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EVALUATION OF GRAVEL DEPOSITS USING REMOTE SENSING DATA, WABASH RIVER VALLEY NORTH OF TERRE HAUTE, INDIANA

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EVALUATION OF GRAVEL DEPOSITS USING REMOTE SENSING DATA, WABASH RIVER VALLEY NORTH OF TERRE HAUTE, INDIANA[1]

by

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ABSTRACT

Valuable gravel deposits adjacent to population centers are in danger of being lost to urbanization. Detailed exploration is needed to locate (within a larger body of coarse-grained sediments) those gravel-rich sites of sufficient size and quality which yield profitable gravel extractions.

Remote sensing provides a reasonably detailed means for rapidly exploring large areas. Satellite imagery (previously ERTS and now LANDSAT) can be used to study large areas of the land surface. Applying surface-materials-mapping techniques, those areas with good drainage (coarse textured soils) can be discerned from those which are more poorly drained. Spectral response of the surface materials in the visible and near infrared portion can be used to subdivide the scene into various categories of materials.

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The test site, located north of Terre Haute, Vigo County, Indiana, is a terrace with more than 100 feet of glacial-outwash sands and gravels on the east side of the Wabash River. In this study, the primary objective was to locate within the 20 square-mile terrace, those areas with the highest concentration of gravel. In general, in excess of 20% gravel (larger than 3/8" diameter) is needed to make a gravel operation profitable in Indiana.

Computer assisted techniques were applied to the LANDSAT imagery using both a supervised and non-supervised approach. Imagery taken at three times of the year (Jan., June, Sept.) was geometrically corrected and overlaid (registered) to provide a single, multiple-channel data tape. A non-supervised analysis of these data proved to be most satisfactory for surface-materials classification.

Field checks of two classes of material, one with a spectral response most similar to known gravel-rich areas, and the other with a very dissimilar response, were performed. Results, though not entirely convincing, suggest a higher gravel-content for those areas designated as gravel-rich on the classification.

Cost of remote sensing analysis as compared to conventional site exploration provided a final evaluation. For the 15,000 ± data points per wavelength band involved in the study the total cost including data aquisition, registration, geometric correction, computer analysis time and personnel, would be about $4900 using current cost figures. This cost, for an area of about 19.5 square miles, equals about one-half dollar per acre. Cost of exploration for an 80 acre site is estimated at between $1,000-2,000 using conventional drilling which yields a value of $12.50 to $25.00 per acre. Of course, conventional exploration would still be needed after remote sensing studies but the amount of exploration should be greatly reduced. Remote sensing analysis has the potential to reduce exploration time and expenditures significantly for gravel extraction operations.

Introduction

Gravel deposits which can be processed economically for construction materials are an important resource. Although gravel is not a rare geologic material it must, owing to the large quantities consumed by construction and its high cost of transportation relative to its low unit value, be located close to market for it to have commercial value. Such a material is said to have a high "place value" (1, p. 93).*

Because of these considerations, a maximum hauling distance of only a few tens of miles is allowed for competitive pricing. To complicate the problem further, gravel is needed close to urban centers where the majority of construction occurs. As urbanization spreads from population centers, gravel-rich areas are commonly covered by housing tracts or commercial development. In addition, as urbanization proceeds, operating gravel pits locally encounter public pressure to minimize noise, dust, traffic, and other environmental factors which act as a deterrent to continued gravel production and future pit expansion.

Economics in Indiana dectate that a viable gravel-extraction operation have a 20-year supply of material and, based on a reasonably small extraction of 200,000 tons per year, an average thickness of 15 feet and a recovery of 80 percent, an area of some 80 acres is needed. For smaller, short-term work, such as a highway construction project in a rural area, much smaller volumes of gravel may prove economical to use. Also, with the steady approach of urbanization in an area, pits with the same thickness of gravel but only 10 acres in size operating for a two year period may prove both economical and necessary.

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*Numbers in ( ) refer to the list of references presented at the end of this paper.

Sand and gravel production in Indiana had a value of nearly $37 million in 1973 (Table 1) or 11% of the state's mineral production for that year. Some 28 million tons of sand and gravel were produced in 1973 at an average value of $1.30 per ton. The total value of gravel production is significantly greater in many of the more populous states and in some areas a shortage of gravel exits. Because of this, the Federal Highway Administration, U.S. Department of Transportation, has recently solicited research proposals on the use of airborne geophysical techniques for the purpose of locating construction materials (3).

