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Industrial Site Study with Remote Sensing

In a preliminary evaluation, the location of sinks and solution activity by remote-sensing techniques was considered to be approx. 85 percent reliable.

ABSTRACT: *A karst terrain surface near Albany, Georgia, was evaluated with remote-sensing techniques as a potential site for industry. There was particular interest in delineating sinkholes and zones of subsurface solution activity prior to the determination of plant layout and foundation design. An area of about 500 acres was photographed with color and color infrared-film and imaged with a Daedalus Scanner in the infrared region of 4.5-5.5 μm by Environmental Systems Corp. The data was interpreted to yield a map of suspected sinkhole and solution zones. Potential problem areas were investigated with borings by Law Engineering Testing Co. The results of the remote-sensor study were compared with boring profiles to provide a measure of the effectiveness and reliability of the remote-sensor study. Approximately 85 percent of the inferred solution zones were confirmed by borings. The cost of the remote sensing and interpretation was about 10 percent of the total cost of all site investigations. The remote-sensing approach was considered to have provided data of value well in excess of its proportionate cost.*

INTRODUCTION

As THE demand for residential, commercial, and industrial facilities increases, the availability of suitable sites will surely decrease. Land reclamation projects, such as in the New Jersey marshes, give testimony to the fact that the most desirable construction sites in developed regions have already been used in much of the United States. The problem now facing the planner and designer is that of trying to select the best of several less-than-optimum alternates as the site for engineered construction.

Th parameters needed for a thorough site evaluation are numerous. Site topography, geology, soil characteristics, drainage, climate, water supply and quality are all of concern. Equally important, but less quantifiable, are such factors as geography, location, urban environment, transportation, markets, and aesthetics. The data used in evaluating alternate sites might range from specifics, such as soil bearing capacity and terrain slope, to qualitative assessments of site aesthetics. Consequently, techniques of data collection can range from the laboratory testing of field soil samples to interviews with local residents.

There is a systematic approach to site selection that can be an efficient means of indentifying an optimum site. This approach can consist of four phases as follows:

- Define site requirements,
- Research available data,
- Obtain additional data as required, and
- Conduct a comparative analysis of alternate sites.

Remote-sensing technology has application to the second, third, and fourth phases. Also, it can be used for site utilization studies, once selection has been accomplished. A large amount of remote-sensor imagery already exists for much of the United States, and as

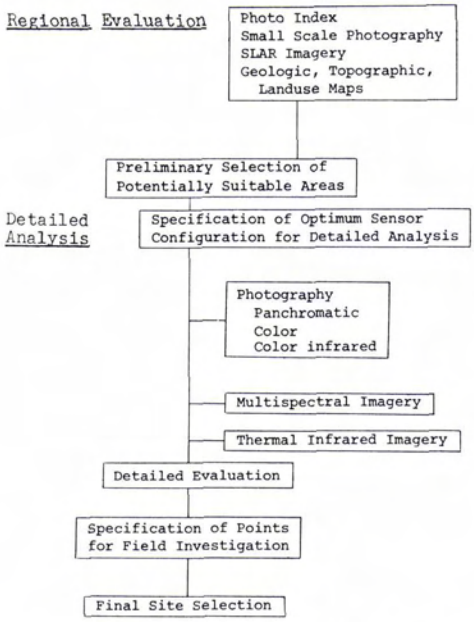

FIG. 1. Schematic diagram of analysis procedure.

such should be considered as existing data. Furthermore, remote-sensing techniques are ideal for obtaining preliminary terrain characteristics in those areas where data is scarce.

Application of Remote Sensing to Site Selection

A most thorough approach to site evaluation with remote-sensing techniques would involve a sequential study of small-scale and large-scale detailed imagery as illustrated in Figure 1. Other forms of site data can be evaluated in conjunction with the remote-sensor data and each will complement the other. Ideally, mission planning for detailed studies can be accomplished with the aid of prior regional evaluations.

