

## FINAL REPORT

VIRGINIA'S USE OF REMOTE SENSING IN THE PRELIMINARY  
AERIAL SURVEY — HIGHWAY PLANNING STAGE

by

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

Virginia Highway Research Council  
(A Cooperative Organization Sponsored Jointly by the Virginia  
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## PREFACE

The interpretation of remotely sensed data is part science, part art. The scientific aspect can be learned, the artistic aspect must be acquired through practice. It should not be expected that a novice interpreter could get as much information from a group of data as could a veteran interpreter. In addition, with the proliferation of data resulting from the use of multisensor techniques, it has become increasingly difficult for even veteran interpreters to efficiently evaluate all the data because of human limitations. Thus computer analysis techniques have been developed to eliminate the human limitations.

The principal investigator for this study was not a trained interpreter of aerial photographs. The conduct of such a project by a novice interpreter was justified in that it demonstrated the information that most highway departments could get from the data using personnel who are not skilled in the interpretation of remotely sensed data.



## SUMMARY

The purpose of the study was to determine whether infrared technology could be used in Virginia to delineate areas with soils having a high moisture content. The study was conducted in cooperation with the FHWA, and personnel of the University of Michigan were engaged as consultants for the remote sensing flights.

Located in Augusta County, Virginia, the study area is mapped geologically, topographically, and pedologically and is heavily farmed and 80 percent nonforested.

Data were collected with a multisensor array, including cameras and multispectral sensors. The electromagnetic spectrum was sensed from the violet through the far infrared. Ground truth in the form of radiometer and thermometer readings and color photographs was taken at the time of the flights. The day and night sensed infrared data and the various types of photographs were interpreted for information about features associated with surface moisture. Attention was also given to subsurface cavities.

It was concluded that: (1) Nighttime thermal infrared imagery is the best technique for the remote detection of surface water; (2) photographs and daytime and nighttime thermal infrared imagery can be used collectively to detect and delineate high moisture content soils; and (3) photographs and daytime and nighttime thermal infrared imagery, used collectively, also have great potential for the location of subsurface cavities.

It was recommended that (1) A trial use of this technology be made on a proposed highway location in a troublesome soil area; (2) verification of the existence of subsurface cavities suggested by the interpretation of the data be sought; and (3) the Virginia Highway Research Council should keep abreast of the computer analysis of the data being made by the FHWA personnel.



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## INTRODUCTION

The technology of remote sensing has moved very fast over the past twenty years, stimulated by such concerns as surveillance for military purposes, space exploration, mineral exploration, and reconnaissance of remote regions. That portion of the electromagnetic spectrum with which man is most familiar, the visible, has received the most attention. However, on both sides of the visible spectrum the shorter ultra violet, X-ray and gamma ray wavelengths and the longer infrared, radar, and radio wavelengths are the subject of research and development. The infrared techniques are well developed and reasonably available for public use. The Federal Highway Administration and various state highway departments have cooperated in research on the application of these techniques to highway problems. The project reported here was part of this federal-state cooperative effort. The Infrared and Optical Sensor Laboratory of the Institute of Science and Technology of the University of Michigan was engaged as a consultant on the study.

Problem

Among the many problems confronting highway engineers are soils with high moisture contents, areas of poor drainage, areas of potential landslides, and areas of active landslides. Water is central to all these problems. Thus in planning the study, it was hoped that detection of high moisture content materials might be accomplished.

## PURPOSE

The principal purpose of this study as stated in the working plan (Noble 1969) was to determine whether remote sensing techniques, in particular those utilizing the infrared portion of the electromagnetic spectrum, could be used to differentiate and delineate the areas along a proposed right-of-way that contain high moisture at the ground surface; and whether this information could be interpreted to provide knowledge of soil moisture conditions at depth. As a by-product of such a study, information might be generated which would contribute to the knowledge of remotely sensed diagnostic properties of natural materials.

## LIMITATIONS

In the interest of efficiency and because of the time constraint placed on the project, it was limited to those activities thought to be necessary to attain the objectives set forth under "Purpose". Many other aspects of the subject — such as the efficacy of the infrared technique on different topographies, a comparison of its cost with that of the conventional method, a cost-benefit analysis, and application of the technique to study a major landslide or a water pollution problem — are of interest, but each would warrant a study in itself.

## SITE SELECTION AND DESCRIPTION

It was desirable that there be good geologic, pedologic, and meteorologic data on the study site. In addition, for studying soil properties, it was desirable that the area be extensively farmed so that large tracts of soil would be exposed, and that as wide a variety of soil types as possible be embraced. Areas in both the Piedmont and Valley and Ridge physiographic provinces were evaluated. Approximately six sites, having good ground control data, were considered and field checked. A site in Augusta County was chosen (see Figure 1).

The Great Valley of Virginia passes through the middle of Augusta County. The eastern boundary of the county lies within the Blue Ridge Mountains, and its western quarter is within the Folded Appalachian Mountains. The central two-thirds, running approximately NE-SW, is underlain by great thicknesses of tilted limestone and shale. Because of the moderate natural fertility of the soils derived from these rocks, the area is extensively farmed. Along the twelve mile, NW-SE trending traverse, approximately 80 percent of the land is nonforested and is either cultivated or in pasture.

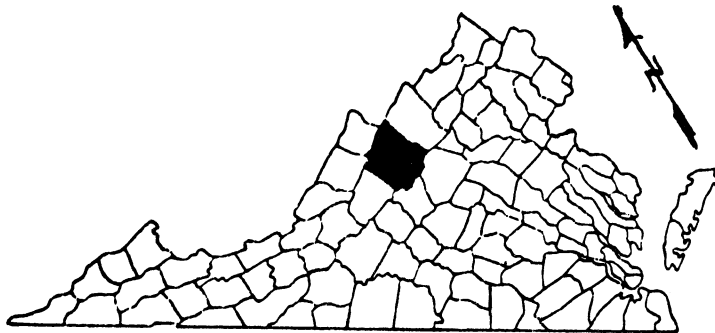


Figure 1. Index to Augusta County, Virginia location.