TABLE 1. Gravel Production in Indiana

Year	Total Value of Indiana's Mineral Production ($1000's)	Total Value of Indiana's Sand & Gravel Production ($1000's)	Total Sand and Gravel (1000's of short tons)	Value of Sand & Gravel as % of Value of Mineral Production
1963	202,530	20,683	22,840	10.2
1964	211,783	21,811	24,416	10.3
1965	218,567	22,220	24,867	10.1
1966	230,010	23,542	24,992	10.2
1967	244,921	25,588	26,265	10.4
1968	235,386	26,160	25,774	11.1
1969	241,871	27,438	26,218	11.3
1970	228,786	25,796	23,476	11.3
1971	281,521	29,094	24,982	10.3
1972	322,608	33,290	27,978	10.3
1973	340,915	36,734	28,257	10.7
1974	344,989	34,694	25,421	10.1

Based on data from the U.S. Bureau of Mines (2).

The increasing worth of sand and gravel in Indiana is illustrated in Figure 1. Sand and gravel production in 1,000's of tons and in 1,000's of dollars of value is plotted for the years 1963-74 based on data from Table 1. The cross over point in 1967-68 can be noted where sand and gravel worth exceeded $1.00 per ton. Of major significance is the slope of the two curves from 1970-74. The comparative steepness of the curves indicates the rapid growth in value per ton of sand and gravel caused mostly by inflation. Hence it is to be expected that the worth of sand and gravel will continue to increase considerably per ton in the next decade. The effects of reduced construction activity is shown by the 1974 data. However, the slope of upper plot is not as steep as that of the lower one for 1974, showing an increase in unit cost.

Because of the increasing demand for construction materials, the loss of gravel extraction sites due to urban sprawl, and the high place-value of gravel deposits, it has become necessary for gravel producers to increase their exploration efforts to locate new sources. Cost of exploration for an 80-acre site is estimated at between $1000 and $2000 using conventional drilling augmented by subsurface geophysical techniques. With these comparative costs in mind, it is apparent that if remote sensing analysis can reduce the costs for exploration by designating prime areas for detailed study, a valuable savings can be made.