The information derived from a detailed study of remote-sensor data should be sufficient to identify the best of several alternate sites. However, final selection should certainly be based on a planned program of field observation, sampling, and laboratory testing. The remote-sensor data provides an ideal base from which a field investigation can be planned. Rather than establishing a repetitive, fixed-interval field sampling grid, the delineation of terrain parameters from remote-sensor data can provide for optimum sampling. Complex areas can be intensely sampled, whereas areas of apparent similar condition can be characterized with a minimum of sampling. The result is that of efficient sampling with the number of samples in proportion to the complexity of the situation. Thus, one can collect field data which will be complemented, but not duplicated, by remote-sensor data.

Case-Study Background

The Procter and Gamble Co. commissioned a site evaluation study for determining prospective plant sites near Albany, Georgia. Remote-sensing techniques were utilized to help determine the presence and extent of karst features at several locations within a 500-acre site. The remote-sensor data acquisition was done by Environmental Systems Corp. Data evaluation in addition to that performed by Environmental Systems Corp. was conducted by the authors and is reported herein.

The initial objective of the study was to identify existing sinkholes or other forms of active limestone solutioning and to determine their effect on plant layout and foundations. Although the remote-sensor data acquisition was accomplished during the time of field investigations conducted by Law Engineering Testing Co. the full capabilities and significance of the remote sensor data did not become apparent in time for it to be fully used as a means of selecting field sampling sites. Thus, the net effect of the study was one of

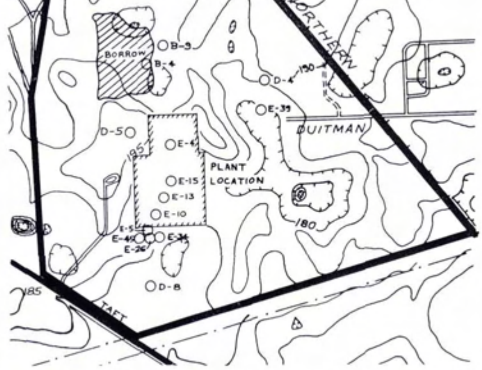

FIG. 2. Site topography, culture and boring plan.

TABLE 1. IMAGERY AND MISSION DATA

Imagery	*Source*	*Conditions*
Color Photography (Kodak 2448)	Hasselblad	1000 and 2000 feet altitude, 10:50-11:30 EDT, 0.2 cloud cover
Color Infrared Photography (Kodak 8443)	Hasselblad	1000 and 2000 feet altitude, 10:50-11:30 EDT, 0.2 cloud cover
Thermal Infrared (4.5 − 5.5 μm)	Daedalus Scanner	07:00-07:30 EDT 19:08-19:11 EDT, morning weather good, evening 100% overcast

demonstration rather than active utilization.

The site evaluated consists of about 500 acres and is illustrated in Figure 2. The site has a gently rolling terrain with a maximum relief of approximately 15 feet. The geology is described as undifferentiated Eocene and Oligocene limestone. The site was partially covered by a pecan grove and several borrow pits. The remainder was under cultivation.

REMOTE SENSOR DATA & INTERPRETATION

The remote-sensor imagery and flight data is described in Table 1. The imagery and data were interpreted to yield inferences based on analysis of repetitive land form patterns and associations of land-use features. The basic terrain patterns and characteristics used to infer karst features included topographic form, surface soil moisture characteristics, vegetation vigor, and apparent temperature patterns. Representative annotated stereogram examples of photography are illustrated in Plate 1 (color photographs) and Plate 2 (color-infrared photographs). The stereograms cover the northern third of the site. A composite overlay of delineated suspected karst features is illustrated in Figure 3. The overlay represents the composite inferences derived from color, color-infrared, and thermal-infrared imagery. The interpretation logic which accompanies the overlay and annotations on the stereograms is summarized in Table 2.

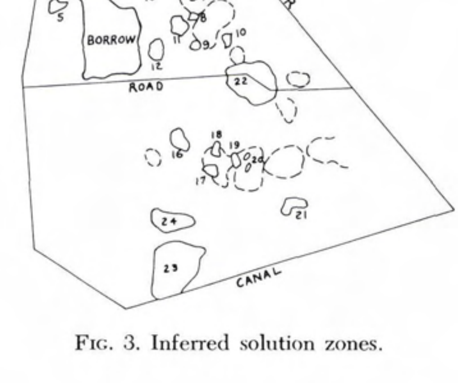

FIG. 3. Inferred solution zones.