### Topography

The topography along the traverse may generally be characterized as rolling. The elevations above sea level of the ridges at the NW end of the traverse are between 1,800 and 1,900 feet. Toward the SE, the ridge and hill tops become lower until at mid-traverse they are at approximately 1,500 feet. Near Stuarts Draft, they rise to elevations of 1,700 feet. The local relief varies between 230 to 270 feet except along the two principal streams, where it is much less.

### Geology

The geology of the region was described in detail by Rader (1967). The flight line followed the approximate NW-SE trace of a structural cross section, presented on the quadrangle maps. Thus the flight line was at approximately 90 degrees to the NE-SW trend of the structural elements. Limestones, dolomites, and shales of Cambrian and Ordovician age and sands and gravels of questionable Quaternary age were traversed. See Figure 2 for the areal distribution of all but the possibly Quaternary age material.

The materials for which data are given in Table 1 are important because of their extensive areal distribution. The Quaternary travertine, which is not included in Table 1, is quite local in extent but of some importance for reasons to be detailed later.

### Relationship of Geology to Other Areal Elements

It will be shown in the following discussion how the geology affects other areal elements. Special attention will be given to the effect of the characteristics of the rocks. As the discussion is considered, it might be well to keep in mind that rocks, exposed at the surface, are not in equilibrium with the environment. Weathering and erosion are processes that tend to develop an equilibrium condition.

The topography that is developed will depend on how uniformly or differentially the rock types respond to attack by these processes. Of the several lithologies, at least two, those of the Conococheague and the Beekmantown, have very distinct topographic expressions which show well on stereo pairs. The sandstone beds in the Conococheague tend to form ridges, such as Chestnut Ridge near Folly Mills, while the heavy deposits of residual chert from weathering of the Beekmantown give rise to conical hills such as "Round Hill" and "White Hill" near Stuarts Draft. Most of these bedded rocks dip rather steeply, which fact, coupled with their differential susceptibility to weathering, causes the outcrops of bedrock to be long linear (ledgey) features. The importance of travertine forming along Folly Mills Creek is that for the creek water to contain sufficient calcium and bicarbonate ions in solution such that the calcium carbonate of the travertine can form upon evaporation of splashed creek water, there must be a significant solution of limestone occurring within the area. In addition, there is an area of incipient karst topography at the NW end of the traverse where there are two small sinkholes. Thus the existence of underground cavities in these areas is a distinct possibility.

MISSISSIPPIAN



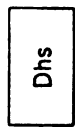
Pocono formation  
*Sandstone and conglomerate*