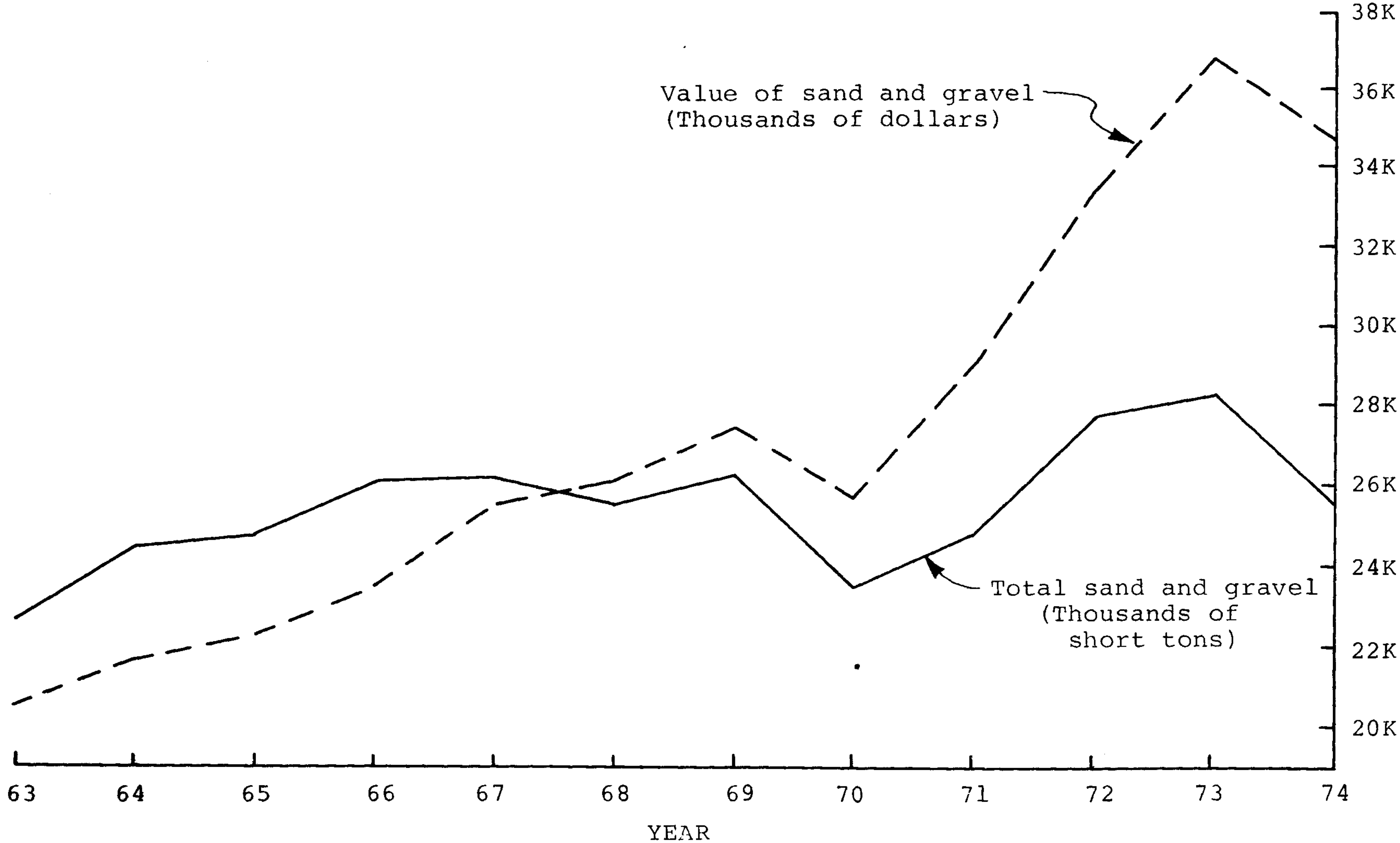


Figure 1. Comparison of Indiana's sand and gravel production by year versus sand and gravel value.

Setting Objectives

A test site located north of Terre Haute in Vigo County, Indiana was selected for study (Fig. 2). The use of remote sensing to locate gravel supplies was suggested by LARS and the Indiana Geological Survey because of the significance of the problem and the special potential of remote sensing for solving it. Study results would influence decision making relative to resource inventory, mineral extraction and land use planning.

The study site is a river terrace on the east side of the Wabash River and immediately north of Terre Haute (Fig. 2). The bedrock valley of the Wabash River was filled with more than 100 feet of sand and gravel (glacial outwash), which was deposited as the glacial melt-water flow diminished. The surface of this deposit in the Wabash Valley is known as the Shelbyville Terrace, and lies about 75 feet above the present Wabash River.

Massive glaciers advanced into Indiana at least three times during the Pleistocene Epoch. The earlier invasions extended far south of Vigo County, but the last ice sheet stopped just to the north of Terre Haute. Each glacier deposited till from the ice and also produced large quantities of sand-and-gravel-bearing outwash. From a meandering stream, such as the present-day Wabash, the coarsest gravel is deposited on the insides of the bends, and the deposit builds toward the center of the channel along bars. However, a glacial meltwater stream, which is highly charged with