EVALUATION OF REMOTE-SENSING APPROACH

A large number of soil borings were made over the southwest quarter of the site by Law Engineering Testing Co. of Atlanta, Georgia. This area had been selected prior to the remote-sensing study as the best building location for minimum topographic expression of sinks, best access, minimal grading, and future expansion. Other areas were sampled with widely spaced borings. The boring plan is indicated in Figure 2 along with the previously described site topography.

It was possible to evaluate the effectiveness of the remote-sensing study by comparing interpreted characteristics with bore-hole data. A summary of compared features is presented in Table 3. In only two areas was inferred solution actively unconfirmed by borings. In both cases, the borings were approximately 50 feet away from the delineated sink areas.

SUMMARY AND CONCLUSIONS

The remote-sensing study was judged to have been helpful and well worth the effort and expense for the specific goal of locating potential limestone solution features. In considering the other uses of remote sensing, such as plant layout and future site modification, the value of the permanent image data base is enhanced even more. The cost of image acquisition and interpretation was less than 10 percent of the cost of soil boring, sampling, testing, and interpretation. As

TABLE 2. INTERPRETATION LOGIC

Delineated Location	*Color Photographs*	*Color Infrared*	*Scanner IR (morning)*	*Interpretation*
1	Yellow soil, topographic depression.	High reflectance from bare soil, no indication of high soil moisture.	No significant data.	Borrow pit, man-made depression, solutioning will be accelerated.
2	Dark brown soil, accumulation of silt & clay in depression, some cloud shadows.	Dark gray tones, high moisture contents, poor internal drainage, some cloud shadows.	High return from trees, high return from depressed areas.	Silty-clay filled solution depression.
3	Slightly depressed area, enhanced brush growth, dark brow soil colors.	Dark gray soil color, high moisture content.	No additional data.	Solution depression; no evidence of cavity
4	Slightly enhanced vegetative growth.	No additional data.	No additional data.	Possibly part of drainage system into feature #3.
5	Topographic depression possible external drainage.	No evidence of moisture concentration.	Low return from trees.	Solution depression.
6-15 (similar)	Lush green vegetation, slight depressions, brown soil colors due to clay accumulation.	Gray colored soil, high moisture content.	Low return from soil, high return from vegetation.	Solution depressions, dashed lines are connecting features—primarily soil moisture features.
16-21 (similar)	Lush green vegetation, light white bare soil.	Dry soil, white tones.	No additional data.	Moderately well-drained solution depressions, sandy surface, possibly active solutioning.
22	Circular zone of white bare soil, lush vegetation near center.	Moderate moisture content evidenced by gray colors.	Low, cool emissions from vegetation (evening flight).	Drained solution depression.
23-24 (Similar)	Slightly depressed, tree cover.	No moisture concentration.	No additional data.	Developing solution feature.

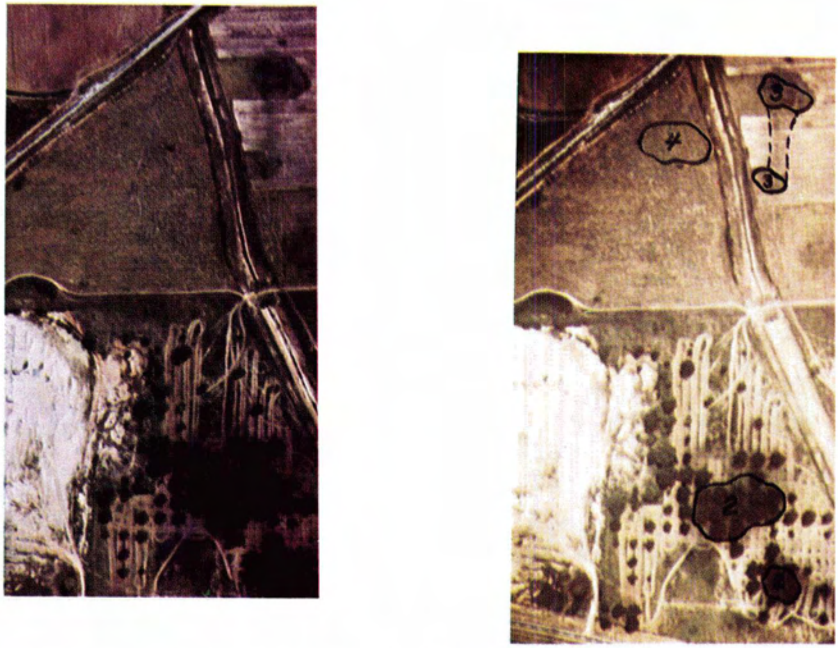

Plate 1. Example of a stereogram with full-color photographs. The interpretation is described in Table 2.