ORDOVICIAN



Ordoevician formations; Middle and Upper, undivided

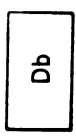
DEVONIAN



Hampshire formation  
*Shale and sandstone, red.*



Chemung formation  
*Shale and sandstone*



Brallier formation  
*Shale.*



Devonian formations, Lower and Middle, undivided

SILURIAN



Tuscarora formation  
*Quartzite, thick-bedded. Includes Clinch sandstone*

CAMBRIAN



Conococheague formation  
*Limestone and dolomite*



Elbrook formation  
*Dolomite, thick-bedded, shaly*



Rome formation  
*Shale and sandstone*

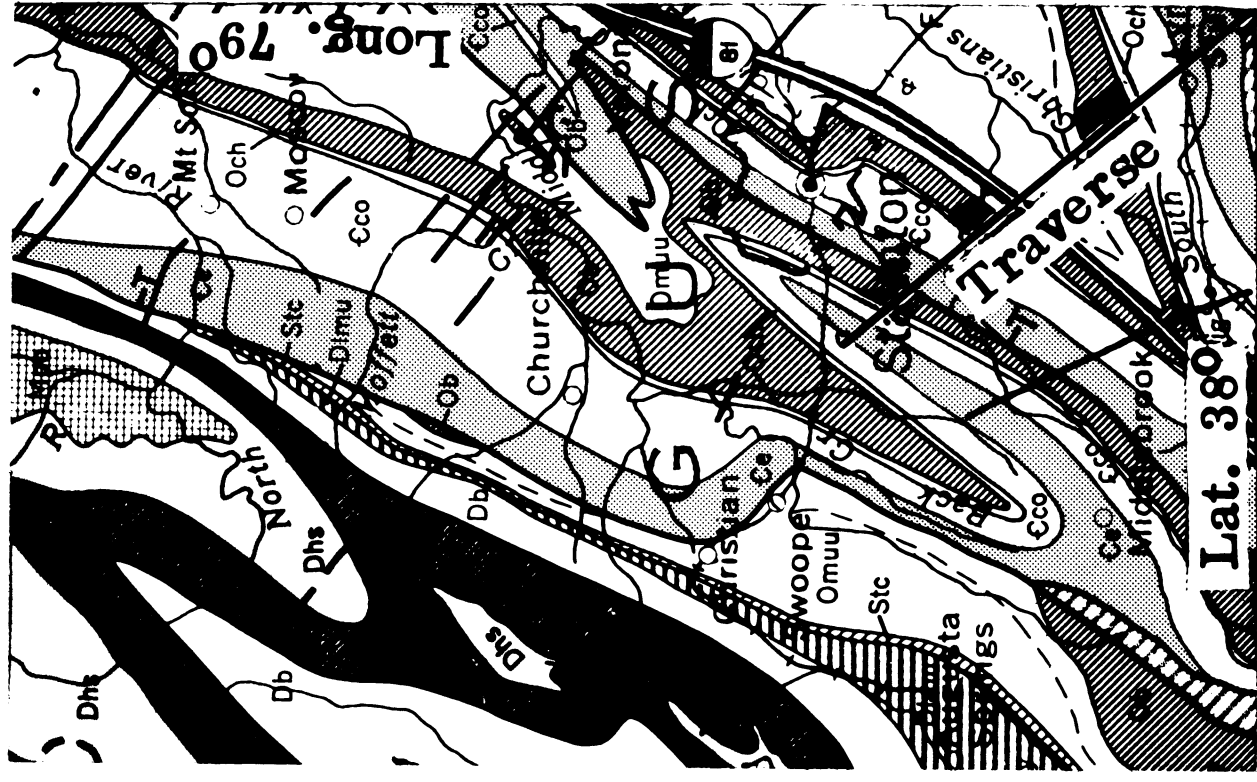


Figure 2. Geology of the Staunton Virginia area. From Calver and Hobbs (1963).

TABLE 1  
DATA OF CERTAIN ROCK TYPES OF AUGUSTA COUNTY, VIRGINIA

Formation	Age	Rock Type	Color	Texture	Bedding	Structural Attitude	Deviant Materials
Elbrook	Cambrian	a. Dolomite and limestone	Medium to dark gray	Medium to fine	Thick	Tilted	
		b. Dolomite and limestone	Light to medium gray	Fine to medium	Thin	Tilted	Clays
Conococheague	Cambrian	a. Limestone and dolomitic limestone	Medium gray to bluish gray		Thin	Tilted	Minor amounts chert throughout
		b. Dolomite to dolomitic sandstone	Light to medium gray		Thick	Tilted	Quartz sand
Beekmantown	Ordovician	Chiefly dolomite	Medium to dark gray	Fine with some coarse		Tilted	Large lenses chert in lower portion
Edinburg	Ordovician	Clayey limestone	Black	Fine		Tilted	Clay
		Some shale		Fine	Thin	Tilted	
Martinsburg	Ordovician	Shale	Gray to olive, weathers buff	Fine	Thin	Tilted	
—	Possibly Quaternary	Alluvium and gravel	Yellowish brown to dark gray	Varied		Approximately horizontal	
—	Quaternary	Travertine	Tannish	Porous			Twigs and rock fragments

Zones of fracture such as the Pulaski-Staunton Fault (regardless of whether they are active or inactive), joints along the crests of folds, and the abandoned and filled channels on the South River flood plain are areas that might localize water.

### Soil Types

The soils most commonly occurring within the study area are described in Table 2 (Hockman et al., 1969). The data are necessarily generalized.

### Relationship of Soils to Other Areal Elements

It was stated earlier that the sandy and cherty carbonate rocks affect the topography in that their resistant members form ridges and conical hills respectively. Soils, on the other hand, are a reflection of the many factors that affect their genesis -- factors such as:

1. Parent material
2. Climate
3. Plant and animal life, on and within
4. Relief -- topography
5. Time subjected to soil forming processes.

Thus, the soils reflect the presence of chert and quartz sand in the Conococheague limestone, chert in the Beekmantown dolomite, and the clay and silt in the Martinsburg shale. The climate is temperate with an average annual precipitation of 37 inches relatively evenly distributed over the year. Such climatic conditions are conducive to chemical attack of limestone and dolomite. Therefore, the greatest soil thicknesses occur over portions of the carbonate rocks. Where slopes are level to gentle, erosion is minimized and there is sufficient time for the development of thick, mature soil profiles over the carbonates.

TABLE 2  
 DATA OF CERTAIN SOILS OF AUGUSTA COUNTY, VIRGINIA

(After Hockman et al.)

Soil Name	Color	Tenaciousness	Texture	Depth	Drainage Class	Permeability	Susceptibility to Erosion	Depth Seasonal High Water Table	Genesis
Dandridge silt loam	Dark brown to yellowish brown	Very friable surface soil	Silt loam or shaly silt loam	Shallow (12 - 20 inches)	Well to excessively	Moderately rapid	High	4 feet plus	Residual
Frederick	Yellowish brown to red in "B"	Friable surface soil	Silt loam to clay in "B"	Deep (4 - 30 feet)	Well	Moderate	Moderate to high	6 feet plus	Residual
Floodplain and terrace soils: Braddock, Laidig, Melvin, Monongahela, Newark, Purdy, Tyler	Yellowish brown to dark gray	Friable to very friable surface soil	Sandy to silt loam	Deep (6 - 10 feet)	Relatively poor	Low to moderate	Low to moderate depending on slope and regional relief	Shallow (0 - 3 feet) with ponding on floodplain	Transported

## GROUND CONTROL DATA

The Photogrammetry Section of the Location and Design Division, Virginia Department of Highways prepared an uncorrected photo-mosaic at a scale ratio of 1 to 24,000 for field use. They also acquired the aeronautical charts of the study area for the consultant. Topographic maps and geologic maps of the 7.5 minute series of the study area were obtained from the Virginia Division of Mineral Resources. The United States Department of Agriculture, Soil Conservation Service was preparing a soil survey report of Augusta County and kindly made the preliminary draft available. Very useful data were obtained in the form of soil boundaries on a black and white aerial photo format, plus the soil descriptions, which contain data on the physical properties of the soils and information on their agricultural, forest, engineering, and urban suitability.

## GROUND TRUTH MEASUREMENTS

Ground truth measurements are a necessary complement to the data taken during aerial flights. In remote sensing from aircraft, the atmosphere is the medium through which radiation is transmitted. The atmosphere is composed of gases and particulate matter; the former will absorb radiation while the latter will scatter it (Rib 1966). Thus, the radiation that arrives at the sensors in the plane is not identical to what is radiated and reflected from the surfaces on the earth. Knowledge of the surface conditions at the time of the flight enhances the interpretation of the data, because the interpreter can judge whether or not the atmosphere has selectively absorbed energy to such a degree as to drastically alter the spectrum received at the sensors.