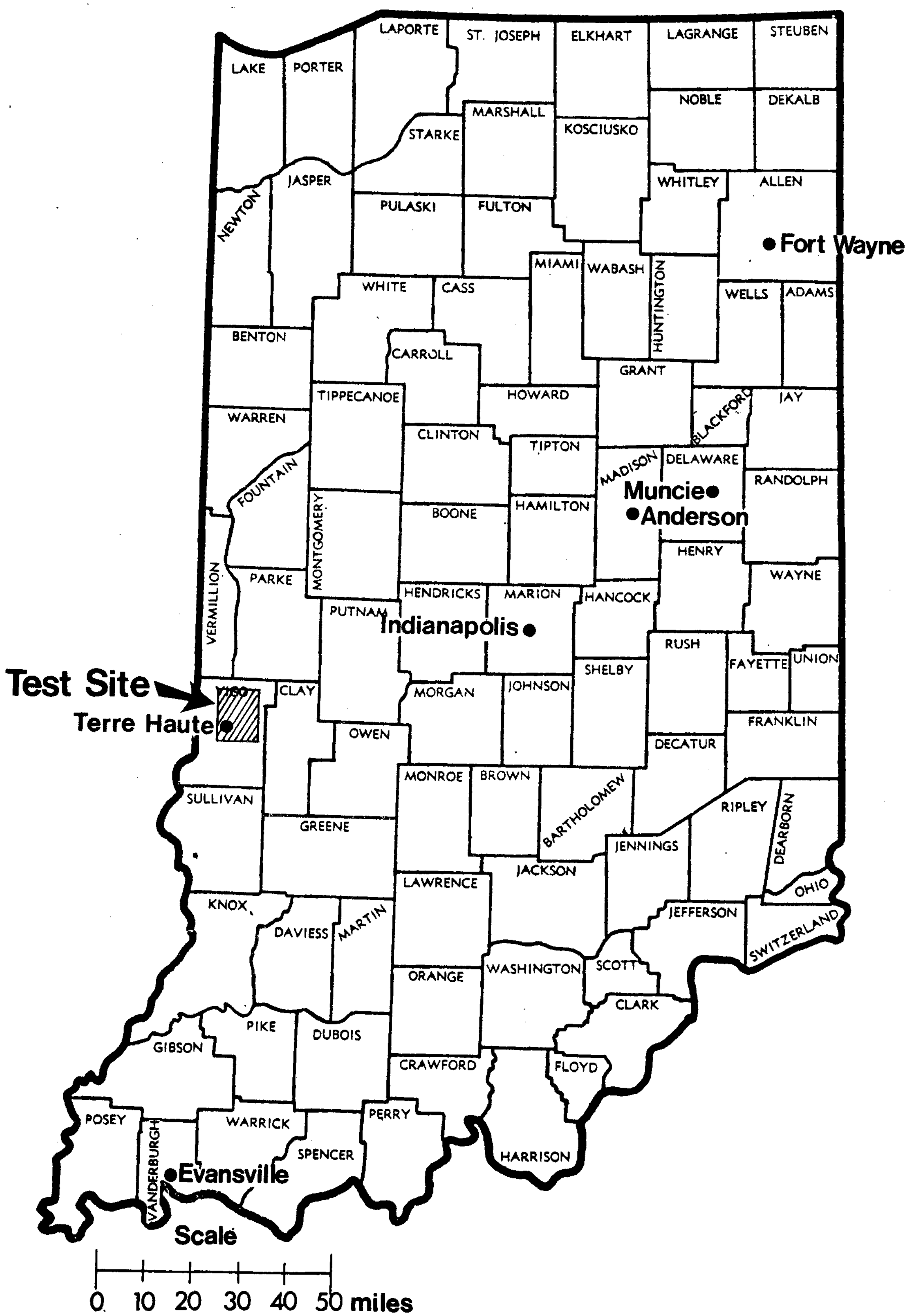


Figure 2. Location map, Terre Haute, Indiana Study Site.

sediment, deposits the coarse material within the center of a broad flat, braided channel in the form of diamond-shaped bars that are elongated in the direction of flow.

In this study the primary objective was not merely to locate sandy materials which hopefully contain some gravel because it was already known that essentially all the Shelbyville Terrace at Terre Haute has some gravel present; but instead, to locate the bars bearing the coarsest gravels. The area of study was some 20 square miles, and about 1/2 of it consisted of the Shelbyville Terrace.

The proportion of gravel necessary to yield an economical operation varies with the intended use of the gravel and the market for the remaining sand. Generally for Indiana, few pits operate with less than 25% of the material being larger than 3/8" in diameter. Pits with 80% sand containing a good masonry sand, or with a market for large volumes of fill sand, however, do operate at a profit. Therefore, it was concluded that locating deposits with a minimum of 20 to 25% gravel (larger than 3/8" diameter) would be the objective of this analysis.

Procedure

Remote sensing is the science of aquiring information about objects from measurements taken at a distance without physical contact with those objects. The primary means of transmission from object to observer is by electromagnetic fields. At LARS, studies are concentrated on the portion of the electromagnetic spectrum which includes the visible-reflective infrared-, and thermal infrared wavelengths with special emphasis on machine (computer) processing of these spectral data.

The primary remote sensing data used in this study consisted of three sets of LANDSAT imagery obtained during the months of January, June and September, 1973. Previously, these data had been geometrically corrected and the imagery for the three LANDSAT passes overlaid to provide a single, 12-channel data tape. This combined-data tape served as the basis for land use mapping of Vigo County, Indiana in an earlier study (4) thus reducing data aquisition costs for the current research.

In addition to the LANDSAT data, high altitude (6,000'), 1:120,000 scale, infrared photography of Vigo County, flown in May 1971, was also available at LARS. A surface geology map of the area north of Terre Haute was developed by the authors, from published information and compiled on two 7 1/2 minute (1:24,000 scale) topographic maps, the Rosedale and New Goshen quadrangles. A smaller scale, somewhat generalized map, based on that surface geology information, is presented as Figure 3. The locations of eight known gravel-extraction operations are also plotted on the quadrangle maps.

The initial step was to locate accurately the study area in the LANDSAT data. This can be time consuming