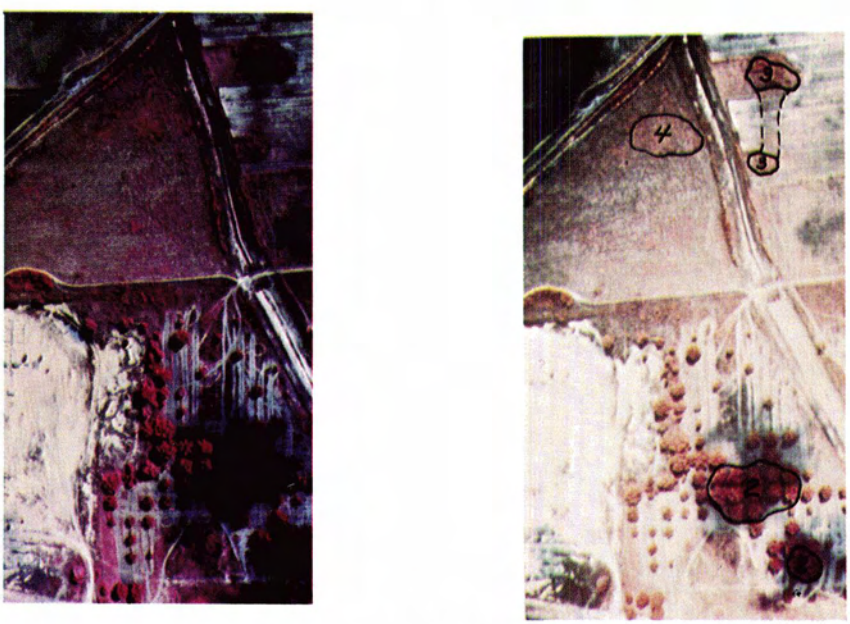

Plate 2. Stereogram of color-infrared photographs.

TABLE 3. COMPARISON OF MAPPED SINKS VS. SOIL BORING DATA

Sink Area Interpreted from Remote Sensor Imagery (Refer to Figure 5)	*Boring (Refer to Figure 2)*	*Note*
2	B-3	0
11	B-9	1
12	B-4	1
14	D-2	1
16	Ex4	2
17	E-13	0
22	E-39	1
23	D-4	1
24	D-8	1
24	E-45	1,2,3
24	E-26	2,3
24	E-34	3
24	E-5	1,3
24	E-10	1,3
	E-15	1,3

Notes: 0. No significant data from boring to confirm sink, or solution activity.
1. *Soft soil* (sampler blow count 5) just above limestone bedrock to confirm sink.
2. *Large void* in limestone bedrock to confirm sink.
3. *Depression* in limestone bedrock to confirm sink.

judged by the user, the remote-sensing study returned data with value in excess of its share of site evaluation costs.

The color and color-infrared photographs were of greatest value in this study. The thermal imagery confirmed some ambiguous interpretations. However, night-time imagery in the 8 to 14 micrometer portion of the spectrum would have been better for this study had it been possible to acquire it.

The location of sinks and solution activity at this site by remote-sensing techniques was considered to be approximately 85 percent reliable. Knowledge of karst feature locations definitely affected site layout. It was confirmed by evaluation of the remote sensor imagery that the most suitable quadrant for building location was the southwest. Also, as a result of the remote-sensing study a railroad spur embankment and a large fuel oil storage tank were relocated to avoid two large sink areas. The location with respect to sinks of a building containing large critical process equipment strongly indicated the need for special foundations. Also, Procter and Gamble is now better prepared to cope with a wide area of solution activity in the natural direction of building expansion to the east.

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