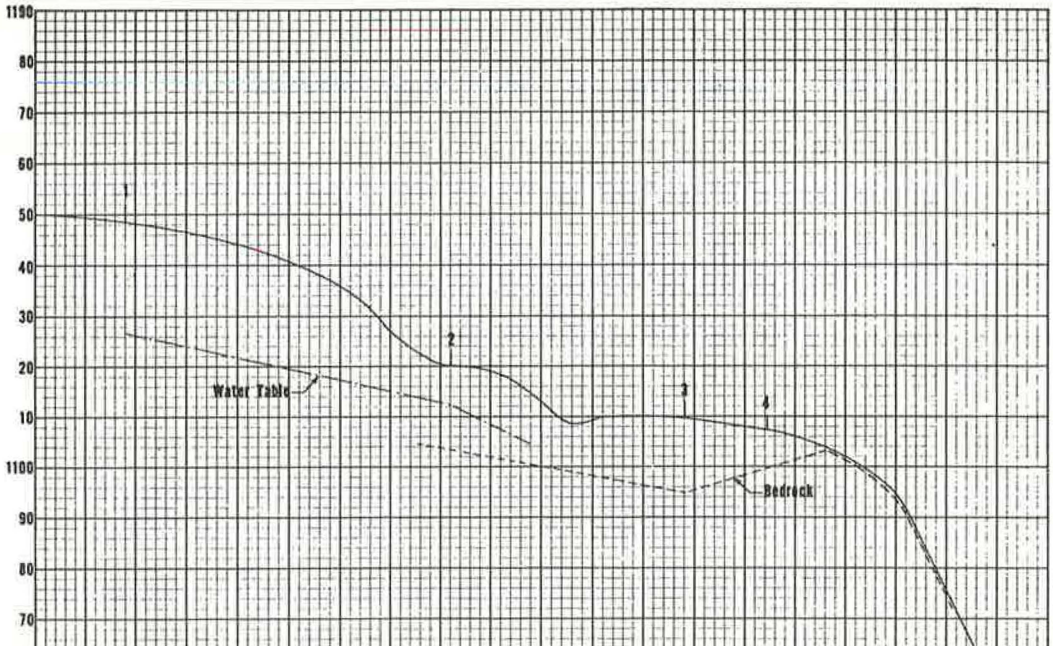
CONCLUSIONS

The following conclusions are based on the visual analysis of the various photography and imagery obtained for this study.

1. Color, small-scale (1:10,000) photography is the best single source of soil information. The low-altitude color (1:2,000) had a scale too large for use in effective soil mapping.

Figure 5. Infrared imagery (Oskaloosa area) (8- to 14-micrometer range, scale = 1:36,000, black = cold, and white = hot).

Figure 6. Profile for infrared imagery (Oskaloosa area).



2. Contrast of soils can be enhanced by use of narrow-band photography in the red and infrared portion of the spectrum.

3. Color infrared photography provided information similar to that provided by color photography; additional contrasts revealed vegetation changes. This medium could possibly provide as much information as any single sensing method if proper photographic techniques are used and if the photography were acquired when optimum climatic and environmental conditions prevailed.

4. Day infrared imagery provided information primarily attributable to superficial conditions. Little additional information could be obtained, other than the location of springs and wet areas. Night infrared imagery used in conjunction with the photography was useful in mapping bedrock outcrops and spring areas and in ascertaining relative soil depths, high groundwater levels, and wet areas. Significant delineations were made in areas where uniform ground conditions existed over large portions of the terrain; that is, most of the area was characterized by pastureland, and thermal changes due to marked differences in land use practices did not obliterate the more subdued changes that may have been evident because of different thermal characteristics of soils.

5. The combined use of color aerial photography and infrared imagery (8- to 14-μm range, nighttime, high-altitude) renders the most distinctive evidence for detection, evaluation, and mapping of engineering soil groups.

6. SCS data provide a general knowledge of an area that could serve as a base on which the remote-sensing data could be applied. Modifications and redefinition of engineering soil groups could be accomplished during the analysis of the remote-sensing data.

REFERENCE

1. Stallard, A. H., and Myers, L. D. Soil Identification by Remote Sensing Techniques in Kansas, Part I. State Highway Commission of Kansas, Final Rept., 1972.