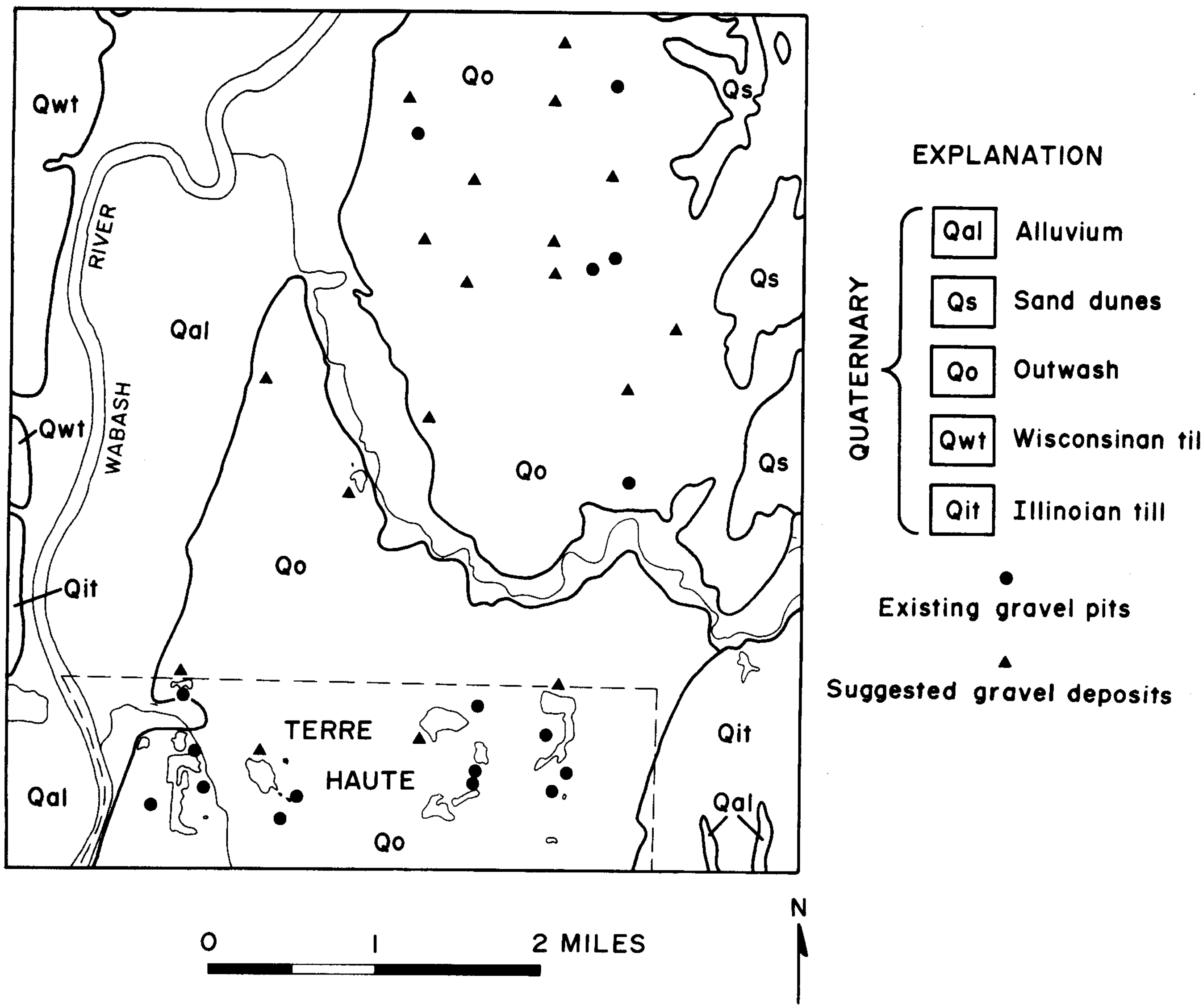


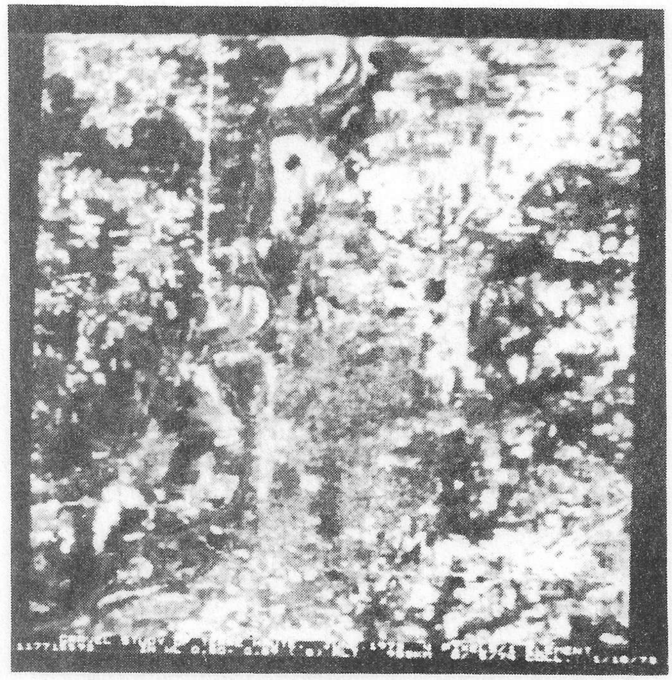
Figure 3. Surface Geology Map of Area North of Terre Haute, Indiana

because of the limited scale and resolution of the imagery. Use was made of the visual display unit at LARS, recognizing the features of the Wabash River and adjacent drainage patterns. Also, the 1:60,000 scale infrared photography proved particularly helpful in determining the specific location within the LANDSAT imagery.