The traverse was field checked so as to establish, based on the previous year's farming practices, potential ground truth sites that might be bare at the time of the flight. As many types of material and conditions as possible were selected. Aside from the ground truth sites in relatively level fields, a site for a water reading was established just off a bridge over Christians Creek because of the minimum diurnal fluctuations in the water's temperature; and several check points were established for reading embankments, which were affected to a lesser degree by solar radiation and nocturnal cooling than were the level fields. Inasmuch as the ground truth data were collected using cars and trucks for transportation, it was desirable to locate the sites in the proximity of the roads.

Many parameters might or could have been checked at the time of the flight. However, the number and types of parameters were restricted by the time and the number of personnel available. Consideration of equipment and personnel dictated that parameters such as soil moisture content and precise meteorological conditions not be checked. Thus the ground truth checks were organized so as to acquire the greatest amount of information on a few parameters judged to be the most useful in terms of a correlation with the flight data. Ground temperature and color photographs were taken, and visual estimates of meteorological conditions were made.

### Temperature Measurements

For both the day and night flights, two crews composed of FHWA and Virginia Highway Research Council personnel took surface temperatures at the selected sites. Both contact thermometers and remote infrared radiometers were employed. The surface thermometer was placed on the soil surface, the stem of the dial thermometer was placed just under the surface, and the radiometer was focused on the soil surface, but scanned over a relatively large area. These readings were recorded along with the site notation, the time, and instances when the aircraft was overhead.

The day before the flight a last minute check of the traverse was made. Recent changes in field conditions were noted. Where necessary, the sites of ground truth checks were changed. An approximately 4-5 foot, brightly painted stake was driven into each field to serve as a reference point so that the instrument man would take measurements at approximately the same location.

### Color Photographs

During the day flight, Virginia Highway Research Council personnel equipped with 35 mm. cameras loaded with ektachrome film and 7.5 minute quadrangle topographic maps for locating sites, photographed specific fields and conditions on selected segments of the traverse. The purpose of this photography was to provide reasonably close-up photographic evidence of ground conditions at the time of the flight. Some of the photographers had had very little experience with the type cameras provided, and the photographs were of necessity taken in a hurried manner. The results of this photography demonstrated that the best photographs were taken with the most automatic cameras. Use of a hand held light meter resulted in underexposures.

## PLANNING OF FLIGHT

### Technological Aspects

#### Selection of Sensors and Film Types

The personnel of the Virginia Highway Research Council lacked expertise in the area of remote sensing. Therefore, considerable reliance was placed on the advice of the personnel with the Infrared and Optics Laboratory of the University of Michigan, the FHWA, and the Photogrammetry Section of the Virginia Department of Highways. The wavelength bands within the electromagnetic spectrum selected for electronic sensing are listed in Table 3. Wavelength bands were chosen so that the entire visible spectrum was covered. At night, the only wavelength bands sensed were the middle and far infrared. The films chosen for the photography are listed in Table 4; the personnel of the University of Michigan used the 70 mm. film and the Virginia Department of Highways used the 9 x 9 inch film.

TABLE 3

## SPECTRAL BANDS SENSED BY ELECTRONIC SENSORS

Time of Day	Name	Wavelength Band, (micrometers)	Field of View, (degrees)	
Day	Violet	.40 - .44	80	
	Blue	.44 - .46		
		.46 - .48		
		.48 - .50		
	Green	.50 - .52		
		.52 - .55		
		.55 - .58		
	Yellow	.58 - .62		
	Orange	.62 - .66		
	Red	.66 - .72		
	Near Infrared	.72 - .80		
		.80 - 1.0		
		1.0 - 1.4		
	Middle Infrared	1.5 - 1.8		37
		2.0 - 2.6		
2.0 - 2.6 low gain				
Far Infrared	8.0 - 13.5			
	8.0 - 13.5 low gain			
Night	Middle Infrared	4.5 - 5.5	37	
		4.5 - 5.5 low gain		
	Far Infrared	8.0 - 13.5	80	
		8.0 - 13.5 low gain		
		8.0 - 10.0		
	10.0 - 11.0			



TABLE 4

## FILM TYPES USED ON DAY FLIGHTS

Name	Film Type	Size	Filter	Camera
Black & White	2402	70 mm	W12	P-2
Black & White I. R.	2424	70 mm	89B	P-2
Ektachrome	8442	70 mm	1A	KB-8
Color I. R.	8443	70 mm	W15	P-220
Black & White (xx)	2405	9 inch	W12	Wild RC-8
Ektachrome	8442	9 inch	anti-vignetting	Wild RC-8
Color I. R.	8443	9 inch	W12	Wild RC-8

The purpose of the aerial photography was to provide the type of data to which the photo interpreter is accustomed. The use of normal black and white, ektachrome color, infrared black and white, and infrared color permitted the evaluation of which parameter a specific film showed best and also permitted the combining of several photographic records for documentation purposes.

As a means of calibration, eight 20 by 40 foot, coated, canvas panels of known reflectances were staked in a relatively level field near the beginning of the traverse; the site could have been anywhere along the traverse. Five gray tone panels had reflectances ranging from 0 to 80 percent in 20 percent increments. The three colored canvasses were red, blue and green.