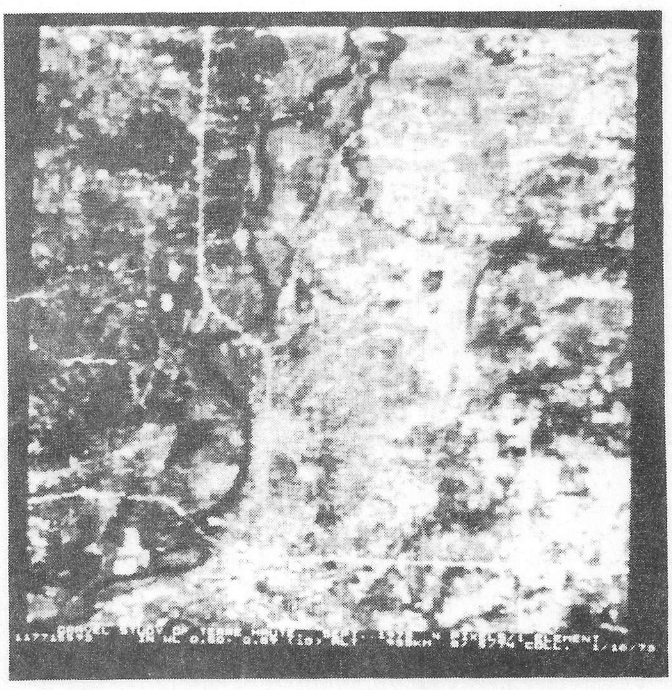
After the study area of 108 lines by 116 columns (4.4 miles by 4.5 miles) was designated in the LANDSAT data, an attempt was made to determine surface features distinctive of gravel deposits. Some of those considered were vegetative cover, drainage pattern, soil cover, and temporal changes in these features in the January, June and September imagery. If distinctive features were found, a unique, spectral signature of the gravel deposits could be isolated through computer-assisted analysis. Figures 4a, 4b, and 4c show the variations between seasons in the Shelbyville Terrace near the center of the study area, using filters to simulate a false color-type image of spectral response. The colors and pattern in the terrace area change with the seasons showing that temporal LANDSAT imagery provides additional detail for purposes of analysis.

The first computer-assisted analysis of data involved a non-supervised or clustering approach. Seven spectral classes were specified with each data point assigned to that cluster class of the seven showing the greatest spectral similarity. Thus, water might be one class, vegetative

4a. January



4b. June



4c. September

Figure 4. Digital display images of January, June, and September, 1973, Landsat data, Terre Haute, Indiana Test Field. Simulated infrared imagery (black and white reproduction of color original).

cover another, bare soil a third, with similar properties comprising other classes. Clustering was performed on the January, June and September parts individually and also on the combined, overlay tape consisting of all twelve channels of data. If a unique gravel class exists, this classification would likely point it out.

The second computer-assisted analysis was a supervised approach in which the computer was programmed to recognize a specific signature of known materials outlined for it in the data. Based on the statistics of the designated area (means, standard deviation) and applying a normal or Gaussian distribution, points possessing similar statistical descriptions in other portions of the study area are located. To program the computer, eight sites of present-or recently-abandoned-gravel operations were designated. To obtain the highest location accuracy (position accuracy was within one or two resolution elements) each site was represented by nine pixels (resolution elements), the central one plus its eight surrounding, nearest neighbors. Also, ten pixels correspond to an area of approximately ten acres which is about the minimum size of an economically feasible gravel extraction site, even in a suburban area.

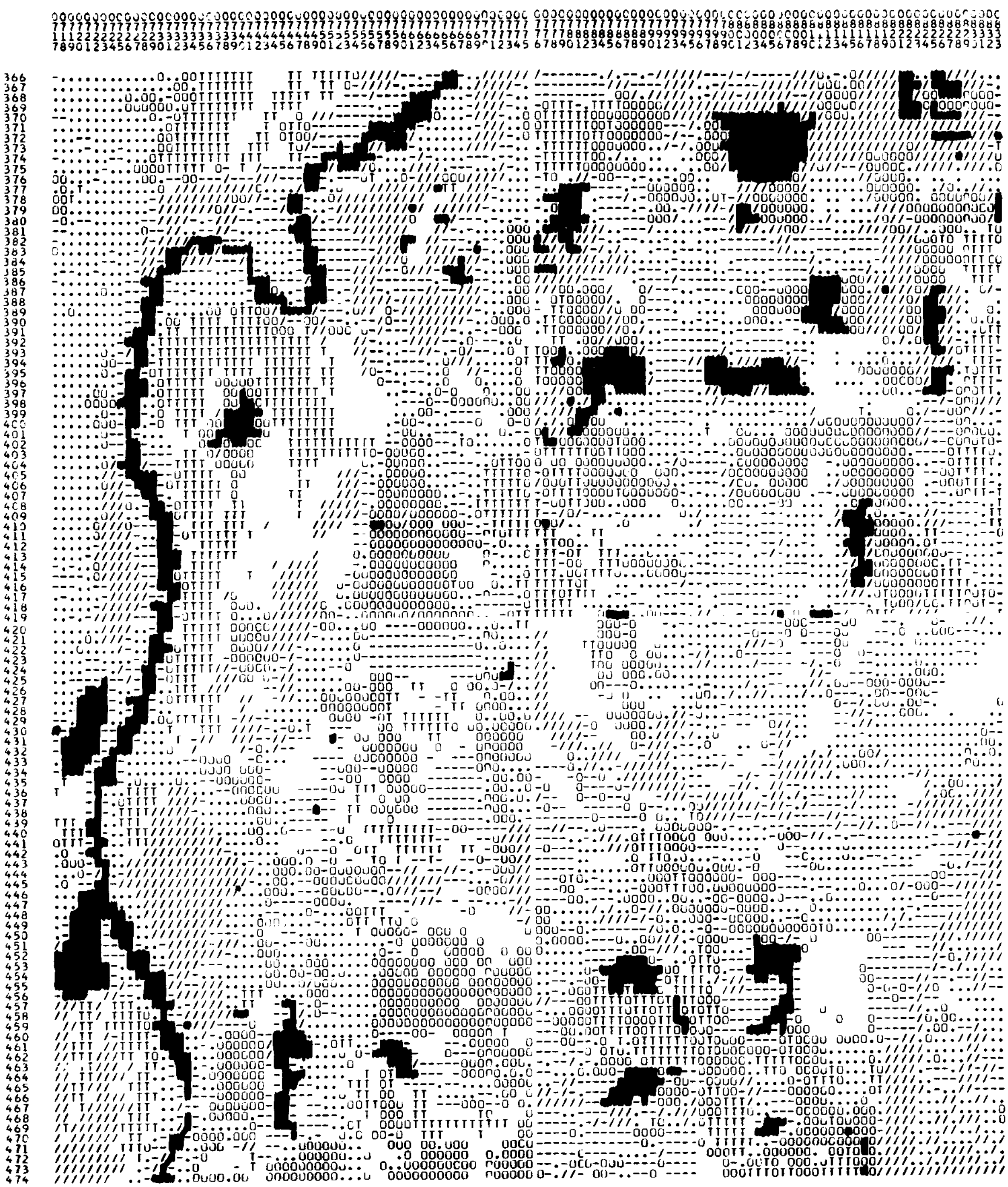
Using the eight known areas containing gravel as training sites for the computer, the entire area was classified. As only one training class was considered (gravel), the entire study area must be included in this single class but to insure that only similar materials would persist, a threshold of 75% was applied to the classification. Thresholding, in effect, deletes the tails of the Gaussian (normal) distribution which in this case leaves only the central portion (25%) of the distribution remaining. This classification was performed using the individual LANDSAT frames for the three seasons plus the combined twelve-channel data tape. Despite the severe curtailment by thresholding, much of the study area was still designated as within the gravel class.

Classification Results and Field Evaluation

The supervised approach described in the previous paragraphs did not accomplish the desired results. On all three of the one-season LANDSAT frames, more than half of the total area was assigned to the gravel class despite the 75% threshold. The classification did not single out locations possessing a high gravel content or even designate those where sand and gravel predominated. Instead, not only was the terrace assigned to the gravel class, but also parts of the floodplain and ground moraine. The supervised classification of the twelve-channel overlay of these three frames, however, yielded better results although specific areas of high gravel content were not designated. Outlined instead was the entire sand-gravel Shelbyville

Terrace excluding the landforms covered by finer textured soils (floodplain and ground moraine). Even though the desired result of locating high-gravel content areas within the terrace was not accomplished, the results demonstrated that coarse textured materials (sand and gravel) could be distinguished from fine textured ones (silts and clays) using the classification of overlay data. It is believed that the poor results arose from an insufficient number of test sites used, and that those sites included were too small. However, more data would not normally be available in other potential areas.

The non-supervised analysis proved more successful than the supervised. Seven classes were used to cluster the three LANDSAT frames and the 12-channel overlay combination (Fig. 5). As with the supervised classification, the 12-channel overlay data yielded better results. On all four classifications the existing gravel pit locations and the area adjacent to the Wabash River were represented by a common symbol. Apparently the high moisture area of the river had a seasonal variation in spectral response similar to that of the coarse gravel deposits in the terrace. The 12-channel classification was judged superior to the others because it contained less scatter of these "gravel cluster" symbols. Other sites in addition to the existing gravel pit sites were delineated in the terrace deposit by the gravel-cluster symbol (designated by the letter W but blackened over for emphasis). These areas were judged



Dark areas - suggested sites with high-gravel percentages
Symbol T - suggested sites with low-gravel percentages

Figure 5. Non-supervised classification of 12 channel overlay of LANDSAT data, January, June, and September 1973

to have a high gravel-to-sand ratio. After reviewing the classification results soil auger holes were drilled at four locations with the Indiana Geological Survey power auger. The results in general seemed to indicate that the gravel-rich classification was reasonably correct as gravel was found in three of the four holes within 8 feet of the surface.