### Flight Times

Initially it was hoped that one flight could be made during the wet spring of the year, and that another could be made after a dry late summer or early fall so that the effect of the moisture contrast might be observed. Early April was chosen for the wet season flight because at this time it was expected that there would be little if any snow cover or deciduous foliage to obscure the differences in the soil conditions and types. The time considered most desirable for the day flight was between 1000 and 1400 hours. The object was to have maximum sun, minimum shadow, and minimum cloud cover. Therefore, the flight time was set at 1000 hours to avoid the usual mid-day cloud buildup. The primary constraint on the timing of the night flight was that all residual energy absorbed during the day should have been dissipated so that the only radiation coming from the earth would be that which was characteristic of the material and its temperature. The night air was quite cool (approximately 0° Celcius) and an equilibrium condition was reached well before the flight time of 2300 hours.

The second flight was planned for mid-November, but because of equipment breakdown, it was postponed until mid-December. The delay was fortuitous in that few fields were bare in November, but winter plowing bared numerous of them by the December flight date. The times for the flights were similar for the reasons mentioned earlier. Unfortunately, a low sun angle caused pronounced shadows.

### Post Flight Data Check

After completion of the day and night flights the consultant recommended checking several of the electronically sensed wavelength bands in order to verify that data were acquired and that they were on the desired flight line.

## Physical Aspects

### Length and Elevation

The general choice of location for the traverse assured such variety in materials and terrain that the precise length of the traverse was somewhat a matter of convenience. The traverse was flown at two altitudes so that interpretations of data with different degrees of resolution could be compared and a judgment could be made on the value to highway needs of high flights with relatively poor resolution but great areal coverage. Inasmuch as the reels of magnetic tape on which the data were recorded would accommodate twenty-four miles of data, it was decided to make the flight line twelve miles long. Thus the flights at two altitudes would use a roll of tape.

To judge the applicability of multispectral remote sensing to highway planning and engineering, it was decided to fly the flight line at an elevation above mean ground altitude that would amply cover the minimum right-of-way required for an interstate road. Safe operation of the aircraft was also a consideration, and the lowest elevation above mean ground altitude that would cover the right-of-way was too low for safety. Thus elevations of 2,000 and 5,000 feet above mean ground altitude were chosen. These elevations gave a minimum and maximum ground coverage of 1,338 and 8,390 feet for the 37° angle and 80° angle fields of view respectively.

### Details of Preparation

Coordination between the crews collecting ground truth data and the flight crews was important. Therefore, the following procedures were utilized:

1. A local airfield large enough to accommodate a C-47 aircraft and as close to the project area as possible was used as a base of operations.
2. Telephone contact was maintained between the ground and flight crews up to flight time for last minute consultations.

- 011
3. A signal was arranged by which the flight crew could indicate to the ground crews that the mission was completed.
  4. Radio contact was possible among several Department of Highway vehicles and the Department plane.

There were two other preparations worthy of note. One was the placement of strobe lights along the flight line as an aid to night navigation. The other was that notifying the local police about the impending night activity saved the citizens in the area some confusion and alarm.

## ANALYSIS OF DATA

### Format

The electronically sensed data were recorded on magnetic tape. Duplicates of the original tapes were prepared for both the Council and the FHWA. In addition, the data on the tape were converted to gray tone images and presented on 70 mm. film (negatives and prints) for visual interpretation. The gray tone images had the advantage of being in a form that was familiar to most people, but they were deficient in that the film did not have sufficient tones of gray to represent the many variations that the magnetic tape was capable of recording (Hasell 1970).

Negatives and prints of both the spectral data and the 70 mm. film exposed by the consultant and the 9 by 9 inch film used by the Department were supplied to the Council and the FHWA.

### Division of Responsibility

The Council had prime responsibility for the visual interpretation of the data; the FHWA planned to concentrate its interpretive effort on the computerized analysis of the data as recorded on the magnetic tapes. This division of responsibility was primarily dictated by the interests and capabilities of the two groups and by the intent to hold any duplication of effort to a minimum.

### Approach to Visual Analysis

Specific features and conditions, such as sinkholes, faults, filled ox-bow lakes and other channel cut-offs, and leakage from reservoirs which are known to have high moisture associated with them were investigated by use of the film strips. This approach was taken because the principal purpose of this study, as stated earlier, was to determine whether remote sensing techniques, in particular those utilizing the infrared portion of the electromagnetic spectrum, could be used to differentiate and delineate the areas along a proposed right-of-way that contain high moisture at the ground surface. Secondly, this approach was taken because interpretation of all of the data as fully as possible would have taken more time than was available.

Wien's displacement law says that "black body" terrain objects which have temperatures ranging from  $-40^{\circ}\text{F}$  to  $+150^{\circ}\text{F}$  (the range of natural landscape temperatures) have peak emissions from 8.6 to 12.4 micrometers (Becker and Lancaster 1966). Rib and Miles (1969) state that most of the tonal contrasts seen on the 8 to 14 micrometer band are also evident, but not as distinct, on the 4.5 to 5 micrometer band. This phenomenon was anticipated since the peak for the terrain temperatures normally encountered was about 10 micrometers. In addition, Rib and Miles (1969) state that "Considering all infrared bands where soils were analyzed, the maximum information was obtained in the 8 to 14 micrometer band." Tanguay and Miles (1970) found that the thermal infrared band (8.0 to 13.5 micrometers) was particularly useful in detecting surfaces that were relatively hot and emitting strongly and surfaces that were relatively cool. Water bodies and vegetation, which are considered relatively cool, showed as dark areas on the imagery. Tonal variations in the 8.0 to 13.5 micrometer band change over a 24-hour period in a drastic way as the surface temperature of materials changes and may eventually result in tonal inversions on imagery obtained at night. Such a phenomenon may be of value in evaluating the nature of the sensed material. Therefore, to use the far infrared 8.0 to 13.5 micrometer band to the maximum, the imagery should be obtained during both the day and night. Rib and Miles (1969) concluded that infrared imagery cannot be used as a primary source for engineering soils mapping because of its small scale, poor resolution, and lack of stereoscopic viewing capabilities. Its primary value was that it provided supplementary information not obtainable by any other means and of a type that aided in the interpretation of soils and soil conditions from the various types of photographs available.