To test the possibility that similar gravel deposits existed in many other locations in the terrace but were not outlined by the classification, the cluster class most dissimilar to the "gravel cluster", (the class among the remaining six which showed the greatest spectral difference from the gravel clusters) was singled out for review to determine if indeed, it corresponded to a different soil material. This class, (designated by T in Figure 5) should have the lowest probability of indicating a gravel-rich area. Seven sites were designated in the terrace where the T cluster symbol was present. The drilling results at these sites in general showed that gravel did not occur within the uppermost 8 feet to as great an extent as it did in the first series of holes.

The evaluation of gravel content in the drilled holes is somewhat subjective as the materials were obtained with a continuous flight auger which is far from ideal for sampling sand and gravel materials. However three of the four "gravel-designated" borings contained the coarsest material throughout the total section drilled while the fourth hole had only a small amount of gravel present. By contrast only one of the "non-gravel" borings had abundant gravel present but this was located below a clayey, surface material.

Critique of Results and Recommendations for Future Work

Though results of the gravel study are encouraging, other aspects deserve consideration. Cost of remote sensing analysis as compared to that of more conventional site exploration is important. Data aquisition of the three LANDSAT frames, image registration (overlay) of the three, plus geometric correction for each data point had been accomplished for this site in a previous study at LARS. For the 15,000 ± data points per channel involved in this Terre Haute study the cost of data aquisition, registration, and correction would total about $3000 using current costs.* Cost of computer time to analyze the data plus the cost of personnel totaled about $1900. Therefore, a reconstructed cost to perform the study, using current LARS charges would total $4900.

Unit cost per site would decrease significantly if a number of such tracts within a county or other large division of the land surface were being studied at one time. The

*The actual cost for the one-fourth ERTS frame covering Vigo County, of which this Terre Haute gravel study represents nearly one-half the area, was approximately $14,000 when performed on an experimental basis in 1974.

$4900 cost is for an area of about 19.5 square miles which is about $240 per square mile or less than one-half dollar per acre. In addition, if this technique were placed in an operational mode, a larger, faster computer than the IBM 360 Model 67 (now employed at LARS) could be used, resulting in substantial savings in computer charges. Finally, as previously stated, the estimated cost for detailed exploration of an 80 acre tract using conventional methods is from $1000 to $2000 or $12.50 to $25.00 per acre. This total might be substantially reduced if remote sensing analysis was performed first.

Further study should be undertaken to obtain computer training sites where LANDSAT data were obtained prior to extraction of gravel material. In the current study, the training sites were operating and abandoned gravel pits where obviously a high concentration of gravel existed. A more-typical spectral signature would be obtained for an undisturbed area but the existence of high-gravel-bearing material would have to be established for that training site. Better sampling techniques and more sampling points would be needed to obtain a statistically significant evaluation for the presence or absence of gravel in the near subsurface.

The final problem of note is the limited resolution of LANDSAT imagery compared to the detailed desired in this study. Image resolution elements for LANDSAT are approximately one acre in size. In contrast, multispectral scanners mounted in aircraft obtain imagery with much greater resolution. For example, a 3,000 foot flight yields an image resolution element 9 feet by 9 feet. However, there are disadvantages associated with aircraft data. One of the most significant is the narrow, one-mile wide strip of data obtained. In flights at higher elevations, the path width increases but the resolution decreases. For the four mile wide area involved in the Terre Haute study, a 12,000 foot flight would have been ideal, yielding resolution elements approximately 36 feet square as compared to LANDSAT resolution elements of one acre or 210 ± feet square. A consideration of vehicles other than LANDSAT is needed for collecting multispectral data for land surface studies in which minute detail is important.

A follow-on study building on the analysis techniques presented in this paper but applied to multispectral data possessing greater resolution is needed. The results would be evaluated using statistically significant sampling techniques to prove more conclusively the utility of locating gravel-rich areas by analysis of remote sensing data.

Conclusions

From this study it is concluded that the non-supervised classification of the LANDSAT, 12-channel overlay data was able to designate reasonably well those areas with a high probability of possessing gravel-rich zones near the surface. The supervised classification was also able to designate the broad categories of coarse textured soils (here terrace deposits) from other fine textured soil areas (floodplain and ground moraine).

It is concluded that this technique as augmented by available geologic, agricultural soils and photographic information can be used to locate areas with a higher potential for gravel deposits of an economic value. Subsequently, field studies employing the electrical resistivity method, followed by subsurface drilling can be used for successive refinement of the areas designated as gravel rich, based on the remote sensing study. The combined approach of remote sensing and conventional exploration should result in a savings of time and expense as compared to a totally conventional method.

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