Considering the purpose of this study and the findings referred to above, it was decided to evaluate the data from both the reflected and emitted infrared bands in conjunction with the ektachrome color and infrared color to determine what could be ascertained about those features expected to have water associated with them. With as much information as possible garnered from the infrared imagery, attention was turned to the various types of photographs available to compare the information interpreted from the two types of sensed data.

## RESULTS AND DISCUSSION

Surface water, because of its relative warmth at night and relative coolness during the day, had strong emittance at night, low emittance during the day, and bright and dark images respectively on the film strips. Natural and artificial ponds and drainageways containing surface water were easily detected on the night sensed 8.0 - 13.5 micrometer band at a moderate to high gain (see Figure 3). Features that could be observed on black and white and ektachrome color prints, but could not be interpreted as containing water, could be so interpreted on all the night sensed infrared imagery though to differing degrees. Infrared color also provided a good indication of surface water.

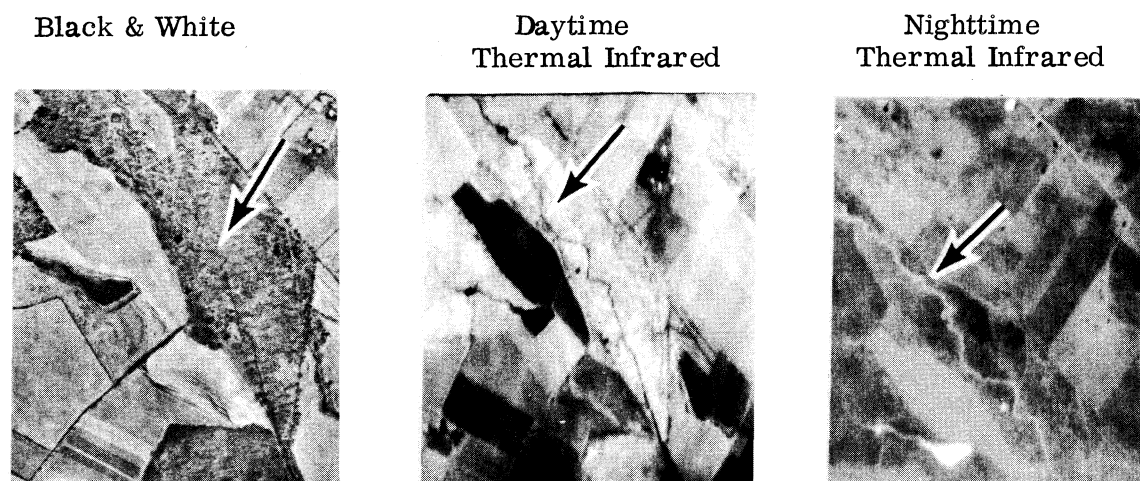


Figure 3. Comparisons of black and white aerial photographs with daytime and nighttime thermal infrared imagery. Arrows designate position of stream.

Soils with a high moisture content were detected by comparing the black and white photographs and the daytime and the nighttime imagery in the 8.0 - 13.5 micrometer band (thermal infrared). Dark images on the photographs may represent dark colored soils, various types and densities of vegetation, or soils with a high moisture content. On the daytime imagery, relatively dry dark soils have a light toned image because the dark material absorbs more energy and is at a higher temperature than the lighter colored materials and so it emits a greater intensity of infrared radiation. Vegetation, surface water, and materials with a high moisture content have dark images because transpiration and evaporation respectively keep the materials relatively cool and thus they are weak emitters. A check of the various types of photographs can confirm the presence or absence of vegetation, its color (ektachrome color) and its vigor (infrared color). The absence of vegetation confirms the presence of high moisture content soils. The presence of vegetation necessitates inspection of the nighttime imagery. On nighttime imagery, relatively dry soils have images of various tones of gray representative of the basic nature of the materials; the images of water are the lightest because it is relatively warm and emits strongly, trees are also light but not as light as the water, and the low vegetation remains dark. Therefore, the coincidence of a dark photographic image, a dark daytime thermal infrared image, and a light nighttime thermal infrared image indicates the presence of high moisture content material. Examples of the black and white photographs and the daytime and nighttime thermal infrared imagery may be compared in Figure 4. It is interesting to note in this figure that despite some intermittently cloudy and rainy weather for about two weeks prior to the December flight and showers the day of the night flight, the flood plain region of the South River was much drier than it was at the time of the April flight.

Black & White

Daytime  
Thermal Infrared

Nighttime  
Thermal Infrared

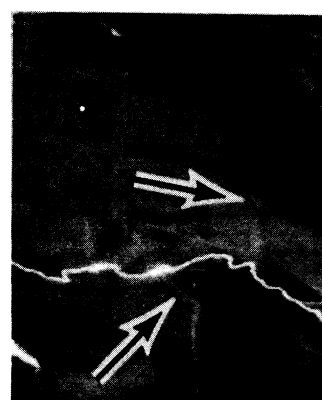
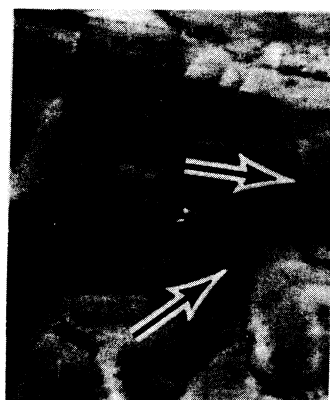
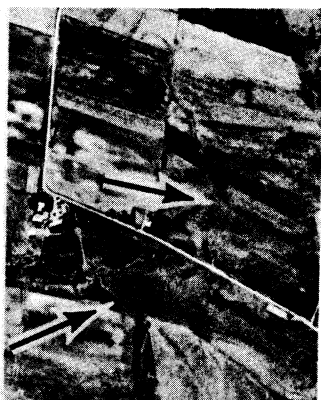
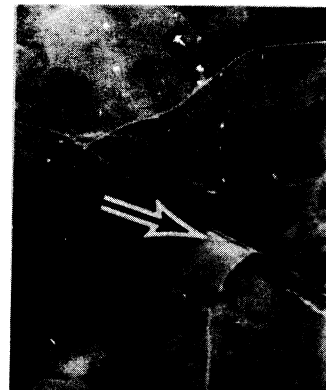
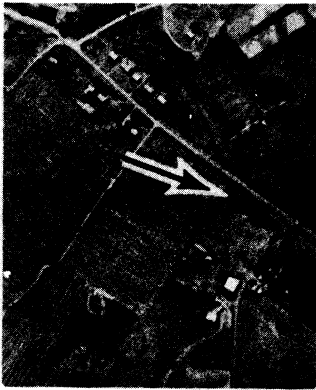
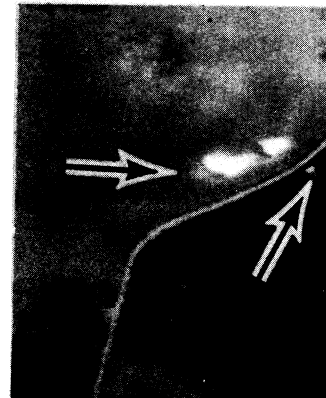
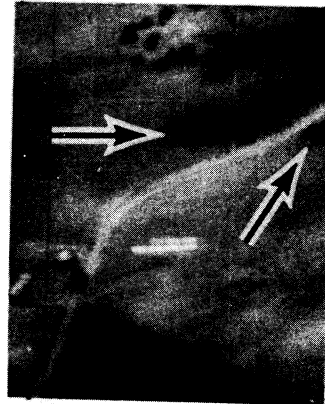
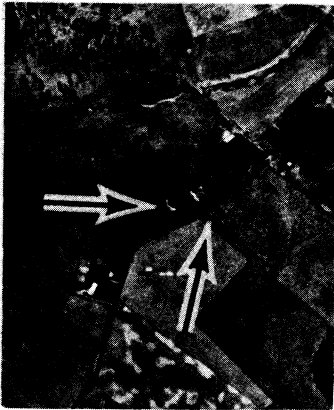
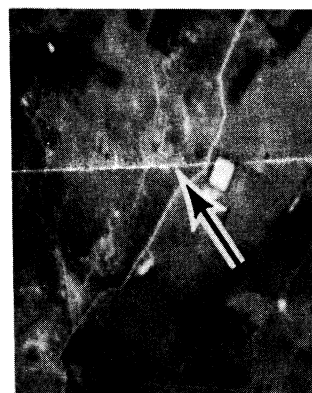
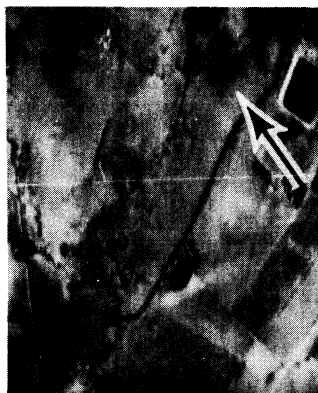
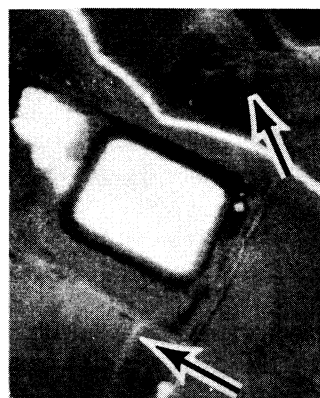
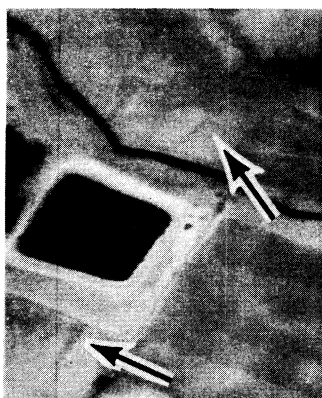
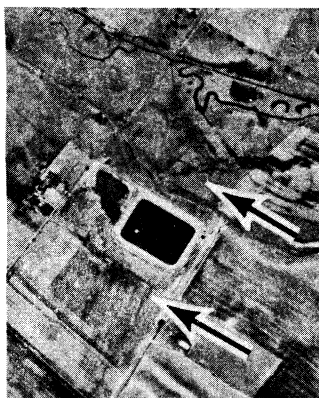


Figure 4. Examples of black and white photos and daytime and nighttime thermal infrared imagery. Arrows point to zones of high moisture content.

**Black & White**

**Daytime  
Thermal Infrared**

**Nighttime  
Thermal Infrared**



**Flood Plain  
April, 1970**

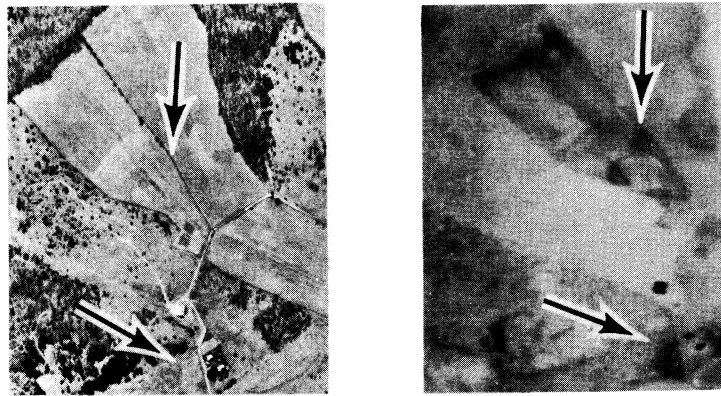
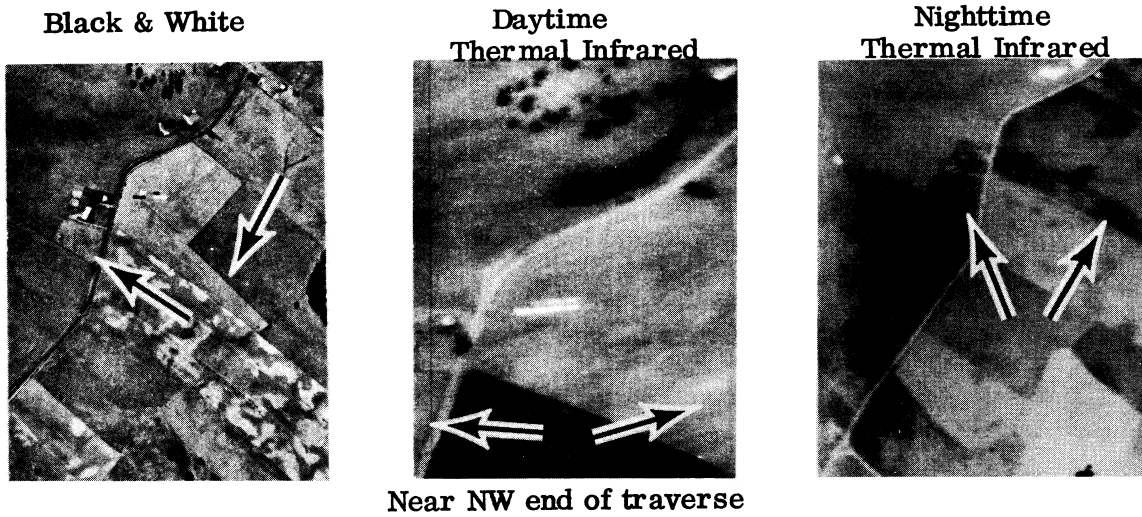


**Flood Plain  
Dec., 1970**

**Figure 4. Continued.**

There was a closed but rather freely draining sinkhole at the NW end of the traverse. Several of the night sensed infrared bands contained a medium gray image that coincided with the location of the sinkhole. This image was best differentiated on the film strip of the 10.0 - 11.0 micrometer band. At least two other medium gray spots coincided with depressions that appeared to result from the same type collapse associated with sinkholes. A group of nine irregularly shaped images of a similar gray tone were detected on the 10.0 - 11.0 micrometer band for an area 2 to 2½ miles SE of the NW end of the traverse (see Figure 5). There was nothing distinctive about the daytime imagery for this area. The area was somewhat removed from the network of county roads and had not been observed on the ground. A check of the topographic map showed three depressions in the area. A field check confirmed that sinkholes and depressions of varying reliefs existed at the sites of seven of the medium gray toned images. The other two areas were high on slopes and did not show any depression. Initially it was expected that the depressions would be wetter and warmer than the surrounding areas, thus they would have a stronger emittance and have a lighter gray toned image than the surrounding, drier and cooler area. The opposite finding might be explained by the occurrence of cavities that insulated the surface from the normal heat flow in the area and caused the depressions to be cooler than the surrounding area. The darker image might also be explained by a higher density of vegetation within the depressions, but no evidence for such an interpretation was found on the ektachrome color or infrared color prints.





2-2½ miles SE of NW end of traverse

Figure 5. Several of the gray toned images that coincided with depressions. Arrows point to features.

## CONCLUSIONS

1. Nighttime thermal infrared imagery, the 8.0 - 13.5 micrometer band, is the best band for the remote detection of surface water. It has great value in:
  - a. Establishing water-soil boundaries,
  - b. determining which drainageways are carrying water, and
  - c. locating surface water obscured by the image of vegetation on the other imagery and on the photographs.
2. A combination of photographs and daytime and nighttime thermal infrared imagery can be used to detect and delineate areas of soil that have a high moisture content. However, presently the principal investigator can detect only zones of extremely high moisture content, such as areas that are in proximity to surface water or areas that coincide with drainageways.
3. It appears that photographs and daytime and nighttime thermal infrared imagery may be used as a guide to the location of subsurface cavities. These cavities cannot be verified by simple visual observation in the field as were the other phenomena, but the sensor data and the presence of sinkholes strongly suggest their existence.

## RECOMMENDATIONS

The following recommendations are made in the most general sense and will be pursued in much greater detail should they be deemed to have merit.

1. The detection and delineation of surface water and soils with a high moisture content and the potential for detecting subsurface cavities are important to the Virginia Department of Highways. Considering the many alternatives in terms of the availability of equipment and consultation, it appears the time is appropriate for the operational testing of remote sensing technology. Therefore, it is recommended that the principal investigator of this study cooperate with the Department's personnel who are responsible for photogrammetry, air photo interpretation, and the preliminary planning of projects in the trial use of this technology on a proposed highway location in a troublesome soil area.
2. The existence of subsurface cavities was suggested by the interpretation of the sensor data and the presence of sinkholes. However, their existence has not been verified. Therefore, it is recommended that such verification be sought.

3. The division of responsibility for the analysis of the data was mentioned earlier. It was also stated that magnetic tape is a much more sensitive recorder of signals than is black and white film. Considering the potential of the computerized analysis of the data, it is recommended that the principal investigator maintain contact with the FHWA personnel responsible for the computer analysis of the data so as to keep abreast of their program and to avail the Department of the benefits of such information as it is developed.



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